Soil environment and nutrient status of Norway spruce (*Picea abies* [L.] Karst.) underplantings in conditions of the 8th FAZ in the Hrubý Jeseník Mts.

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ABSTRACT: The main objective of this study was to investigate the causes of nutrient deficiency symptoms in Norway spruce (*Picea abies* [L.] Karst.) underplantings in the Hrubý Jeseník Mts. In the area concerned 19 research plots were established, representing the ridge sites of the 8th FAZ of acid edaphic categories. On these plots samples were taken from topmost soil horizons and needle samples were collected in two series – from healthy and from damaged trees. The results of this study demonstrate that the nutrient deficiency symptoms and reduced vitality of evaluated underplantings were caused by the insufficient uptake of main nutrients (Mg, P, K, N_t). High contents of toxic elements Al, S in damaged needles are another factor that negatively influences the health status of these underplantings. A statistical survey showed that damage to underplantings increased with decreasing proportions of main nutrients (N_t, Mg, Ca, K) in organomineral horizons. At the same time the content of basic nutrients (N_t, Mg, Ca, K) was found to increase in this horizon with an increasing proportion of oxidizable organic carbon (C_{ox}). The proportion of humus substances and the content of basic nutrients (N_t, Mg, Ca, K) in organomineral horizons become a limiting factor for the normal growth and development of Norway spruce plantings in the ridge part of the Hrubý Jeseník Mts.

Keywords: Norway spruce; nutrient deficiency symptoms; stand nutrition; soil environment

The soil component creates an essential environment for ensuring the basic physiological processes of plants and is an irreplaceable part of the forest ecosystem. Longer-term temperature and precipitation fluctuations and short-term air pollution are currently the main factors causing damage to forest stands (Uhlířová, Kapitola 2004). The mechanism of forest damage is usually triggered by the root system damage and stand nutrition disorders (Podrázský et al. 2003).

Forest tree species nutrition is monitored according to the elemental composition of assimilatory organs as one of the effects of environment by plant interaction (Begon et al. 1987). Great attention is usually paid to elements taken obligatorily by the plant from soil, the dynamics of which is related, among others, to litterfall decomposition on the soil surface (Vera 1992; Lomský 1998; Hyvönnen et al. 2004; Novák, Slodičák 2004). These elements are bound in soil in exchange bonds to the sorption complex. Mg deficiency in assimilatory organs is a frequently reported cause of nutrient imbalance in mountain spruce monocultures (Zimmerman et al. 1998; Lomský et al. 2006; Vacek et al. 2006). The cause of imbalances in nutrient uptake may also be excessive deposition of N that leads to the relative deficit of other nutrients and to soil acidification after gradual leaching of nitrogen (Podrázský et al. 2003). The nutrition of forest tree species can also be negatively influenced by an excessive amount of aluminium in the soil component (Podrázský et al. 2003; Vavříček et al. 2006; Pavlů et al. 2007) that

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. MSM 6215648902

may be reflected in high Al content in damaged needles (Ditmarová et al. 2007).

The condition of mountain forests in the Hrubý Jeseník Mts. is differentiated in relation to specific on-site conditions (Samec et al. 2007). In the ridge parts of the Hrubý Jeseník Mts. visual symptoms of insufficient nutrition were observed in Norway spruce (*Picea abies* [L.] Karst.) underplantings that were accompanied by the overall diminished vitality of affected trees. Stand nutrition disorders are manifested there by homogeneous yellowing of needles (chlorosis) and overall diminished vitality of affected trees. In total 19 localities were selected in Loučná nad Desnou Forest District (FD), Javorník FD, Janovice FD, Jeseník FD and Hanušovice FD that represent the ridge sites of the 8th forest altitudinal zone (FAZ) of acid edaphic categories. The main objective of this study was to investigate the causes of nutrient deficiency symptoms in affected underplantings and to verify whether the soil environment is a part of predisposition factors influencing their poor health status.

MATERIAL AND METHODS

Description of the area concerned and research plots

The massif of the Hrubý Jeseník Mts. is a tectonically uplifted upland, composed of more or less separated mountain clusters with deep saddles and basin-like depressions between them, while the Jesenická kotlina basin is the most pronounced. Mountain ridges, often rising above 1,200 m a.s.l., are typically massive and round, with deep, young erosion valleys cutting into them, often with smaller waterfalls. The territory is built of very complicated complexes of the crystalline basement, formed of

