Soil properties as a component of predisposition factors of Norway spruce forest decline in the Hanušovická highland mountain zone

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ABSTRACT: Mature Norway spruce (*Picea abies* [L.] Karst.) stands affected by decline symptoms were selected in the northern part of the Hanušovická highland (Czech Republic) at Jeřáb Mt. foot and summit (1,003 m a.s.l.). Spruce stand (SS) 1 (700 m a.s.l.) was situated in conditions of the fir-beech forest altitudinal zone (FAZ). SS 2 (880–900 m a.s l.) was situated in conditions of the spruce-beech FAZ. Research plots (RPs) of the area 400 m^2 were selected in the stands according to the different level of damage and stand diversity. On the basis of the complex soil analysis it was proved that the soil environment could be a part of stress factors, influencing the predisposition of non-natural Norway spruce monocultures at mountain locations of the Krkonoše Mts.-Jeseníky Mts. elevation. High Al^{3+} concentrations in soil mineral horizons were determined in a direct correlation with decline of stand enclaves on the selected RPs. The concentrations of Al^{3+} and limiting content Mg^{2+} make root systems exist mainly in H-horizons or Ae/Ep-horizons. This causes stand predisposition to climatic drought and drought episodes.

Keywords: forest decline; drought episode; stress; Hanušovická highland; Norway spruce stand

Long-term human landscape management led to changes in the forest stand composition and also to a loss of forest auto-regulation mechanisms. Forests responded by their decline to the long-term ecological destabilisation. Forest decline took place in concordance with the concept of stress theory (Manion 1991) as a complex of stress factors whose synergies overreached energetic limits of organism alarm reaction reversibility at the stress occurrence (Selye 1956; McLaughlin 1985; Saxe 1993; Badea et al. 2004).

Forest decline was mostly described as a synergistically functioning combination of air pollution depositions, drought episodes, root pathogens and parasitical insects (Modrzyński 2003). Although the level of air pollution has decreased in Central Europe (Erisman et al. 2005; Percy, Ferretti 2004) and deposition impacts into soil are still mobile and continuously eliminated (Lochman et al. 2004), its residues are detected according to its ecological impact (Van Straalen 1998). Some air pollution components are in the environment widen (Jones et al. 1988) and are of considerable eco-toxicological importance for physiological and biochemical processes in living systems. Forest stand predisposition to the leverage of abiotic and biotic stressors is a general consequence (Chappelka, Freer-Smith 1995).

Natural stands and production monocultures are affected by a forest decline symptom to a different extent. Whereas natural biocoenoses are able to reach a dynamic balance with the soil environment in the range of continual succession development, man managed monocultures do not have this ability (cf. Badea et al. 2004; Dittmar et al. 2003). Forest stand sensitivity generally increases with the elevation and changes also in correlation with the soil matrix. Dependence of forest ecological stability on

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Table 1. Some basic mensurational data of selected stands (according to forest management plans 1999–2008, Ruda nad Moravou forest district)

Stand number	Species composition	Percent distribution (%)	Medium stem		Standing volume (m^3/ha)	Stand basal area (m^2/ha)
			$d_{1.3}$ (cm)	h (m)		
1	*Picea abies*	96	34	31	505	553
	Fagus sylvatica	2	31	25	5	6
	Abies alba	1	36	30	5	6
	Larix decidua	1	46	33	5	5
2	*Picea abies*	98	32	25	373	382
	Fagus sylvatica	1	34	24	4	3
	Larix decidua	1	28	17	2	2

soil properties increases with the elevation above sea level at the same time.

The natural Central European mountain forests were portrayed especially as ecosystems in conditions of fir-beech (FAZ 5), spruce-beech (FAZ 6), beech-spruce (FAZ 7) and spruce (FAZ 8) forest altitudinal zone (cf. Ellenberg 1988, 1996; Zatloukal et al. 2000; Haniš et al. 2000). Even-aged spruce monocultures dominate in their sites nowadays. These stands are often and significantly damaged by air pollution load and are consistently susceptible. In the European standards the mountain forests are currently significantly damaged especially by tropospheric O_3 deposition and heavy metals (Smidt, Herman 2004) although SO_2 impact is decreasing and NO_x impact is slightly increasing. These substances have an effect on forest stand predisposition to sensitivity especially to extremely low temperatures and soil moisture deficiency (Chappelka, Freer-smith 1995). The increasing extremity of climatic conditions in mountain locations prefigures also the increasing sensitivity of mountain soil to outside disturbances (Hruška et al. 2000). Mountain soils in dependence on the soil matrix properties are permanently marked by high resistance, but naturally low resiliency (Begon et al. 1987). Especially in mountain conditions the dependence of biota on dead organic matter is increasing (Jančařík 2000). Basically insufficient content of dead wood is reflected in a decrease of biodiversity and soil biota activity, endangering the ecosystem nutrition flow and humus genesis (Fabiszewski, Wojtun 2000). A physicochemical podzolisation process with the establishment of soil with dominant illuvial horizon Bs and eluvial horizon Ep ordinarily becomes the determining process of soil genesis in mountain conditions. In the conditions of FAZ 8 podzolisation is often necessary and can be reduced only by influence of lateral water or by trophic proportion of soil matrix (Vavříček, Šimková 2000).

