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Experimental drought alters rates of soil respiration and methanogenesis but not carbon exchange in soil of a temperate fen

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ABSTRACT

The impact of intensified drought and rewetting on C cycling in peatlands is debated. We conducted drying/rewetting (DW) experiments with intact monoliths of a temperate fen over a period of 10 months. One treatment with original vegetation (DW-V) and one defoliated treatment (DW-D) were rewetted after an experimental drought of 50 days; another treatment was kept permanently wet (W-V). Soil water content was determined by the TDR technique, C fluxes from chamber measurements and gas profiles in the soils, and respiration from mass balancing CO_2 and CH_4 fluxes in the peat using hourly to weekly data. Zones of high root associated respiration were determined from a ^{13}C labeling experiment. Autotrophic respiration contributed from 55 to 65% to an average ecosystem respiration (ER) of 92 (DW-D), 211 (DW-V), and 267 mmol m^{-2} d^{-1} (W-V). Photosynthesis ranged from 0 (DW-D) to 450 mmol m^{-2} d^{-1} (W-V), and strongly declined for about 30 days after rewetting (DW-V), while ER remained constant during the drying and rewetting event. Drying raised air-filled porosity in the soil to 2–13%, temporarily increased respiration to estimated anaerobic and aerobic rates of up to 550 and 1000 nmol cm^{-3} d^{-1}, and delayed methane production and emission by weeks to months. Root associated respiration was concentrated in the uppermost peat layer. In spite of clear relative changes in respiration during and after drought, the impact on carbon exchange with the atmosphere was small. We attribute this finding to the importance of respiration in the uppermost and soil layer, which remained moist and aerated, and the insensitivity of autotrophic respiration to drought. We expect a similar dynamics to occur in other temperate wetland soils in which soil respiration is concentrated near the peatland surface, such as rich minerotrophic fens.

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1. Introduction

Peatlands cover less than 3% of the earth's surface yet store about 30% of the world's soil carbon stocks (Gorham, 1991) and also contribute 2–10% to the global atmospheric methane (CH_4) burden (Mikaloff Fletcher et al., 2004). Net ecosystem exchange (NEE) and CH_4 emissions of peatlands are sensitive to changes in the soil temperature and hydrologic regime (Lafleur et al., 2005; Smemo and Yavitt, 2006). The impact of rising temperature and changes in the hydrologic regime on carbon dynamics is thus of interest. In particular, increases in precipitation in winters and drier summers with strong rainfalls driven by local and regional heat convection have been predicted for some northern regions (IPCC, 2001). These changes may decrease CH_4 emissions and increase carbon release from peatlands (Moore et al., 1998).

Effects of mean changes in temperature and moisture on peatland carbon cycling have been identified but the impact of extreme weather is still uncertain. Soil moisture and CH_4 emissions are, for example, not always related owing to complex interactions between CH_4 transport, production, and oxidation (Walter et al., 1996). This raises the question what the net effect of short-term drought on CH_4 production and emissions will be, as existing studies mostly focused on long-term changes in average water table position. The impact of hydrologic conditions on the carbon balance is even less understood due to the variable importance of individual processes and interactions between them. Soil and ecosystem respiration provide an example in this respect. In laboratory experiments with peat, presence of oxygen increased soil respiration by a factor of 2–6 (Moore and Dalva, 1997; Yavitt et al., 1997), and rewetting of aerated and dried soil samples resulted in short pulses of respiration (Clein and Schimel, 1994; Fierer and Schimel, 2003). Qualitatively similar results were obtained in mesocosm experiments that included part of the vegetation (Blodau and Moore, 2003; Blodau et al., 2004) and some field studies (Silvola et al., 1996a; Alm et al., 1999). However, the water table level, and thus aeration, was not related to ecosystem respiration (ER) in dry ombrotrophic bogs (Updegraff et al., 2001; Lafleur et al., 2005; Blodau et al., 2007) and a subalpine fen when the water table level dropped below 6 cm (Chimner and Cooper, 2003). The authors

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speculated that changes in soil respiration at greater depths had little impact on ER due to low temperatures, recalcitrant litter, incomplete aeration, and the predominance of autotrophic processes for ecosystem respiration. Uncertainty further arises from the response of autotrophic respiration of vascular plants and mosses to water availability and anaerobism, which can greatly differ for different types of vegetation. The productivity of mosses, for example, can be sensitive to drying (Robroek et al., 2007), whereas this may not be the case for vascular plants that access deeper soil layers.

