

Chapter 11

Modeling Time Patterns of Forest Soil Acidification for Various Deposition Scenarios

Willem de Vries¹, Maximilian Posch² and Juha Kämäri³

Summary

A soil acidification model has been developed to estimate long-term chemical changes in soil and soil water in response to changes in atmospheric deposition. Major model outputs include base saturation, pH and the Al/BC ratio, where BC stands for divalent base cations. The processes accounted for are restricted to geochemical interactions, including weathering of carbonates, silicates and aluminum hydroxides, cation exchange and CO₂ equilibria. With the exception of silicate weathering, all processes are described by equilibrium reactions. Model parameters mainly refer to equilibrium constants for the various processes, while model variables include the amounts of base cations and aluminum in carbonates, hydroxides, the exchange complex and in soil solution. The model behavior in the different buffer ranges between pH 7 and pH 3 has been evaluated by analyzing the response of an initially calcareous soil to a constant high acid load (5000 mol_c ha⁻¹ yr⁻¹) over a period of 500 years. In calcareous soils, weathering is fast and the pH remains high (near 7) until the carbonates are exhausted. In non-calcareous soils the response in the range between pH 7 and pH 4 mainly depends on the initial amount of exchangeable base cations. Although the model cannot be strictly verified for its ultimate use of long-term predictions, it can be used as a tool to obtain a conceptual understanding of long-term soil responses for the broad concern of resource managers and policy makers. Therefore it will be linked to the Regional Acidification Information and Simulation model (RAINS) to analyze the impact of various emission scenarios on a European scale.

¹Netherlands Soil Survey Inst., P.O. Box 98, 6700 AB Wageningen, The Netherlands

²International Inst. for Applied Systems Analysis, A-2361 Laxenburg, Austria

³Water and Environment Res. Inst., P.O. Box 250, SF-00101 Helsinki, Finland

Introduction

Apart from direct visual damage of the forest canopy the deposition of S and N can affect forest ecosystems by indirect, soil-mediated effects on the roots. The most notable effect is the inhibition of nutrient uptake (especially Ca^{2+} and Mg^{2+}) either by mobilization of Al^{3+} (acidification) or by accumulation of NH_4^+ (eutrophication), which leads to unfavorable ratios of these compounds to base cations (Ulrich and Matzner 1983; Roelofs et al. 1985).

As to acidification, the development of unfavorable ratios of Al^{3+} to divalent base cations strongly depends on the buffer mechanisms of the soil. In highly buffered soils decades or even centuries may be required before measurable changes in this ratio occur, even with high levels of atmospheric deposition, whereas it may take less than a decade in very sensitive soils.

Information on the long-term effects of acid deposition on soils is very important for the formulation of policies for emission reductions. In this respect models provide an important tool to assist decision makers in evaluating the effectiveness of abatement strategies. Consequently, at the International Institute for Applied Systems Analysis (IIASA) a Regional Acidification Information and Simulation model (RAINS) has been developed that analyzes environmental impacts on a European scale for different emission scenarios. Predictions are based on quantitative descriptions of the linkages between emissions, deposition and environmental impacts such as soil acidification and effects on terrestrial and aquatic ecosystems (Alcamo et al. 1987). Similar model systems, mostly on a national level, have been developed in Denmark (Christensen et al. 1985), Finland (Johansson et al. 1988) and the Netherlands (De Vries in press).

Within the overall framework of the RAINS model the soil acidification submodel forms an important link between atmospheric deposition and effects on forests, surface waters and groundwater. The earlier RAINS soil model predicts pH as a function of sulfur deposition (Kauppi et al. 1986). This model was based on the concept of buffer ranges as introduced by Ulrich (1981a, 1983). Here we describe a new model, Simulation Model for Acidification's Regional Trends (SMART). SMART includes the effects of natural soil acidification due to dissociation of CO_2 and the impact of NO_x - and NH_3 -deposition. Furthermore the model predicts the major components of the soil solution, i.e. H^+ , Al^{3+} , BC^{2+} , NH_4^+ , NO_3^- , SO_4^{2-} and HCO_3^- . The ratios of Al^{3+} and NH_4^+ to divalent base cations (represented by BC^{2+}) are more relevant parameters with respect to effects on forests.

Our objective is to demonstrate the model behavior by analyzing the time evolution of forest soil acidification for various deposition scenarios. The attention is focused on the time lag between changes in atmospheric deposition and changes in soil chemistry, i.e. pH, base saturation and Al/BC ratio.

Model Structure and Modeling Approach

H^+ -transfer in the soil is influenced by numerous reactions (De Vries and Breeuwsmma, 1987). In order to minimize data input requirements in applying SMART for producing temporal and geographical patterns of forest soil acidifications in Europe the following assumptions have been made:

- The soil solution chemistry is only determined by the net element input from the atmosphere and the geochemical interactions (weathering and cation exchange) in