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Limited effects of six years of fertilization on carbon mineralization dynamics in a Minnesota fen

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Abstract

Peatlands, including fens, are important ecosystems in the context of the global carbon cycle. Future climate change and other anthropogenic activities are likely to increase nutrient loading in many peatland ecosystems and a better understanding of the effects of these nutrients on peatland carbon cycling is necessary. We investigated the effects of six years of nitrogen and phosphorus fertilization, along with liming, on carbon mineralization dynamics in an intermediate fen in northern Minnesota. Specifically, we measured CO_2 and CH_4 emission from intact peat cores, as well as CH_4 production and CH_4 consumption at multiple depths in short-term laboratory incubations. Despite increased nitrogen and phosphorus availability in the upper 5 cm of peat, increased pH, and clear shifts in the vegetation community, fertilization and liming had limited effects on microbial carbon cycling in this fen. Liming reduced the net flux of CO_2 approximately 3-fold compared to the control treatment, but liming had no effect on CH_4 emissions from intact cores. There were no nutrient effects on CO_2 or CH_4 emissions from intact cores. In all treatments, rates of CH_4 production increased with depth and rates of CH_4 consumption were highest near the in situ water-table level. However, nutrient and liming had no effect on rates of CH_4 production or CH_4 consumption at any depth. Our results suggest that over at least the intermediate term, the microbial communities responsible for soil carbon cycling in this peatland are tolerant to wide ranges of nutrient concentrations and pH levels and may be relatively insensitive to future anthropogenic nutrient stress.

Keywords: Carbon dioxide; Methane; Nitrogen and phosphorus fertilization; Peatlands; pH

1. Introduction

Although they occupy less than 3% of the terrestrial land surface (Bridgham et al., 2001), peatlands are important ecosystems in the context of global climate change as they are currently responsible for approximately 8% of the global methane (CH_4) emissions (Bartlett and Harriss, 1993). Further, an estimated 455 Pg of carbon (Pg $=10^{15}$ g), approximately one-third of the terrestrial soil carbon pool, is stored in peatlands. These ecosystems have the potential to release this stored carbon as additional carbon dioxide (CO_2) or CH_4, both of which are important greenhouse gases (Gorham, 1995; Bridgham et al., 1995; Moore et al., 1998; Wieder, 2001). As CH_4 has an estimated 26 times the global warming potential of CO_2 (Lelieveld et al., 1993), even small changes in CH_4 emissions could have important consequences for global climate change.

The net CH_4 flux from any ecosystem is the difference between CH_4 production and CH_4 consumption, minus any short-term change in storage. These processes are microbially mediated by methanogens and methanotrophs, respectively, and are controlled by a number of physical and environmental variables, including water-table level, substrate carbon quality, pH, redox state, nutrient availability, and plant community composition, biomass, and productivity. For example, the low pH of peatland ecosystems may limit methanogenesis (Williams and Crawford, 1984; Dunfield et al., 1993; Valentine et al., 1994; Hines and Duddleston, 2001), possibly due to

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the inhibition of hydrogen-producing and -consuming processes at low pH (Goodwin and Zeikus, 1987; Goodwin et al., 1988).

The role of nutrients in controlling CH_4 emissions in peatlands is important because many peatlands, like other natural systems, are currently experiencing increased nutrient (nitrogen and phosphorus) loading due to increased atmospheric deposition, agricultural inputs, and other anthropogenic activities (Vitousek et al., 1997; Richardson and Qian, 1999; Tilman, 1999; Noe et al., 2001; Galloway et al., 2003). Nutrient dynamics in these ecosystems are also likely to change in response to future climate change (Bridgham et al., 1995; Keller et al., 2004). The effects of nutrients on ecosystem CH_4 dynamics are complicated and may take place at biochemical, microbial, and ecosystem levels (Schimel, 2000). At the biochemical level, nitrogen (as NH_4) often inhibits CH_4 consumption (increasing net CH_4 flux) by competing for methane monooxygenase, the enzyme used to oxidize CH_4 (Hanson and Hanson, 1996). Nutrients can also act at a microbial level by directly stimulating or inhibiting methanogens or methanotrophs, with resulting increases or decreases in net CH_4 flux. Finally, nutrients can act at an ecosystem level over longer time scales by changing the dominant vegetation community. Such shifts in vegetation could affect CH_4 dynamics through changes in (1) litter inputs and resultant changes in soil quality (Chapin III et al., 1995; Moore and Dalva, 1997), (2) labile root exudates (Hutchin et al., 1995; Joabsson et al., 1999; Megonigal et al., 1999; Updegraff et al., 2001), or (3) CH_4 and oxygen transport through plant aerenchyma (Schütz et al., 1991; Whiting and Chanton, 1993).

