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Effect of nitrogen deposition reduction on biodiversity and carbon sequestration

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ABSTRACT

Global warming and loss of biodiversity are among the most prominent environmental issues of our time. Large sums are spent to reduce their causes, the emission of CO_2 and nitrogen compounds. However, the results of such measures are potentially conflicting, as the reduction of nitrogen deposition may hamper carbon sequestration and thus increase global warming. Moreover, it is uncertain whether a lower nitrogen deposition will lead to a higher biodiversity. We applied a dynamic soil model, a vegetation dynamic model and a biodiversity regression model to investigate the effect of nitrogen deposition reduction on the carbon sequestration and plant species diversity. The soil and vegetation models simulate the carbon sequestration as a result of nitrogen deposition and they provide the biodiversity model with information on the soil conditions groundwater table, pH and nitrogen availability. The plant diversity index resulting from the biodiversity model is based on the occurrence of 'red list' species for the tree soil conditions. Based on the model runs we forecast that a gradual decrease in nitrogen deposition from 40 to 10 kg N ha^{-1} y^{-1} in the next 25 years will cause a drop in the net carbon sequestration of forest in The Netherlands to 27% of the present amount, while biodiversity remains constant in forest, but may increase in heathland and grassland.

1. Introduction

Human activities have led to a worldwide decrease in biodiversity (Chapin et al., 1998; Swift et al., 1998; Smith et al., 2000; Dobson, 2005), often caused by land use change (Vitousek et al., 1997; Swift et al., 1998; Zebisch et al., 2004). Intensified land use caused an increase of reactive nitrogen in the atmosphere and soil in agricultural areas, but atmospheric reactive nitrogen also increased due to more intense traffic (Hogg et al., 1995; Kelly et al., 2002; Lameire et al., 2000; Wright et al., 2001; Bobbink and Lamers, 2002; Tarasón et al., 2003; Holland et al., 2005). Moreover, industrial activities have lead to an increase of CO_2 in the atmosphere, which may lead to higher temperatures causing an even higher pressure on biodiversity. Whether or not a higher CO_2 concentration will affect biodiversity directly still remains uncertain (Peterson and Melillo, 1985; Smith et al., 2000; Chapin et al., 2000; Malcom et al., 2002; Thomas et al., 2004). We investigated what the effect of a reduction of nitrogen deposition on the biodiversity and the carbon sequestration is. The global issues at stake have been the subject of several international conferences where many countries have agreed on countermeasures to prevent further loss of biodiversity and to stop global warming (e.g. the Rio and Johannesburg conferences and the Kyoto conference leading to the Kyoto protocol). Main targets resulting from the conferences are to stop further decrease of biodiversity and to stop global warming. The latter may be reached by a reduction of CO_2 release into the atmosphere or by an increase of carbon sequestration. In areas that are densely populated or have an intensive agricultural use biodiversity may be enhanced by a reduction of nitrogen deposition. These areas can be found mainly in Western Europe, e.g. England, Belgium, Denmark, Germany and The Netherlands, and some parts of the U.S.A. The policy goals, however, could be conflicting since a decrease in nitrogen deposition may negatively affect carbon sequestration. A lower nitrogen deposition, however will also lead to a lower input in the atmosphere of N_2O with a warming potential of 300 times that of CO_2. Experimental research has revealed a positive relation between N addition and growth, and thus carbon sequestration, in Scandinavian forests where nitrogen strongly limits growth

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(Tamm et al., 1999). This positive effect may be reduced when other factors, such as other nutrients, temperature or air pollution, restrict productivity. The relation between N addition and biodiversity has also been experimentally tested (Bobbink and Roelofs, 1995; Bobbink et al., 1998; Tilman, 1993; Thomas et al., 1999; Reich et al., 2001; Aerts et al., 2003) and showed that N addition leads to a decrease in biodiversity. However, research into the combined effect of nitrogen deposition on both carbon sequestration and biodiversity is scarce, especially on a regional scale (Reich et al., 2001; Huston and Marland, 2003).

Measures to reduce nitrogen emission have begun to take effect, and deposition has a downward trend at least in some areas (Kelly et al., 2002; Tarasón et al., 2003). But the deposition is still high; for instance the average deposition in Western Europe is approximately 18 kg ha^{-1} N, whereas the estimated background deposition is approximately 3 kg ha^{-1} N (Galloway et al., 1982; Galloway et al., 1984; de Vries, 1994; Tarasón and Schaug, 2000). However, for many of the newly defined world biodiversity hotspots (Myers et al., 2000) the nitrogen deposition is expected to rise even further (Phoenix et al., 2006). Several sources claim that increased N deposition will enhance carbon sequestration, although the extent of this effect shows a great deal of variation (Peterson and Melillo, 1985; Schindler and Bayley, 1993; Townsend et al., 1996; Holland, 1997; Nadelhoffer et al., 1999; Hungate et al., 2003), and some of these studies suggest that it is only of minor importance (Townsend et al., 1996; Nadelhoffer et al., 1999). Although there is ample evidence that increased N deposition results in a decrease of floristic diversity, at least in grassland and heathland communities (Aerts et al., 1990; Bobbink et al., 1998; Roem and Berendse, 2000; Aerts et al., 2003; Stevens et al., 2004), it is not certain whether a decrease in deposition will also lead to an immediate return of lost species. This may depend on e.g. the presence of diaspores in the seed bank or in the neighbourhood for recolonisation. However, a decrease in N deposition will lead to improved environmental conditions for these species in terms of soil pH and N availability. Another positive effect of a lower nitrogen deposition is that the resulting emission of the greenhouse gas nitrous oxide is lower as well and thus compensating for the lower carbon sequestration.

