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Microbial dynamics and litter decomposition under a changed climate in a Dutch heathland

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ABSTRACT

Climate change scenarios predict changes in temperature and precipitation. The effect of a modest temperature increase and repeated summer droughts on the rate of litter decomposition and microbial biomass dynamics was studied by a field scale manipulation experiment at a phosphorus (P) deficient dry heathland ecosystem in the Netherlands. Retractable covers were used to create artificial nighttime warming or prolonged summer drought in the experimental plots. The warming treatment initially enhanced litter mass loss and two consecutive years of summer drought retarded litter decomposition rate. Microbial carbon (C), nitrogen (N) and P immobilization was affected by the warming treatment as well as by the drought treatment. Enhanced temperatures resulted in increased microbial biomass C during the first half year of incubation, whereas the first drought treatment significantly retarded microbial N and P immobilization. The delayed net microbial N and P immobilization in the drought plots prevented net N and P mineralization. After 1 year microbial biomass C, N and P were significantly higher in the drought plots, probably as a result of availability of new substrate caused by the drying and rewetting process. Although microbial biomass was higher in the drought plots, the microbial C/N ratio was equal to the control and varied between 6 and 8. This suggested that in both the control and drought plots, the microbial community was dominated by bacteria at the longer term. Both treatments reduced net P mineralization and together with decreased foliar P concentrations this indicated the progressive importance of P limitation in restraining plant growth in this N saturated ecosystem.

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1. Introduction

Microbial activity plays an important role in decomposition of organic matter and the immobilization and mineralization of nutrients. Numerous factors, such as soil mineral sources, amount and quality of soil organic matter, soil texture, atmospheric input, water content, soil temperature and freezing, affect microbial activity (Panikov, 1999). These factors are considered to be dynamic and changing in the course of hours, days and months. Ecosystem functioning is adapted to this daily, monthly and seasonal variability in environmental conditions. However, changes in mean global air temperature and precipitation patterns are predicted, resulting in increased temperatures of between 1.4 and 5.8 °C over this century as well as more severe droughts and floods (Houghton et al., 2001). This climate change will affect key ecosystem processes such as plant growth, plant net photosynthetic and transpiration rate, plant nutrient uptake

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(Llorens et al., 2004; Peñuelas et al., 2004), microbial activity (Sowerby et al., 2005), and nutrient mineralization, immobilization and leaching (Jonasson et al., 1999; Rustad et al., 2001; Schmidt et al., 2004). Microbial nutrient mobilization is an important process for the regulation of plant growth in nutrient-deficient ecosystems (Harte and Kinzig, 1993; Jonasson and Michelsen, 1996). The impact of climate change might alter microbial dynamics, decomposition of organic matter and mineralization of nutrients. Together these changes may have a strong impact on the functioning of nutrient-poor ecosystems. At the Dutch heathland area 'Oldebroekse heide' climate conditions have been manipulated since May 1999 by nighttime warming and summer drought (Beier et al., 2004). The site has a highly weathered, acid sandy soil, with very low phosphorus (P) concentrations, whereas because of high nitrogen (N) deposition N leaching is high (Schmidt et al., 2004). Decomposing litter is an important nutrient pool for plants and microorganisms but microbial biomass itself is also considered as an important nutrient pool (Kouno et al., 2002). The dominating dwarf shrub at this site, *Calluna vulgaris* (L.) Hull. produces P poor litter, with an N/P ratio of >16, indicating that P is the most important nutrient limiting vegetation growth (Koerselman and Meuleman, 1996). In order to study the effect of changes in climate on (1) the decomposition rate of *C. vulgaris* litter and (2) the size and dynamics of the microbial biomass decomposing this litter and (3) the subsequent nutrient mineralization, we performed a litterbag incubation experiment at this site.