Nitrogen fertilization has resulted in increased CH_4 emissions in peatlands (Aerts and Toet, 1997; Aerts and de Caluwe, 1999; Saarnio and Silvola, 1999), likely as a result of an inhibition of CH_4 consumption. A number of laboratory studies have supported nitrogen inhibition of CH_4 consumption in peatlands (Crill et al., 1994, Kravchenko, 1999a,b, 2002). However, recent work suggests that in some wetlands nitrogen may have the opposite effect and stimulate CH_4 consumption, and thus decrease CH_4 emissions. Bodelier et al. (2000a,b) found that the CH_4 emissions from rice paddy soil were reduced following nitrogen fertilization due to stimulation of methanotrophs. They suggested that high concentrations of CH_4 counterbalanced potential competitive inhibitory effects of nitrogen on methane monooxygenase. Updegraff et al. (2001) also observed a negative relationship between CH_4 flux and pore water NH_4 concentrations in bog and fen plots receiving several heating and water-table treatments. They hypothesized that one likely mechanism for this relationship was direct stimulation of a nitrogen-limited methanotrophic community.

While the role of nitrogen in controlling CH_4 dynamics has received considerable attention, the role of phosphorus has been less studied. Changes in phosphorus availability may affect CH_4 flux in peatlands because plant productivity in these ecosystems is often phosphorus limited (Bridgham et al., 1996; Bedford et al., 1999; Chapin et al., 2004). Phosphorus availability could also directly affect CH_4 flux by stimulating methanogens and/or methanotrophs.

This experiment was designed to examine the effects of six years of nitrogen and phosphorus fertilization and liming on CH_4 and CO_2 emissions in a fen in northern Minnesota. Specifically, we hypothesized that (1) nitrogen fertilization would stimulate CH_4 oxidation and thus decrease CH_4 emissions, (2) phosphorus fertilization would stimulate CH_4 production through increases in primary production and thus increase CH_4 flux, (3) CO_2 flux would increase in response to fertilization, and (4) liming would increase rates of CH_4 and CO_2 emissions by removing the pH limitation on microbial metabolism.

2. Materials and methods

2.1. Study site

Research was conducted at a fen in Alborn township in northeastern Minnesota (47° 00′ 42″ N, 92° 34′ 30″ W), which has been described in detail previously (Malterer et al., 1979; Santelmann, 1991; Bridgham et al., 1998; Chapin et al., 2003, 2004). This intermediate fen has a pH of ∼4.9, with low areas (flarks) dominated by the graminoids *Carex exilis* Dewey, *C. livida* (Whal.) Wild., *C. limosa* L., *C. lasiocarpa* Ehrh., *Rhyncospora alba* (L.), and *R. fusca* (L.) Ait. F. The mean annual temperature in this region is 3.16 °C and the mean annual precipitation is 497 mm. Water levels in the fen during the growing season (May–October) range from about −10–+2 cm relative to the peat surface.

2.2. Fertilization treatments

The fertilization treatments utilized in this study are described in detail by Chapin et al. (2003, 2004), and a brief summary is provided below. Twelve, 3-m^2 circular plots were established in flarks (i.e. wet depressions), and 1-mm thick rubber roofing material was buried to of depth of 30–50 cm around the perimeter of the plots to prevent lateral loss of applied nutrients and calcium carbonate. These rings were installed in the winter to prevent unnecessary damage to surface vegetation of the fen. Wooden boardwalks were constructed to minimize further impacts to the plots.

Beginning in 1995, two nitrogen (N) levels (2.0 or 6.0 $g\ N\ m^{-2}\ y^{-1}$ as NH_4Cl) and two phosphorus (P) levels (0.67 or 2.0 $g\ P\ m^{-2}\ y^{-1}$ as a mixture of NaH_2PO_4 and Na_2HPO_4) were combined to produce four different fertilizer treatments: low N-low P ('LN-LP'), high N-low P ('HN-LP'), low N-high P ('LN-HP'), and high N-high P ('HN-HP'). Control (no fertilization) and liming (no fertilization with pH adjusted to ∼6.4 with calcium