Agricultural and Forest Meteorology 256–257 (2018) 470–481

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Annual emissions of CO_2, CH_4 and N_2O from a temperate peat bog: Comparison of an undrained and four drained sites under permanent grass and arable crop rotations with cereals and potato

Tanka P. Kandel*, Poul Erik Lærke, Lars Elsgaard

Department of Agroecology, Aarhus University, P.O. Box 50, DK-8830, Tjele, Denmark

ARTICLE INFO

Keywords:
Agricultural land-use
Drainage
Greenhouse gas flux
Natural bog
Peat soil

ABSTRACT

Peatlands drained for agriculture are sources of atmospheric carbon dioxide (CO_2) and nitrous oxide (N_2O). Resulting emissions may depend on land-use, often as grassland or cropland, but few studies have directly compared the effects of land-uses. Here, we measured annual emissions of CO_2, N_2O and methane (CH_4) from five sites in a temperate bog, representing an undrained natural bog (NB) site, and four drained sites used as permanent grassland (PG) and croplands with rotations of oat-potato, oat-spring barley and potato-spring barley (PO:SB) in the study year. Gas fluxes were measured at 1–2 week intervals using static chambers, and auxiliary data were obtained, such as temperature, depth of water table, ratio-vegetation index, pH and soil mineral N. Annual CO_2 emissions were derived from empirical modelling, whereas CH_4 and N_2O emissions were linearly interpolated between measurement dates by bootstrapping. Soil respiration was lower at the NB site (1.8 Mg CO_2-C ha^{-1} yr^{-1}) than at the drained sites where emissions were in the range of 5.0–8.8 Mg CO_2-C ha^{-1} yr^{-1}. The N_2O emission was negligible at NB (0.3 kg N_2O ha^{-1} yr^{-1}), low at three of the drained sites (1.5–3.7 kg N_2O ha^{-1} yr^{-1}), but high at PO:SB (37.7 kg N_2O ha^{-1} yr^{-1}). The CH_4 emission was high at NB (172 kg CH_4 ha^{-1} yr^{-1}), but negligible at the drained sites (-1.5 to 1.5 kg CH_4 ha^{-1} yr^{-1}). The soil respiration at the drained sites indicated that peat losses were rather similar among the different cropping systems and depended mostly on drainage status, although soil respiration and peat mineralization may not scale directly. The pattern of N_2O emissions suggested an increased risk of N_2O emission from potato cultivation before and after the period of potato growth, likely due to microbial availability of NO_3^- outside the growing season. For initiatives aiming at reduction of greenhouse gas emissions from agricultural peat soils, this means that, e.g., conversion from cropland to permanent grassland should preferably be accompanied by measures of rewetting, whereas for potato cropping, N availability outside the growing season should be minimized.

1. Introduction

Pristine peatlands accumulate organic carbon (C) as the rate of plant C input exceeds the biological mineralization rate that is restricted by slow diffusion of oxygen at high soil water content. Low mineralization rates may be sustained also by low soil pH, low nitrogen (N) availability and low temperatures, which are common at least in Northern bog peatlands (Wu and Blodau, 2013). A recent assessment suggests that Northern peatlands have accumulated 500 ± 100 Pg C (Yu, 2012), which is comparable to the current atmospheric content of carbon dioxide (CO_2), corresponding to ~847 Pg CO_2-C (Le Quéré et al., 2016).

Drainage of pristine peatlands for agriculture stops the accumulation of C and rather leads to increased peat mineralization and emissions of CO_2 as the drained peat soil is exposed to oxic conditions as well as management practices, often including tillage, fertilization and liming (Maljanen et al., 2010; Tiemeyer et al., 2016). Thus, drainage and agricultural use of peat soils result in continued peat loss, eventually changing the status of the soils as they become depleted in organic C. In Denmark, for example, the estimated area of cultivated peat soils with > 12% organic C diminished from 107,962 ha in 1975 to 70,176 ha in 2010, indicating a 35% loss of nominal peat soils within a few decades (Greve et al., 2014).

