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Acidification and recovery of soil at a heavily impacted forest catchment (Lysina, Czech Republic)—SAFE modeling and field results

T. Navrátil[a,*], *D. Kurz*[b], *P. Krám*[a], *J. Hofmeister*[a], *J. Hruška*[a]

[a] *Czech Geological Survey, Klárov 3, 118 21 Prague 1, Czech Republic*
[b] *EKG Geo-Science, Ralligweg 10, CH-3012 Bern, Switzerland*

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ABSTRACT

Soil and soil solution chemistry were simulated using the dynamic multi-layer soil chemistry model SAFE for the Lysina catchment, located in the western part of the Czech Republic. Modeled soil solution chemistry and properties were compared to a 10-year-long time series of monthly measurements of soil solution data at 5, 15, 20 and 80 cm depths. Historically high deposition of S and N compounds caused a significant decrease in soil base saturation and caused severe changes in the soil solution chemistry. Since year 1990 deposition of S and N compounds decreased substantially due to improved control on S emissions. SAFE predicted an increase in base saturation at Lysina in the Oi + Oe and Oa layers, from 36% and 18% in 1994 to 50% and 22% in 2004, respectively. On the other hand, base saturation of the deeper soil horizons B and C, which represent the main mass of the soil at the Lysina catchment, has decreased even further (in B horizon from 4% in 1994 to 3% in 2004 and from 4% to 2% in horizon C). The measured values of base saturation from year 2004 fit the modeled results of base saturation development at the Lysina catchment. If atmospheric deposition remains at the 2006 level, the predicted base saturation in the B and C horizons for the year 2100 will increase by approximately 2% to reach only 4.6% and 3.8%, respectively. The increasing molar ratio Bc/Al [(Ca + Mg + K)/Al] in soil solution of Oi + Oe, Oa and E horizons during the first half of the 21st century represents recovery in the top 20 cm of the soil profile, only. This change may have a positive effect on the health status of shallow rooting spruce trees. The Bc/Al ratio in soil solutions in the main mass of the soil (horizons B and C), however, will remain below the critical value (<1) in the first half of 21st century. At the Lysina catchment, the values of the Bc/Al ratio are predicted to increase over the critical value (<1) in solutions of the B and C horizons in the years 2050 and 2060, respectively.

1. Introduction

The northwestern part of the Czech Republic experienced extraordinarily high acid atmospheric deposition in the second half of the 20th century, but this was followed by rapidly decreasing acid deposition during the 1990s (Hruška and Krám, 2003; Kopáček and Veselý, 2005).

A major buffering process in soils is the desorption of cations, which are bound to negatively charged soil particles. In ecosystems not impacted by acid deposition, the pool of

* *Corresponding author*.
E-mail address: navratilt@gli.cas.cz (T. Navrátil).
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base cations (calcium [Ca], magnesium [Mg], sodium [Na] and potassium [K] ions) is normally of considerable size. Soil acidification causes the soil content of base cations to be depleted and replaced by hydrogen and aluminum [Al] ions. Three base cations (Ca, Mg, K) are important nutrients for plants, but soil acidification can lead to their shortage and impaired forest growth (van Breemen et al., 1984).

Due to differences in properties of individual soil horizons, different parts of the soil profile acidify and recover at different rates. There could be a significant delay from the topsoil, which is first affected by acid deposition, to the bottom of the soil profile. During acidification, hydrogen and Al ions mobilized in the soil solution may exchange with the base cations on a cation exchangeable complex and delay the decrease in pH. During recovery, the reverse process could occur, and while the upper layers recover, simultaneously the bottom layers may still acidify (Sverdrup et al., 2005).

Norway spruce plantations enhance the level of acid deposition and thus the acidification of forest soils. Due to Norway spruce planting at sites with increased sensitivity to acid deposition, these ecosystems have been the subject of numerous studies in Central Europe (Jonsson et al., 1995; Bredemeier et al., 1998; Walse et al., 1998; Kurz et al., 1998; Hruška et al., 2002; Navrátil et al., 2002; Oulehle and Hruška, 2005). The health status of Norway spruce plantations in the Czech Republic and elsewhere has been also correlated with the molar Bc/Al ratio [(Ca + Mg + K)/Al] of the soil solution (Hruška et al., 2001).