To identify the impact of drought and rewetting on carbon cycling we characterized carbon exchange and belowground respiration in mesocosms from a weakly acidic temperate fen during a drying/rewetting cycle. Other controls, such as soil temperature and irradiation, were held constant. By incubating one mesocosm devoid of vegetation, the effect of plant cover on the dynamics of carbon fluxes and soil respiration was studied. We hypothesized that a simulated drought would decrease CH_4 production and emission from the peat becoming aerated and results in prolonged periods of low or absent CH_4 production after rewetting. We also expected that drought would shift the carbon balance towards losses to the atmosphere by increasing soil respiration, with peak respiration rates after changes in hydrologic conditions. Photosynthesis may on the other hand remain unaffected, as the dominating vascular vegetation can be expected to have access to deeper soil layers and is thus less sensitive to drying.

2. Materials and methods

2.1. Sampling and treatment

Three peat cores (60 cm diameter, 60 cm depth, "mesocosms") were collected in September 2005 at the Schlöppnerbrunnen fen site in northeastern Bavaria (50°08′38″N, 11°51′41″E, Fichtelgebirge, Germany). The site is moderately acidic (pH 3.5–5.5) and minerotrophic with highly decomposed soils rich in sulfur (up to 4.6 mg kg^{-1}) and iron (up to >16 mg kg^{-1}) and is dominated by graminoids and only few mosses. The site is located at 750 m, has a mean annual precipitation of 1150 mm, and a mean annual temperature of ~5 °C. The mean *in-situ* water table level is 0.13 ± 0.19 m, but may drop down to >0.76 m below surface (Paul et al., 2006), thus leading to redox cycles. The site is small, heterogeneous in terms of peat depth and vegetation, and intensively studied by other researchers within ecosystem manipulation experiments; we therefore could not retrieve peat cores with exactly the same vegetation. Two mesocosms contained *Agrostis* sp., *Nardus stricta*, *Molinia coerulea*, *Sphagnum fallax*, *Brachythecium rivulare*, *Atrichum undulatum* and *Galium hercynicum*. In one of these, which was the only containing *Carex rostrata*, water table was kept constantly high ("Wet-Vegetation" or "W-V"), and the other ("Drying/Wetting-Vegetation" or "DW-V") and a non-vegetated ("Drying/Wetting-Defoliated" or "DW-D") were dried and rewetted. The vegetation had been eliminated by inhibiting re-growth after winter 2005 by covering the plot. The Von Post index of decomposition (Stanek and Silc, 1977) increased from 3 on a scale of 1 to 10 at depths of 0–10 cm to 7–9 at a depth of 25–60 cm below surface. The mesocosms were incubated in a climate chamber at 15 °C for 10 months (~60% rH, 12 h light/dark cycles, 660 μmol s^{-1} photosynthetic photon flux) to isolate the effect of drying and rewetting on carbon cycling.

