



Effect of site conditions and tree species composition on physico-chemical properties of soil environment in the Western Carpathians area

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The objective of pedological research conducted in the Kněhyně–Čertův mlýn National Nature Reserve was to verify to what extent the properties of the soil environment are influenced by: a) chemistry of soil-forming substrate, b) site conditions, c) species composition of forest stand. The results of this study document that the soil taxonomic units in the area of interest are of podzol character and that the altitudinal soil zonality has not developed there. The total content of basic macrobioelements in soil-forming substrates is not in correlation with their accessible fraction in top genetic horizons of the profile depth. The results of this study also show that lead content reaches a significantly hazardous boundary level at sites of ridge stands in the exposure of northern quadrants. The soil environment under forest stands with prevailing Norway spruce (*Picea abies* /L./ Karst.) is enriched with C-compounds and active humus in the entire profile more than the soil under stand types with prevailing European beech (*Fagus sylvatica*). In top horizons of soil Norway spruce influences significantly negatively humus quality (C:N) and also the content of accessible potassium which decreases in humification horizons below the limit of 200 mg·kg⁻¹.

Keywords: site conditions, soil-forming substrate, species composition of forest stand, soil type, humus

Introduction

The soil component creates an essential environment for the basic physiological processes of plants and is an integral part of the forest ecosystem. Soils are formed under the frequently antagonistic action of an open set of soil-forming factors. The very top layer of soil consists of forest floor which fulfils many key functions in the forest ecosystem (Green et al. 1993). The character and parameters of humus forms significantly influence the cycle of nutrients, moisture and temperature regimes of top layers of soil. They also represent the root zone

for forest tree species, influencing on-site production to a great extent (Podrázský et Remeš 2005). Other studies have also confirmed that the components of colloid humus are important factors of sorption properties of soil. Long-term disturbance of humification processes may be connected with a disorder of the nutrient status of biocoenoses and their decline (Purdon et al. 2004; Modrzyński 2003; Laughlin et Percy 1999).

Some studies aimed at vegetation-soil relations have demonstrated that in relation to the species composition forest stands substantially change the humus status and simultaneously

nutrient content in the soil (Ulbrichová et al. 2005; Podrázský et al. 2004; Podrázský et al. 2009), creating conditions for their persistence in an ecosystem and for the persistence of an ecosystem in the given shape or more frequently for a change in the species composition of stands (further development of the ecosystems concerned) (Van Breemen et al. 1998; Binkley et al. 1998; Finzi et al. 1998). Norway spruce has been proved to exert a degradation effect on the soil (Podrázský et al. 2009; Matějka et al. 2009). Litterfall of this tree species causes acidification of the top layer of soil (Fabianek et al. 2009; Menšík et al. 2009), and in general, lower base saturation (Binkley et al. 1991; Augusto et al. 2003) and in some cases a higher amount of aluminium (Hagen-Thorn et al. 2004) were found out under Norway spruce trees.

The influence of tree litterfall on the soil diminishes with an increasing profile depth while the influence of soil-forming substrates and other pedogenetic factors, mainly of topography, becomes more intensive there. The relief in mountain areas is generally largely broken and it usually contributes to the origination of a highly heterogeneous soil environment. E.g. Philips et al. (1996) collected an extensive material showing that especially the soil catenas of distinctive texture are characterised by high diversity of soil units. In enclaves of the Kněhyně Mt. massif up to 22 soil units per 30 ha were determined (Vavříček et al. 2008). The buffering capacity of different forest types is able to significantly differentiate the dynamics of decline of close-to-nature and non-natural forests as well as different rate of monoculture decline in generally identical economic conditions (Posch et al. 1995; Schmidt et al. 2004; Purdon et al. 2004).

The objective of the present study is to evaluate to what extent the properties of the soil environment in the Western Carpathians are influenced by: a) chemistry of the soil-forming substrate, b) site conditions, and c) species composition of forest stand.

Method

Description of the area of interest and research plots

The Moravian-Silesian Beskids are a pronounced mountain range of the folded and faulted structure, composed of mountain ridges in the ENE – WSW direction. The highest northern ridge composed of hard Godula sandstones sharply rises from the northern foreland of

300 – 700 m above sea level by a high slope in the form of so called front mountains (Kněhyně, Smrk, Lysá hora, Travný). Geologically, the Moravian-Silesian Beskids are formed of flysch sediments. These are particularly Godula sandstones of the Cretaceous period and in places claystones, marlstones, conglomerates and shales (Demek et al. 1987). Cambisol is the markedly most widespread soil type. Cryptopodzols and Podzols occur at the highest locations while Fluvisols are found in the environs of streams (Průša 2001).

The massif of the National Nature Reserve (NNR) Kněhyně – Čertův mlýn is situated in the central part of the Moravian-Silesian Beskids. In this area of interest a total of 11 research plots were established with comparable site conditions; Tab. 1 shows their detailed description. The altitude of these plots is in the range of 890 – 988 m a.s.l. while from the aspect of soil taxonomy podzolised soil units (different subtypes of Cryptopodzols and Podzols) prevail there. In the species composition of forest stands occurring on the above-mentioned research plots European beech (*Fagus sylvatica*) and Norway spruce (*Picea abies* /L./ Karst.) are dominant tree species. Silver fir (*Abies alba* Mill.) is an interspersed species in these stands. The stands are incipient high forests or high forests, from the aspect of forest management these are production forests in the protection zone of the Kněhyně–Čertův mlýn NNR.

