Factors influencing distribution of different Al forms in forest soils of the Jizerské hory Mts.

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ABSTRACT: Soil acidification processes are the main factor influencing the distribution of different Al forms in forest soils. The intensity of these processes is given by different stand conditions and anthropic activity. This paper describes the influence of four selected stand factors on the distribution of basic soil characteristics and two Al forms in forest soils of the Jizerské hory Mts. Altitude, liming, soil type and forest cover type are studied as selected factors. Distribution of most soil characteristics in the organic horizon, including organically bound Al, is influenced by the altitude. Distribution of mobile Al form is mainly influenced by liming. In the mineral horizon, no decisive factor affecting the distribution of variables was found. Cartograms of spatial distribution of pH, mobile Al form and total Ca content documenting their spatial relationships are shown.

Keywords: aluminium forms; forest soils; acidification

About 1,000 km^2 of spruce stands died during the last three decades in the Czech Republic. Deforestation is ascribed to direct effects of SO_2 on spruce canopy, to cultivation of spruce in a clear-cutting system, and also to soil acidification including an increase in mobile Al concentration in soils (Pierzynski et al. 2000). The Jizerské hory Mts. are one of the most affected areas in the Czech Republic. High concentrations of acidificants in the atmosphere have led to damage of forest and soils. At present, concentrations of acidificants in the atmosphere are below immission limits. However, forests are still threatened by long-term changes in soil conditions (Hruška, Cienciala 2001).

The aluminium concentration in soil solution depends mainly on soil pH as it has been observed and proved by many researches. However, the influence of soil pH on Al behaviour is strongly modified by the presence of complexing fractions of soil organic matter (Berggren, Mulder 1995; Wesselink et al.

1996; Van Hees et al. 2000; Lofts et al. 2001). The complexation of Al by natural organic substances is of considerable significance in regulating concentrations of the highly toxic Al^{3+} ion in acid soils and natural waters (Sposito 1996).

Forest litter is the main source of organic matter in forest soils. Different forest types, that means different mixtures of tree species or their monoculture, produce organic matter of variable composition. These variants implicate differences in pedogenetic processes. The rate and quality of mineralization and humification are determined by the litter type. Final products of these processes influence aluminium distribution in the soil profile due to different hydrophobicity, mobility and affinity to Al (Hruška, Cienciala 2001; Misson et al. 2001).

The form of Al plays a decisive role in its potential bioavailability and toxicity. Toxicity to plants qualitatively decreases in the order: Al_{13} (not in the form of phosphates or silicates), Al^{3+}, $Al(OH)^{2+}$,

$Al(OH)_2^+$. Aluminium bound in fluoride or organic complexes and $Al(OH)_3$ are supposed to be non-toxic (Sposito 1996; Boudot et al. 1994).

This study is focused on differences in the distribution of potentially dangerous organic and inorganic Al forms and other indicators of soil acidification between beech forest and spruce forest in the Jizerské hory Mts. area. Beech forest is natural in this area except the summit parts and spruce monocultures are a product of anthropic activity there. This substitution of natural forest is supposed to lead to an increase in acidification processes and to mobilization of toxic Al forms. The effects of other factors are also assessed. The results of the study of these problems should be used for new forest management below the boundary of natural occurrence of spruce.