MATERIAL

A part of the Hanušovická highland was selected (Natural Forest Region 28 – Předhoří Hrubého Jeseníku) where long-term drought during the vegetation season 2003 led to a fast change in forest decline dynamics and its dieback. Marked defoliation and forest stand discoloration became specific of these symptoms as well as the occurrence of tree dieback in bio-groups. Research plots (RPs) were established in two mature damaged spruce stands (SSs) (Table 1) on hillsides of Jeřáb Mt. (1,003 m a.s.l.). The Hanušovická highland is a forming part of the geotectonic unit Silesicum. The bedrock is mainly built of biotite – muscovite gneiss. On both sides originated conditions for dominant occurrence of Haplic Podzol (ISSS-ISRIC-FAO 1998) [L – F – H – Ep (Ae/Ep) – Bhs – Bs – C]. Hemimor

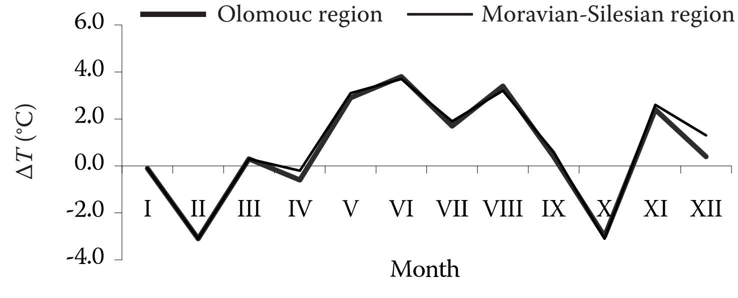

Fig. 1. Annual course of mean temperature variances in 2003 (data source ČHMÚ 2004)

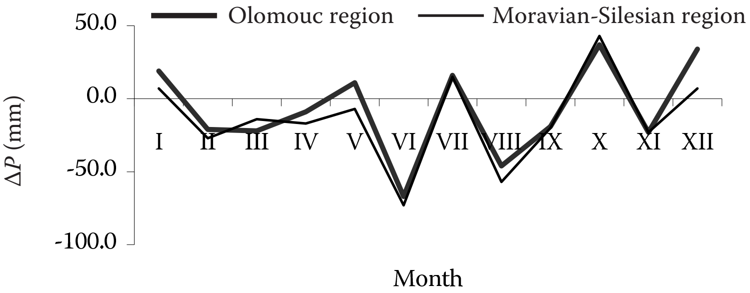

Fig. 2. Annual course of precipitation variances in 2003 (data source ČHMÚ 2004)

generally developed as the basic form of uppermost humus (cf. GREEN et al. 1993). The potential natural vegetation of this region is generally represented by the *Luzulo-Fagion* (*Luzulo-Fagetum*, in the mountain locations often *Calamagrostio villosae-Fagetum*) association (cf. ELLENBERG 1996; CULEK 1996; VACEK, LEPŠ 1991).

The mean annual temperature in the whole area of the natural forest region (NFR) ranges from +7.5 to +4.5°C (average +6.0°C). The mean annual precipitation in this area ranges between 600 and 1,100 mm (average 850 mm). Average temperature during the vegetation period is +12.0°C and average precipitation 560 mm (ÚHÚL 2002). The year 2003 was significantly above the normal during the vegetation season according to the temperatures while precipitation was rather subnormal (PAVLÍK et al. 2003). The annual course of temperatures pointed out constant difference of considerable territory (Fig. 1) with correlative data of the Olomouc Region and Moravian-Silesian Region r = 0.99. The regional, anemographic and orthographic data specifically reflected in the development of total rain (Fig. 2) from the Olomouc Region and Moravian-Silesian Region with decreased data correlation r = 0.95.

The selected RPs had similar bedrock, soil type and approximate exposition. They differed in elevation above sea level, micro-relief and terrain micro-configuration, forest type group (FTG) and forest decline symptoms (VAVŘÍČEK et al. 2005). SS 1 (224C 12/1a) was situated on a slope with north-west exposition 700 m a.s.l. The conditions of this plot corresponded to FAZ 5 and FTG 5K. SS 2 (216C 9) was situated on a ridge part of a slope with northern exposition 880–900 m a.s.l. This plot corresponded to FAZ 6 and FTG 6K. Sheet landslide significantly affected soil genesis. While SS 1 showed symptoms of decline especially by means of discoloration of spruce needles and tree defoliation relatively equally distributed on side, SS 2 was characterised by diverse of levels of tree damage and tree groups decline.

METHODS

Methods of pedological survey and analyses

In the sites SS 1 and SS 2 RPs were selected according to the evaluation of the characteristics tree defoliation (BADEA et al. 2004), degree of stand diversity (KORF et al. 1972) and composition of understorey phytocoenosis (VAVŘÍČEK et al. 2005). Two RPs were established on SS1. Five RPs were established on SS 2. The area of each RP was 400 m^2 (20 × 20 m) and defoliation degree was determined by qualified appraisal (RP1 = 0; RP2 = 1; RP3 = 2; RP4 = 2/3; RP5 = 3/4). The field investigation and soil sampling were carried out during October 2004. At the same time on RPs SS 2, samples of annual shoots and first-year spruce shoots were collected from the upper third of the crown in the case of selected sample trees and analysis of selected chemical elements from the assimilatory apparatus was carried out (cf. ZBÍRAL 1994). The complete soil analysis was carried out aiming at physical, physico-chemical and chemical properties.

