Soil Biology & Biochemistry 42 (2010) 1437–1446

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Emissions of CO_2, CH_4 and N_2O from Southern European peatlands

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ARTICLE INFO

Article history:
Received 14 October 2009
Received in revised form
23 April 2010
Accepted 4 May 2010
Available online 21 May 2010

Keywords:
Greenhouse gas emissions
Peatland
Drainage
Bog
Fen
Groundwater level
Carbon dioxide
Methane
Nitrous oxide

ABSTRACT

Peatlands play an important role in emissions of the greenhouse gases CO_2, CH_4 and N_2O, which are produced during mineralization of the peat organic matter. To examine the influence of soil type (fen, bog soil) and environmental factors (temperature, groundwater level), emission of CO_2, CH_4 and N_2O and soil temperature and groundwater level were measured weekly or biweekly *in loco* over a one-year period at four sites located in Ljubljana Marsh, Slovenia using the static chamber technique. The study involved two fen and two bog soils differing in organic carbon and nitrogen content, pH, bulk density, water holding capacity and groundwater level. The lowest CO_2 fluxes occurred during the winter, fluxes of N_2O were highest during summer and early spring (February, March) and fluxes of CH_4 were highest during autumn. The temporal variation in CO_2 fluxes could be explained by seasonal temperature variations, whereas CH_4 and N_2O fluxes could be correlated to groundwater level and soil carbon content. The experimental sites were net sources of measured greenhouse gases except for the drained bog site, which was a net sink of CH_4. The mean fluxes of CO_2 ranged between 139 mg m^{-2} h^{-1} in the undrained bog and 206 mg m^{-2} h^{-1} in the drained fen; mean fluxes of CH_4 were between −0.04 mg m^{-2} h^{-1} in the drained bog and 0.05 mg m^{-2} h^{-1} in the drained fen; and mean fluxes of N_2O were between 0.43 mg m^{-2} h^{-1} in the drained fen and 1.03 mg m^{-2} h^{-1} in the drained bog. These results indicate that the examined peatlands emit similar amounts of CO_2 and CH_4 to peatlands in Central and Northern Europe and significantly higher amounts of N_2O.

1. Introduction

Peatlands cover only approximately 3% of the Earth's surface but store about 26% of soil organic carbon (Smith et al., 2004). Although these soils have acted for millennia as sinks for C and N through accumulation of organic C (Gorham, 1991) and N (Driesen, 1978), there is global concern that they may become an important source of greenhouse gases (GHG), due to enhanced mineralization of soil organic matter (SOM) caused by drainage, agricultural use and other anthropogenic disturbances leading to climate change. The type and magnitude of individual GHG loss is strongly dependent on environmental factors such as groundwater level, temperature and soil organic matter content (Aerts and Ludwig, 1997; Chimner and Cooper, 2003; Smith et al., 2003). Soil moisture is the main determinant of the type of C and N gaseous losses, whereas temperature affects the magnitude of GHG emissions both seasonally and regionally (reviewed in Jungkunst and Fiedler, 2007). A latitudinal trend in the relative reduction of CO_2 emissions by 10–20% and 30–60% with rising groundwater was found for tropical and temperate zone conditions, respectively, whereas these values were over 60% for boreal zones (Jungkunst and Fiedler, 2007). In the latter a strong dependence of GHG emissions on seasonal variations in temperature and groundwater level could be observed with the highest emissions of CO_2, CH_4 and N_2O during summer, when the groundwater was below 10–20 cm (Von Arnold et al., 2005a, 2005b). Methane emissions did not exhibit temperature dependent responses to rising groundwater but did increase above a threshold groundwater depth of 10 cm below the soil surface (Jungkunst and Fiedler, 2007). Methane emissions decrease with decreasing soil water content and peat soils may eventually become a net sink for methane (reviewed in Laiho, 2006). Temperature, however, may affect methanogenic pathways (Schulz and Conrad, 1996; Avery et al., 1999; Hines et al., 2001; Duddleston et al., 2002,).