Pedological survey of sites

Site conditions (altitude, exposure, slope) were evaluated on the particular research plots; a soil pit of the depth reaching the substrate horizon C was dug at each site. The soil taxonomy of exposed soil profiles was described using the FAO WRB (2007) international classification. In the Results section of this paper for clearer differentiation of the intensity of podzolization processes the term Cryptopodzol is used [(according to the Taxonomic Classification System of Soils of the Czech Republic, (Němeček et al. 2001)], which corresponds to the term Entic Podzol in the used FAO WRB classification and in Tab. 1. Top horizons of soil were described according to the taxonomy of humus forms (Green et al., 1993).

Collection of samples

On each research plot soil samples were taken from one pit and from four sample squares 50 x 50 cm in size. From soil pits soil samples were collected from all horizons beginning with humification horizon H and ending with

substrate horizon C. From each sample square 1 sample of humification horizon and 1 sample of organomineral horizon were taken. In total, on each research plot 5 samples of humification and organomineral horizons and 1 sample from each of the other subsurface, spodic and substrate horizons were collected using the above-mentioned method.

Laboratory methods

Laboratory techniques in an accredited laboratory of the company Laboratoř Morava, s.r.o. included the analyses of active (pH/H₂O) and potential (pH/KCl) soil reaction using a pH-meter with a combined glass electrode (soil/H₂O or 1M KCl = 1/2.5), soil adsorption complex characteristics (S - base content, CEC - cation exchange capacity, V - base saturation) according to Kappen (Zbřal et al., 1997), H⁺ concentrations on the principle of pH double measurement (Adams et Evans 1990) and accessible 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 Gohler method, phosphorus content in Ae/Ep, Bs horizons was determined spectrophotometrically in a solution of ascorbic acid, H₂SO₄ and Sb³⁺. 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. Carbon contained in humus acids (hereinafter C-HS) was determined spectrophotometrically according to characteristic absorbances in pyrophosphate. Carbon contained in humic acids (hereinafter C-HA) and carbon contained in fulvic acids (hereinafter C-FA) were detected. Based on these data the C-HA/FA ratio was calculated (Vavřiček et al. 2006). Total nitrogen (N_t) was determined by the Kjeldahl method (Zbřal et al., 1997). The sulphur content was determined on the basis of annealing and combustion in HCl with subsequent precipitation of sulphur by BaCl₂ on BaSO₄. Lead (Pb) content was determined in the extract of 2M HNO₃.

Statistical evaluation

The Statistica Cz programme was used for a statistical evaluation. The main assessed relationship in the framework of statistical evaluation was the evaluation of correlations between the species composition of forest stands and the values of physicochemical properties of soil. The influence of soil-forming factors on soil properties was evaluated by correlation analyses. Parametric analysis of variance (ANOVA)

including subsequent Scheffe's comparison was employed for the evaluation of specific differences among the particular localities. All hypotheses concerning relations among the studied variables were tested at $p = 0.05$.

Results and Discussion

Soil taxonomic units in the studied area of Kněžyně – Čertův mlýn NNR

Soils of the geomorphologically differentiated enclave Kněžyně – Čertův mlýn are characterized by the prevailing podzolization process with the occurrence of two basic soil units, Podzols and Cryptopodzols (Tab. 1). They are influenced in places by an increased proportion of soil water in the profile and continuous process gleization at larger depths of soil profiles. The influence of the accumulation of gravitational water is not related with the altitude above sea level but it is closely connected with the geomorphological structure and with the character of substrate horizons. It is associated particularly with the foliation of disintegrating rock, content of clay fractions and consistency of deep horizons. The influence of gravitational water depth on soil-forming processes is exerted ca. in 50% of the plots. In the framework of soil-forming processes a local increase in skeleton content at various profile depths is a significant factor that conditions the development of psephitic or ranker subtypes or varieties.

The occurrence of Podzols and Cryptopodzols, which account for ca. 27% on the investigated plots, is not related with altitudinal zonation. In the area concerned Cryptopodzols occur both in locations at the lowest altitude (865 m a.s.l.) and in locations of ridge enclaves at the altitude of 935 – 975 m a.s.l. Podzols are present in the entire range of altitudinal zonation of 890 – 988 m a.s.l. Průša (2001) also reported that in the Moravian-Silesian Beskids the altitudinal soil zonality has developed minimally thanks to the flysch bedrock and favourable microclimate. Podzolization is an essential soil differentiation process in these locations (Vavřiček et Šimková, 2000). Basic soil units of Podzols and Cryptopodzols have intermingled with each other. Intensive podzolization processes have been eliminated and attenuated in places especially due to different texture and trophicity of the bedrock, more favourable microclimate and the related lower accumulation of raw humus. Humus form is connected with the reserve of forest floor. It is an important factor indicating mutual relations between soil and vegetation cover

(Emmer 1999). The heterogeneity of the flysch zone is one of the main factors of a deviation that conditions the occurrence of Cryptopodzols also at higher altitudes.

All soils are characterized by great depth, with a minimum intrasoil erosion factor. The basic genetic depth oscillates between 60 and 80 cm. The only exception is a below ridge site of the NNW exposure with modal Cryptopodzol at an altitude of 966 m a.s.l. where the genetic depth of soil is only 40–50 cm. The soil taxonomic units are not conditioned by the stand type. Many studies have documented that tree species influence only the forest floor (Menšík et al. 2009, Fabianek et al. 2009, Kacálek et al. 2010, Vavříček et al. 2008) while their influence decreases with an increasing exposure to climatic conditions in mountain locations. The development of organomineral and mineral horizons is a very long-term process whereas especially gradual pedogenetic changes and persisting predisposition to high heterogeneity are reflected in the dynamics of these horizons (Samec et al. 2008).

