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Effect of water table level on CO_2, CH_4 and N_2O emissions in a freshwater marsh of Northeast China

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ABSTRACT

We quantified the effects of the water table on CO_2, CH_4 and N_2O emissions from microcosms in a freshwater marsh in Sanjiang Plain, Northeast China. From July to September in 2005, CO_2, CH_4 and N_2O emission rates were measured in an undisturbed natural marsh (in natural) and microcosms of three manipulated water table treatments: a reference, a high water table (HW) and a low water table (LW). The averages of CO_2, CH_4 and N_2O emissions were 360.2 mg m^{-2} h^{-1}, 7.43 mg m^{-2} h^{-1} and 12.84 μg m^{-2} h^{-1}, respectively, close to those in reference ($p < 0.05$), averaging 394.5 mg m^{-2} h^{-1}, 8.92 mg m^{-2} h^{-1} and 13.3 μg m^{-2} h^{-1}. This means microcosm installation had no significant effect on CO_2 efflux. Averaged CO_2 ($p = 0.03$) and CH_4 ($p = 0.001$) emissions were significantly different across the treatments, but that of N_2O emission ($p = 0.36$) was not. To quantify the effects of water table position, three typical classes of water table were considered, i.e. +2 to +14 cm, −11 to 0 cm and −28 to −11.3 cm (+, above the soil surface. −, below the soil surface). Mean CO_2 and N_2O emissions were lowest at the higher water table positions (+2 to +14 cm) and increased by 120% and 60% at the lower water table positions (−11 to 0 cm), respectively, and the corresponding CH_4 emissions decreased by 75%. However, at lowest water table positions (−28 to −11.3 cm), little additional effects on gas emissions were not found. Our results suggested that there could be considerable changes of greenhouse emissions as a response of water drawdown due to wetland drainage.

1. Introduction

Wetlands play an important role in carbon storage, especially at high latitudes, where they store nearly one-third of the global soil carbon (Gorham, 1991). Although these soils have acted as sinks for carbon and nitrogen through the accumulation of organic carbon and nitrogen, there is global concern that they may become an important source of greenhouse gases due to the enhanced mineralization of soil organic matter caused by drainage, agricultural use and other anthropogenic disturbances leading to climate changes (Smith et al., 2004). Greenhouse gas emissions from wetlands have always been very important for predicting the biospheric feedbacks of terrestrial ecosystems to global changes. According to the estimation by Brix (1990), approximately 15% of the net assimilated carbon of wetland plants is released to the atmosphere. Wetlands are also among the primary sources of atmospheric CH_4, accounting for approximately 15–30% of the total annual CH_4 emissions, 50–60% of which come from high-latitude wetland areas (Cicerone and Oremland, 1988; Barklett and Harriss, 1993). When wetlands are drained, they are considered potential sources of N_2O (Regina et al., 1996). As soluble nitrogen is often limited, soil-atmosphere fluxes of N_2O tend to be small, although with the global warming potential of about 300 times that of CO_2 on a 100-year perspective they can still contribute significantly to total greenhouse gases budget (Jauhiainen et al., 2012).

The water table, because it determines the depth of the oxic/anoxic boundary and redox level within the wetland soil, can have important effects on greenhouse gas production (Dinsmore et al., 2009). Saturated soils limit the diffusion of atmospheric oxygen

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into the wetland, limiting aerobic microbial activity and decomposition rates. Conversely, a water table drawdown increases oxygen diffusion into soils allowing aerobic decomposition (Silvola et al., 1996; Nykänen et al., 1998). CH_4 emissions are high under strictly anaerobic conditions, and CO_2 effluxes from soils are elevated under aerobic conditions (Moore and Dalva, 1993). Maximum N_2O emissions are typical for intermediate conditions (Davidson et al., 2000). The general consensus from previous studies is that lowering the water table increases carbon mineralization and decreases CH_4 emissions (Moore and Dalva, 1993; Hargreaves and Fowler, 1998; MacDonald et al., 1998; Blodau and Moore, 2003a), whereas rising water table decreases CO_2 emissions and increases CH_4 emissions (Ding et al., 2002; Chimner and Cooper, 2003; Blodau et al., 2004). Studies by Aerts and Ludwig (1997) and Regina et al. (1999) have concluded that lowering the water table depth leads to a net increase in N_2O emissions from wetlands. Dinsmore et al. (2009) reported CO_2 and N_2O emissions were high in the low water table treatment and CH_4 emissions were high in the saturated mesocosms. Jungkunst and Fiedler (2007) reviewed that CO_2 emissions were relatively reduced by 10–20% and 30–60% with rising ground water in tropical and temperate wetlands, respectively, whereas these values were over 60% in boreal wetlands.