Table 1. Brief characteristics of research plots

Stand	Exposure	Altitude	Degree of damage	Soil type	Bedrock
Forest district Loučná nad Desnou					
101 A 13/0s	SW	1,340	4	folic podzol	mica schist gneiss
406 B 0a	SE	1,200	3.5	histic podzol	mica schist gneiss
419 B10/0p	NW	1,310	3	haplic podzol	mica schist gneiss
504 A 16 a/0t	NW	1,230	5	haplic podzol	mica schist
718 C 1c	W	1,180	2	folic podzol	gneiss
Forest district Janovice					
402 D 10	SE	1,120	5	hyperskeletic haplic podzol	phyllite
503 A 12	SE	1,260	3	haplic podzol	mica schist gneiss
504 B 17	0	1,200	2	haplic podzol (skeletic)	phyllite
Forest district Hanušovice					
210 B17/ 0p	NW	1,250	2	haplic podzol	mica schist gneiss
210 C 9 a/0p	W	1,160	2	epigleic histic podzol	gneiss
220 D9/ 1b	NW	1,180	2	folic podzol	greywacke
359 B 15 a	NW	1,260	3	folic podzol	gneiss
508 A 17/0p	E	1,200	3	haplic podzol	gneiss
801 A 17/0p	W	1,200	3	folic podzol	gneiss
804 A 17 a/0p	W	1,220	5	folic podzol	gneiss
Forest district Jeseník					
233 A 14	SV	1,220	3	haplic podzol	mica schist gneiss
319 A 15 p	NW	1,200	4	folic entic podzol	mica schist gneiss
Forest district Javorník					
660 C 15 b/1	NW	1,250	3	haplic podzol	gneiss
660 C 15c	NW	1,240	1	entic podzol	gneiss

narrow strips of rocks and extended from northeast to southwest. Prevailing rocks are acid, mostly poor in nutrients (gneisses, mica schists, phyllites, granitoids at a smaller amount) (Culek 1996).

The condition of mountain forests in the Hrubý Jeseník Mts. is differentiated in relation to the specific on-site conditions (Samec et al. 2007). Despite of a dramatic reduction in the emissions of sulphur oxides in the last decades the impacts of air-pollution disaster are still obvious in the ridge parts of the CR mountain ranges. A list of 19 research plots in the studied area with specification of on-site conditions is given below (Table 1). From the aspect of soil taxonomy podzolic groups of soils prevail there while Folic Podzol and Haplic Podzol are the most frequent soil types.

Pedological survey of sites

On-site conditions (relief, altitude, exposure) were evaluated on each of 19 research plots; a soil pit of a depth reaching the substrate horizon C was dug at each site. Soil taxonomy was described in excavated soil profiles applying the FAO WRB international classification.

Evaluation of underplanting damage

The degree of damage to underplantings was evaluated on each research plot, based on the frequency of occurrence of visual symptoms of deficient nutrition (chlorosis), and the general vitality of the stand concerned was also evaluated. A scale of underplanting damage was developed according to the chosen method (Innes 1990) in order to compare damage in the particular localities and for further statistical evaluation. It is a 5-degree scale showing the degree of damage to underplantings due to nutrient deficiency from the lowest (I) to the highest (V). Trees with the occurrence of visual symptoms on more than 20 percent of all foliage were regarded as damaged (degree II and higher).

Sample collection and laboratory analyses

On each of 19 research plots (their list is shown in Table1), soil samples for laboratory analyses were taken from humification (H), organomineral (Ae, Ep) and spodic horizons (Bs, Bv). For a more detailed and objective evaluation of the Norway spruce (*Picea abies* [L.] Karst.) rhizosphere environment the samples from humification (H) and organomineral (Ae, Ep) horizons were collected by the method of soil preparation. In each of 19 research localities, three plots 50 × 50 cm in size were selected. On these 3 plots, one composite sample of H horizon, one composite sample of Ae/Ep horizon was taken. Soil from spodic horizons Bs was taken by the classical sampling method directly from soil pits. In this way, 19 composite samples of H horizon, 19 composite samples of Ae/Ep horizon and 19 samples of Bs horizon were collected in 19 research localities. For the reason of the restricted length of this paper, tabular results of laboratory analyses (Tables 2–4) are published in shortened

Table 2. Chemical and physicochemical properties of selected horizons (mean ± standard deviation)

Forest district	Horizon	pH (H_2O)	pH (KCl)	S (mmol·kg^{-1})	T (mmol·kg^{-1})	V (%)
Loučná nad Desnou	H	3.41 ± 0.16	2.73 ± 0.23	81.40 ± 19.67	654.60 ± 221.47	22.07 ± 20.12
	Ae/Ep	3.60 ± 0.14	3.02 ± 0.16	15.60 ± 11.22	192.00 ± 68.88	8.90 ± 6.12
Janovice	H	3.60 ± 0.17	2.82 ± 0.12	102.00 ± 52.08	1,050.0 ± 151.40	6.92 ± 0.92
	Ae/Ep	2.91 ± 0.08	2.53 ± 0.07	27.20 ± 10.31	188.33 ± 60.47	14.40 ± 1.77
Jeseník	H	3.76 ± 0.09	3.22 ± 0.18	42. 00 ± 4.00	926.00 ± 57.00	4.58 ± 0.71
	Ae/Ep	3.43 ± 0.16	3.16 ± 0.11	30.50 ± 28.50	146.00 ± 45.00	16.45 ± 14.45
Hanušovice	H	3.90 ± 0.25	3.29 ± 0.38	60.44 ± 34.91	938.00 ± 316.27	6.94 ± 3.38
	Ae/Ep	3.50 ± 0.33	3.07 ± 0.23	14.43 ± 14.85	160.71 ± 55.49	8.19 ± 5.91
Javorník	H	3.53 ± 0.16	2.76 ± 0.10	87.00 ± 1.00	1,227.00 ± 71.00	7.11 ± 0.33
	Ae/Ep	2.98 ± 0.04	2.93 ± 0.01	17.50 ± 16.50	118.00 ± 68.00	10.10 ± 8.10