Soil-forming substrates and their influence on the content of available nutrients in soil environment

The soil units are not correlative with the unbalanced mineral strength of the soil-forming substrate. The soil substrates of rhythmic flysch are highly varied in texture and trophicity. By the character of their parameters they are significant for the below ridge length and inclination of slope and for the altitude of the site. In soil-forming substrates the values of calcium and magnesium significantly increase with the below ridge length of slope. A negative correlation was proved in the altitude that is closely correlated with the slope length. Calcium and magnesium significantly increased at higher accumulation with decreasing altitude (Tab. 2). The deep enrichment with these macrobioelements is significant, mainly at sites influenced by mixed substrates of Godula sandstones and green-grey claystones. Due to the mixed character of sedimentary rock the content of potassium as the basic element of Godula strata is significantly variable. In substrate horizons (C_1) it ranges from the low content of 12–13 g·kg⁻¹ to the level of good concentration ca. 26–27 g·kg⁻¹ of potassium (Tab. 3). The low and high values were recorded both at ridge sites and in colluvial deposits.

The high mineral strength of the soil-forming substrate was observed mainly on specific plots No. 3 and No. 4 (Tab. 3). The values of all

parameters are high. The levels of magnesium and calcium are very low at the other sites.

The higher trophicity of soil-forming substrates on plots No. 3 and 4 may be caused by an admixture of carbonate cement with the spot occurrence at deep layers of Turonian sandstones in this area. The total content of the basic macrobioelements in soil-forming substrates is not in significant correlation with the fraction of accessible nutrients in the other horizons (Tab. 2). In medium-deep and deeper genetic horizons the correlation is significant only between the accessible form of potassium and the iron content in substrate. The content of accessible calcium at medium depths of soil is also correlative with the content of free aluminium in substrate horizons. A significant proportion of hydrous micas (glauconite) in Godula sandstones augments the content of total potassium and iron (Vavříček et al. 2008). Combined with the cement and picrite sedimentary component calcium and oxalate iron released from weathering processes intermingle with each other.

In conditions of deep mountain soil profiles with markedly prevailing podzolization processes the influence of the mineral strength of soil-forming substrates on the values and variability of contents of accessible nutrients in the particular sequences of genetic horizons is minimum (Tab. 3). A positive feature of the flysch zone in higher mountain locations is based mainly on textural optimization and at a continuous increase in CEC on the sorption of basic nutrients.

Topography and its influence on top layers of soil

A significant influence of the **slope inclination** was reflected in humification and organomineral horizons only in parameters of soil reaction and accessible magnesium content (Tabs. 4, 7). The pH value and the value of accessible magnesium decrease with the higher value of slope inclination implying predisposition to more intensive erosion. The content of accessible calcium nearly copies these characteristics. In mountain locations at a high precipitation amount the slope inclination may have an influence on the eluviation of bivalent bases that diminish their proportion in the sorption complex. C-compounds in humification horizons are not influenced by the slope inclination. The **slope exposure** has a significant influence only on lead contamination. Deposition of these substances dates back to the past to historical air-pollution stress.

Tab. 1: Locality of the Kněhyně - Čertův mlýn NNR, brief characteristics of research plots [Alt. - altitude above sea level (m a.s.l.); Exp. - exposure; Sp. Comp. - species composition (%)].

Site No.	Alt.	Exp.	Slope	Position (GPS)	Sp. Comp.	Soil type
1	950	NE	12-14°	49°27'83"N; 18°19'16"E	SP 93, BE 7	Haplic Podzol Endoskeletal
2	925	E	10°	49°27'77"N; 18°19'29"E	SP 86, BE 10, JD 4	Haplic Podzol Endoskeletal
3	865	EES	8-10°	49°27'74"N; 18°19'29"E	SP 19, BE 81	Haplic Podzol Semi-Gleyic
4	929	SE	10-15°	49°27'64"N; 18°19'19"E	SP 68, BE 31, JD 1	Haplic Podzol
5	966	NNW	8-9°	49°27'71"N; 18°18'86"E	SP 32, BE 51, JD 17	Entic Podzol Semi-Gleyic
6	944	E	12°	49°27'62"N; 18°18'95"E	SP 96, BE 4	Haplic Podzol Semi-Gleyic
7	988	S	9-10°	49°27'81"N; 18°18'49"E	SP 45, BE 50, JD 5	Haplic Podzol Endoskeletal
8	973	S	7-8°	49°27'77"N; 18°18'56"E	SP 95, BE 5	Umbric Entic Podzol
9	935	S	8-10°	49°27'67"N; 18°18'47"E	SP 50, BE 50	Entic Podzol Endoskeletal
10	931	S	6-7°	49°27'65"N; 18°18'58"E	SP 70, BE 30	Haplic Podzol Semi-Gleyic
12	890	SSW	15-16°	49°27'48"N; 18°18'79"E	SP 20, BE 70, JD 10	Folic Podzol

Note:

* In the Results section of this paper for clearer differentiation of the intensity of podzolization processes the term Cryptopodzol is used [according to the Taxonomic Classification System of Soils of the Czech Republic (Němeček et al. 2001)], which corresponds to the term Entic Podzol in the used FAO WRB (2007) classification.