After 40 days (first 'dry period') the water table was raised in all mesocosms from about 30 to 10 cm below surface by irrigation with 30 (DW-V, DW-D) and 40 mm (W-V) in 2 days. The water table was then kept constant at ~11.9 ± 1.3 (DW-V) or at 9.9 ± 0.9 cm (DW-D) for 70 days ('wet period'), by irrigating up to 7 mm d^{-1}. DW-V and DW-D were subsequently dried for 50 days to a water table of 55 cm by reducing irrigation to 0 (DW-D) and 1 mm d^{-1} (DW-V) (second 'dry period'). This way we induced a comparable decrease in water table levels in both treatments. The mesocosms were then rewetted ('rewetted period') by irrigation with 54 (DW-V) and 53 mm (DW-D) within 2 and 5 days, respectively. During the rewetted period, the mean water table was held at 12.7 ± 1.8 (DW-V) and 9.8 ± 1.8 cm (DW-D). Time series of water table levels and volumes of irrigate applied are given in the supporting information. The irrigate was mixed according to precipitation chemistry at the site and contained Na^+ (5 μmol L^{-1}), Ca^{2+} (6 μmol L^{-1}), SO_4^{2-} (10 μmol L^{-1}), Cl^- (12 μmol L^{-1}), NH_4^+, NO_3^- (40 μmol L^{-1}), DIC (~15 μmol L^{-1}) at a pH of 4.82.

Volumetric gas content was derived from total porosity and volumetric water content recorded with calibrated TDR probes at 10, 20, 30, and 40 cm depth (IMKO, Germany). Total porosity was measured by oven-drying of 100 cm^3 samples and water tables were monitored in piezometers. To characterize root activity, we applied a ^{13}C-CO_2 pulse label for 1 h at the end of the experiment, using a transparent chamber with a 63% ^{13}C-CO_2 atmosphere of ~900 ppm total CO_2, and traced the label in the soil CO_2.

The experiment was terminated after 43–44 weeks by sampling the solid phase in 10 cm depth intervals. Peat cores of 100 cm^3 were extruded in triplicate in 10, 20, and 30 cm depth and incubated for 5 days (15 °C) in 450 ml jars to determine potential aerobic CO_2 production rates. A second set of cores was incubated after 1 week of drying at room temperature. CO_2 production was calculated from regression of CO_2 concentration over time.

2.2. Analytical techniques and flux measurements

Soil gases were sampled weekly from horizontally inserted silicon samplers at 5, 10, 15, 20, 30, 40, and 50 cm depth, consisting of a reinforced 20 cm closed silicon tube (10 mm diameter, 1 mm wall) with a stop cock at one end (Holter, 1990). CO_2 and CH_4 concentrations were analyzed on a gas chromatograph (FID and CO_2 methanizer, 8610C SRI Instruments, USA). Soil solution was sampled from Rhizon® samplers at the same depths (polymer, <0.2 μm pore size) and values of pH were determined using a glass electrode. CO_2 concentrations were additionally recorded by GMP221 or GMP222 latex covered CO_2-sensors inserted into the soil at 5, 10, 20, and 30 cm and using a MI 70 logger (Vaisala Oyi, Finland). The isotopic signature of the soil CO_2 was measured using a Trace GC 2000 gas chromatograph connected via Combustion III interface to a DELTA^{plus} isotope ratio mass spectrometer (Thermo Finnigan MAT, Germany).

CO_2 and CH_4 fluxes were measured weekly using a static chamber approach, placing transparent and shrouded chambers of 20 cm diameter, and 30 cm height for 20 min on top of a previously inserted collar and taking samples every 5 min, analyzing the gas as described. A gas flux was calculated from the linear increase in the gas concentrations in the chamber over time. During irrigation, we used "irrigation chambers" covering the entire mesocosm at a height of 30 cm with a double lid providing a sieve-like structure to spread the irrigate homogeneously.

2.3. Calculations

Dissolved inorganic carbon (DIC) and CH_4 concentrations were recalculated from gas samples assuming equilibrium and using Henry's constants for 15 °C (K_{CO_2} = 0.0463 mol L^{-1} atm^{-1}, K_{CH_4} = 0.0017 mol L^{-1} atm^{-1}) (Sander, 1999). DIC speciation was calculated using pore water pH. Net turnover of DIC and CH_4 in depth layers of peat was calculated from Eq. (1) and averaged concentration gradients between sampling dates:

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