S – instantaneous content of exchangeable basic cations in forest soil, T – cation exchange capacity – total amount of basic cations the soil is able to bind, V – basic saturation (saturation degree of the soil sorption complex by basic cations). For the reason of the restricted paper volume, tabular results of laboratory analyses (Tables 2–4) are published in a shortened form. The values of soil characteristics were averaged in research localities from a common forest district

Table 3. Chemical and physicochemical properties of selected horizons (mean ± standard deviation)

Forest district	Horizon	S	C_{ox}	N_t	C:N
		(%)			
Loučná nad Desnou	H	0.18 ± 0.02	35.39 ± 3.26	1.63 ± 0.20	21.90 ± 1.76
	Ae/Ep	–	6.25 ± 2.71	0.28 ± 0.11	22.31 ± 2.76
	Bs	–	4.52 ± 1.19	0.19 ± 0.04	23.13 ± 2.54
Janovice	H	0.14 ± 0.07	36.63 ± 6.88	1.48 ± 0.09	24.96 ± 5.85
	Ae/Ep	–	8.40 ± 1.23	0.34 ± 0.03	24.87 ± 1.50
	Bs	–	4.53 ± 2.15	0.20 ± 0.07	21.32 ± 3.15
Jeseník	H	0.22 ± 0.02	35.46 ± 4.73	1.61 ± 0.13	21.93 ± 1.17
	Ae/Ep	–	5.21 ± 2.98	0.26 ± 0.17	22.13 ± 2.65
	Bs	–	5.91 ± 0.36	0.25 ± 0.03	24.22 ± 1.00
Hanušovice	H	0.21 ± 0.05	33.83 ± 9.61	1.58 ± 0.31	21.14 ± 4.07
	Ae/Ep	–	4.09 ± 2.69	0.20 ± 0.12	19.23 ± 5.97
	Bs	–	2.87 ± 1.61	0.14 ± 0.09	20.73 ± 4.31
Javorník	H	0.19 ± 0.01	36.02 ± 6.69	1.56 ± 0.22	23.22 ± 0.97
	Ae/Ep	–	5.01 ± 3.33	0.25 ± 0.20	22.63 ± 3.39
	Bs	–	9.63 ± 2.19	0.24 ± 0.00	41.17 ± 10.17

S – content of sulphur

form. The values of soil characteristics were averaged in research localities from a common forest district.

Needles for the evaluation of stand nutrition at given sites were collected at the end of growing season. Annual shoots were taken always from the upper third of the developed crown of a given tree. Two composite samples were taken on each of 19 research plots: the one from trees without damage (hereinafter "healthy" trees) and the other from trees with visible symptoms of nutrient deficiency (hereinafter "damaged" trees). Each of composite samples was taken from twenty trees minimally. In the case of composite sample from damaged trees, shoots with visual symptoms of insufficient nutrition were taken. Trees with visual symptoms on more than 20 percent of total foliage were regarded as damaged degree II and higher (Innes 1990).

Laboratory techniques in an accredited laboratory of the company Ekola Bruzovice s.r.o. included the analyses of active (pH/H_2O) and potential (pH/KCl) soil reaction using a pH-meter with a combined glass electrode (soil/H_2O or 1M KCl = 1/2.5), soil adsorption complex characteristics (S – base content, T – cation exchange capacity, V – base saturation) according to Kappen (Zbíral et al. 1997), H^+ concentrations on the principle of pH double measurement (Adams, Evans 1990) and available mineral nutrients (Ca, Mg, K) from extracts by Mehlich II method of atomic adsorption spectrophotometry (Mehlich 1978).

Phosphorus content in H horizons was determined by the Gohler method, phosphorus content in Ae/Ep, Bs horizons was determined spectrophotometrically in a solution of ascorbic acid, H_2SO_4 and Sb^{3+}. Oxidizable organic carbon (C_{ox}) was determined by endothermic extraction in a chromium sulphur mixture. The combustion mixture was in surplus, the unreacted residue was determined by dead stop titration with Mohr salt. Total nitrogen (N_t) was determined by the Kjeldahl method (Zbíral et al. 1997). The sulphur content was determined on the basis of annealing and combustion in HCl with subsequent precipitation of sulphur by $BaCl_2$ on $BaSO_4$. Contents of nitrogen, phosphorus, calcium, magnesium and potassium were determined in needle samples. Nitrogen was measured coulometrically. The other elements were determined by an extraction-spectrophotometric method (Zbíral 1994).