Evaluation of physical properties was focused on the textural analysis of soil layers. The determined fine earth I size fraction (ČSN 75 0145) was defined according to the taxonomic classification system of soils (NĚMEČEK et al. 2001). The determination of selected basic physico-chemical and chemical soil properties was concentrated into the uppermost layers of soil profiles, especially into horizon H and organic-mineral horizon Ae (in fact into mineral horizon). Soil acidity (pH/H_2O and pH/KCl) was determined with a conjunct glass electrode (soil/H_2O or 1M KCl = 1/2.5). Cation exchange capacity (*CEC*) was determined by the modified Kappen method (KLEČKOVSKIJ, PETERBURSKIJ 1964; IVANČIČ et al. 1985) and the Mehlich accumulation method (ZBÍRAL 2002) with consideration of present Al^{3+}, determined by Sokolov method (SOKOLOV 1939). The plant available mineral nutrients (Ca^{2+}, Mg^{2+}, K^+) were determined by atomic absorption spectrophotometry from an extract by the Mehlich II method. Content of phosphorus was determined by spectrophotometry in the solution of ascorbic acid, H_2SO_4 and Sb^{3+} (Mehlich 1978). Analyses of plant available nutrients in H-horizon were carried out in Gohler extract with the ratio of soil/macerate = 1/10, whereas phosphorus content was accomplished in the presence of $CH_3COONa+CH_3COOH$.

The content of oxidisable organic carbon (C_{ox}) was determined by the oxidation $H_2Cr_2O_7 + H_2SO_4$ when unconsumed chromic acid was determined by titration of Mohr salt solution. Total nitrogen (N_t) content was determined by Kjeldahl method (Zbíral et al. 1997). Humus substances (Ugolini, Spaltenstein 1992) from samples of H- and Ep (Ae/Ep)-horizon were determined by spectrophotometry based on the level of absorbance of humus substances in pyrophosphate (Kononova, Bělčikova 1961). Total fixed carbon was determined by the method of determination of humus compounds (C_{org}), carbon from humic acids (C-HA), carbon from fulvic acids (C-FA) and the ratio C-HA/FA.

Methods of statistical analyses

The evaluations of data statistics were mostly done at standard level of significance ($P < 0.05$), after basic predisposition for data selection was completed. In cases of significantly disturbed data normality and homogeneity the significance level had to be decreased (Anderson 1987; Miller, Miller 1984). $P < 0.50$ was taken as the limit for methods of the general linear modelling (GLM) (Meloun, Militký 2002). One-way analysis of variance (ANOVA) was used as the basic analytic procedure of statistical data processing. Its robustness was verified by using non-parametric Kruskal-Wallis (K-W) test (Zar 1994). The linear model constructions were proposed on the basis of interpretation of correlation coefficient significance (r) during evaluation of chemical or eco-physiological data (cf. Zemánek et al. 2004).

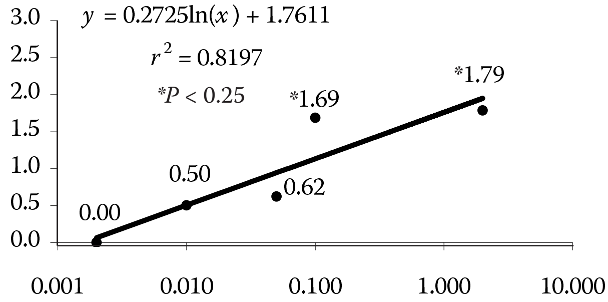

Fig. 3. Logarithmic trend of F-criterion values ($F_{critical} = 5.32$ at $P < 0.05$) in dependence on various grain fractions

RESULTS

Main differences between the stands

Based on the soil analyses, differences between SS 1 and SS 2 were determined in the parameters deducible from exposure to mesoclimate changes. These differences were ordinarily conjoined with the soil physical properties. The particle-size analysis (Table 3) partly indicated generally similar physical soil properties in both stands, although similar grain size distribution in the soil was only found in the fraction < 0.05 mm. The differences between stand soils at the decreased significance $P < 0.25$ were determined in the case of larger fractions (Fig. 3). The differences were sporadically determined only as a result of significantly interrupted normality distribution of reviewed data and high variance in chemical (Tables 3 and 4) and physicochemical soil (Table 5) properties. This result on $P < 0.15$ was adequate to differences in the content of phosphorus in soil and on $P < 0.32$ to differences in the content of CEC_{Kappen}.