Tab. 2: Locality of the Kněhyně Čertův mlýn NNR; matrix of correlation coefficients, expression of relations between element content in substrate horizons (C) and content of available nutrients in other horizons (H, Ae/Ep, Bhs, Bs) [N = 11; exceeding the boundary significance of $r \geq 0.60$ at $p < 0.05$ is in bold].

Horizon	H										Ae/Ep										Bhs										Bs																																																																						
	C	Altitude	P	Mg	Ca	K	P	Mg	Ca	K	C	Altitude	P	Mg	Ca	K	P	Mg	Ca	K	C	Altitude	P	Mg	Ca	K	P	Mg	Ca	K	C	Altitude	P	Mg	Ca	K																																																																	
Fe	-0.21	-0.06	-0.15	-0.15	-0.08	-0.27	-0.33	-0.28	-0.31	-0.14	0.65	0.12	0.09	-0.08	0.01	0.12	0.11	0.11	-0.11	-0.21	-0.30	0.24	-0.27	-0.40	0.30	-0.17	-0.05	-0.08	0.45	0.29	0.45	0.07	-0.21	0.59	0.67	0.27	-0.24	-0.16	-0.25	-0.25	-0.47	0.50	-0.29	-0.52	-0.39	-0.39	0.03	-0.29	-0.40	-0.51	-0.10	-0.50	-0.54	0.45	-0.01	-0.15	0.30	-0.14	-0.51	-0.32	-0.40	0.03	-0.24	-0.22	-0.40	-0.45	-0.39	-0.54	0.39	-0.09	-0.09	-0.18	0.30	-0.23	-0.48	-0.21	-0.35	0.10	-0.21	-0.42	-0.44	-0.36	0.12	0.38	0.38	0.32	0.07	0.30	0.20	0.25	0.25	-0.23	0.58	-0.18	-0.04	-0.20	-0.05	-0.20	-0.20	-0.20	0.33

Tab. 3: Locality of the Kněhyně - Čertův mlýn NNR, physicochemical and chemical properties of C horizons in 2010 [Fe, Al (g/kg); P, Mg, Ca, K (mg/kg)].

Site No.	pH/H ₂ O	pH/KCl	Fe	Al	P	Mg	Ca	K
1	4.43	3.94	2.81	4.29	517	8440	4970	13200
2	4.32	3.99	3.25	3.1	238	3358	1321	16848
3	4.55	3.98	2.67	5.56	662	44400	23700	26000
4	4.49	4.11	2.96	4.4	430	40800	23100	25000
5	4.20	4.06	1.45	1.9	575	4350	4600	25100
6	4.31	3.98	7.51	7.67	490	4519	905	19714
7	4.18	3.68	1.88	10.4	321	7807	1105	23837
8	4.53	4.16	2.44	4.26	180	5207	872	21722
9	4.36	4.06	1.32	6.36	275	4823	1310	15075
10	4.27	3.86	1.26	3.78	216	1242	3156	26519
12	4.53	4.12	4.65	20.7	250	3053	1739	11948

Higher values of lead content in holoorganic horizons were measured mainly in exposures of northern quadrants, oriented towards the Ostrava industrial agglomeration. These results correspond with conclusions of Sparks (2003) and Šály (1998), who considered the relief as one of the most important factors in the formation of mountain soils. The broken relief causes the patchy action of the particular components of ecotope and climatope, and related changes in the soil environment, even to short distances (Samec et al. 2008).

Humification horizons and their influencing by the species composition of forest stand

Humification horizons are very well developed at sites of mountain locations. Their formation and origination are a part of the polyfactorial problem where the essential role is played by a sufficient supply of the organic component from litterfall of the tree species of stand types and by climatic conditions of the area. The **depth** of humification horizon is not related either with the species composition of stand type or with the terrain relief. Only historically deposited contaminants of sulphur and lead are significantly accrued with greater depth (Tab. 4). Their levels are the highest at sites of ridge localities of northern quadrants without the influence of stand type or potentially of the soil taxonomic unit. Lead exceeding the limit of 400 mg·kg⁻¹ (Tab. 5) reaches the boundary level of hygienic limits 60 mg·kg⁻¹ of mineral soils. We cannot speak about the values of ecological background in this case. The **soil reaction** oscillates on the level of highly acidic to acidic soils (Tab. 5). The values are quite normal for

humification horizons characterized by a podzolization process in the mountain zone.

Cation exchange capacity is unbalanced (Tab. 5). The values are very high in organic horizons. The relations are significant mainly from the aspect of water and macrobioelement retention. The limits of 1 000 mmol·kg⁻¹ are exceeded almost on 65% of the plots. This capacity is closely related with the content of humus, a long-term source of C-compounds (Waring et Running 1998) that are on a high level in humification horizons (ca. 27 – 36%). In the given area of the Beskids flysch they are not correlative with the tree species composition of stand types. Total carbon correlates with total content of active humus (Tab. 4) when some independent fractions, e.g. humic acids and fulvic acids, reach the values up ca. to 3 000 – 4 000 mmol·kg⁻¹. Humus substances under Norway spruce are more mobile and penetrate to deeper soil layers than under stands with a significant admixture of European beech. Norway spruce is a tree species that significantly increases maximum sorption (Tab.4).

Cation exchange capacity (CEC) of humification horizons is influenced to a greater extent by the fraction of humic acids that show a highly correlative relation with CEC (Tab. 4).

