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Comparison of Al speciation and other soil characteristics between meadow, young forest and old forest stands

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ABSTRACT

The aim of this paper is to describe the influence of spruce (*Picea abies*) afforestation on soil chemical properties, especially on soil acidity and aluminium (Al) mobilization and speciation in soil. For our study we used a unique set of three adjacent plots, including a meadow and two spruce forest stands of different age, in otherwise comparable conditions. The plots were located in the region of Giant Mountains, north-eastern Czech Republic. In general, pH values decreased and Al concentrations increased significantly after afforestation. Speciation of KCl-extractable and water-soluble Al in soil samples was done by means of HPLC/IC method. The concentrations of $Al(X)^{1+}$ and $Al(Y)^{2+}$ forms (in both extracts) are higher in humic and organically enriched (Bhs) horizons. The highest concentration of Al^{3+} in both extracts is in the B horizons of old forest.

Generally, in all studied stands majority of Al in aqueous extract is in the $Al(X)^{1+}$ form, which indicates that a large amount of mobile Al is bound in organic complexes. It suggests that actual toxicity is rather low. On the other hand, we have proved that majority of KCl-extractable Al exists in Al^{3+} form. Thus we can conclude that disturbance of existing equilibrium may cause massive release of highly toxic Al^{3+} from soil sorption complex to the soil solution, and consequently it can endanger the whole ecosystem. Moreover, continuous soil acidification accelerated by anthropogenic factors leading to Al mobilization represents a chemical time bomb.

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1. Introduction

Intensive coniferous afforestation has been shown to lead to profound changes to both the living and the non-living components of ecosystems [1,2].

Massive plantation of conifers, especially of Norway spruce (*Picea abies*), in the temperate European forests, has been suspected to influence soil quality in an unfavorable way [3–5]. Frequently cited mechanisms of the influence of spruce on soils are: increased inputs of strong acid anions resulting from greater deposition to the forest canopy [6], production of highly resistant organic matter that undergoes a slow decomposition with the formation of acidic aromatic compounds [7], and increase in base cations uptake and their removal due to wood harvesting [2].

In consequence of above mentioned processes, the soil acidification is being enhanced and mobilization of Al and other potentially toxic metals can occur [for example, 8–10]. In low pH conditions metals in ionic forms such as Al^{3+} can be mobilized and interfere with root functions or be taken up by plants creating chemical stress [11]. Once released into soil solution, there is greater potential for metals to reach also water sources, where they can be toxic to macro-invertebrates and fish [12].

In the Giant Mts., north-eastern Czech Republic, original beech–spruce–fir forests have been destroyed by logging since the middle ages. In the 17th and 18th centuries, the major parts of the area were used for intensive pasturing. Conversion of those semi-natural grasslands to plantation forests has been the major land-use change over the past 100 years.

Soil acidification in studied region has been driven by natural and anthropogenic factors. The soils in this region are generally acid, with low base status, underlined by base-poor bedrock. The natural soil acidification was enhanced in consequence of spruce plantation in monoculture form and high acidificants concentrations in the atmosphere in the 2nd half of the 20th century. Together with other stress factors (frost, drought) it has led to serious forests damages and soil degradation, similar to other comparable regions [13,14]. Although acid deposition in recent 15 years has decreased, forests are still threatened by long-term changes in soil conditions [3]. At present, the focus has turned to recovery of mountainous forests.

No detailed study of soil chemical changes and Al speciation development during the time after afforestation has been performed so far. This study is focused on the interaction between soil

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acidity, Al contents and organic matter changes associated with the conversion of meadow to spruce plantations, using a unique set of three different adjacent stands in the Giant Mountains.

2. Materials and methods

2.1. Site description

In order to determine whether there were any changes in soil chemistry over time due to afforestation, soils were studied in a 50-years-old spruce forest (F50 – young forest), and a 100-years-old spruce forest stand (F100 – old forest), both planted on former grassland, and an adjacent meadow (M – meadow) that has not been afforested. The studied area was located at the Giant Mountains National Park, 150 km north-east of Prague (Fig. 1). The altitude at the site is 750 m a.s.l., the mean annual precipitation is approximately 1322 mm, and the mean annual temperature is 4.7 °C [15]. The stands are situated on a north-west facing hillslope, the terrain is steep. The soils were classified according to World reference base for soil resources (WRB) [16] as Cambisols at the meadow and young forest, and Podzols at the old forest stand. The parent material is formed by gneiss.

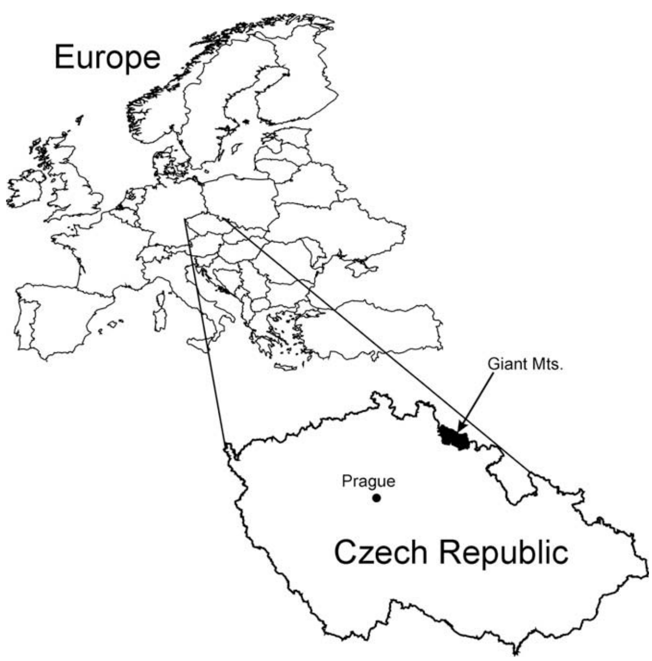

Fig. 1. The localization of studied area on the map of the Czech Republic.