To mitigate soil CO_2 emissions, and to preserve nature quality and biodiversity, Danish ministerial incentives were launched in 2015 providing subsidies for voluntary extensification of agricultural peat soils (Ministry of Environment and Food of Denmark, 2017). This implies cease of tillage, fertilization and pesticide use on areas where existing drains are either disconnected or left in place, but not

---

* Corresponding author. Current address: USDA-ARS Grazinglands Research Laboratory, 7207 W. Cheyenne Street, El Reno, OK 73036, USA.
E-mail address: Tanka.Kandel@okstate.edu (T.P. Kandel).

https://doi.org/10.1016/j.agrformet.2018.03.021
Received 27 September 2017; Received in revised form 18 March 2018; Accepted 25 March 2018
0168-1923/

maintained. The future agricultural use of these areas would thus be confined to extensive permanent grasslands for grazing or cutting.

Land-use changes of peat soils, such as indicated above, influence emissions not only of CO_2, but also of methane (CH_4) and nitrous oxide (N_2O), which are 28 and 265–298 times stronger greenhouse gases (GHGs) than CO_2, respectively, on a 100-year timescale (Myhre et al., 2013). Basically, GHG emissions from peat soils are linked to the hydrological conditions with deep water tables (WT) favoring CO_2 emissions, shallow WT (less than ~20 cm) favoring CH_4 emissions, and fluctuating WT potentially being conducive of N_2O emissions (Couwenberg, 2011; Petersen et al., 2012; Karki et al., 2016; Poyda et al., 2016; Wilson et al., 2016). Thus, drained agricultural peat soils are principal sources of CO_2 and often N_2O, whereas pristine peat soils are sources of CH_4, although the emissions may vary by climate, soil biogeochemical conditions and agricultural management (Maljanen et al., 2010; Eickenscheidt et al., 2015; Tiemeyer et al., 2016).

For CO_2 emissions from drained organic soils, a systematic effect of land-use as grassland or cropland is included in the default Tier 1 emission factors (EFs) by the Intergovernmental Panel on Climate Change (IPCC, 2014). Across boreal and temperate climate zones, the EFs for CO_2 are 23–54% lower for grasslands than for croplands, depending on the grassland nutrient and drainage status (IPCC, 2014). These EFs, compiled from various studies, imply that land-use change from arable crops to permanent grassland may substantially reduce CO_2 emissions and associated peat losses from organic soils. Yet, direct comparisons of CO_2 emissions from drained grasslands and croplands on organic soils are infrequent and have shown divergent results, i.e., indicating either lower, similar, or higher CO_2 emissions from fields with perennial grasses as compared to neighboring fields with arable crops (Maljanen et al., 2001, 2004; Elsgaard et al., 2012; Kandel et al., 2013). Recently, Poyda et al. (2016) found that CO_2 losses were similar for intensively managed grassland and arable cropland at comparable WT in a cultivated fen in northwestern Germany. However, in the same study, N_2O emissions as related to rates of applied N were disproportionally higher for the arable cropping systems than for grasslands (Poyda et al., 2016). Other recent studies compared CO_2 and N_2O emissions from grass, cereals and row crops on organic soils in southern Sweden and concluded that differences in emissions, measured during the growing season, were greater between sites than between cropping systems (Norberg et al., 2016a, b). In summary, a number of studies have indicated that CO_2 and N_2O emissions from drained organic soils may not conclusively depend on the cropping system, and so the consequences of land-use changes, e.g., from cropland to grassland, may need to be addressed in a more detailed context.

To quantify the role of land-use and cropping systems on GHG emissions from a cultivated temperate peat bog, we measured annual fluxes of CO_2, CH_4 and N_2O with manual static chambers at different sites representing drained agroecosystems with permanent grass and arable crop rotations with cereals (oat and barley) and a row crop (potato). As a reference, GHG emissions were measured at an undrained natural part of the bog. We hypothesized that the major difference in GHG emissions would be between undrained and drained sites, whereas the effects of different cropping systems would be moderate due to the superseding effect of deep drainage.