MATERIAL AND METHODS

The Jizerské hory Mts. area is located in the north of Bohemia. A set of 98 sampling sites was studied. Altitudes of these sites ranged from 400 m to 1,000 m above sea level. Beech (*Fagus sylvatica*), spruce (*Picea abies* or *Picea pungens*) and mixed forests are the prevailing vegetation cover. The highest parts of the mountains are covered by reed bentgrass (*Calamagrostis villosa*) to a large extent because of damage to spruce forest, but new young trees, mainly spruces, have been planted there recently. Soils were identified as Podzols, Cambisols, Gleysols, and Leptosols, all on the granite bedrock. Soil samples from all sufficiently thick horizons were collected in these localities. In all cases, one sample was taken from the surface organic O (F + H) horizon and at least one sample from the mineral horizon, usually spodic or cambic B horizon. Samples were air dried and passed through 2-mm sieves. Basic soil characteristics were determined by commonly used methods: pH_{H_2O} and pH_{KCl} potentiometrically; humus quality was assessed by the ratio of absorbances of pyrophosphate soil extract at the wavelengths of 400 and 600 nm (A_{400}/A_{600}). Total contents of C and N were measured with an automated analyzer LECO CNS-2000 (MI USA) and C/N ratio was calculated. Effective cation exchange capacity (CEC) of mineral horizons was determined by Mehlich method with unbuffered 0.1M $BaCl_2$ extraction solution. This analysis provided also the concentrations of exchangeable Al form (Al_{exch}). Total content of Ca (Ca_{tot}) was measured after soil digestion with aqua regia. Contents of two different Al forms were determined according to Drábek et al. (2003): mobile Al forms were extracted with 0.5M KCl solution (Al_{KCl}), the assessment of "total organically bound" Al forms (Al_{org}) was based on Al amounts extracted with 0.05M $Na_4P_2O_7$ solution, Al_{KCl} amount as the inorganic form was deducted. Aluminium concentrations in both extracts were determined by means of ICP-OES (VARIAN Vista Pro, VARIAN, Australia). Statgraphics Plus for Windows 4.0 (Manugistics 1997) was used to perform multifactor ANOVA.

RESULTS AND DISCUSSION

Table 1 shows mean values of the studied soil properties. Most variables had normal distribution. Logarithmic transformation was used for normalization of Al_{KCl} in the B horizon.

Four factors that influence the distribution of soil characteristics were selected. The first one was the effect of liming. Sampling sites were divided into four classes according to Ca_{tot} content in the O horizon. Most sampling sites (68) were included in the first class with Ca_{tot} content below 500 mg/kg. 16 sites belonged to the second class (500–1,000 mg/kg), 9 sites to the third class (1,000–1,500 mg/kg), and 2 sites to the fourth class (1,500–2,000 mg/kg). Content of Ca_{tot} is influenced almost entirely by the intensity of liming. Another selected factor was the effect of altitude. Three altitude classes were suggested: class below 800 m above the sea level (41 sites), 800–900 m (27 sites), and more than 900 m (30 sites). Type of forest cover was the third factor. Sampling sites were covered by spruce forest (74 sites), mixed forest (6 sites) and beech forest (18 sites). The last factor was the effect of soil classification unit. Cambisols were identified at 34 sites, Podzols at 50 sites, Leptosols at 12 sites and Gleysols at 2 sites.

Table 1. Mean values of the studied variables in O and B horizons

| Horizon | Al_{KCl} | Al_{exch} | Al_{org} | pH_{H_2O} | pH_{KCl} | Ca_{tot} | A_{400}/A_{600} | C/N | CEC |
	(mg/kg)					(mg/kg)			(mmol/100 g)
O	1,236	nd	3,812	3.9	3.2	503	7.4	19.6	nd
B	832	1,956	7,555	4.0	3.6	221	9.1	21.7	7.8

nd – not determined

Table 2. O horizon: *p*-values of the significance of the factor effect computed by multifactor ANOVA

Main effects	Al_{KCl}	Al_{exch}	Al_{org}	pH_{H_2O}	pH_{KCl}	A_{400}/A_{600}	C/N	CEC
Liming	**0.020**	nd	0.054	0.053	0.122	0.115	0.728	nd
Altitude	0.155	nd	**< 0.001**	**0.001**	**< 0.001**	**0.010**	**0.010**	nd
Forest	0.210	nd	0.054	**0.027**	**< 0.001**	0.410	0.316	nd
Soil	0.470	nd	0.691	0.777	0.177	0.207	0.951	nd

nd – not determined

Table 3. B horizon: *p*-values of the significance of the factor effect computed by multifactor ANOVA

Main effects	Al_{KCl} (log)	Al_{exch}	Al_{org}	pH_{H_2O}	pH_{KCl}	A_{400}/A_{600}	C/N	CEC
Liming	0.191	0.894	0.609	0.625	0.289	0.407	**0.023**	0.630
Altitude	0.099	0.184	0.666	0.132	0.526	0.054	0.631	0.672
Forest	0.071	0.170	0.630	**0.040**	0.121	0.830	0.914	0.337
Soil	**0.017**	**0.011**	0.413	0.950	0.407	0.361	**0.020**	**0.029**

Multifactor ANOVA was used to determine which factor had the main effect on the distribution of soil characteristics. Tables 2 and 3 show *p*-values of the significance of differences between the classes computed for variables separately in O horizon and B horizon.