Table 2. Soil particle analysis of selected spruce Norway stands

Spruce stand	Horizon	Physical clay < 0.002 mm	I. clay < 0.01 mm	II. silt 0.01–0.05 mm	III. silty sand 0.05–0.10 mm	IV. sand 0.10–2.00 mm
1	Ep	8.50	32.15	20.10	16.30	56.45
	Bhs	5.90	11.80	13.00	7.00	68.20
	Bs1	7.35	14.75	20.40	11.15	53.70
	Bs2	9.05	15.20	27.25	16.70	40.85
	C	10.05	15.85	16.80	14.90	52.45
2	Ep	7.80	15.40	26.10	17.00	41.50
	Bhs	7.50	14.80	31.40	17.00	41.50
	Bs1	5.20	17.00	24.00	15.20	43.80
	Bs2	7.50	15.30	17.80	14.00	51.00
	C	9.00	11.80	20.60	11.60	56.00

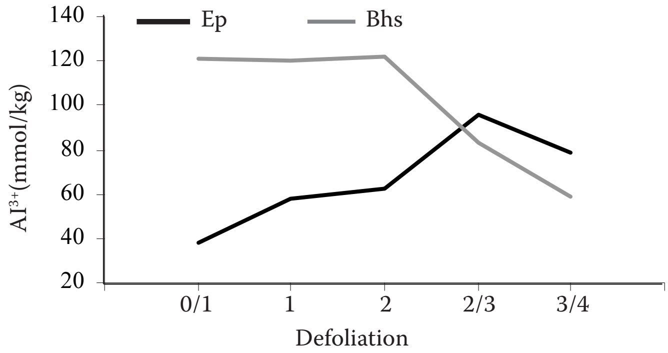

Fig. 4. Concentration stage of Al^{3+} in Ep- and Bhs-horizons in dependence on defoliation class of the RPs

Soil properties of the stands

Spruce stand 1

The coarse sandy geest of biotite-muscovite gneiss was typically determined as the parent rock at site RPs that fundamentally participated in the determination of the texture of whole soil profiles. Due to this fact soil profiles of RPs were permeable and without marks of profile water stagnation. This fact had an influence on the edatope of tree root systems and increased the root system physiological depth. The pH/H_2O values in the H-horizon were determined in the interval 3.66–3.81, pH/KCl values in the interval 2.74–2.93. Soil acidity reached the values ranging from 3.75–4.60 to 2.87–4.06 (Table 5) in the uppermost soil horizons. *CEC* in the H-horizon was determined in the interval 1,043 to 1,284 mmol/kg. It was determined in correlation with the used analytical method in the interval 182.00 to 290.40 mmol/kg in the A-horizon or Ep-horizon. The content of physiologically active phosphorus in the H-horizon reached 17–18 mg/kg. Mg^{2+} content was determined at an approximate level 90 mg/kg for H-horizon with a significant decrease to 30–40 mg/kg in the mineral horizon. Ca^{2+} (Table 3) also showed an analogous character of the concentration changes in the H-horizon (378 to 384 mg/kg) and mineral horizons (average 154.50 mg/kg for Ep). Content of K^+, as the only determined biogenic ion in the study, was distinctly influenced by podzolisation of the soil profiles. SS 1 showed relatively lower contents of C-HA (2.86%) according to the content of C-FA (1.27%) in the H-horizon, which was also reflected in a relatively decreased ratio C-HA/FA = 2.25 (Table 4). C_{ox} content in the H-horizon (24.70–33.20%) generally appeared as relatively less ambivalent. It also displayed in the final C/N ratio value in the interval 24.41–27.75.

Spruce stand 2

The particle-size analysis of soil profile in SS 2 (Table 2) indicated a typical relative fraction increase from silt fraction to sand fraction in the fine earth of samples for this site. This stage led to fast podzolisation in combination with high total precipitation, cation leaching and accelerated hydrolytic weathering. This effect was reflected in a higher content of K^+ in the C-horizon (20–25 mg/kg) and in high mobility of Al^{3+}. High Al^{3+} concentrations were determined in connection with stand decline in the uppermost soil horizons of RPs (Fig. 4). The Al content in the Ep-horizon was 96 mmol/kg on RPs with a high degree of spruce damage, conversely Al content amounted to only 38 mmol/kg in soil on RPs with relatively low spruce damage. The content of phosphorus in the H-horizon significantly corresponded with SS 1 condition, however in the organic-mineral and mineral horizons its content was found to be 2–3× higher (21.60–32.00 mg/kg). The higher biological activity of uppermost soil layers depended on this stage and also on more intensive humification that was detected in the H-horizon by means of relatively higher content of C-HA (3.80%) and lower content of C-FA (1.04%). The C-HA/FA ratio was 3.66 (Table 4).

Table 3. Analysis of mineral macrobiogenic elements for soils of the selected Norway spruce stands (mg/kg)

Spruce stand	Horizon	P	Ca	Mg	K	S
1	H	17.50	381.00	87.50	195.00	1.44
	Ep	10.50	154.50	38.00	49.00	–
	Bhs	7.00	147.50	34.50	32.00	–
2	H	14.80	278.80	61.20	176.60	1.56
	Ep	32.00	143.60	33.20	60.20	–
	Bhs	21.60	110.60	28.20	51.00	–

Table 4. List of organically bound biogenic elements on the basis of C_{org} (%) [C-HA and C-FA (%); C-HA/FA (1)], C_{ox} (%) and N_t (%) [C/N (1)]

Spruce stand	Horizon	C_{ox}	N_t	C/N	C_{org}	C-HA	C-FA	C-HA/FA
1	H	28.95	1.13	25.73	4.13	2.86	1.27	2.25
	Ep	3.65	0.20	18.72	1.54	0.53	1.01	0.52
	Bhs	2.71	0.18	15.06	–	–	–	–
2	H	33.14	1.04	31.80	4.83	3.80	1.04	3.66
	Ep	3.10	0.17	18.00	1.10	0.52	0.58	0.89
	Bhs	4.42	0.28	15.89	–	–	–	–