In view of the above, the big questions are (a) whether or not the biodiversity will improve after a decrease of nitrogen deposition and (b) how a decrease of nitrogen deposition will influence the carbon sequestration. To answer these questions, we explored the effect of nitrogen deposition on carbon sequestration in combination with its effect on potential floristic diversity by scenario analyses using the model chain SMART2–SUMO2–NTM3 (Berendse, 1994; Kros, 2002; Van Dobben et al., 2002; Wamelink et al., 2003) on a regional scale. We choose floristic diversity because nitrogen deposition has a close effect on the occurrence of plant species. Some species tend to get locally extinct when deposition rates increases, while other fast growing species tend to increase. The fast growing species tend to acquire the extra nitrogen more efficient, resulting in a higher aboveground growth thus outcompeting slower growing species in the competition for light. The effects of climate change (raised temperature and carbon dioxide) on the growth of the vegetation are not included in this research.

2. Material and methods

2.1. Models

The SMART2 (Kros et al., 2002; Kros, 2002) model simulates soil processes, SUMO2 (Berendse, 1994; Van Dobben et al., 2002) simulates vegetation processes and succession, whereas NTM3 (Wamelink et al., 2003) predicts the 'potential floristic diversity' based on groundwater level, nitrogen availability and pH (the latter two simulated by SMART2–SUMO2). SMART2 and SUMO2 are dynamic process models that include complete nitrogen and carbon cycles, based on time steps of one year.

The model SMART2 (Kros et al., 2002; Kros, 2002) considers linked biotic and abiotic processes in the soil solution as well as in the solid phase. It represents the inorganic soil and two organic soil compartments. The model consists of a set of mass balance equations, describing the soil input–output relationships and rate-limited and equilibrium soil processes. The soil solution chemistry depends on the net element input from the atmosphere and groundwater, canopy interactions, geochemical interactions in the soil (CO_2 equilibria, weathering of carbonates, silicates and/or Al hydroxides, SO_4 sorption and cation exchange), and nutrient cycling (litterfall, mineralisation, root uptake, nitrification and denitrification). Nutrient uptake by the vegetation and litterfall (including the amount of dead roots and dead wood) are provided by SUMO2. SMART2 delivers the nitrogen availability to SUMO2 as the sum of external N input and mineralisation. Solute transport is described by assuming complete mixing of the element input within one homogeneous soil compartment with a constant density and fixed depth.

Like SMART2, SUMO2 (Berendse, 1994; Wamelink et al., 2005, Wamelink, 2007) is a process-oriented model that simulates vegetation succession and biomass production for time steps of one year. The biomass development is simulated for five functional types (FT), herbs and grasses (1), dwarf shrubs (2), shrubs (3), and two tree species (4 and 5). The five FT compete with each other for nitrogen (including nitrogen deposition), light, and moisture. Competition for nitrogen is based on the relative biomass present in the roots of the FT. Competition for light is simulated as a result of the height and the leaf biomass of the FT. Actual biomass growth of each FT is the result of a reduction of the maximum growth by moisture, nitrogen and light availability. The biomass can also be reduced as a result of management (mowing in grassland, sod cutting in heathland, thinning in forest). Mowing, sod cutting and thinning imply the removal of biomass and thus carbon and nitrogen from the system. SUMO2 requires information on soil type and groundwater level, the initial vegetation type and the management. Management is usually unknown and is therefore derived from the vegetation type. In this study grassland is mown once each year, sod cutting takes place in heathland every 30 years and in forest trees are thinned depending on the tree species and the biomass growth. The initial biomass (and nitrogen content) is derived per vegetation type and age class from a standard database containing biomass and nitrogen content for an average stand in The Netherlands. The model is initialised for 10 years to adjust the biomass and nitrogen content to the local circumstances.

NTM3 (Wamelink et al., 2003) is a regression model based on the criteria of the red list, i.e. the rarity, the temporal trend and the size of the distribution area of each species. It is a regression model that predicts the potential floristic diversity at given values of the soil characteristics nitrogen availability, soil pH and moisture availability. The nitrogen availability and soil pH are simulated by SMART2, the moisture availability as spring groundwater level is derived from a hydrological map. A nature conservation value (NCV) was assigned to the vascular plant species occurring in The Netherlands, based on the red list criteria, rarity, temporal trend and size of the distribution area (Mace and Stuart, 1994). The rarity was based on the occurrence of the species in the Dutch national 5 km grid, and the trend is based on the change of occurrence of the species on the national grid between 1950 and 1990. The distribution area indicates the importance of the occurrence of the species in The Netherlands for its total distribution area. Rare and decreasing species that have their major distribution in The