The highest N_2O emissions are found at intermediate groundwater levels, which allow their aerobic and anaerobic production (Martikainen et al., 1993). Aerobic production of N_2O via nitrification may be substantial (up to 80% of total N_2O emissions) (Webster and Hopkins, 1996; Pihlatie et al., 2004), and another product of nitrification is nitrate, which is the rate controlling factor for anaerobic N_2O production via denitrification (Conrad, 1996; Davidson et al., 2000; Öquist et al., 2007).

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doi:10.1016/j.soilbio.2010.05.004

Very few studies have compared the effects of groundwater level and temperature on GHG emissions in ombrotrophic acid bogs and minerotrophic neutral to alkaline fens (Martikainen et al., 1995; Laine et al., 1996; Silvola et al., 1996; Nykänen et al., 1998). These two main types of peatlands differ in peat composition (sedge peat in the former and sphagnum peat in the latter), total organic carbon content and bulk density, which affects the soil water holding capacity and moisture regime at fluctuating groundwater level (Ausec et al., 2009).

In fen and bog peatlands drainage increased CO_2 emissions (Fiedler et al., 1998; Von Arnold et al., 2005a, 2005b) and decreased CH_4 emissions by one to several orders of magnitude (Laine et al., 1996; Von Arnold et al., 2005a, 2005b). At similar groundwater levels fens emitted more CH_4 than bogs (Laine et al., 1996). N_2O emissions from fen and bog sites were variable. In the fen area, drainage substantially increased annual N_2O fluxes (Martikainen et al., 1995; Laine et al., 1996), but had less pronounced or negligible effects in the bog areas (Laine et al., 1996; Von Arnold et al., 2005a, 2005b). However, at similar groundwater levels annual N_2O fluxes were higher in fens than in bogs (Laine et al., 1996).

GHG emissions have been studied most extensively in Northern peatlands, due to their largest area and potential global importance (Martikainen et al., 1993, 1995; Nykänen et al., 1998; Von Arnold et al., 2005a, 2005b). Despite their smaller size, however, peatlands in Central and South Europe may be important for regional inventories of GHG emissions (Lokupitiya and Paustian, 2006).

The Ljubljana Marsh is in a large drained peatland covering 160 km^2 in central Slovenia that is dominated by fens with isolated bog fragments not exceeding 200,000 m^2 each. The drainage system in the Ljubljana Marsh was established in the early 19th century but in spite of peat excavation, drainage and agriculture, the area still provides unique habitats for wetland fauna and flora. Conservation and restoration efforts have been initiated, including attempts to raise the groundwater level in some areas. This indicated the need to obtain data on GHG fluxes in the field before the start of restoration efforts and compare the data to microcosm experiments simulating the situation after rewetting (Stres et al., 2008). Microcosm studies with fen soil indicated that CO_2 fluxes were affected most by temperature, whereas N_2O fluxes correlated positively with nitrate availability and waterlogged conditions (Stres et al., 2008). Methane was produced in fen soil only after a lag of two months and at elevated temperature (Jerman et al., 2009). Another reason to study GHG emissions locally is a need for country specific emission factors (Lokupitiya and Paustian, 2006), which are used in national GHG inventory reports, according to UNFCCC (UN Framework Convention on Climate Change). Despite its relatively small area, the diversity of habitats in the Ljubljana Marsh offers a unique opportunity to study the effect of physico-chemical properties of peat soils on GHG emissions under the same climatic conditions. Two fen and two bog sites differing significantly in organic matter content, C/N ratio, pH, bulk density, water holding capacity and groundwater level were selected for this study with the following objectives: (i) to determine the fluxes of CO_2, CH_4 and N_2O in relation to physico-chemical properties of peat soils, (ii) to quantify the influence of seasonal changes in temperature and groundwater level on fluxes of CO_2, CH_4 and N_2O and (iii) to compare GHG fluxes in a South European peatland to those in Northern peatlands in Germany, Sweden and Finland.