Table 5. Characteristics of basic physicochemical soil properties [pH and cation exchange capacity – *CEC* (mmol/kg)] of the selected Norway spruce stands

Spruce stand	Horizon	pH/H_2O	pH/KCl	CEC_{Kappen}	$CEC_{Mehlich}$
1	H	3.74	2.84	1,163.50	–
	Ep	3.75	2.89	182.00	290.40
	Bhs	4.30	3.70	150.50	267.00
2	H	3.55	2.79	1,248.00	–
	Ep	3.85	3.00	252.59	211.24
	Bhs	4.14	3.50	227.02	368.09

Although a significantly lower content of C-FA (0.58%) was determined in the organic-mineral horizons, the C-HA/FA ratio remained relatively higher (0.89). The level of organic reactants polymerisation at humification was also detected through the *CEC*. The *CEC* values in the H-horizon reached on average 1,248 mmol/kg. *CEC* average values in the uppermost mineral horizons were 252.59 mmol/kg (Table 5). pH/H_2O values in the H-horizon were in the interval 3.45–3.77, pH/KCl values in the interval 2.61–3.00. The level of soil acidity in uppermost soil horizons ranged from 3.73–4.01 to 2.81–3.23. Ca^{2+} content in the soil profile was apparently determined as decreased in correlation with the predicted intensity of podzolisation processes. Table 3 shows that Ca^{2+} content was 278.80 mg/kg in the H-horizon, 143.60 mg/kg in the Ep-horizon and only 110.60 mg/kg in the Bhs-horizon. Mg^{2+} content on site SS 2 was determined primarily very low (61.20 mg/kg in the H-horizon and 30.70 mg/kg in the uppermost mineral horizons) and limiting for indication of discoloration changes in the spruce needles.

The high Al^{3+} contents in site SS 2 were displayed in a significantly shallower root system. The limiting Mg^{2+} values meant basic deficiency for plant nutrition in this site. Correlations of Mg^{2+} and Al^{3+} contents in the Ep- and Bhs-horizons were obtained only at the limit significance level $P < 0.50$. The content of Al^{3+} in the Ep-horizon was in relation

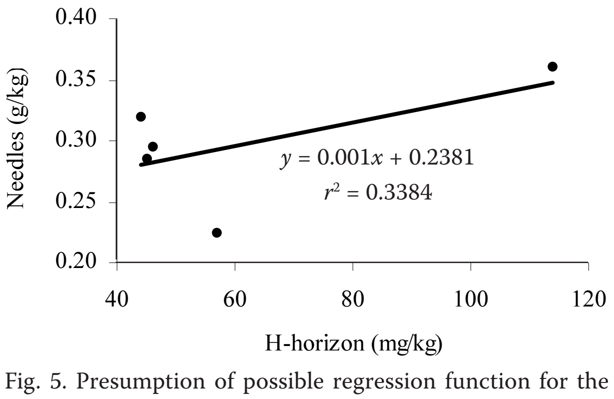

Fig. 5. Presumption of possible regression function for the predicted correlative amount of Mg^{2+} in spruce needles and in H-horizon

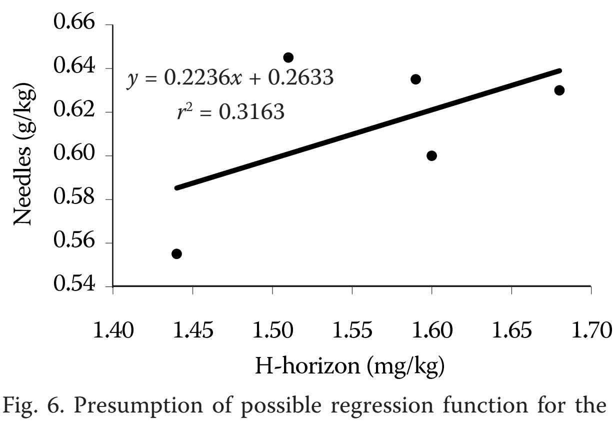

Fig. 6. Presumption of possible regression function for the predicted correlative amount of sulphur in spruce needles and in H-horizon

Table 6. Analysis of the selected biogenic elements in spruce needles from the apical section of sample tree crown on the individual research plots (RPs) in stand 216C 9 (SS 2); DC – defoliation class (according to Badea et al. 2004)

RP number	DC	Needle age	Needle element					
			N	P	K	Ca	Mg	S
			(%)	(g/kg from dry matter)				
1	0	1-year	1.42	1.87	5.52	1.38	0.37	0.53
		2-year	1.24	1.54	4.21	1.58	0.22	0.58
2	1	1-year	1.38	1.97	6.99	2.64	0.42	0.61
		2-year	1.07	1.66	5.27	1.69	0.22	0.66
3	2	1-year	1.11	2.30	7.05	1.91	0.49	0.66
		2-year	1.08	1.64	4.46	1.99	0.23	0.63
4	2/3	1-year	1.33	1.94	6.00	1.55	0.29	0.59
		2-year	1.07	1.44	4.72	2.03	0.16	0.61
5	3/4	1-year	1.25	1.94	7.76	1.78	0.36	0.69
		2-year	1.14	1.74	5.16	2.87	0.21	0.57

to biological activity determined as negatively affecting. The positive correlations were found between Al^{3+} concentration and C/N ratio ($r = 0.56$ at $P < 0.30$) and C-FA ($r = 0.72$ at $P < 0.15$). The C/N ratio partially corresponded with a decreased N content in the spruce needles and indicated that recorded values of soil N_t resulted especially from nitrogen substances in the physiologically inaccessible form. Accordingly, the C/N ratio value 31.80 could be seen as a conducive effect to the limitation of the site trophic potential (STP).