In the species composition of the particular localities CEC is in correlation with the Norway spruce proportion. The **HA and HA/FA** ratio rises with the increasing proportion of spruce. A higher content of humic acids under spruce stands than under beech stands was reported by Matějka et Starý (2009). The evaluation of humus quality according to the **HA/FA ratio** is problematic in humification horizons and need not fulfil the hypothesis presented by

Tab. 4: Locality of the Knežhyně - Čertovo Mlýn NNR, matrix of correlation coefficients among selected characteristics (physicochemical and chemical properties of H horizons and site parameters) in 2010 (N = 11; exceeding the boundary significance of $r^2 \geq 0.60$ at $p < 0.05$ is in bold).

	Depth	SP	BE	Slope	pH/KCl	S ₁	T(CEC)	V	S ₂	P	Mg	Ca	K	Pb
Depth	1.00	-0.29	0.18	0.42	-0.07	-0.02	-0.12	-0.01	0.52	-0.04	-0.46	-0.43	0.46	0.59
SP	-0.29	1.00	-0.99	-0.07	0.08	0.51	0.59	0.26	-0.50	-0.17	0.23	0.58	-0.77	0.21
BE	0.18	-0.99	1.00	0.05	-0.13	-0.51	-0.59	-0.25	0.46	0.18	-0.19	-0.58	0.77	-0.30
Exposure	0.24	-0.63	0.52	-0.08	0.09	-0.53	-0.35	-0.49	0.26	-0.04	-0.18	-0.28	0.28	-0.17
Slope	0.42	-0.07	0.05	1.00	-0.52	0.08	0.38	-0.15	0.30	0.30	-0.69	-0.47	0.07	0.10
Alt.	0.12	0.45	-0.53	-0.30	0.03	0.09	0.27	-0.13	0.06	-0.07	0.10	0.21	-0.27	0.21
pH/H ₂ O	-0.32	0.30	-0.32	-0.48	0.81	0.29	-0.15	0.45	-0.71	-0.23	0.56	0.59	-0.44	-0.22
pH/KCl	-0.07	0.08	-0.13	-0.52	1.00	0.36	-0.20	0.63	-0.49	-0.19	0.65	0.61	-0.13	-0.03
C _{ox}	0.11	0.32	-0.37	0.23	-0.07	0.73	0.84	0.39	0.41	0.73	0.20	0.47	-0.08	0.28
N _t	0.21	-0.45	0.40	0.07	-0.32	-0.01	0.21	-0.12	0.88	0.64	-0.14	-0.17	0.48	0.30
C/N	-0.15	0.78	-0.76	0.12	0.26	0.55	0.44	0.39	-0.65	-0.12	0.26	0.52	-0.62	-0.05
C-HS	-0.21	0.54	-0.57	0.04	0.35	0.66	0.68	0.42	-0.37	0.33	0.52	0.70	-0.37	-0.15
C-HA	-0.30	0.61	-0.62	0.03	0.30	0.70	0.75	0.43	-0.37	0.34	0.54	0.75	-0.43	-0.15
C-FA	0.14	0.19	-0.26	0.10	0.48	0.40	0.25	0.31	-0.30	0.21	0.31	0.35	-0.12	-0.10
C-HA/FA	-0.49	0.67	-0.63	0.03	-0.01	0.62	0.84	0.31	-0.23	0.29	0.39	0.68	-0.51	-0.15

Note: SP – proportion of Norway spruce in the species composition of forest stand (%); BE – proportion of European beech in the species composition of forest stand; Depth – depth of H horizon (cm); S₁ – instantaneous content of exchange base cations (mmol/kg); T(CEC) – cation exchange capacity (mmol/kg); V – base saturation (%); S₂ – sulphur content (g/kg); Alt. – altitude above sea level (m)

Tab. 5: Locality of the Knežhynč – Čertův mlýn NNR, physicochemical and chemical properties of H horizons in 2010 [(mean \pm standard deviation); S_r T(CEC), V(%); P, Mg, Ca, K, Pb (mg/kg)].

Site No.	pH/H ₂ O	pH/KCl	S ₁	T(CEC)	V	P	Mg	Ca	K	Pb
1	3.38 ± 0.01	2.66 ± 0.07	70.00 ± 8.23	1243.00 ± 256.32	5.63 ± 2.23	10.33 ± 2.62	55.00 ± 2.16	197.33 ± 19.01	197.00 ± 9.27	402.00 ± 31.00
2	3.83 ± 0.04	2.89 ± 0.03	88.00 ± 6.54	1138.00 ± 321.56	7.73 ± 4.11	12.50 ± 1.50	67.50 ± 5.70	283.25 ± 26.95	149.25 ± 15.97	349.50 ± 8.50
3	3.47 ± 0.04	2.73 ± 0.03	50.00 ± 10.23	873.00 ± 115.24	5.73 ± 1.56	14.00 ± 1.41	68.67 ± 6.02	193.00 ± 25.51	264.33 ± 16.11	292.50 ± 57.50
4	3.38 ± 0.11	2.60 ± 0.00	50.00 ± 8.56	1296.00 ± 365.77	3.86 ± 2.31	14.67 ± 0.47	51.67 ± 6.65	193.67 ± 25.14	160.67 ± 17.25	282.50 ± 26.50
5	3.54 ± 0.06	2.78 ± 0.04	32.00 ± 5.56	830.00 ± 236.89	3.86 ± 1.23	9.00 ± 2.16	56.67 ± 6.02	180.00 ± 19.61	220.67 ± 26.91	418.50 ± 35.50
6	3.65 ± 0.01	2.73 ± 0.02	44.00 ± 8.65	1066.00 ± 236.78	4.13 ± 1.20	9.00 ± 2.12	58.00 ± 4.06	185.00 ± 30.47	163.75 ± 12.38	297.00 ± 41.00
7	3.62 ± 0.07	2.74 ± 0.06	60.00 ± 3.23	1103.00 ± 236.89	5.44 ± 1.23	15.5 ± 3.50	64.00 ± 3.08	190 ± 23.89	230 ± 14.58	241.00 ± 11.00
8	3.67 ± 0.10	2.77 ± 0.09	70.00 ± 15.23	1313.00 ± 398.55	5.33 ± 3.21	13.75 ± 3.11	77.75 ± 12.70	190.00 ± 70.69	174.25 ± 14.25	263.50 ± 26.50
9	3.63 ± 0.05	2.68 ± 0.08	26.00 ± 5.65	747.00 ± 256.89	3.48 ± 1.23	6.75 ± 2.49	54.75 ± 5.49	166 ± 11.70	173 ± 30.01	208 ± 60.00
10	3.68 ± 0.06	2.85 ± 0.03	48.71 ± 5.56	930.71 ± 365.45	5.40 ± 2.20	6.14 ± 2.16	68.00 ± 6.02	241.00 ± 16.23	161.71 ± 13.56	178.25 ± 32.23
12	3.52 ± 0.08	2.73 ± 0.12	50.00 ± 21.32	1083.00 ± 78.00	4.62 ± 2.25	13.25 ± 1.64	53.5 ± 6.10	168.25 ± 9.09	219.5 ± 38.21	199.5 ± 8.50