2. Materials and methods

2.1. Study site

The study was conducted in the bog area of Store Vildmose, Denmark (57.23 °N, 9.84 °E). Mean annual temperature in the area is 7.9 °C and mean annual precipitation is 740 mm (1985–2015). Store Vildmose is a raised sphagnum peat bog (~5000 ha) that was ditched (~2 m depth) and tile drained (~1 m depth) in the 1920s primarily for establishment of white clover (*Trifolium repens*) for grazing cattle (Kristensen, 1945; Pedersen, 1978). The drained peat soils were later used also for arable crops, including oat (*Avena sativa*), barley (*Hordeum vulgare*) and potato (*Solanum tuberosum*), with potato now being the major cash crop in the area. Large areas were re-drained starting in 1945–1950 due to peat subsidence from mechanical compression and biological mineralization. In central parts of the drained bog, the peat depth was 3.8 m in 1930, but had decreased to 1.6 m in 1974 (Pedersen, 1978).

For the present study, five sites were selected for annual GHG flux measurements (10 June 2014–9 June 2015). One site was an undrained natural bog (NB) area, and four sites were drained agroecosystems, i.e., an unfertilized permanent grassland (PG) used for cattle grazing, and three sites in arable crop rotation with the following crop sequences in the study year: oat-potato (OT:PO), oat-spring barley (OT:SB) and potato-spring barley (PO:SB). The two OT sites were neighboring fields with differences in soil pH due to differences in liming practice, as informed by local extension services. The five sites were located within a radius of 1.5 km (Supplementary Fig. S1). A timeline of crop rotations and field operations at the arable sites is shown in Fig. 1.

2.2. Ecosystem respiration and fluxes of CH_4 and N_2O

The CO_2 flux from ecosystem respiration (R_{eco}), and fluxes of CH_4 and N_2O, were measured using two-part static chambers as previously described (Petersen et al., 2012). At each site, three replicated PVC collars (55 × 55 cm) were inserted to a soil depth of 10 cm and at a mutual distance of 5–10 m to cover small-scale heterogeneity. In potato fields, with ridges and furrows, collars were placed to centrally include a ridge. The collars had a 4-cm wide flange (parallel to the soil surface) that served as support for top chambers. The collars were inserted on 28 May 2014, i.e., after crop establishment and two weeks prior to the first flux measurement. The NB soil was typically swampy and permanent boardwalks (1 m^2) were placed in front of each collar to minimize

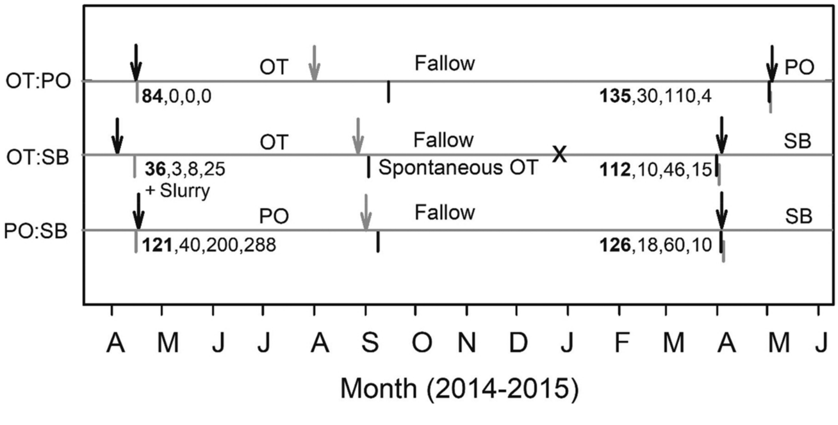

Fig. 1. Timeline of crop rotations and field operations at the arable sites (OT:PO, oat-potato; OT:SB, oat-spring barley; PO:SB, potato-spring barley). Black arrows indicate sowing, grey arrows indicate harvest and vertical black marks indicate ploughing. Vertical grey marks indicate fertilization with specified rates (kg ha^{-1}) of mineral N, P, K and S (N rates in bold) and cattle slurry (25 Mg ha^{-1}; only at OT:SB). Oat from fallen seeds at OT:SB spontaneously grew in autumn 2014 and were killed by frost in December (marked by cross). Gas flux measurements were conducted from 10 June 2014 to 9 June 2015.