The discoloration indication causes based on spruce needle analysis (Table 6) showed that there were not any statistical significant differences in the chemical composition between sample trees. The correlations between elements in the needles and H-horizon characteristics were generally determined as inconclusive. The correlation between the chemical composition of spruce needles and pH was not determined. Only for the level of Mg^{2+} ($r = 0.58$) and S ($r = 0.56$) was a statistically significant dependence determined at $P < 0.32$. Linear regression was laden by outliers error (cf. Figs. 5–6).

DISCUSSION

Discussion about the particular results

CEC was one of the most important soil properties. *CEC* was directly dependent on soil acidity, mineral composition of parent rock and buffering capacity of soil solution. It was determinant for total site trophic potential (STP). The importance of *CEC* for STP increased especially in the conditions of permanent anthropogenic load. The air pollution deposition was mostly considered as the main cause of stress in the Central European environment (Ulrich 1995; Erisman et al. 2005; Percy, Ferretti 2004). Although the level of air pollution stress in the territory of the Czech Republic does not currently represent a limiting factor for the existence of forest ecosystems, in the case of ecotoxicology it remains evident as residual soil acidification (Purdon et al. 2004). The current SO_2 loading in the region reached on average 5–25 μm/m³ (Vavříček et al. 2005).

The soil buffering capacity was dependent especially on soil hydric regime, parent rock weathering and humification intensity. Clay minerals especially increased its representation due to hydrolytic weathering of feldspar and ensured the long-term stability of soil buffering capacity and also determined the stabile component of *CEC*. Variable components of sorption complex (especially colloid humus) asserted in the relatively short-term scale on the soil buffering capacity and *CEC*. Exact *CEC* determination depended on the use of proper methods (Sumner, Miller 1996). Both methods of *CEC* determination used for the soil sample analysis from both SSs were estimative, although the method according to Mehlich could generally provide results correlative with determination of the effective cation exchange capacity (Vranová 2005). No statistically significant differences were found between the results of CEC_{Kappen} and $CEC_{Mehlich}$. The results were not reciprocally correlative. These results did not prove any significant and long-term influences of air pollution deposition on *CEC*. These results supported the theory that significant changes in the soil buffering potentiality in the Central European conditions were more related to biological activity changes in the reflection of humification and production of colloidal humus (Ulrich 1995).

These results corresponded especially with determined sulphur content in the H-horizon that correlated with biogenic inputs and was not significantly supported by atmospheric deposition. Soil acidification problems in both localities were especially related to the surplus of low molecular FA as products of decomposition that could be washed out. Low molecular FA was secondarily cumulated in Bhs- and Bs-horizon in the podzol soil profiles (Vranová 2004). In case biogenically fixed Ca^{2+} was incorporated into waste decomposition, it led to humification stimulation and decreased release of organic acids into the soil profile (Andersson et al. 2000). The environment with naturally low concentration Ca^{2+} on all RPs was not able to decrease the rising ratio of FA. However, acid conditions supported the activity of mycorrhizas (Hýsek, Šarapatka 1998; Kozlowski 1971) and as a result the factor of ecological substitution ensured the fast and effective accessibility of phosphorus for plant nutrition. Haplic Podsol on RPs in SS 1 reported the stage of chemical and physicochemical properties adequate to sites of FAZ 5 (Vavříček et al. 2005). The sites of RPs in SS 2 were characterised by lower Ca^{2+} content, limiting Mg^{2+} content but sufficient content of available PO_4^{3-}. Soil properties of SS 2 were a typical result of acid parent rock, high precipitation and intensive leaching of substances from the soil profile. This was adequate to natural factors in the FAZ 6–8 conditions.

Norway spruce is a tree species with the naturally shallow root system. Its root biomass was concentrated in the H- and Ae/Ep-horizons on the RPs. In the H-horizon up to 75% of all fine roots could be located (Mauer 1999). Norway spruce dependence on the process in the H- and Ae/Ep-horizons also meant potential danger by spell of drought. In case these stands had long-term predisposition, they were marked by lowered vitality, physiological activity and disrupted interactions with soil biota and sorption complex. These stages of stands corresponded indirectly with the high values of C/N ratio determined at SS 2. At simulated seasonal dry spells the spruce could be endangered even by 30% losses of fine roots (Persson et al. 1995). If the destruction of mycorrhizal interrelationship appeared, forest decline was unavoidable (Pavlík 1999).