Note: S₁ – instantaneous content of exchange base cations (mmol/kg); T (CEC) – cation exchange capacity (mmol/kg); V – base saturation (%)

Tab. 6: Locality of the Kněhyně - Čertův mlýn NNR, physicochemical and chemical properties of Ae/Ep horizons in 2010 [(mean \pm standard deviation); P, Mg, Ca, K, Pb (mg/kg)].

Site No.	P	Mg	Ca	K	Pb
1	11.33 \pm 2.05	30.67 \pm 2.62	200.00 \pm 83.54	22.00 \pm 2.45	10.40 \pm 5.65
2	12.00 \pm 5.83	35.75 \pm 1.92	160.00 \pm 30.63	37.75 \pm 5.36	19.00 \pm 4.33
3	7.67 \pm 1.25	31.00 \pm 2.45	137.00 \pm 8.60	39.00 \pm 5.10	26.00 \pm 15.11
4	2.67 \pm 1.33	27.00 \pm 7.40	126.33 \pm 13.16	25.67 \pm 23.37	9.58 \pm 24.55
5	9.00 \pm 1.41	37.00 \pm 2.94	141.00 \pm 6.38	57.67 \pm 7.41	71.70 \pm 23.60
6	3.00 \pm 1.41	41.25 \pm 7.33	157.00 \pm 4.64	57.50 \pm 23.48	28.90 \pm 11.23
7	21.5 \pm 2.18	44.25 \pm 3.77	199.75 \pm 10.18	60.75 \pm 11.32	33.60 \pm 8.65
8	24.50 \pm 11.32	38.25 \pm 2.59	152.50 \pm 7.63	39.00 \pm 9.35	41.40 \pm 12.36
9	2.75 \pm 0.83	46.25 \pm 4.97	196.50 \pm 11.72	51.00 \pm 5.87	37.60 \pm 8.65
10	6.50 \pm 1.12	60.00 \pm 3.56	672.00 \pm 6.35	58.75 \pm 12.5	85.35 \pm 11.12
12	4.00 \pm 1.58	35.25 \pm 0.83	201.75 \pm 20.91	29.75 \pm 2.86	8.71 \pm 2.65

some authors (Zacanda et al. 2003, Slepčienė et Slepčytis 2005) that humus quality rises with the increasing content of humic acids. In the analyses of C-HA fraction the determined values are often distorted by an admixture of lignin which has a higher proportion (18%) in spruce needles than in litterfall from beech leaves (12%). For this reason humus quality decreases with the increasing proportion of spruce in the species composition of forest in spite of the higher C-HA content.

The instantaneous content of exchangeable base cations (hereinafter S) is quite variable on the studied plots (Tab. 5) and fluctuates there in the range of low to medium-high values. Similarly like in CEC, a close correlation with the content of humus substances (C_{ox}) and humic acids (C-HA) was found out as documented in Table 4. With an increase in these characteristics the S value also increased. The influence of the species composition on this variable was not proved as documented by the low value of correlation coefficient in Table 4.

Base saturation of humification horizons coincides with the site of Podzols (BS = 3.7 – 7.7%; Tab. 5). Similarly low values of this parameter were also recorded in the Moravian-Silesian Beskids by other researchers (Pavlů et al. 2007; Barszcz et Malek 2008).

Base saturation correlates with the values of a very low exchange reaction of soil that is on the level of mountain Podzols 2.6 – 2.9 pH/KCl. Similar values were reported by Huber et al. (2002), who recorded 2.8 – 3.0 pH/KCl in humification horizons and 3.0 pH/KCl in organomineral horizons that were found out in dystric Cambisols at intermediate locations of Höglwald in Germany. At very low values the base saturation (BS)

is more increased in deep horizons under stands with a higher proportion of Norway spruce.

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Sulphur correlates with the content of nitrogen (Tab. 4), with which it is bound especially to amino acids. In the cases concerned its fraction is mostly of organic character. It is not connected with historically exposed sites like lead.