Dynamic soil chemistry models are valuable tools for the reconstruction of effects of past acid deposition and site management in the future. The dynamic model, Soil Acidification model of Forest Ecosystems, SAFE (Warfvinge et al., 1993) was calibrated to soil and soil solution chemistry monitoring data of the Lysina catchment in the western part of the Czech Republic. There, SO_2 emissions declined by 90% compared to the 1980s (Kopáček and Veselý, 2005), and total deposition of sulfate [SO_4^{2-}] to the catchment decreased from about 160 mequiv. m^{-2} year^{-1} in 1990 to roughly 50 mequiv. m^{-2} year^{-1} in 2000.

This study simulates soil solution chemistry, compares it with the measured data and then simulates the past and future development of the soil solution and soil properties.

2. Methods

2.1. Site description

The Lysina catchment is situated in western Bohemia, the Czech Republic (Fig. 1). The catchment covers an area of 0.273 km^2 and is covered with a Norway spruce (*Picea abies*) monoculture. Altitude of the site is between 829 and 949 m a.s.l. with a mean slope of 11.5%. The region was not glaciated during Wisconsinan time, and soils are developed from residuum bedrock. The bedrock at the Lysina catchment is coarse-grained leucogranite. The bedrock consists dominantly of quartz, orthoclase, plagioclase and mica. The oxides SiO_2 and Al_2O_3 comprise 87% of the rock by weight (Krám et al., 1997). The CaO content of the leucogranite is 0.52%; MgO content is only 0.11%. Due to very low Ca and Mg content in the bedrock, the Lysina catchment is considered to be a low "end-member" with respect to the buffering capacity of bedrock. Soils in the catchment are Dystric Cambisols. The catchment is drained by a perennial stream that begins at about 900 m a.s.l.

2.2. Site history

In the former Czechoslovakia after World War II, massive production of energy from the burning of brown coal, resulted in high emissions of SO_2 into the atmosphere. In the first half of the 1980s, SO_2 emissions leveled off and began to decrease sharply in period 1985–2000 due a decrease in energy consumption in the early 1990s and sulfur [S] emission controls.

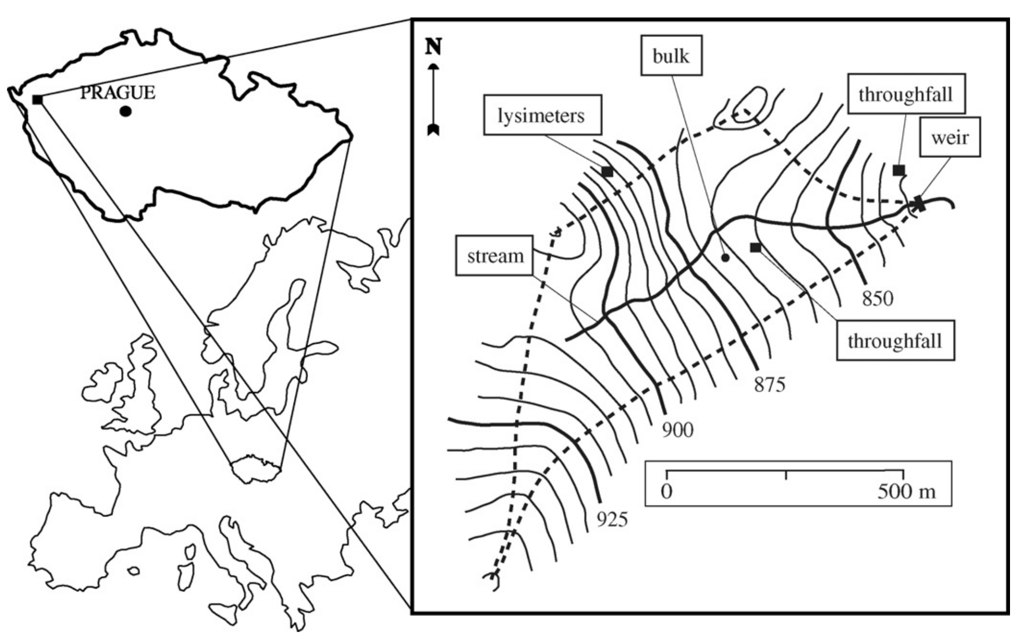

Fig. 1 – Location of the Lysina catchment in Europe and in the Czech Republic.