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Effect of temperature and soil organic matter quality on greenhouse-gas production from temperate poor and rich fen soils

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ABSTRACT

Production of carbon dioxide (CO₂) and methane (CH₄) from peatland soil is controlled by rates of organic matter decomposition; soil organic matter (SOM) decomposition is influenced by the quality of the SOM and the soil temperature. This study determined the effect of increasing temperature and SOM quality on rates of greenhouse-gas production in lab incubations from peat soils formed under different plant functional types found in temperate rich and poor fens of southern Ontario, Canada. Peat derived from different plant functional type (sedge, shrub, and non-vascular vegetation) between the fens was composed of different amounts of SOM, lignin, and cellulose. Rates of CO₂ and CH₄ production from the lab slurries increased with increasing temperature; however, the relative increases were specific to the vegetation type overlying the soils. Anaerobic to aerobic production ratios ranged from 7% (*Chamaedaphne* soils) to > 30% (*Sphagnum* soils). Ratios of potential anaerobic production (CO₂ to CH₄) generally decreased with increasing temperature. The interaction between temperature and SOM quality was demonstrated through the range of Q₁₀ values (1.09–2.38 for CO₂; 2.98–21.40 for CH₄). These measures were correlated to lignin and cellulose content and the lingo-cellulose index. Results of this study indicate the variability of greenhouse-gas fluxes from peatland soils is influenced by the SOM quality derived from the overlying vegetation. As the climate warms soil temperatures will increase rates of decomposition, and this study will improve models of temperate peatland carbon cycling and can inform land management planning by providing options for minimizing carbon loss.

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1. Introduction

Peatlands store one-third of the global terrestrial carbon pool, despite covering just 3% of the global land surface area (Gorham, 1991). Peatlands have relatively low rates of primary production (Lafleur et al., 2005), yet organic carbon accumulation in peatlands proceeds due to concomitant low rates of decomposition (Frolking et al., 2001). Peat soil respiration is inhibited in part by elevated water table producing anoxic conditions, low air and soil temperatures, and poor quality of organic carbon substrates (Moore and Basiliko, 2006; Juszczak et al., 2013). Despite the long-term accumulation of organic carbon peatlands are the greatest global natural emitters of methane (CH₄), a potent greenhouse gas with a global warming potential 25-times that of carbon dioxide (CO₂) over a 100-yr period (IPCC, 2007). Thus, the CO₂ uptake-respiration dynamics of peatlands need to be weighed carefully with rates

of CH₄ emission when considering the carbon-storage function of peatlands. Rising global air temperatures will increase peatland soil temperatures, which are likely to increase rates of respiration and CH₄ production (Turetsky et al., 2014). Additionally, rates of CO₂ and CH₄ production are influenced by the organic substrates of the peat itself (Liefeld et al., 2012). The quality of soil organic matter (SOM) is controlled by the overlying vegetation (Heller et al., 2015); therefore, rates of CO₂ and CH₄ emission from peatlands in response to global warming will be influenced by shifting peatland species composition.

Vascular and non-vascular vegetation have different amounts of various carbon compounds depending on plant functional type (graminoid, herbaceous, woody shrub, moss) and even within a type (ex., grass versus shrub) (Lambers et al., 2008). These compounds include waxes and other lipids, pectin, simple sugars, proteins, and progressively less labile material including hemicellulose, cellulose, and lignin (Lambers et al., 2008). Because of their chemical structure and C:N:P ratios these compounds represent a spectrum of decomposability once dead plant tissue becomes incorporated in the SOM (Melillo et al., 1989; Reddy and DeLaune, 2008; Wilson et al., 2016). Moore et al. (2007) found that peatland

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leaves decayed quicker than stems, with no difference between sedge and shrub leaves. Sedge-derived peat soils lost significantly less organic carbon than heath- and tussock-derived soils in an Alaskan peatland due to higher proportions of lignin (Shaver et al., 2006). Leifeld et al. (2012) identified a strong decline in polysaccharide content with depth through the peat profile that resulted in decreased rates of respiration.

Peatland type also has a strong influence on SOM processing. The bog-poor fen-rich fen continuum is based on increasing soil pH due to increasing connection to surrounding landscapes that supply calcium carbonate, yet contain representatives from the same plant functional types (Mitsch and Gosselink, 2015). Heller et al. (2015) found increasing biochemical activity and lower proportions of lignin in SOM with increasing minerotrophic status in peatlands. Methane and CO₂ fluxes were greater in laboratory columns of bog peat compared to fen peat subjected to the same environmental conditions (Moore and Dalva, 1993). Analysis of a large number of sites throughout the globe revealed that the differential rates of greenhouse-gas production between bogs and fens are related to the antecedent moisture conditions and subsequent wetting event timing (Turetsky et al., 2014). Presently there is a lack of information on the comparison of rates of greenhouse-gas production from peat soils derived from equivalent plant functional types between peatland types, particularly in response to elevated temperatures.