Statistical survey

A statistical survey was done in the Statistica Cz programme, all hypotheses about relations among

Table 4. Contents of basic nutrients in selected horizons (mean ± standard deviation)

Forest district	Horizon	P	Mg	Ca	K
		(mg·kg^{-1})			
Loučná nad Desnou	H	6.10 ± 2.94	97.40 ± 43.55	220.00 ± 100.34	312.20 ± 84.94
	Ae/Ep	14.40 ± 10.97	35.00 ± 13.99	105.00 ± 41.12	40.20 ± 10.46
	Bs	6.80 ± 6.14	21.20 ± 4.75	73.20 ± 30.76	18.20 ± 6.01
Janovice	H	12.20 ± 8.50	61.20 ± 12.42	254.00 ± 194.44	181.60 ± 35.86
	Ae/Ep	9.88 ± 12.68	27.25 ± 4.09	115.50 ± 27.14	43.00 ± 14.51
	Bs	5.75 ± 2.75	17.00 ± 1.00	105.00 ± 3.00	25.00 ± 8.00
Jeseník	H	1.00 ± 0.00	64.50 ± 11.50	154.00 ± 4.00	168.00 ± 45.00
	Ae/Ep	10.00 ± 4.08	21.50 ± 6.94	98.00 ± 18.78	25.00 ± 10.61
	Bs	11.75 ± 7.25	25.5 ± 1.50	114.50 ± 3.50	23.50 ± 1.50
Hanušovice	H	3.36 ± 2.96	94.71 ± 55.06	194.43 ± 108.56	177.00 ± 68.52
	Ae/Ep	8.50 ± 3.49	27.82 ± 13.35	114.18 ± 33.45	26.27 ± 8.13
	Bs	13.44 ± 11.98	21.63 ± 7.05	106.75 ± 28.69	21.25 ± 4.74
Javorník	H	9.00 ± 0.00	69.00 ± 10.00	222.00 ± 25.00	129.50 ± 14.50
	Ae/Ep	8.83 ± 5.78	32.00 ± 15.12	145.67 ± 54.66	36.67 ± 27.35
	Bs	6.75 ± 1.75	25.50 ± 0.50	144.00 ± 14.00	17.00 ± 2.00

the studied variables were tested at $P < 0.05$. The state of underplanting nutrition was evaluated according to Bergmann (1988). To evaluate potential differences in the elemental composition of needles taken from the series of damaged and healthy trees the t-test for independent samplings was used. The correlation between stand nutrition and pedochemical characteristics of humification and organomineral horizons was also evaluated. Both above-mentioned data sets were compared with the degree of damage to underplantings by means of correlation matrices.

RESULTS AND DISCUSSION

Physicochemical properties of soils and nutrient status of forest stands on research plots

From the aspect of soil acidity the evaluated samples belong to the category of highly acid to very highly acid forest soils. The values of soil reaction in humification and organomineral (Ae, Ep) horizons are mostly in the range of 2.6–3.3 pH/KCl (Table 2). The values from 2.8 pH/KCl and more can be considered as sufficient for acid sites of the 7th–8th FAZ. Extreme climatic conditions, high layer of forest floor and highly acid litterfall cause natural acidification of the soil environment in this case (Hruška, Ciencala 2005; Vavříček 2005; Samec et al. 2008). The values of soil reaction decrease below 2.7 pH/KCl in 20% of the evaluated plots. Spruce is relatively resistant to low values of pH (Úradníček et al. 2009), but a decrease to these values leads to excessive mobilization of aluminium from clay minerals and a high content of Al in the soil solution negatively influences physiological processes of this tree species (Hruška 2005).

The values of base saturation in topmost soil layers (H, Ae/Ep) range from 4% to 17% while in organomineral horizons there is a moderate increase to the values of 6–20% compared to humification horizons (Table 2). From the aspect of sorption saturation the soils at the evaluated sites can be classified to the category of extremely unsaturated soils. Very low values of sorption saturation (5–10%) are normal for highly acid podzolized forest soils. However, the values of base saturation fall below 5% in 25% of the evaluated plots. These values can already be considered as extreme and the application of remediation ameliorative actions (fertilization, liming) should be envisaged on these plots.

The content and reserve of basic nutrients in soil influence the total production potential of a site to a large extent (Průša 2001). Norway spruce (*Picea abies* [L.] Karst.) does not have any great demands on the soil environment trophism but it requires higher soil moisture during the whole growing sea-

Table 5. The matrix of correlation coefficients between selected elements contained in undamaged needles and total damage to stands (N =19) on research plots (exceeding the border significance of $r > 0.49$ at $P < 0.05$ is in bold)

Element	P	K	Mg	Ca	N	S	Al	Damage
P	1.00	0.41	0.28	**–0.55**	**0.78**	0.11	0.19	–0.33
K	0.41	1.00	–0.13	–0.06	0.33	–0.04	0.04	–0.18
Mg	0.28	–0.13	1.00	–0.22	0.46	–0.28	–0.49	–0.26
Ca	**–0.55**	–0.06	–0.22	1.00	**–0.54**	0.27	–0.23	0.49
N	**0.78**	0.33	0.46	**–0.54**	1.00	–0.32	0.04	**–0.50**
S	0.11	–0.04	–0.28	0.27	–0.32	1.00	0.28	0.18
Al	0.19	0.04	–0.49	–0.23	0.04	0.28	1.00	–0.05
Damage	–0.33	–0.18	–0.26	0.49	**–0.50**	0.18	–0.05	1.00

son. A certain deficiency of some nutrients in soil need not indicate a stress factor for the spruce forest ecosystem (Úradníček et al. 2009).

