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Integrating the effects of climate change on terrestrial ecosystems

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Abstract

A model of carbon, nitrogen and water flows within an ecosystem in relation to changes in species composition is nearing completion. This model, which applies to succession on sandy soils, will be used to investigate the effects of temperature, nitrogen deposition and CO_2 concentration in the atmosphere on vegetation succession. The model applies to primary succession on sandy soils. Parameters are being collected in a Dutch drift sand area (Hulshorsterzand). Preliminary simulation show strong interactions between the effects nitrogen deposition and CO_2 concentration: The rate nitrogen is supplied to the ecosystem influences whether species replacement is accelerated, not affected or delayed by increasing CO_2 concentrations. This implies that relative abundances of species may change in response to climate change.

1. INTRODUCTION

One important component of vegetation succession is the modification of the environment brought about by the plants themselves. This modification encompasses changes in the availability of nutrients, light and water for the different plant species. These changes alter the competitive balance between species, which can lead to shifts in their relative abundances. The carbon, water and nutrient flows in ecosystems can be seriously affected by the various aspects of climate change: rising CO_2, changing precipitation patterns and changing temperatures as well as by the changing amounts of nitrogen deposition. This can have pronounced consequences for species composition and biodiversity in natural ecosystems (Pastor & Post, 1986). Short term experiments with one or a few species are insufficient to enable the eventual effects of climate change on plant communities and biodiversity to be predicted with confidence. The solution is to integrate knowledge acquired in these experiments into models. We are therefore in the process of developing a dynamic simulation model to investigate the effects of climate change on succession, which calculates how dominant plant species in a primary succession mediate carbon and nitrogen flows. The final model furthermore will include a water balance.

Species diversity is often found to be correlated with ecosystem parameters such as primary production, vegetation structure, nitrogen mineralization and soil pH (Pausas, 1994). Other variables might be identified as being relevant in this context too. These ecosystem parameters are mainly determined by the external environmental conditions, the successional age of the ecosystem and the dominant plant species. The aim of the model presented is to calculate effect of climate change on the mentioned ecosystem parameters and on the biomass of the dominant plant species. Based on the changes in these variables probable consequences for biological diversity will computed using descriptive models.

2. MODEL DESCRIPTION

The succession model simulates the dynamics of populations of dominant plant species at a certain site through time. In the model plant populations compete for light and nitrogen (Figure 1). A water module will enable competition for water to be investigated too. The model has been specially designed to study the effects of different scenarios of atmospheric nitrogen deposition, CO_2 concentration and temperature on succession. The driving variables of the main model are temperature, CO_2 concentration in the atmosphere and nitrogen deposition. The water module will use additional weather data, such as rainfall and irradiation as driving variables. The time step of the model is one year and the run time is about 150 years.

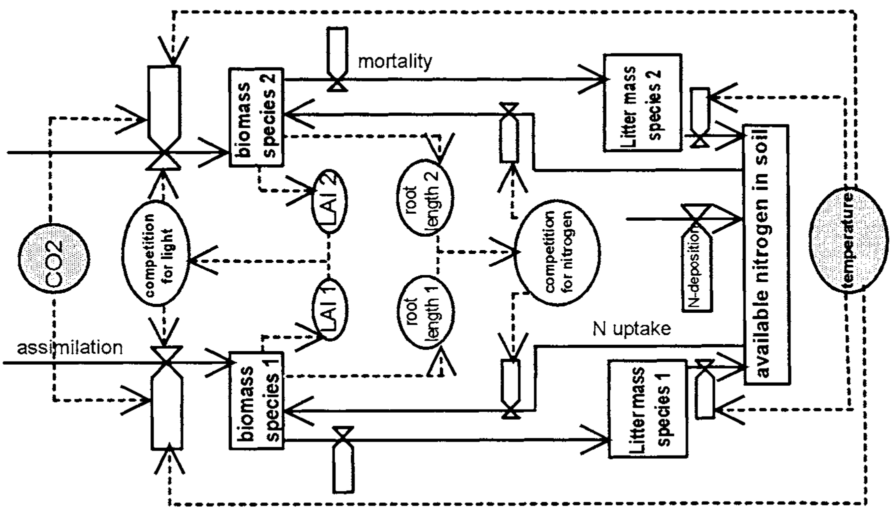

Fig. 1. General structure of a succession model simulating competition for light and nitrogen as influenced by climate change. Solid lines: carbon / nitrogen flow, dotted lines: information flow, grey circles: driving variables.

The model computes at each time step the amounts of carbon and nitrogen in the plant parts of the different species. Furthermore, the amounts of carbon and nitrogen contained in litter and soil organic matter and the amount of mineral nitrogen in the soil are calculated. The latter information is useful because on sandy soils with high rainfall the amount of mineral nitrogen in the soil is a measure of the leaching of nitrogen. Vegetation height , light at soil surface and several other derived values can be produced by the model.