Temperature and SOM quality been found to influence rates of CO₂ and CH₄ production in arctic (Shaver et al., 2006), subarctic (Diakova et al., 2016), boreal (Waddington and Roulet, 1996; Carter et al., 2012; Armstrong et al., 2015), temperate (Lafleur et al., 2005; Aguilos et al., 2013; Juszczak et al., 2013), subtropical (Inglett et al., 2012; Sihi et al., 2016), and tropical (Chimner, 2004) peatlands. It is well established that peatland soil respiration and methane production increase with increasing soil temperature (Conant et al., 2011; Carter et al., 2012; Wilson et al., 2016). The increased rates of greenhouse-gas production from soils due to temperature increases are described by the Q₁₀ factor – the increase in production rate for a 10 °C temperature increase—and have been found to range between 1 and ~30 (Moore and Dalva, 1993; Segers, 1998). Generally, Q₁₀ values are higher for methanogenesis than for aerobic or anaerobic CO₂ production (Inglett et al., 2012). This has potentially significant implications for C-cycling in peatlands in response to climate change. Significant increases in soil temperature may lead to disproportionate increases in CH₄ production; hence, the increased GWP of CH₄ combined with these increased rates of production may lead to large positive feedbacks to climate change. On the other hand, there is the potential that certain peatland vegetation can lead to poor SOM quality that can minimize rates of CH₄ production (Pinsonneault et al., 2016; Inglett et al., 2012). Sihi et al. (2016) suggest that with increasing temperature methanogens are able to utilize recalcitrant SOM with greater efficiency than decomposers, complicating SOM-temperature-greenhouse-gas-production generalizations.

The objectives of this study were to (1) determine the effect of temperature increases on the potential greenhouse-gas production from soils collected from a temperate poor and rich fen; (2), determine whether the overlying vegetation imparts differences in the quality of the accumulated SOM; and (3) determine whether the SOM quality differences influenced the temperature response to potential greenhouse-gas production from the peat soils. In this study soils from a rich and a poor fen in similar hydrogeologic settings were chosen, and incubation experiments were carried out on peat collected from areas of each fen dominated by sedges, shrubs, and non-vascular vegetation. Elucidation of the interaction between the SOM pool and temperature sensitivity of temperate peatland soils will inform predictions of future greenhouse-gas emissions with changing climate. It will also provide information on

the potential effect of certain target species in wetland restoration on soil greenhouse-gas fluxes.

2. Methodology

2.1. Study area

Soil samples were collected from different vegetation communities in two fens of southern Ontario, Canada. Osprey Wetland (44° 15' 13" N, 80° 20' 47" W) is a 130-ha poor fen formed in a depression of the Dundalk Till Plain. It is underlain by sandy silt till resting on top of Guelph formation dolomite (Burwasser, 1974). Peat depth at the poor fen averages 2.1 m. Mean pore-water pH is 5.3, with specific conductivity and calcium concentration 103 μS cm⁻¹ and 21 mg L⁻¹, respectively (Radu, unpublished data). Vegetation is dominated by *Sphagnum* species *S. capillifolium*, *S. rubellum*, *S. fuscum* and *S. magellanicum*, with distinct patches of sedge (*Carex oligosperma* and *Eriophorum vaginatum*) and ericaceous shrub (*Chamaedaphne calyculata*, *Rhododendron groenlandicum*, and *Vaccinium uliginosum*) communities throughout. The Fletcher's Creek Riparian Fen (43° 24' 57" N, 80° 7' 3" W) is a 4-ha extreme rich fen formed in an area of the Guelph Formation devoid of any glacial overburden material (Duval and Waddington, 2012). The peat averages 0.8 m in depth and rests on a thin layer (< 1 m) of sandy silt (Duval and Waddington, 2011). Mean pore-water pH, specific conductivity, and calcium concentration are 7.0, 890 μS cm⁻¹, and 135 mg L⁻¹, respectively (Duval and Waddington, 2011). The rich fen has high vascular plant diversity, dominated by many sedge species of the *Carex* genus, and shrubs such as *Cornus stolonifera*, *Rhamnus alnifolia*, *Salix candida*, and grasses such as *Calamagrostis canadensis*, *Muhlenbergia glomerata*, and *Poa palustris*. More information on the poor and rich fens can be found elsewhere (Radu, 2017 and Duval et al., 2012; respectively).

2.2. Sample collection

Soils were collected from three areas of each fen representing distinct vegetation types: sedges, shrubs, and non-vascular communities (*Carex oligosperma*, *Chamaedaphne calyculata*, *Sphagnum capillifolium* at the poor fen site, and *Carex livida*, *Cornus stolonifera*, and the stonewort *Chara* spp. at the rich fen site, respectively). At each vegetation community the near-surface plant residues were removed and 10-cm soil cores were collected in triplicate at 10-cm depth, on centre, using a serrated blade. Individual cores were sealed in air-tight 6 mil polyethylene bags and stored on ice for transport to the lab, where they were refrigerated until the experiment began within 48 h of collection in the field.

2.3. Experimental setup

To test the effect of soil temperature on production of CO₂, CH₄, and N₂O from collected peatland soil found under different vegetation types, a full factorial experiment modified from Inglett et al. (2012) was conducted. Soils were homogenized in their bags, and 10 g dry-weight of soil was placed in 60-mL clear serum bottles for analysis. Soils from each of the six vegetation communities were incubated at 5 °C in a refrigerator and at 15 and 25 °C in two Sanyo MLR-352 environmental chambers under both aerobic and anaerobic conditions. All incubations were kept in the dark throughout the experiment. The serum bottles of the soils of the aerobic treatment were left uncapped between sampling periods. Aerobic serum bottles were periodically weighed and deionized water was added on a mass-basis as required to keep soils at pre-determined field capacity moisture content. Deoxygenated water was added to the anaerobic treatment to fully saturate the soils and have ~3 mm of

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