The original vegetation was beech (*Fagus sylvatica)* and fir (*Abies alba*), which was logged more than 150 years ago. No fertilizer had ever been applied at the test sites. There were no signs of understorey vegetation under spruce at young forest. The ground was covered by approximately 5 cm of litter, mainly needles. Bilberry (*Vaccinium myrtillus*) was prevailing understorey under spruce of old forest and the ground was covered by approximately 7 cm of litter. The meadow (which is mowed annually) was covered with sod of various herbages.

We established 30 m × 30 m plots within each selected stand for sampling. Four soil pits (three in case of old forest) were dug on each stand. On the meadow, soil pits were located at least 10 m from the forest edge. Soil samples were collected from all sufficiently deep horizons, namely in case of Podzols the surface organic horizons (O), eluvial albic horizons (E), spodic humusosesquioxidic (Bhs), and sesquioxidic (Bs) horizons; in case of Cambisols organic horizons (O) (only in young forest soils), organomineral horizons (A), cambic horizons (Bv), and substrate horizons (C).

2.2. Soil analyses

All samples were air-dried, crushed, and passed through 2-mm sieves prior to analysis. Basic soil characteristics were determined. Active and exchangeable soil reaction (pH_{H_2O} and pH_{KCl}) were determined potentiometrically. The cation-exchange capacity (CEC) was determined using the Bower method with sodium as the index ion [17]. Organic carbon content (OC) was determined oxidimetrically by a modified Tjurin method [18] (it was performed only for samples from the mineral horizons). Humus quality was assessed by A_{400}/A_{600} ratio, i.e. the ratio of absorbances of soil pyrophosphate extract at wavelengths of 400 and 600 nm, respectively [19].

It is known that Al toxicity to plants decreases in this order: Al^{3+}, $Al(OH)^{2+}$, $Al(OH)_2{}^+$, $Al(OH)_4{}^-$, and $Al(SO_4)^+$ (the toxicity of $Al(SO_4)^+$, however, is not always accepted). Aluminium bound in fluoride or organic complexes and $Al(OH)_3$ are supposed to be non-toxic [20,21]. That is why speciation of Al in 0.5 M KCl and aqueous extracts (water soluble) was done. It was performed by means of HPLC/IC method. This method enables to separate Al forms mainly according to their charge: $Al(X)^{1+}$ (e.g. $Al(OH)_2{}^+$, $Al(SO_4)^+$, $AlF_2{}^+$, $Al(oxalate)^+$, $Al(org)^{\leqslant 1+}$); $Al(X)^{2+}$ (e.g. $Al(OH)^{2+}$, AlF^{2+}); and Al^{3+} [22]. Sums of the Al forms in aqueous and KCl extracts are assigned Al_{H_2O} and Al_{KCl}, respectively.

The data were analysed statistically using parametric tests. Analysis of variance (ANOVA) and *t*-test were used to assess the differences between the stands. Correlation analysis was used to identify the relationships between soil chemical characteristics. The level of significance was set at $P < 0.05$ for all statistical analy-

Table 1
Mean values of soil characteristics in separate horizons at each stand. Standard deviations are given in parentheses.

Hor.	pH_{H_2O}	pH_{KCl}	Al_{H_2O} (mg kg^{-1})	Al_{KCl} (mg kg^{-1})	CEC (mmol(+) 100 g^{-1})	OC (%)	A_{400}/A_{600}
F100							
O	3.1 (0.1)	2.0 (0.1)	41.2 (8.1)	744.2 (247.8)	116.4 (38.7)	nd	9.0 (1.2)
E	3.5 (0.1)	2.4 (0.2)	4.8 (1.5)	380.3 (17.8)	8.6 (0.9)	0.3 (0.04)	4.0 (0.1)
B	3.7 (0.3)	3.0 (0.4)	37.5 (24.9)	897.5 (354.9)	47.0 (10.3)	4.4 (0.6)	5.7 (1.0)
F50							
O	3.8 (0.1)	2.8 (0.1)	56.5 (12.4)	273.3 (124.4)	50.4 (5.9)	nd	8.1 (0.5)
A	3.8 (0.1)	2.9 (0.1)	26.7 (5.6)	604.7 (53.1)	24.1 (1.8)	2.3 (0.3)	7.0 (1.1)
B	4.2 (0.3)	3.2 (0.1)	8.9 (2.0)	469.5 (146.8)	16.8 (2.1)	2.0 (0.1)	5.7 (0.3)
M							
A	4.8 (0.3)	3.4 (0.1)	7.3 (0.5)	221.6 (224.4)	26.1 (1.4)	3.5 (0.2)	6.9 (0.6)
B	4.9 (0.3)	3.5 (0.2)	4.1 (0.8)	277.1 (137.0)	19.3 (3.2)	2.2 (0.4)	6.2 (0.8)

nd: not determined.

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