Humus quality described by the **C:N ratio** decreases parallelly with a higher proportion of spruce. Nitrogen content in relation to carbon content is the main indicator of biomass decomposition. The close qualitative relationship of the value of C/N ratio follows from the soil transformation of nitrogen (Cote et al. 2000). Plots with the spruce proportion higher than 85% belong to slightly risky categories when the C:N ratio increases above the value 20. At these sites undesirable deceleration of the transformation and mineralization of organic substances takes place. Humus quality and deteriorates with a higher proportion of spruce. On the

contrary, with an increasing proportion of beech this spruce effect is eliminated and humus quality improves to an optimum level of C:N = 15–18 (Fig. 1), which was defined by Hedde et al. (2008) at a C:N ratio = 16 in beech stands of Normandy, France. The negative influence of spruce on a C:N ratio was also documented in other studies (Fabianek et al. 2009; Menšík et al. 2009). These authors established research plots in the Drahanská vrchovina hills in beech and spruce stands and in a mixed stand. The C:N ratio was found to be statistically significantly higher in spruce stands than in beech stands. The C:N ratio in a mixed stand was between these values.

The **main nutrient** content in the given horizon mostly show optimum values (Tab. 5). Phosphorus contents fluctuate in the range of 9–16 mg·kg⁻¹ while magnesium contents are on the lower boundary of the optimum,

especially when they decrease below the limits of 55 mg·kg⁻¹. Calcium in humification horizons is included in a good classification category unlike the findings of Novotný et al. (2008) and Barszcz et Małek (2008), who reported very low contents of this nutrient in top layers of soil in the Moravian-Silesian Beskids. Accessible **phosphorus** is an important element bound to humus substances. Its content in a humification horizon rises with the increasing proportion of active humus and simultaneously with the increasing value of CEC (Tab. 4). This relationship was confirmed also in conditions of the tableland of the Krušné hory Mts. (Vavříček et al., 2010, 2006).

In humification horizons only **potassium** is correlative with stand types. Its content in soil increases significantly with a higher proportion of European beech. In this relation Norway spruce

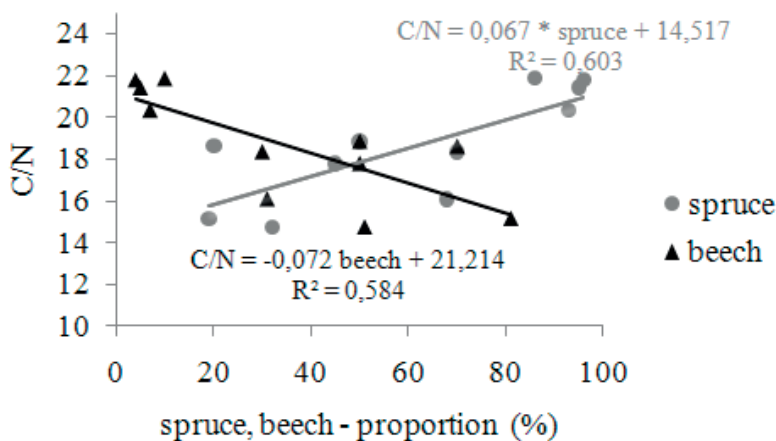


Fig 1: Locality of the Kněhyně – Čertův Mlýn NNR: the correlation between the proportions of selected tree species in the species composition of stands and the C/N ratio in humification horizon H in 2010.

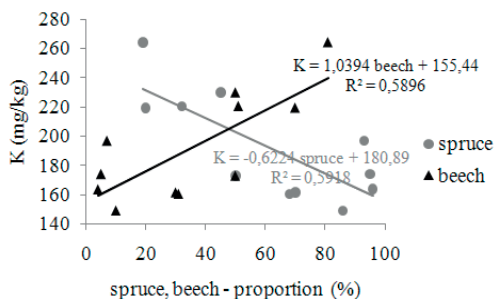


Fig. 2: Locality of the Kněhyně – Čertův Mlýn NNR: the correlation between the proportions of selected tree species in the species composition of stands and potassium content in humification horizon H in 2010.

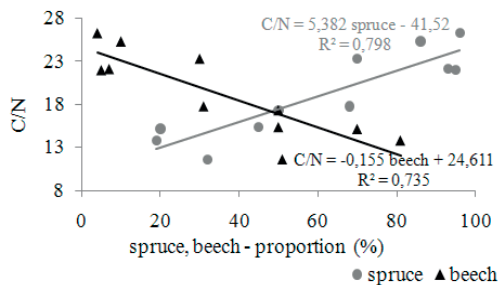


Fig. 3: Locality of the NPR Kněhyně – Čertův Mlýn NNR: the correlation between the proportions of selected tree species in the species composition of stand and the C/N ratio in organomineral horizon Ae/Ep in 2010.

Tab. 7: Locality of the Kněhyně - Čertův Mlýn NNR, matrix of correlation coefficients among selected characteristics (physicochemical and chemical properties of Ae/Ep horizon and site parameters) in 2010 (N = 11; exceeding the boundary significance of $r^2 \geq 0.60$ at $p < 0.05$ is in bold).