2. Materials and methods

2.1. Site description and treatment

The experiment was conducted at a Dutch heathland area called 'Oldebroekse heide' located in the center of the Netherlands (52°24′N, 5°55′E). The site is dominated by the perennial woody dwarf shrub *C. vulgaris* (95% groundcover). The soil is a nutrient-poor, well-drained, acid sandy Haplic Podzol (FAO, 1998), with a mormoder humus form (Green et al., 1993). The site experiences high N deposition (20 kg N ha^{-1} $year^{-1}$) and further site characteristics are presented in Table 1.

Nine experimental plots of 5 m × 4 m each were established in homogeneous areas within the site. Each plot was randomly assigned a treatment: control (C), heating (H) and prolonged drought during the growing season (D), so that three replicate plots per treatment were present. Around each plot, a light scaffolding structure was built of galvanized steel tubes covered by thin plastic sleeves to prevent contaminants leaching into the plot. In the heating plots, this frame supported a retractable, reflective curtain made of strips of infrared reflective material bound into a high-density polyethylene mesh. A small motor activated by a light sensor draws the curtain over the vegetation at night and triggers its removal again during the daytime. This treatment reduces the loss of infrared radiation from the surface at night.

A tipping bucket rain sensor activated the removal of the curtain at night to enable rain to enter the plot. Over the drought plots, the retractable curtain was made of transparent polyethylene plastic. During 2 months in the growing season (generally June and July), the rain sensor activated the motor to extend this cover over the plots once rain was detected and removed the cover when the rain had stopped. Monitoring started in December 1998 (pre-treatment) and the treatments started in May 1999.

Table 1 – Site characteristics 'Oldebroekse heide' (Emmett et al., 2004), N deposition was determined with a funnel above the vegetation

Location	52°24′N, 5°55′E
Altitude (m)	25
Yearly mean air temperature (°C)	10.1
Precipitation (mm $year^{-1}$)	1042
N deposition (kg ha^{-1} $year^{-1}$)	20
Vegetation	*Calluna vulgaris*
Above-ground C (g C m^{-2})	584
Soil type	Haplic Podzol
Humus form	Mormoder
Organic layer	
Depth (cm)	0–4
pH	3.7
C/N (g g^{-1})	22.5
Organic matter (g kg^{-1})	650
Bulk density (g cm^{-3})	0.11
Organic rich mineral horizon	
Depth (cm)	4–16
pH	3.8
Organic matter (g kg^{-1})	33
Bulk density (g cm^{-3})	1.41

Temperature of the air and soil was measured by installation of temperature sensors in the air (20 cm above the soil surface) and in the topsoil (0, −5 and −10 cm). The temperature sensors were PT100 thermistors (Campbell Scientific). One temperature sensor per depth was placed in one control and one adjacent temperature plot. Temperature was measured every 20 min across all seasons. In the topsoil, warming was on average 0.5 °C (−10 to 0 cm). In the air (20 cm above the soil) an average temperature increase of 0.7 °C during the night (04:00 h) was observed, which decreased gradually during the day to 0 °C at 16:00 h (Beier et al., 2004). Precipitation input to each plot was collected two or three weekly by 1 rain gauge (Ø 21.2 cm) per plot placed above the height of the vegetation. The 2-month summer drought treatment reduced precipitation in the growing season (May to September) with 45% compared to control in 1999, 51% in 2000, 43% in 2001, 43% in 2002 and 70% in 2003. Water content in the mineral soil was measured daily at 0–10 cm and 0–45 cm soil depth in 1 control, 1 temperature and 1 drought plot with time domain reflectometry (TDR, Topp et al., 1980). In the other 6 plots soil moisture content was measured two or three weekly, also with TDR. Soil water content in the top 10 cm of the mineral soil was reduced by 82% at the peak of the drought treatment in 1999 and 2000 (Beier et al., 2004), by 80% in 2001, 83% in 2002 and 73% in 2003. Water content of the litter layer, measured in litterbags, is presented in Table 2. Heating did not result in a reduction in litter water content, except at 62 days, when water content was slightly reduced. During the drought treatment (day 160) litter water content was significantly reduced. Further details on the design and treatment effects can be found in Beier et al. (2004).

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