2. Materials and methods

2.1. Study sites

All study sites were located within Ljubljana Marsh, south of Ljubljana, Slovenia, where two drained fen grassland soils (45°58′N, 14°28′E) and two bog forest soils (drained and undrained) (45°59′N, 14°30′E) were investigated. The fen site is grassland cut once or twice annually and classified as *Arrhenatherion*, according to botanical composition of the grass community (Čop et al., 2004). Dominating species on the fen site are *Arrhenatherum elatius*, *Dactylis glomerata*, *Festuca rubra*, *Equsetum palustre* and *Galium mollugo*, followed by *Ranunculus repens*, *Achillea millefolium*, *Leucanthemum ircutianum* and *Centaurea jacea*. A region of the meadow proximal to the main drainage ditch is characterized by fluvial clay deposits, lower content of organic carbon (LC) and lower groundwater level, whereas the region distal from the main drainage ditch has no clay deposits, higher organic carbon (HC) and higher groundwater level. These two fen sites were classified as Rheic Fibric Histosol (HC) and Humic Gleysol (LC) (Hacin et al., 2001). The bog site is a forested area representing a natural succession with *Betula* sp., *Frangula alnus*, *Salix* sp., *Quercus robur* and *Pinus sylvestris* as dominating tree species in the undrained and drained regions (Martinčič, 1987). In contrast, the bottom vegetation in the undrained region (KG1) is dominated by *Sphagnum* sp. and other mosses, *Caluna vulgaris* and some herbaceous species, whereas the bottom vegetation in the drained region (KG2) consists exclusively of *Pteridium aquilinum* (Hacin, unpublished data). The undrained bog soil was classified under World reference base for soil resources (2006) as the Rheic Fibric Histosol (Dystric), while the drained bog soil (KG2) was classified as Rheic Hemic Histosol (Dystric).

2.2. Physical and chemical analysis of the soils

To determine soil chemical properties soil organic carbon (C_{org}) and soil organic nitrogen content (N_{org}), pH and water holding capacity (WHC), nine soil cores were collected from a depth of 0–20 cm on 3 × 5 m plots on three separate occasions (spring (March), summer (August) and autumn (November)) and homogenized through an 8-mm sieve to account for spatial heterogeneity as described by Robertson et al. (1999). Fresh homogenized samples were used for pH and WHC determination, while dried (60 °C), ground (2 mm sieve) samples were used to determine C_{org} and N_{org}. For bulk density determination, three series of cores (0–5–10–15–20 cm) were taken from three locations approximately 1 m apart at each study site. Soil pH was measured with a glass electrode in a 1:5 (v/v) suspension of soil in distilled water or in 1 M KCl according to ISO 10390 standard. WHC was determined as described by Stres et al. (2008). Soil bulk density was determined in soil sampling rings (100 cm^3, Eijkelkamp, NL) according to Forster (1995). C_{org} was measured according to ISO 10694 standard, after combustion in a LECO CNS-2000 analyzer (LECO, USA) and subtraction of $CaCO_3$, determined by a Scheibler's calcimeter. N_{org} was determined by standard Kjeldahl analysis (Bundy and Meisinger, 1994), using a Tecator 2012 digestion apparatus (Tecator AB, Sweden) and micro Kjeldahl distillation apparatus. Soil N_{min} (NH_4^+–N and $NO_3^- + NO_2^-$–N) was determined following 2 M KCl extraction (Bundy and Meisinger, 1994), using a continuous flow analyzer (FlowSys, Alliance Instruments, Austria).

2.3. Gas flux determination

Gas fluxes were determined by the static chamber technique (Martikainen et al., 1993; Nykänen et al., 1995; Alm et al., 1999). Gas concentrations were measured using dark, static, manually sampled, polyvinyl chloride (PVC) chambers (diameter 16 cm and height 9 cm) equipped with butyl rubber septa for gas sampling. The chambers were placed on PVC rings covering an area of 0.02 m^2 inserted into the soil to allow repeated measurements to be made at the same place. The three rings were installed in June 2005