Nitrogen content in topmost soil horizons shows high values on the studied plots (Table 3). In the humification horizon its content ranges between 1.4% and 1.8%. In organomineral horizons with a lower admixture of humus substances it decreases to the values around 0.2%, which is still a very stable and sufficient reserve for this horizon. Nitrogen content in needles of healthy trees is optimum (Bergmann 1988) and always exceeds the limit of 1.3–1.4%. N_t content in damaged trees is statistically significantly lower, decreasing below the limit of optimum accumulation (1.2%) on the majority of the plots (75–80%).

The amount of phosphorus the plant is able to take up is given by the balance between numerous P compounds in soil and different capacities of plants to modify their own rhizosphere environment (Fransson, Bergkvist 2000). Contents of soil phosphorus in humification horizons correspond to extremely low or low concentrations (3–9 mg·kg^{-1}; Table 4). Phosphorus reaches optimum values (10–30 mg·kg^{-1}) only in 20% of the plots. In organomineral horizons the content of this element is more favourable (6–15 mg·kg^{-1}) and decreases below extreme 5 mg·kg^{-1} only in 20% of the evaluated plots. Pronounced deficiency of this element in soil can be explained by the type of bedrock on the studied plots. Soils on gneisses generally show the deficiency of bivalent efficient bases and phosphoric acid (Slodičák et al. 2008). Similarly low contents of this element were determined in the Krušné hory Mts. (Slodičák et al. 2008), in the Hrubý Jeseník Mts. and in the Krkonoše Mts. (Vavříček 2008). Even though the above-mentioned phosphorus content in soil on the studied plots is very low, no phosphorus deficiency in the nutrient status was observed. P accumulation in needles of both healthy and damaged trees of Norway spruce is in the range of optimum values 1.5–2.4 g·kg^{-1} (Fig. 1).

Potassium content in soil is quite low (Table 4), but it does not decrease below the critical limits that would indicate risky low values with regard to the nutrition of forest tree species. Even though the amount of potash in the rock is generally sufficient, it need not be sufficient in an available form in soil. A part of K_2O bound in muscovite, orthoclase and

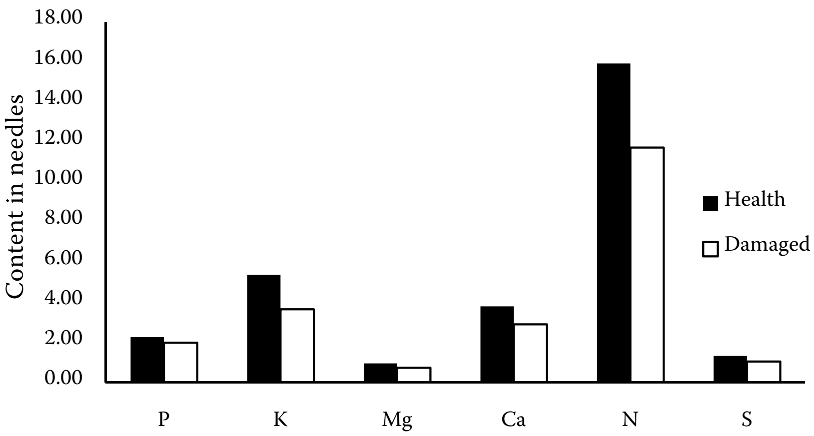

Fig. 1. Average contents of selected biogenic elements in healthy and damaged spruce needles (P, K, Mg, Ca, S (g·kg^{-1}); N (%))

biotite is released only slowly. Potassium contents in humification horizons show low or very low reserves (120–280 mg·kg^{-1}). In organomineral horizons potassium reserves are low (20–50 mg·kg^{-1}) on most plots. K content in needles of healthy trees is in the range of 4–6 g·kg^{-1} (Fig. 1) and it decreases below the limit value of 5 g·kg^{-1} in 50% of the plots. K content in needles of damaged trees is statistically significantly lower, ranging from 2.6 to 4.6 g·kg^{-1}. The causes of the generally low content of this element in needles may be different, e.g. Shen et al. (2001) found out that trees growing on the gneiss bedrock had generally lower concentrations of foliar potassium compared to other rocks.

Magnesium deficiency in soil is reported by some authors as the most probable cause of large-area decline of spruce monocultures in mountain areas (Evers, Hüttl 1990; Podrázský et al. 2003; Lomský et al. 2006; Vacek et al. 2006). The content of soil magnesium on our research plots is also very low (Table 4). In humification horizons it fluctuates at the level of low to very low values (50–100 mg·kg^{-1}). In 20% of the studied plots it is close to the extreme value of 50 mg·kg^{-1} and its content is extremely low there. In subsequent organomineral horizons the values indicate low but sufficient contents (20–50 mg·kg^{-1}). Mg content in needles of healthy trees (Fig. 1) is in the range of 0.4–0.6 g·kg^{-1} and in 50% of the plots it decreases below the limit value of 0.5 g·kg^{-1} (Bergmann 1988). Mg content in needles of damaged trees is statistically significantly lower and its range is 0.26–0.46 g·kg^{-1}, so it is below the limit value of 0.5 g·kg^{-1} on all plots. A low content of this element in needles in a comparable environment of mountain spruce monocultures was reported by a number of Czech and foreign authors (Lomský et al. 2006; Barszcz, Małek 2008). The uptake of this element may be influenced by climatic factors to a large extent. It has been confirmed that drought may significantly block the uptake of this element (Dambrine et al. 1993; Hüttl 1997; Grabařová, Martinková 2001).