General discussion

In cases where spruce stands were grown in the conditions where they could not reach the seral stage of dynamic balance with soil environment, they could not create sufficient auto-regulative interactions with the other components of geobiocoenosis (Modrzyński 2003). They were not able to respond to stressor functioning by ecological substitution and their predisposition consecutively led especially to their increased sensitivity to climatic episodes and weather conditions. Stand defoliation was not only their response to stress; it was also a source of stress (Sierota 1995). Predisposed spruce stands could be affected by the forest decline on a different level according to the specific soil conditions. In sites of the Hanušovická highland more expressive and more differentiable symptoms of forest decline and spruce stand dieback were reported in the areas of FAZ 6. They were less endangered by dry spells by its macroclimatic characters potentially. This stage resulted into synergic actuation of many impacts (cf. Modrzyński 2003; Purdon et al. 2004):

1. Soil environment of SS 2 in the conditions of FAZ 6 was marked by high concentrations of Al^{3+} in the mineral horizons. The main soil biological activity in SS 2 was determined for H-horizon. In the mineral horizons its decrease was displayed by a significant decrease of C-FA content, Ca^{2+} and PO_4^{3-}. Primarily low Mg^{2+} content in the whole soil profiles potentially caused limiting biota dependence on it by its relationship to organic colloids and biomass.
2. The SS 2 edatope was affected by sheet landslide that appeared as considerable differentiation of soil conditions and interior soil genetic conditions. The slope still inclined to landslides and windthrows. The situation where the regression relation between Mg^{2+} and Al^{3+} was detected only at the limit significance level $P < 0.50$ means that the influence of soil environment heterogeneity on predisposition of spruce stands was not unequivocally conclusive, it was not significantly conditioned by soil mineral substances but it could be related with unbalances in the soil organic compound dynamics. This assumption was supported especially by high values of C/N ratio and conclusive correlation of Al^{3+} content in the Ep-horizon and C-FA content as a result of significantly slowed humification.
3. The extremely warm and dry vegetation season 2003 was warmer up to +3.8°C above normal during the period of April–September. During this season the months of June (–70.0 mm), August (–52.0 mm) and September (–19.5 mm) were significantly below normal precipitation in the whole Jeseníky region and Moravian-Silesian Beskids (cf. ČHMÚ 2004).
4. The root system of forest tree species was reduced in correlation with soil environment properties

especially in uppermost soil horizons. At this site a niche for rhizosphere development was provided that contributed to the acceleration of decomposition products with colloidal particles of sorption complex (cf. Rejšek 2004) and it was sensitive to deficiency of soil moisture. Predisposed, open stand and partially defoliated spruce stand was not able to provide sufficient ecological cover for preservation of stable soil moisture (Vavříček et al. 2005) nor stable conditions for the existence of soil microbial communities (cf. Hýsek, Šarapatka 1998).

5. The stand opening contributed to the spreading of considerable abundance of weed-herb storey of understorey vegetation. Blocking of available NH_4^+ and NO_3^- was presupposed in its biomass. Values N_t expressed the presence of physiologically unavailable nitrogen forms that was only progressive in the conditions of slower humification and mineralisation. High values of C/N ratio corresponded with this statement.

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Půdní vlastnosti jako součást predispozičních faktorů při chřadnutí smrkových porostů v montánních polohách Hanušovické vrchoviny

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ABSTRAKT: Byly vybrány dospělé smrkové porosty postižené symptomy chřadnutí v severní části Hanušovické vrchoviny (Česká republika) na úpatí a hřebenu vrcholu Jeřáb (1 003 m n. m.). Smrkový porost (SP) 1 (700 m n. m.) byl situován v podmínkách jedlo-bukového lesního vegetačního stupně (LVS). SP 2 (880–900 m n. m.) byl situován v podmínkách smrko-bukového LVS. V porostech byly zvoleny výzkumné plochy (VP) o dílčí rozloze 400 m^2 na základě různého stupně poškození a stanovištní rozrůzněnosti. Pomocí komplexní analýzy půd se podařilo prokázat, že půdní prostředí může být součástí stresových faktorů, působících v montánních polohách krkonošsko-jesenické elevace predispozici nepřirozených smrkových monokultur. Vysoké koncentrace Al^{3+} v půdních minerálních horizontech byly zjištěny v přímé vazbě na poškození enkláv VP. Koncentrace Al^{3+} a limitní stav Mg^{2+} nutí kořenové systémy stromů existovat převážně v H-horizontech, případně v Ae/Ep-horizontech. To porosty predisponuje vůči klimatickému suchu a suchým epizodám.

Klíčová slova: chřadnutí lesa; suchá epizoda; stres; Hanušovická vrchovina; smrkový porost

Chřadnutí lesů se děje jako synergické působení stresových faktorů. Zatímco přirozené biocenózy jsou schopny v rámci kontinuálního sukcesního vývoje dosáhnout dynamické rovnováhy s půdním prostředím, hospodářské monokultury tuto schopnost nemají. Senzitivita lesních porostů obecně roste s nadmořskou výškou a mění se i v závislosti na půdotvorných substrátech. Zároveň s nadmořskou výškou roste závislost ekologické stability lesa na půdních vlastnostech.