The results of the O horizon show that altitude has the strongest influence on the distribution of most variables. Soil conditions are more favourable at higher altitudes. Both types of pH increase with the increasing altitude. Both soil humus quality indicators (A_{400}/A_{600} and C/N) show the worst quality at the altitudes below 800 m. Whereas Al_{KCl} content is similar at all altitudes, content of Al_{org} is higher at altitudes above 900 m. Content of poten-tially toxic Al form (Al_{KCl}) is influenced mainly by liming. Increasing Ca_{tot} content leads to decreasing concentrations of Al_{KCl}. Forest cover influences significantly only soil pH. The pH values in beech forest are higher than those in spruce forest. It confirms findings published in HRUŠKA and CIENCIALA (2001). Distribution of Al_{KCl} is not influenced by forest cover. However, a difference was found in the case of Al_{org} between beech forest and spruce forest. Al_{org} content is higher in the beech forest.

In the B horizon, no decisive factor affecting the distribution of variables was found. The main effect is ascribed to soil in the case of Al_{KCl}, Al_{exch}, C/N and CEC. Since Gleysols are present only at two sam-
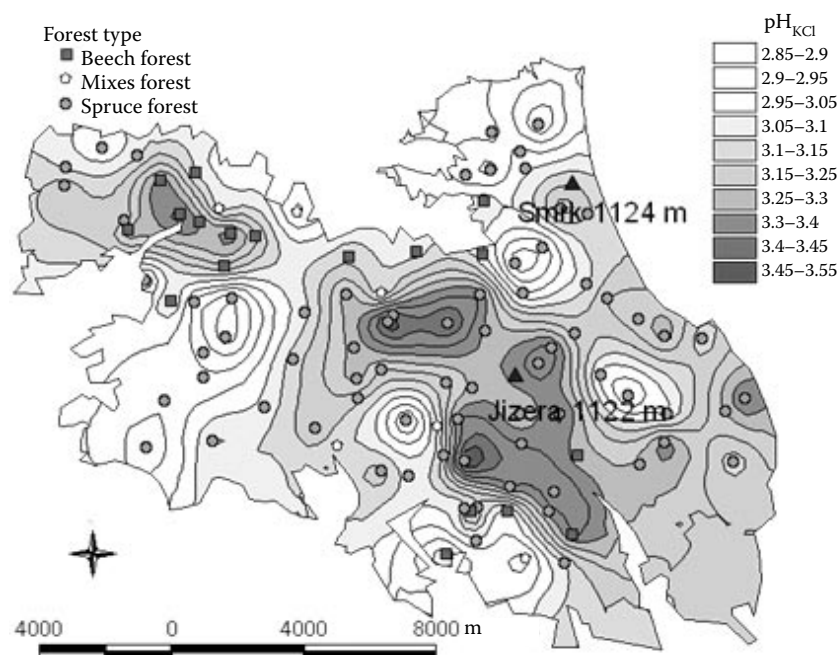