Soils on the gneiss bedrock generally have a low content of bivalent efficient bases (Slodičák et al. 2008), which was also reflected in a low content of soil Ca in the studied area (Table. 4). The content of this element in the humification horizon is low but sufficient, ranging from 120 to 250 mg·kg^{-1}. Only in 15% of the plots it decreases below the limit of the lower optimum of 130 mg·kg^{-1}. In the subsequent organomineral horizon (Ae/Ep) the values of Ca indicate the lower optimum reserves in the range of 80–160 mg·kg^{-1}, and in 15% of the studied plots the content of soil Ca decreases to very low values (below 80 mg·kg^{-1}). Ca representation in the biomass of healthy needles (Fig. 1) assumes very low values with the average 3.8 g·kg^{-1}. In damaged trees Ca content is statistically significantly lower (average content 2.9 g·kg^{-1}).

In spite of a dramatic reduction in sulphur oxide emissions in the last decades there is a long-term effect of sulphur accumulation in the soil environment (Hruška et al. 2001; Uhlířová et al. 2002; Hruška, Krám 2003). Sulphur contents in horizon H are relatively high in general (Table 3) and fluctuate in the range of 0.17–0.28%. In 50% of the studied plots they are above the limit value (0.2%) and can be an excessive load for the forest ecosystem. The content of this element in the nutrient status of healthy needles is statistically significantly lower than in damaged needles (Fig. 1), hence sulphur may play an important role in disorders of the stand nutrition. The persistent problem of a certain air-pollution stress in the Jeseníky Mts. was also documented by Zapletal et al. (2003), who demonstrated a correlation between the crown defoliation and sulphur deposition levels at the end of

Table 6. The matrix of correlation coefficients between selected elements contained in damaged needles and total damage to stands (N = 19) on research plots (exceeding the border significance of r > 0.49 at P < 0.05 is in bold)

Element	P	K	Mg	Ca	N	S	Al	Damage
P	1.00	0.30	0.12	–0.09	0.45	0.01	0.42	**–0.53**
K	0.30	1.00	–0.08	**0.50**	0.39	0.12	0.46	–0.23
Mg	0.12	–0.08	1.00	**0.54**	0.49	0.04	0.06	0.03
Ca	–0.09	**0.50**	**0.54**	1.00	**0.52**	–0.17	0.24	–0.06
N	0.45	0.39	0.49	**0.52**	1.00	0.01	**0.50**	**–0.66**
S	0.01	0.12	0.04	–0.17	0.01	1.00	0.17	0.14
Al	0.42	0.46	0.06	0.24	**0.50**	0.17	1.00	–0.40
Damage	**–0.53**	–0.23	0.03	–0.06	**–0.66**	0.14	–0.40	1.00

Table 7. The matrix of correlation coefficients among selected chemical properties (N = 19) on research plots in humification horizon H (exceeding the border significance of r > 0.49 at P < 0.05 is in bold)

Element	S	C_{ox}	Nt	P	Mg	Ca	K	Al	C:N
S	1.00	**0.52**	**0.61**	–0.09	0.19	0.29	0.28	–0.26	0.14
C_{ox}	**0.52**	1.00	**0.81**	0.28	0.34	0.42	0.28	0.03	**0.72**
Nt	**0.61**	**0.81**	1.00	0.14	0.40	0.44	0.33	0.13	0.18
P	–0.09	0.28	0.14	1.00	–0.22	0.07	0.24	0.10	0.31
Mg	0.19	0.34	0.40	–0.22	1.00	**0.89**	0.09	–0.38	0.10
Ca	0.29	0.42	0.44	0.07	**0.89**	1.00	0.21	**–0.49**	0.20
K	0.28	0.28	0.33	0.24	0.09	0.21	1.00	0.05	0.11
Al	–0.26	0.03	0.13	0.10	–0.38	**–0.49**	0.05	1.00	–0.05
C:N	0.14	**0.72**	0.18	0.31	0.10	0.20	0.11	–0.05	1.00
Damage	0.10	0.39	0.29	0.28	–0.25	–0.09	**0.53**	0.24	0.30

the nineties. Contents of basic nutrients in spodic horizons (Bhs, Bs) are lower in total than in organomineral horizons (Table 4). These horizons are situated at medium depths (30–45 cm) that do not have a pronounced influence on the initial development and growth of spruce plantings any longer.

Results of statistical survey and discussion

Statistical surveys document that foliar concentrations of basic nutrients (Mg, P, K, N) were statistically significantly lower in damaged trees than in healthy trees (Fig. 1). Calcium content in damaged needles is also very low and its difference from undamaged needles assumes statistically significant values. In the Moravian-Silesian Beskids (Barszcz, Małek 2008) foliar concentrations of most nutrients were found to be at the lower limit of an optimum range or even below the limit values. The insufficient uptake of nutrients is a stressor that is closely related with the general health status and nutrient deficiency changes in the studied area of the Hrubý Jeseník Mts. The high content of toxic elements (Al, S) is another factor influencing the Norway spruce nutrition negatively. Particularly as for aluminium, its high concentrations were measured in needles of damaged trees (on average 160 g·kg^{-1}) while its decrease in healthy needles to 108 g·kg^{-1} on average is statistically significant (Fig. 1). A high amount of toxic aluminium in needles of adult trees growing on plots with symptoms of the acute stand decline was also reported by Ditmarová et al. (2007). The hypothesis of insufficient nutrient uptake, leading to subsequent yellowing, was confirmed by another statistical survey when a negative correlation was calculated between the foliar N and P content and the degree of damage to evaluated underplantings caused by nutrient deficiency (Tables 5 and 6). Damage to un-

