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Nitrogen dynamics of a mountain forest on dolomitic limestone – A scenario-based risk assessment

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A combination of the risk factors ''elevated temperature and nitrogen inputs'' will increase the rate of nitrate leaching and the emission of nitrogen oxides from a forest ecosystem in the Austrian limestone Alps.

Abstract

The dominant nitrogen (N) fluxes were simulated in a mountain forest ecosystem on dolomitic bedrock in the Austrian Alps. Based on an existing small-scale climate model the simulation encompassed the present situation and a 50-yr projection. The investigated scenarios were current climate, current N deposition (SC1) and future climate (+2.5 °C and +10% annual precipitation) with three levels of N deposition (SC2, 3, 4). The microbially mediated N transformation, including the emission of nitrogen oxides, was calculated with PnET-N-DNDC. Soil hydrology was calculated with HYDRUS and was used to estimate the leaching of nitrate. The expected change of the forest ecosystem due to changes of the climate and the N availability was simulated with PICUS. The incentive for the project was the fact that forests on dolomitic limestone stock on shallow Rendzic Leptosols that are rich in soil organic matter are considered highly sensitive to the expected environmental changes. The simulation results showed a strong effect due to increased temperatures and to elevated levels of N deposition. The outflux of N, both as nitrate (6–25 kg N ha^{-1} yr^{-1}) and nitrogen oxides (1–2 kg N ha^{-1} yr^{-1}), from the forest ecosystem are expected to increase. Temperature exerts a stronger effect on the N_2O emission than the increased rate of N deposition. The main part of the N emission will occur as N_2 (15 kg N ha^{-1} yr^{-1}). The total N loss is partially offset by increased rates of N uptake in the biomass due to an increase in forest productivity.

Keywords: Nitrogen dynamics; Dolomitic limestone; Global change; Nitrate leaching; N_2O emissions

1. Introduction

Measures to reduce the emission of N are only partially successful and it is to be expected that in the future forest ecosystems will have more N available than at present. Climate change extends the growing season and higher temperatures accelerate soil-microbial transformation processes. So far the N poor forest ecosystems in mountain regions of the Alps have absorbed N. The peculiar land-use history until the mid of 20th century such as litter raking and pollarding had lead

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to an often extreme N depletion of forest soils (Glatzel, 1999). Elevated rates of N deposition since several decades have lead to the replenishment of soil N stocks. Experimental results have shown that in some cases even high levels of N deposition do not necessarily lead to large increases in N leaching. However, the N accumulation capacity in soils is limited and it is of prime importance to understand how long the forest ecosystem will be able to retain N (Aber et al., 1998).

Interest in the response of ecosystems to climate change and N deposition is high and only limited information on the combined effects of these factors is available. A comparison of six vegetation models with respect to the productivity of forests under future climatic conditions was given by Cramer et al. (2001); these models indicated that forest productivity will likely increase globally. Nevertheless, the adaptation to future conditions may slow down within several decades, because the response to increasing temperatures will prevail, whereas the CO_2-fertilization effect is only a one-step increase of growth rates (Körner et al., 2007).

The responses of forests to climate change will likely depend in part on nutrient supplies, and nitrogen enrichment raises concern in Europe, North America, and increasingly in Asia (Fenn et al., 2003; Galloway et al., 2004). The effect of elevated rates of N deposition was deduced from the results of long-term fertilization experiments in Scandinavia where it was shown that under ambient, rather low levels of N deposition, the forests will for a long time remain strongly N limited. Under warmer global conditions the temperate forests will be able to utilize even more additional N (Högberg et al., 2006). A detailed analysis of the response of soil processes considering warmer global conditions was conducted by Rustad et al. (2001) with the findings that soil respiration, N mineralization and plant productivity will increase. A meta-analysis showed that soils can both attenuate and buffer the effects of climatic change.

Large-scale simulations depict a general trend. However, for regionally valid answers a set of local case studies is required. The Northern Tyrolean Limestone Alps have an area of 400,000 ha which includes forests, pastures and unproductive land. The shallow soils have a limited capacity to absorb N and under future climate conditions the forest ecosystems may retain less N. The potential of nitrate release into the groundwater and the emission of nitrogen oxides to the atmosphere have not yet been quantified for this area. The warming trend was well documented from the nearby meteorological station at Mt. Patscherkofel (1950 m a.s.l.) where the annual mean air temperatures have increased by more than 1 °C since the early 1960s; winters are insignificantly cooler and summers significantly warmer (Wieser, 2007). The future climate may prove problematic for the growth of the *Picea abies*-dominated forests.

The objectives of our research were to create a consistent picture of the major N processes that affect the N budget of the study site. We validated a suite of models with field data and simulated the effects of climatic change with climate data that are expected for 2050 and with different rates of N deposition. The overall goal was to improve our understanding of how possible changes in future environmental conditions will influence the emission rates of nitrogen oxides and the rate of nitrate leaching from the soil.

2. Materials and methods

The study site 'Mühleggerköpfl' located in the Northern Tyrolean Alps is an intensively monitored research plot of 0.3 ha. A site description is given in Table 1. The Northern Alps form a natural barrier to the predominating westerly winds. Oncoming air masses are uplifted and the consequence is frequent rainfall and the absence of prolonged dry periods. Under these conditions even low concentrations of N in the rain lead to a considerable deposition load.

A data set from a regionally valid climate simulation was obtained by downscaling global climate predictions by ECHAM3 with the mesoscale meteorological model MM5 (Grell et al., 2000). The main results disclosed an increase in the annual air temperature of 2.5 °C and a changed precipitation regime over the next 50 years (Jandl et al., 2004). In the future summers will be drier and more precipitation will fall in spring. Overall, the precipitation will rise by about 10%. The scenarios of the experiment are given in Table 2.

Biogeochemical fluxes of N were estimated using models because the spatial heterogeneity of the soil and the karstic bedrock make the quantification of the N losses' fluxes in the aqueous and the gaseous phase by field experiments difficult. A set of independent process models was used.

The soil water flux was simulated with HYDRUS (Simunek et al., 1998). The water flux below the rooting zone (60 cm soil depth) and the NO_3-N concentration of the soil solution were used to estimate the annual N output into the aqueous phase. PnET-N-DNDC is an ecosystem model that accounts for nitrification and denitrification and gives estimates for the emission of N_2O, N_2 and NO in soils (Li et al., 2000; Stange et al., 2000). PICUS models

Table 1
Climate, soil properties and stand characteristics at the experimental site Mühleggerköpfl (Herman et al., 2002a; Feichtinger et al., 2002)

Coordinates	11°38′21″ East and 47°34′50″ North			
Elevation	895 m			
Mean annual temperature	6.5 °C			
Mean annual precipitation	1425 mm			
Nitrogen deposition	18 kg N ha^{-1}			
Geology	Dolomitic bedrock			
Forest type	*Picea abies* (125 years) with some *Abies alba* and *Fagus sylvatica*			
Soil types	Mosaic of Chromic Cambisols and Rendzic Leptosols			
Soil chemistry				
Soil depth (cm)	pH	C (g/kg) in the mineral soil	N (g/kg) in the mineral soil	NO_3 (mg/L) in the soil solution
0–15	6.5–7.3	170	10.4	6.2
15–30	7.5	85	5.9	7.5