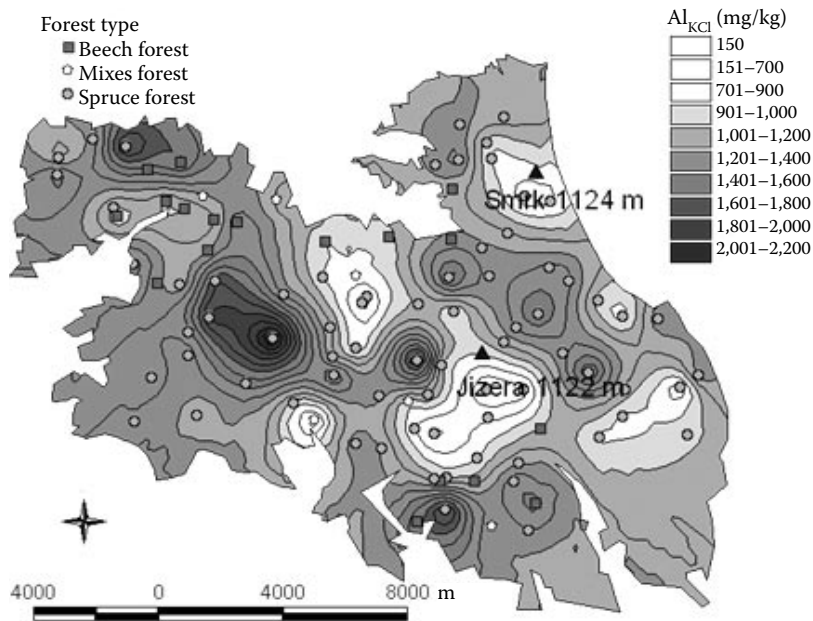Fig. 1. Cartogram of pH_{KCl} distribution in O horizon

Fig. 2. Cartogram of Al_{KCl} distribution in O horizon

pling sites, differences between them and other soil types are not so important. Significant differences between Cambisols and Podzols are shown only in the case of Al_{exch} and CEC. In both cases, lower values of these two characteristics are measured in Cambisols. The effect of forest cover was found significant in the B horizon only in the case of pH_{H_2O}. The value of pH_{H_2O} is higher in beech forest than in spruce forest. In three cases (Al_{org}, pH_{KCl}, A_{400}/A_{600}) no main effect was found.

On the basis of geostatistical analysis, a series of cartograms was created. Details of analysis are published separately. Selected results are considered in this contribution, namely evaluation of spatial variability of pH_{KCl}, Al_{KCl}, and Ca_{tot} in the O horizons (Figs. 1 to 3) and B horizons (cartograms not shown).

In both horizons, distribution of the lowest values of pH_{KCl} in the studied area is similar to distribution of the highest Al_{KCl} contents. Ca_{tot} cartogram shows one area with very high content of Ca_{tot} (above 500 mg/kg) in O horizon, where liming was almost surely applied. This area is characterized by high pH_{KCl} and low Al_{KCl} content. There probably exist relationships between Ca_{tot} content, Al_{KCl} content and pH_{KCl} in all partial areas. Increasing Ca_{tot} content leads to an increase in pH_{KCl} and a decrease in Al_{KCl} content. However, because of the existence of areas with high pH_{KCl} and low Al_{KCl} content, but also with low Ca_{tot} content, it is possible to reject the hypothesis that liming as a source of Ca_{tot} can be the only dominant factor influencing distribution of pH_{KCl} and Al_{KCl}. The situation is different
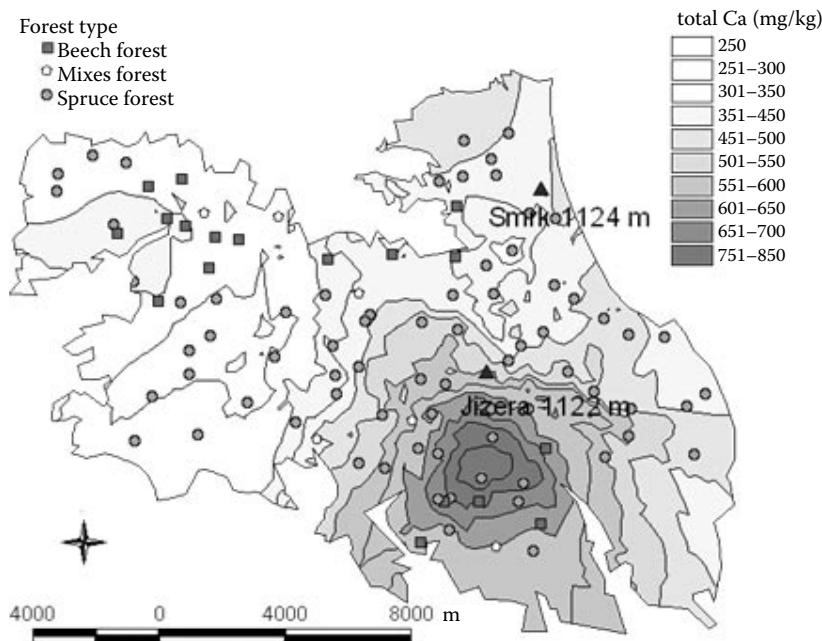

Fig. 3. Cartogram of Ca_{tot} distribution in O horizon

in B horizon where the concentrations of Ca_{tot} are low in the whole studied area. They range between 120 and 330 mg/kg.