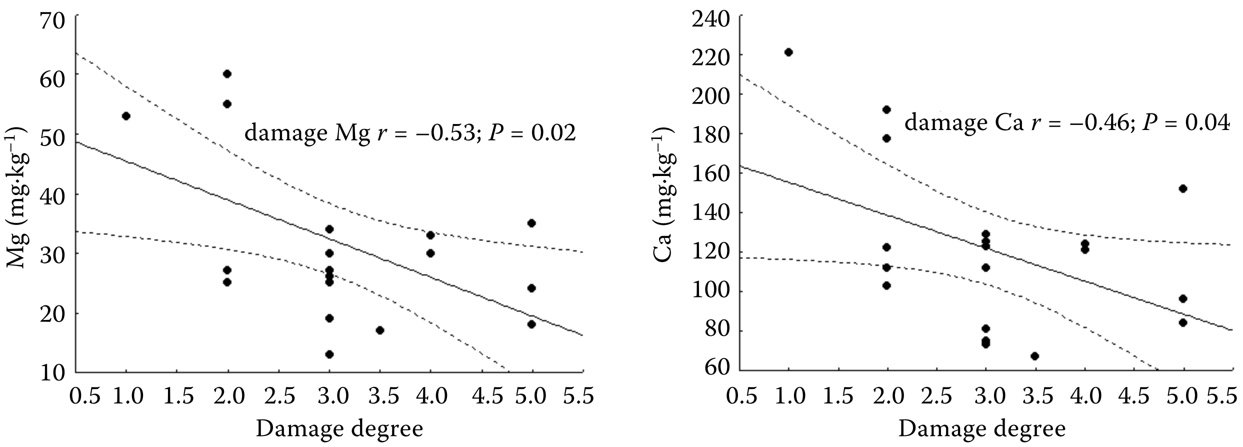

Fig 2. The correlation between Mg and Ca content in the organomineral horizon and the degree of damage to underplantings due to nutrient deficiency

Table 8. The matrix of correlation coefficients among selected chemical properties (N = 19) on research plots in humification horizons (Ae, Ep) (exceeding the border significance of $r > 0.49$ at $P < 0.05$ is in bold)

Element	C_{ox}	N_t	C:N	P	Mg	Ca	K	Damage
C_{ox}	1.00	**0.87**	0.40	0.21	**0.64**	**0.48**	**0.71**	–0.41
Nt	**0.87**	1.00	–0.06	0.27	0.70	**0.63**	**0.76**	–0.40
C:N	0.40	–0.06	1.00	–0.04	–0.01	–0.16	–0.04	–0.09
P	0.21	0.27	–0.04	1.00	–0.05	–0.05	0.11	0.27
Mg	**0.64**	**0.70**	–0.01	–0.05	1.00	**0.71**	**0.70**	**–0.53**
Ca	**0.48**	**0.63**	–0.16	–0.05	**0.71**	1.00	**0.55**	**–0.46**
K	**0.71**	**0.76**	–0.04	0.11	**0.70**	0.55	1.00	–0.45
Damage	–0.41	–0.40	–0.09	0.27	**–0.53**	**–0.46**	–0.45	1.00

derplantings increases with a decreasing content of these nutrients in needles. An opposite correlation was determined for aluminium: with an increasing proportion of this element in nutrition the coefficient of damage increases evenly. This correlation approaches statistical significance and confirms the results of a preceding statistical survey.

Contents of the majority of basic macrobioelements in topmost soil horizons (H, Ae/Ep) fluctuate at the level of very low or medium low reserves (Table 4), whereas in potassium, phosphorus and magnesium they decrease to critically low and risky values on some plots that already may negatively influence the development and growth of forest tree species. Low contents of basic nutrients may be reflected in the poor nutrition of tree species at the sites concerned, which leads to discoloration changes in the assimilatory organs and to a reduction in the total resistance potential of plants. This relationship was also demonstrated by a statistical survey when correlations between nutrient contents in soil and degree of damage to underplantings were tested at the sites concerned (Tables 7 and 8). Damage to the studied underplantings increases with a decreasing proportion of basic nutrients (N_t, Mg, K, Ca) (Fig. 2). This correlation was significant mainly in nutrient contents in organomineral horizons.

The root system of Norway spruce is usually flat and does not reach a great depth in the soil profile. The root penetration to a greater depth in mountain locations is restrained by adverse conditions deeper in the soil profile. Al^{3+} concentration and the limit value of Mg^{2+} make the root systems of trees exist mostly in H horizons or in Ae/Ep horizons (Vavříček et al. 2005). The compounds of colloidal humus are important carriers of sorption properties of soil at these depths, and the long-term disturbance of humification processes may be connected with a disorder of the nutrient status of biocoenoses and with their decline (Ulrich 1995; McLaughlin, Percy 1999; Modrzyński 2003; Purdon et al. 2004). In humification horizons at the studied sites the content of humus substances is above standard.

