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Effects of climate change on decomposition of soil organic matter in a boreal ecosystem

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Abstract

In the CLIMEX project, two catchments are manipulated to investigate the effects of elevated temperature and CO_2 on decomposition of soil organic matter. Litterbag studies do not show a clear treatment effect after five months of manipulation. Due to the treatment, however, the contribution of organic anions to the total charge balance of the soil solution appears to decrease. Laboratory experiments show that C loss from soil columns as CO_2 and TOC increases with temperature. Because N uptake by vegetation is absent, nitrification increases with temperature resulting in increased acidification of the outflow water.

1. INTRODUCTION

Yearly, at global scale, 50-100 Gt of C cycles along the photosynthesis-decomposition pathway against an annual net addition of 2.8 Gt C to the atmosphere as CO_2 [1]. Therefore, changes in decomposition rate of Soil Organic Matter (SOM) due to climate change might significantly influence the net exchange of C between the atmosphere and the land surface. An increase in atmospheric CO_2 is most likely to affect decomposition by influencing Net Primary Productivity and chemical composition of the litter. Also changes in soil physical conditions might occur due to a change in water use by the vegetation [2]. An increase in temperature could affect decomposition by stimulating biological activity [3] and by changing the physical environment through increased evapotranspiration. Increased decomposition could result in higher N mineralization. Especially in areas where plant growth is N-limited, as in many temperate ecosystems, plants might benefit both from increased N availability and from CO_2 fertilization. If N mineralization exceeds plant uptake, N could leach to surface and/or groundwater resulting in acidification and eutrophication.

2. METHODS AND RESULTS

2.1. Site description

Field experiments take place within the CLIMEX project in Norway [2]. In this experiment two small forested catchments are being manipulated. The largest catchment (KIM; 1,200 m^2) is enclosed by a greenhouse and receives rain cleaned from acidifying components. In this catchment, CO_2 is increased by 200 ppmv and temperature by 5°C above ambient conditions. In a second, covered, catchment receiving acid rain (EGIL; 800 m^2), soil temperature is increased 5°C above ambient conditions. In both catchments, one-third of the catchment is not manipulated and acts as control section. Two non covered catchments (METTE; 650 m^2 and ROLF; 220 m^2) are used as reference to account for possible roof effects. These catchments receive ambient, acid, rain. The climate treatments started in June 1994.

2.2. Decomposition of fresh litter

Using litterbags, we investigate the influence of temperature and substrate quality on the decomposition rate of fresh litter under field conditions. Before the start of the manipulation, we carried out a pilot experiment with litter from Scots pine to detect possible site differences. Mass loss of needles incubated under heather in KIM, EGIL and ROLF after one year was 307±53, 250±39 and 222±43 mg/g respectively.

In April 1994, we incubated birch litter produced at 350 and 700 ppmv CO_2 in the treatment and control parts of KIM and EGIL. This setup allowed for separation of 'treatment-effect' from 'substrate-quality effect'. After six months of incubation, we found a statistically higher decomposition rate in KIM corresponding with the pilot study. Within the catchments, we could not find any effect due to differences in substrate quality or climate treatment.

2.3. Soil solution chemistry

Cleaning of the rain has caused a clear change in runoff chemistry over the past eight years [4]. The percentage of the total positive charge balanced by organic anions proved to be sensitive to the rain treatments. Therefore, we used this parameter to detect whether the treatment has affected soil solution chemistry. In the control sections of the manipulated catchments, the contribution of organic anions to the charge balance increased significantly in the two consecutive years (Table 1). This increase was less pronounced in the treatment sections. We cannot fully explain the observed trend yet. We speculate that increased N mineralization, followed by nitrification will cause an increase in nitrate. If plants do not take up this nitrate, the contribution of organic anions to the charge balance decreases. However, field data do not show a statistically significant increase in N mineralization in the treatment sections.

Table 1
Positive charge balanced by organic anions during June-August (%)

		1993	1994
KIM	control	34 (10) b	56 (12) c
	treatment	32 (13) b	35 (19) b
EGIL	control	9 (8) a	27 (7) b
	treatment	9 (7) a	20 (12) d
METTE	control	25 (15) b,d	33 (16) b

Standard deviation in parentheses. Different letters show significant differences at the 95% confidence level.

2.4. C mineralization in isolated soil columns

Carbon mineralization can be estimated by measuring CO_2 evolution from soil columns without vegetation. In the field, interference of CO_2 originating from root respiration makes interpretation of CO_2 emission measurements difficult. We have incubated undisturbed soil columns (16 cm wide and 60 cm long) at 5, 10 and 17°C to follow the effect of temperature on C mineralization and chemistry of the outflow water.

Table 2
Average values for selected parameters in soil column experiment after 10 weeks

		5°C	10°C	17°C
CO_2 emission	gCO_2 $column^{-1}$ $week^{-1}$	0.85	1.18	1.69
pH in outflow	-	4.52	4.53	3.96
TOC[1] in outflow	mg l^{-1}	3.7	3.7	6.0
Al^{n+} in outflow	µeq l^{-1}	143	242	484
NO_3 in outflow	µeq l^{-1}	120	288	344

[1] Total Organic Carbon

These results show increased C loss both as CO_2 and TOC in drainage water with increasing temperature (Table 2). Simultaneously, more N is mineralized which is nitrified resulting in increased acidification of the drainage water. Since plants are absent, the acidification due to N mineralization followed by nitrification is probably more severe than in systems with vegetation. The increase in inorganic Al in the outflow with temperature reflects the increasing acidification.

3. DISCUSSION

Background data obtained before the start of the treatments suggest that SOM does not behave similarly in all catchments. Some differences can be ascribed to the 'roof-effect' (litterbag studies), others to the rain treatment (soil solution chemistry). After half a year of treatment, field data do not show a clear treatment effect except the soil solution chemistry. However, the treatments only started in June 1994. We expect changes in decomposition rate of SOM to be more pronounced in winter because at lower temperatures biological processes respond more clearly to a change in temperature than at high temperatures [3]. One major difficulty with the interpretation of field data is that they result from an assembly of environmental conditions. Therefore, additional laboratory studies under controlled conditions are needed to separate different processes occurring simultaneously. Based on the column experiments we can expect an increase in N mineralization at increased temperature as well as higher TOC levels in runoff. Acidification of soils and surface waters will only occur if N mineralization exceeds plant uptake.

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