CONCLUSIONS

It was shown that altitude was a decisive factor influencing a majority of the studied soil properties in O horizon. Effect of liming was dominant only in the case of Al_{KCl} distribution in O horizon. The type of forest cover influenced significantly only soil pH in this horizon. The pH values in beech forest were higher than those in spruce forest. No factor appeared dominant in describing acidification mechanisms in B horizon. Cartograms showed spatial relationships among Ca_{tot}, Al_{KCl}, and pH_{KCl} in O horizon in the limed parts of the mountains. Increasing Ca_{tot} led to an increase of pH_{KCl} and a decrease of Al_{KCl}. Ca_{tot} content is markedly lower in remaining part of studied region in this horizon and there was found a spatial relationship only between Al_{KCl} and pH_{KCl}, but not with Ca_{tot} content. There is a place for another factor influencing distribution of pH_{KCl} and Al_{KCl}, probably type of forest cover. This hypothesis was supported by results of a small area in the North East region part covered by beech forest where soils had relatively high pH_{KCl} and low Al_{KCl} content.

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Faktory ovlivňující rozložení různých forem Al v půdách Jizerských hor

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ABSTRAKT: Hlavním faktorem ovlivňujícím zastoupení jednotlivých forem Al v lesních půdách jsou acidifikační procesy. Jejich intenzita je dána různými stanovištními podmínkami a lidskou činností. Příspěvek popisuje vliv čtyř vybraných stanovištních faktorů na rozložení základních půdních charakteristik včetně dvou forem Al v lesních půdách Jizerských hor. Vybranými faktory jsou nadmořská výška, vápnění, půdní typ a typ dřevinného krytu. Rozložení většiny půdních charakteristik v organickém horizontu včetně organicky poutané formy Al je nejvíce ovlivněno nadmořskou výškou. Rozložení mobilní formy Al je především ovlivněno vápněním. V minerálním horizontu nebyl zjištěn žádný převažující vliv. Kartogramy dokumentují prostorové rozložení pH, mobilní formy Al a celkového obsahu Ca. Prostorové závislosti těchto půdních charakteristik jsou z nich zřejmé.

Klíčová slova: formy hliníku; lesní půdy; acidifikace

Příspěvek se zabývá rozložením různých forem Al, ale i dalších půdních charakteristik v půdách Jizerských hor. Odděleně jsou hodnoceny nadložní horizonty (O) a vnitřní spodické či kambické horizonty (B).

V odebraných vzorcích byla měřena půdní reakce (pH_{H_2O}, pH_{KCl}), kvalita humusu v podobě barevného kvócientu ($Q_{4/6} = A_{400}/A_{600}$) a v podobě poměru C/N, efektivní kationtová výměnná kapacita podle Mehlicha (KVK = CEC), celkový obsah vápníku (Ca_{tot}) a obsahy tří forem Al. Jedná se o formy extrahovatelné 0,5M KCl (Al_{KCl}), 0,1M $BaCl_2$ (Al_{exch}) a 0,05M $Na_4P_2O_7$. Z poslední jmenované formy byl odečtením Al_{KCl} vypočten obsah organicky poutaného Al (Al_{org}).

Jako faktory ovlivňující rozložení studovaných půdních charakteristik byly zvoleny následující stanovištní podmínky. Jako první byl hodnocen vliv povrchového vápnění. Odběrové lokality byly rozděleny podle celkového obsahu Ca_{tot} v horizontu O do čtyř kategorií. Jednalo se o kategorie s obsahem Ca_{tot} do 500 mg/kg, dále pak 500–1 000, 1 000 až 1 500 a 1 500–2 000 mg/kg. Druhým studovaným stanovištním faktorem byla nadmořská výška. Byly vytvořeny tři kategorie odběrových lokalit: do 800 m n. m., 800–900 m n. m. a nad 900 m n. m. Třetím třídícím kritériem byl zvolen typ porostu, tedy porost smrkový, bukový či smíšený. Posledním třídícím kritériem byl půdní typ. Na odběrových lokalitách byly určeny půdní typy kambizem, podzol, ranker a glej.