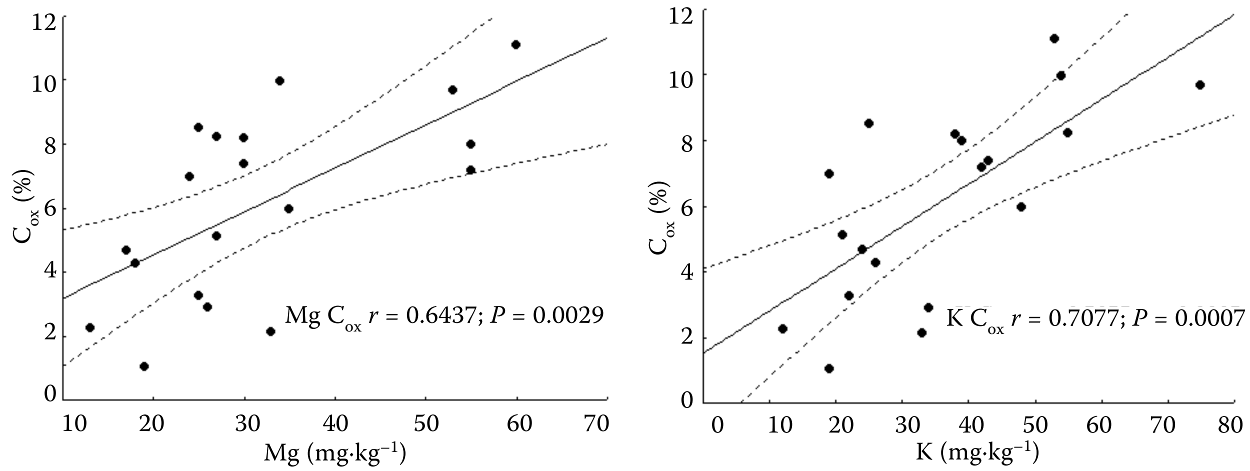

Fig. 3. The correlation between C_{ox} and Mg and K contents in the organomineral horizon

With average depth of this horizon 8–10 cm where no gravel is admixed the balance reserve of humus is very high. For the organomineral horizon of ca 5–8 cm depth the balance reserve of humus substances decreases to several times lower values in dependence on the podzolization process and with 50% skeleton content in places. Total lower nutrient reserves in these soil layers are connected with lower humus content in the organomineral horizon. This hypothesis was also confirmed by a statistical survey when a negative correlation was calculated between the content of oxidizable organic carbon (C_{ox}) and the content of nutrients (N_t, Mg, Ca, K) (Table 8) that correlate with the overall damage to stands (see the above paragraph). With a diminishing proportion of C_{ox} in Ae/Ep horizons the content of basic nutrients decreases there (Fig. 3). The proportion of humus substances (C_{ox}) in the organomineral horizon and the content of basic nutrients become limiting factors for the normal growth and development of Norway spruce monocultures in the area concerned.

CONCLUSION

- Nutrient deficiency symptoms and reduced vitality of Norway spruce underplantings in the studied ridge part of the Hrubý Jeseník Mts. are caused by insufficient uptake of basic nutrients. Foliar contents of Mg, P, K, N were statistically significantly lower in damaged trees compared to healthy trees and were below the limit of optimum values.
- The hypothesis about insufficient uptake of basic nutrients was also confirmed by the calculated statistically significant correlation between the foliar content of N and P and the degree of damage to underplantings caused by nutrient deficiency. The degree of damage to evaluated underplantings decreases evenly with a higher proportion of these elements in the assimilatory organs of Norway spruce.
- High uptake of toxic elements (Al, S) is another factor negatively influencing the Norway spruce nutrient status in the area concerned. The content of these elements in needles of damaged trees is statistically significantly higher than in healthy trees.
- Statistical survey revealed a negative correlation between the content of oxidizable organic carbon (C_{ox}) and that of the main nutrients (N, Mg, Ca, K). With a decreasing proportion of C_{ox} in organomineral horizons the content of basic nutrients also decreases.
- The representation of humus substances in organomineral horizons and also the content of basic nutrients (N_t, Mg, Ca, K) become limiting factors for the normal growth and development of Norway spruce underplantings in the area concerned.
- Based on the above-mentioned findings recommendations for forest operations in mountain areas of the CR with the air pollution past can be formulated. The best condition of underplantings was observed at sites with the sufficiently developed and humus organomineral horizon. This environment can be simulated during outplanting by mixing humification and organomineral horizons at a 3:1 volume ratio in a planting pit 40 × 40 cm in size. Such an optimized substrate mixture that can ensure and increase favourable values of the basic parameters of sorption complex, especially CEC, will improve the quality of the plant root system development. A mixture with a higher value of CEC underlies the more efficient use of basic nutrients from point applications of fertilizer tablets. The particular macrobioelements on formed bonds of the humus-clay complex are utilized more efficiently for subsequent nutrition of stands.

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Received for publication April 20, 2010
Accepted after corrections December 20, 2010

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