Sanjiang Plain, located in Heilongjiang province of Northeast China, covers an area of 10.89×10^4 km^2, and 9.56% of the total area is marsh (Liu and Ma, 2000). At present, marsh in this area is only less than that in Qinghai–Tibet Highland in China (Zhao, 1999). Since the 1970s, 73% of the marsh area has lost and arable lands doubled (Song et al., 2008b). Meanwhile, massive water diversion ditches, with a total length of more than 1.4×10^4 km, have been excavated to drain marshes to arable lands (Liu and Li, 2005). Hydrologic conditions have changed in wetlands due to drainage and water table has decreased 20–50 cm in some marshes for the past 30 years (Liu et al., 2004). Water table often serves as the dominant control on greenhouse gas emissions in northern wetlands (Moore and Roulet, 1993; Turetsky et al., 2008), and lower water tables and increasing acrotelm thickness with drainage in wetlands generally increase CO_2 and N_2O emissions and reduce atmospheric CH_4 fluxes (Alm et al., 1999; Berglund and Berglund, 2011). The sensitivity of wetlands to water table change is critical to evaluating the effects of hydrologic changes due to wetland drainage. Therefore, it is necessary to quantify the effects in different regions because greenhouse emissions sometimes have different water table responses with the variety of climates, soils and vegetations. In this region, the influences of water table on greenhouse gas emissions have been reported by field studies in different marshes (Ding et al., 2002; Liu et al., 2003; Yang et al., 2006a; Yu et al., 2007a, 2007b; Song et al., 2008a). Although these studies support the concept that water table can alter the gas emissions, their results are not able to differentiate the effects of different water table positions. To quantify the influence of water table change on greenhouse gas emissions from marsh, we designed three water table levels in a freshwater marsh, without minimizing the ambient seasonal fluctuations in water table position that typically characterize the marsh environments.

2. Study site and methods

2.1. Study site

The experimental site is located at a freshwater marsh (47°35.29′ N, 133°31.81′ E) in Heilongjiang province in Sanjiang Plain, Northeast China. The average temperature and precipitation in the measured year were −1.9 °C and approximately 350 mm, respectively. There are three types of natural communities, varying from *Deyeucia angustifolia*, *Carex lasiocarpa* and *Carex pseudocuraica* with increasing standing water depth. The *D. angustifolia* community was selected as the experimental plot for our study, which dominates in the higher topography, where vegetation covers 80% and the annual water table depths range from −25 to +10 cm. The soil in the studied plots is gley soil and the profile is composed of root layer and gley layer. The thickness of root layer is about 35 cm. The gley layer is the bottom of soil underneath root layer, with water content of about 25–30%. Average total organic carbon, total nitrogen, $NO_3^- - N$ and $NH_4^+ - N$ concentrations and pH values in the soil of profile and also plant biomass are shown in Table 1.

2.2. Experimental design

The microcosms for water table manipulation and gas sampling are shown in Fig. 1. Polyvinyl chloride (PVC) pipes, 80 cm long and 30 cm in diameter, were used to construct microcosms for reference, low water table (LW) and high water table (HW) treatments, respectively. At the experimental plot, a homogeneous area of about 400 cm × 600 cm was randomly selected, where the microcosms were installed. Plant roots and soil were cut to 45 cm depth with a circular corer of the same diameter as the PVC pipe. Plants above ground within the corer were harvested, and then microcosm was inserted. To avoid gas leakage when sampling, clay soil was used to seal the fissure between the PVC pipe and soil. There were three microcosm repeats for each treatment, and a total of nine microcosms were manipulated, between which, the intervals were maintained at 150 cm to avoid disturbing each other.

Three microcosms were randomly selected as reference microcosms and we cut slots through the PVC to allow ground water levels to remain in equilibrium with the surrounding undisturbed marsh. The remaining microcosms for LW and HW treatments had no slots; instead, the water table levels were regulated through manual controls. In the LW microcosms, at the position of 10 cm below the soil surface, holes were opened on PVC and connected to a water tank with silicone tubes. The water tank was installed in the soil at 15 cm below the soil surface. These manipulations maintained the water table beneath 10 cm depth below the soil surface. In the HW microcosms, the water table levels were controlled through injecting marsh water into the microcosms with the beginning level at +20 cm. To measure the water table depth, a slotted PVC pipe 1.0 cm in diameter was also installed in all microcosms. We have made the plants restore the roots for a week before microcosm incubation for different water table treatments.

At the same time, gas emissions were also measured with the static-chamber method in an undisturbed natural area nearby the

Table 1
Soil quality and plant above-ground biomass at the experimental plot. The data are presented as the mean ± standard deviation. TOC stands for total organic carbon and TN stands for total nitrogen.

Soil depth (cm)	pH value	TOC (mg kg^{-1})	TN (mg kg^{-1})	$NH_3^+ - N$ (mg kg^{-1})	$NO_3^- - N$ (mg kg^{-1})	Above-ground biomass (g m^{-2})
0–5	5.3 ± 0.2	943.8 ± 20.6	7126.5 ± 697.9	28.61 ± 4.51	1.60 ± 0.17	895.1 ± 170.6
5–10	5.4 ± 0.1	528.6 ± 18.0	5574.1 ± 622.2	15.15 ± 6.73	1.01 ± 0.04	
10–20	5.6 ± 0.5	107.1 ± 10.9	1416.4 ± 335.3	6.30 ± 4.79	0.97 ± 0.06	
20–40	5.9 ± 0.6	74.0 ± 8.8	939.4 ± 136.6	4.46 ± 1.13	0.93 ± 0.01	