Pro zhodnocení vlivu jednotlivých stanovištních faktorů na rozložení půdních charakteristik byla využita vícecestná analýza rozptylu. Podmínku normálního rozdělení splňovaly všechny charakteristiky kromě Al_{KCl} v horizontu B, kde byla nutná logaritmická transformace.

Na rozložení většiny půdních charakteristik v horizontu O se podílel vliv rozdílné nadmořské výšky. Oba typy půdní reakce dosahovaly vyšších hodnot ve vyšších nadmořských výškách a zároveň rostla kvalita humusu podle obou studovaných ukazatelů s nadmořskou výškou. Rovněž byly zjištěny vyšší obsahy Al_{org} ve vyšších nadmořských výškách. V horizontu O se projevil vliv vápnění pouze na rozložení obsahu Al_{KCl}. Jeho obsah klesal s rostou-

cím obsahem Ca_{tot}. Typ porostu ovlivnil rozložení hodnot půdní reakce. Pod bukovými porosty byly hodnoty obou typů pH vyšší než pod smrkovými. V horizontu O se nijak neprojevil vliv půdního typu.

V horizontu B nelze označit žádný stanovištní faktor za převažující. Půdní typ sice ovlivnil rozložení čtyř (Al_{KCl}, Al_{exch}, C/N a KVK) z osmi studovaných půdních charakteristik, ale u Al_{KCl} a C/N se lišil pouze glej od ostatních půdních typů. Vzhledem k tomu, že glej byl zastoupen jenom na dvou odběrových lokalitách, není vhodné tento závěr zobecňovat. U kambizemí byly zjištěny nižší hodnoty KVK a nižší obsahy Al_{exch} než u podzolů. Dále byl v horizontu B prokázán vliv typu porostu na rozložení hodnot pH_{H_2O}. Stejně jako v horizontu O byly i zde hodnoty vyšší v bukových porostech než v porostech smrkových. U řady půdních charakteristik horizontu B se žádný z hodnocených stanovištních faktorů neprojevil jako rozhodující.

Další možností hodnocení vlivu stanovištních faktorů na rozložení půdních charakteristik je geostatistické zpracování dat. Detailnější informace jsou publikovány odděleně. V příspěvku je na třech kartogramech dokumentována prostorová závislost pH_{KCl}, Al_{KCl} a Ca_{tot} v horizontu O. Oblasti nejvyšších obsahů Al_{KCl} odpovídají oblastem s nejnižším pH_{KCl}. Na kartogramu obsahu Ca_{tot} je zřetelná oblast s vysokými obsahy vápníku, tedy oblast pravděpodobně v minulosti vápněná. V této oblasti je zároveň vyšší pH_{KCl} a nižší obsah potenciálně toxického Al_{KCl}. Je zde tedy možné připustit pozitivní vliv vápnění. Na distribuci pH i Al_{KCl} se však mohou podílet i jiné faktory, jak dokumentují lokální maxima i minima těchto charakteristik ve zbytku studované oblasti s nízkými obsahy Ca_{tot}.

Obecně lze tedy říci, že v horizontu O se na rozložení většiny půdních charakteristik podílí nadmořská výška, v níž je zahrnuta řada dalších dílčích stanovištních faktorů. Obsah potenciálně nebezpečné formy Al_{KCl} v tomto horizontu souvisí s obsahem Ca_{tot}, tedy pravděpodobně s povrchovým vápněním. Hodnoty pH jsou vyšší v bukových porostech než ve smrkových porostech. V horizontu B nebyl zjištěn žádný dominantní faktor. Byla zjištěna prostorová závislost pH_{KCl}, Al_{KCl} a Ca_{tot} v horizontu O.

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