	SP	BE	Slope	pH/KCl	P	Mg	Ca	K	Pb
SP	1.00	-0.99	-0.07	-0.11	0.25	0.09	0.09	-0.11	-0.06
BE	-0.99	1.00	0.05	0.03	-0.27	-0.06	-0.05	0.08	0.02
Quadrant	0.09	0.03	-0.44	-0.27	0.08	0.41	0.20	0.48	0.27
Exposure	-0.63	0.52	-0.08	0.44	-0.05	0.16	0.03	0.33	0.44
Slope	-0.07	0.05	1.00	-0.66	-0.37	-0.57	-0.40	-0.58	-0.77
Alt.	0.45	-0.53	-0.30	0.22	0.60	0.26	-0.02	0.42	0.32
pH/KCl	-0.11	0.03	-0.66	1.00	0.22	0.47	0.52	0.31	0.76
C _{ox}	0.46	-0.44	-0.52	0.24	-0.08	0.79	0.57	0.68	0.63
N _t	-0.12	0.09	-0.63	0.45	-0.09	0.70	0.36	0.90	0.84
C/N	0.89	-0.86	-0.03	-0.11	0.02	0.25	0.28	-0.08	-0.08
C-HS	0.32	-0.33	-1.42	0.54	0.30	0.72	0.50	0.61	0.78
C-HA	0.35	-0.34	-0.70	0.49	0.19	0.75	0.61	0.58	0.75
C-FA	0.25	-0.28	-0.78	0.57	0.37	0.66	0.37	0.62	0.76
C-HA/FA	0.20	-0.12	0.19	-0.24	-0.36	0.11	0.36	-0.13	-0.11

Note: the abbreviations of variables are explained below Tab. 4.

has an adverse effect on the concentration of accessible potassium (Fig. 2). It shows a negative correlation when potassium decreases below the optimum level of 200 mg·kg⁻¹. This decrease is pronounced mainly at sites with the Norway spruce proportion higher than 60%. Different contents of potassium in stands with spruce and beech were also reported by other authors. Unlike our finding they reported a positive influence of beech on the content of other nutrients such as calcium or magnesium. E.g. Podrázský et al. (2005) compared nutrient content in humification horizons in beech and spruce stands. In the uplands Českomoravská vrchovina (Žákova hora NNR) beech was found to have a positive influence on the representation of main nutrients in forest floor horizons.

This hypothesis was confirmed by the study of Kacálek et al. (2010), who evaluated the soil-improvement influence of tree species on the formation of forest floor in the afforestation of agricultural lands at the foothills of the Orlické hory Mts. Matějka et Starý (2009) laid out an experiment in the Šumava Mts., where the condition of top soil layers was compared under spruce and beech stands. In their study these authors reported a higher content of magnesium under beech stands. Similar results were obtained by Pavlů et al. (2007), who determined a higher amount of magnesium and calcium under beech stands in the Jizerské hory Mts. compared to spruce stand.

Organomineral horizons and their influencing by the species composition of forest stand

The contents of **main nutrients** in these horizons reach medium-low values. The locally hazardous content of magnesium in the fraction of holoorganic horizons is eliminated there by the concentration of 30–50 mg·kg⁻¹ (Tab. 6). Similarly low reserves were also documented in other studies from the area of the Moravian-Silesian Beskids (Pavlů et al. 2007, Barszcz et Małek 2008). Spruce may be one of the factors causing the above-mentioned degradation because it shows a negative, though insignificant, correlation with all macrobioelements (Tab. 7). In these horizons continuous impairment of humus quality occurs on the level of a highly significant positive correlation. As a result of spruce admixture the **C:N ratio** in epipedons increases to ca. 23–26 (Fig. 3). A similar C/N ratio 23–27 was reported by Vesterdal et al. (1995) in the southern Denmark. A significantly negative influence of spruce on the C/N ratio in organomineral horizons was also documented in the study of Kacálek et al. (2010); a degradation influence of spruce on humus quality was also observed by Podrázský et al. (2005) and Emmett et al. (1998) reported the critical value of the C/N ratio in coniferous stands to be ca. 24. Spruce is a significant degradation element for sites at higher locations of the flysch zone that may be substantially eliminated by an admixture of beech at its minimum proportion of ca. 40%.

Conclusion

The soil taxonomic units in the Kněhyně – Čertův Mlýn area are of Podzol type and do not correlate with altitudinal zonation whereas 50% of the plots are influenced by a deep gleization process mainly of substrate horizons. These are deep soils (>60 cm) that are not exposed to intra-soil intraskeletal erosion in spite of the locally increased skeleton content.

The mineral strength of substrate horizons oscillates in very low to good quality classes where the total content of magnesium and calcium correlates with slope length and decreasing altitude above sea level. The total content of basic macrobioelements in soil-forming substrates is not correlative with their accessible fraction in genetic horizons of the profile depth.

The soil environment under stands with dominant Norway spruce is enriched with C-compounds and active humus in the entire profile significantly more than the soil under stand types with dominant European beech. In top horizons of soil Norway spruce influences significantly negatively humus quality (C:N) and also the content of accessible potassium which decreases in humification horizons below the

limit of 200 mg·kg⁻¹. Spruce is in a negative, though insignificant, correlation with the other elements.

Lead content reaches a significantly hazardous boundary level at sites of ridge stands in the exposure of northern quadrants. It is a result of the deposition of contaminants from the Ostrava industrial agglomeration that lasted by the eighties of the last century.

To ensure a higher proportion of European beech in the framework of transformation of the particular stand types of mountain forest to close-to-nature forest is an essential measure underlying revitalisation of the soil environment of the 6th – 7th forest altitudinal zone in the flysch zone of the Moravian-Silesian Beskids. To eliminate the degradation influence of spruce monocultures and to optimise soil parameters it is necessary to increase the proportion of European beech in the species composition to 40% at least.

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