Byla vybrána část Hanušovické vrchoviny (Přírodní lesní oblast 28 – Předhoří Hrubého Jeseníku), kde v průběhu vegetačního období roku 2003 došlo v důsledku dlouhotrvajícího sucha k rychlé změně dynamiky chřadnutí porostů a k jejich odumírání. Imisní depozice tohoto regionu (5–25 μm/m^3) nepůsobí jako limitní faktor existence lesních ekosystémů a zdejší montánní stanoviště nebývají obvykle zasahována klimatickým suchem (Zatloukal et al. 2000). Výzkumné plochy (VP) byly založeny ve dvou dospělých poškozených smrkových porostech (SP) (tab. 1) na svazích kóty Jeřáb (1 003 m n. m.). V rámci SP 1 (224C 12/1a; 5K) byly na základě stupně rozrůzněnosti porostu (Korf et al. 1972) a vymezitelných stupňů defoliace stromů (Badea et al. 2004) vybrány dvě VP, v rámci SP 2 (216C 9; 6K) bylo vybráno pět VP. Na každé VP byly odebrány půdní vzorky z celého profilu [L – F – H – Ep (Ae/Ep) – Bhs – Bs – C]. Z VP na SP 2 byly odebrány i vzorky jehličí z letorostů a ročních prýtů. Byly provedeny komplexní analýzy půdních vzorků s rozlišením vlastností fyzikálních (Němeček et al. 2001; Zbíral et al. 1997), chemických (Ugolini, Spaltenstein 1992; Kononova, Bělčikova 1961; Zbíral et al. 1997) a fyzikálně-chemických (Ivančič et al. 1985; Zbíral 2002). Z jehličí byl vyhodnocen obsah hlavních bioelementů (Ca^{2+}, Mg^{2+}, K^+, PO_4^{3-}, S, N) (Zbíral 1994).

Výsledky dokládají, že v rámci půdních vlastností se podmínky v obou vybraných smrkových porostech liší především v parametrech přímo závislých na klimatických činitelích a na procesech zvětrávání, které klima ovlivňuje. SP 1 obecně vykázal méně exponované podmínky edatopu, které jsou pravděpodobně jedním z důvodů, že se symptomy chřadnutí tohoto porostu vyskytují jen roztroušeně a pouze ve formě diskolorace a většinou slabé defoliace stromů. Půdní prostředí SP 2 bylo vyhodnoceno jako soubor činitelů, které mohou přímo podporovat predispozici nepřirozených smrkových monokultur. Specifikem zde zaznamenaných symptomů chřadnutí se stala výrazná defoliace a diskolorace lesních porostů a výskyty hynutí stromů v bioskupinách. Výsledky a diskuse umožňují následující interpretace:

1. Půdní prostředí SP 2 v podmínkách LVS 6 se vyznačuje vysokými koncentracemi Al^{3+} v minerálních horizontech. Hlavní biologická aktivita půdy byla zjištěna pro H-horizont. V minerálních horizontech se její snížení projevilo výrazně nízkým obsahem C-FK, Ca^{2+} a PO_4^{3-}. Primárně nízký obsah

Mg^{2+} v celém půdním profilu potenciálně působí limitní závislost bioty na něm prostřednictvím jeho vazeb na organických koloidech a biomase.
2. Edatop SP 2 byl postižen plošným svahovým sesuvem, který se projevil značným rozrůzněním půdních podmínek a vnitropůdních genetických podmínek. Svah je stále náchylný k sesuvům a vývratům. Situace, kdy regresní vztah mezi obsahem Mg^{2+} a Al^{3+} byl detekován pouze při krajní mezi významnosti $P < 0,50$ znamená, že vliv heterogenity půdního prostředí na predispozici smrkových porostů není jednoznačně průkazný, není významně podmíněn minerální složkou půd, avšak může souviset s výchylkami v dynamice organické složky půd. Tuto domněnku podporují především vysoké hodnoty C/N a průkazná korelace obsahu Al^{3+} v Ep-horizontu a fulvokyselin v důsledku výrazně zpomalené humifikace.
3. Extrémně teplé a suché vegetační období roku 2003 bylo v úseku duben–září až o +3,8 °C nadnormálně teplejší. Během tohoto období byly v celém regionu Jeseníků a Moravskoslezských Beskyd srážkově výrazně podnormální měsíce červen (–70 mm), srpen (–52 mm) a září (–19,5 mm) (ČHMÚ 2004).
4. Kořenový systém lesních dřevin se v závislosti na vlastnostech půdního prostředí omezil hlavně na svrchní půdní horizonty. Zde sice poskytuje niky pro rozvoj rhizosféry, což přispívá k urychlení interakcí produktů dekompozice s koloidními částicemi sorpčního komplexu, je však citlivý na nedostatek půdní vlhkosti. Predisponovaný, prosvětlený a částečně defoliovaný smrkový porost nedokázal poskytnout dostatečný ekologický kryt pro udržení stabilní půdní vlhkosti ani stabilní podmínky pro existenci půdních mikrobiocenóz.
5. Prosvětlení porostu přispívá k šíření značné abundance trávobylinného patra podrostní vegetace. V její biomase je předpokládána blokace přístupného dusíku (NH_4^+, NO_3^-). Hodnoty N_t vyjadřují především přítomnost fyziologicky nepřístupných forem dusíku, které se za podmínek přirozeně zpomalené humifikace mineralizují jen postupně. S tím zřejmě korespondují i vysoké hodnoty poměru C/N.

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