The model parameters are currently being measured in a chronosequence in a Dutch drift sand area (Hulshorsterzand, 52°20' N, 5°44' E). Validation data are being collected in independent measuring campaigns.

3. RESULTS TO DATE

As the model is still being developed, the results reported here are preliminary.

Parameters were tuned in such a way that a doubling of the CO_2 concentration would under optimal conditions result in a 30% increase of production for all species.

At intermediate levels of nitrogen input, simulations with a high CO_2 concentration (of 560 ppm) showed lower N to C ratios in living tissue and in fresh litter. This in turn resulted in lower decomposition and mineralization rates (Figure 2). Due to reduced N availability, in these cases CO_2 enrichment did not lead to increased production, compared to simulations with present-day CO_2 concentrations (of 350 ppm). At low N input, little changed; at high N input simulations showed increased total production. Simulations with parameters for *Calluna vulgaris* (L.) Hull and *Deschampsia flexuosa* (L.) Trin. (from Bakema *et al.* 1994) showed that the relative abundances of species may be influenced by increased CO_2 concentrations (Figure 3).

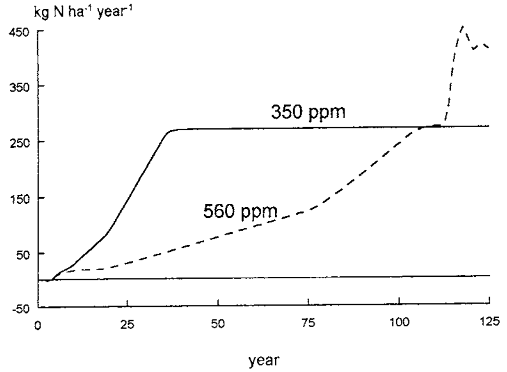

Fig 2. N mineralization rates under a Calluna - Deschampsia vegetation at two CO2 concentrations and 30 kg N / ha / year as atmospheric deposition.

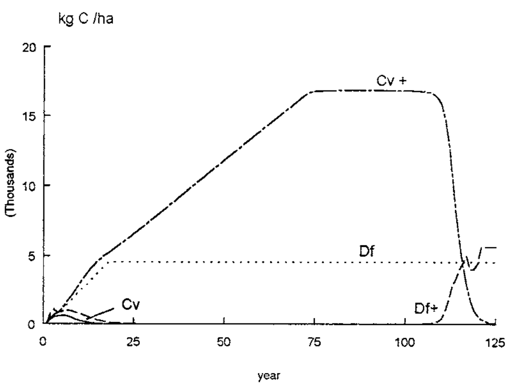

Fig 3. Biomass development of C. vulgaris and D. flexuosa at two CO2 concentrations and 30 kg N /ha/year as atmospheric deposition.

4. DISCUSSION AND CONCLUSIONS

So far, we have only investigated the effects of nitrogen deposition and CO_2 concentration on vegetation and soil processes. However, the water balance module has not yet been used, so simulations have not included competition for water. The effects of changes in temperature have not yet been studied either. The simulations to date have shown that enhanced CO_2 concentration results in a lower nitrogen supply if one of the species is light-limited. This light-limited species will produce lower quality litter than under present-day CO_2 levels and this will slow down mineralization. Decreased nitrogen availability will limit the production of species that are nutrient-limited. Although the production of the light-limited species usually increased, in most simulations total production did not increase.

In some cases increased CO_2 concentration led to a shift in dominance if a light-limited species were suppressed by a nutrient-limited species. However, the light-limited species profited most from the increase in CO_2 concentration. This effect is largely opposite to the effect of increasing N deposition. In heather ecosystems heavy atmospheric N deposition has been shown to benefit the nutrient-limited grasses more than the more light-limited heather species, which may lead to an accelerated expansion of grasses (Berendse & Elberse, 1990). Clearly, there are strong interactions between the effects of CO_2 enrichment and nitrogen deposition.

In a dry, nutrient-poor ecosystem, like that of our study site on drift sand, the impact of CO_2 on plant water use efficiency may be a very important effect of climate change (Arp, 1991). This aspect of CO_2 enrichment will have strong interactions with temperature.

During succession nitrogen availability often increases, and concomitantly the competition for light becomes more important. Often early species in the succession suffer from light shortage more than later species. An increase in CO_2 concentration might slow down succession in some stages by benefiting early species more than late species. However, an increase in total production might accelerate succession, for example canopy closure may be attained sooner.

Our preliminary conclusions are that increasing CO_2 concentration may seriously affect succession patterns in poor ecosystems, but probably to a lesser extent in extremely nutrient-poor ecosystems. The direction and magnitude of the changes will differ between ecosystems and successional stages. CO_2 enrichment and nitrogen deposition operate antagonistically in some aspects, though both may increase production and both may accelerate succession.

The relations between different ecosystem parameters and species richness vary between vegetation types and between successional stages. These relations will have to be established for actual situations. However, it seems probable that a faster disappearance of early successional stages will reduce total species richness on a landscape scale.

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