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Effects of soil warming, rainfall reduction and water table level on CH_4 emissions from the Zoige peatland in China

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ABSTRACT

The Zoige Plateau features approximately 4605 km^2 of peatlands, making it the largest peatland area in China. This area stored 2.9 Pg peat during the Holocene, yet little is known about methane (CH_4) emissions from this region. In this study, we designed a mesocosm experiment to measure CH_4 emissions during the growing seasons of 2009–2010 under different scenarios involving soil warming, 20% reduction in rainfall and changes in the water table level. Our results showed that CH_4 emissions were higher in 2009 than in 2010 under all experimental conditions. Average soil temperature was approximately 11.4 °C under control conditions, 13.3 °C under soil warming conditions, 12.7 °C with 20% rainfall reduction, and 13.4 °C under combined conditions of soil warming and 20% reduced rainfall. For the single factor effect, soil warming treatment increased average CH_4 emissions by 28%, while rainfall reduction increased it by 30%; however, neither increase was statistically significant. In contrast, the combined effect of soil warming and rainfall reduction significantly decreased CH_4 emissions by an average of 58%. Extending this result across the entire peatland area in the Zoige Plateau translates into approximately 5.3 Gg of CH_4 uptake per year. These results suggest that a drier and warmer Zoige Plateau will become a CH_4 sink. Our study also found a positive relationship between water table level and CH_4 emissions. Average CH_4 emissions decreased by approximately 82% as water drawdown varied from 0 (0.94 mg CH_4 m^{-2} h^{-1}) to −50 cm (0.17 mg CH_4 m^{-2} h^{-1}). When we simultaneously examined the effect of all three factors of water table level, soil warming and rainfall reduction on CH_4 emissions, we found soil warming and rainfall effect on CH_4 emissions varied with water table levels. However, none of the three factors significantly affected CH_4 emissions at a water table depth of 30 cm below peat depth.

1. Introduction

Peatlands contain one third of the world's soil organic carbon (C), accumulating more than 600 Pg C (1 Pg = 10^{15} g) during the Holocene. These large, long-term C sinks (Gorham, 1991; Yu et al., 2010) significantly affect the global carbon cycle, and are a primary natural contributor to atmospheric CH_4 budgets (Frolking et al., 2011; Yu et al., 2010), giving off approximately 0.03 Pg CH_4 yr^{-1} globally into the atmosphere (Frolking et al., 2011; van Winden et al., 2012a). Climate warming may accelerate the decomposition of soil carbon in peatlands, significantly increasing the levels of greenhouse gases in the atmosphere (Dise, 2009; Dorrepaal et al., 2009). Thus, understanding the complex interactions between climate change and greenhouse gases emission is necessary for peatland ecosystems and particularly for the peatlands on plateaus given their specific region and climate sensitivity.

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CH_4 emissions from peatlands are likely determined by numerous factors, including water table levels, precipitation, soil temperature and vegetation composition (Mills et al., 2013; Ward et al., 2013; Wright et al., 2013; Yang et al., 2013). Changes in water table level, precipitation and temperature all affect CH_4 emissions from peatlands by influencing organic matter decomposition and carbon mineralization (Taggart, 2010; van Winden et al., 2012b; Ward et al., 2013). More specifically, the water table level influences the aerobic/anoxic boundary and redox level of the soil (Dinsmore et al., 2009a). The aerobic environment caused by water table drawdown decreases CH_4 emissions due to limited methanogen activity (Fenner and Freeman, 2011). Conversely, higher water table levels caused by increased precipitation and runoff decrease respiration and increases CH_4 emission by decreasing methanotrophy (Laine et al., 2009).

Soil warming appears to exert complex effects on CH_4 emissions in peatlands (Dijkstra et al., 2012), with some researchers reporting a positive relationship between warming and CH_4 emissions (Gao et al., 2011; Parrenin et al., 2013; Turetsky et al., 2008) and others reporting a negative relationship (Eriksson et al., 2010). In most peatlands, water table showed a greater effect on CH_4 emissions than direct warming (Turetsky et al., 2008). Compared with the effects of single factors on CH_4 emissions, the interactive effect of water table and temperature on CH_4 emission is more complex because climate warming may increase (through permafrost thawing which would increase peatland moisture content) or decrease (through drought or water drainage) water table levels to influence CH_4 emission (Roulet et al., 1993; Strack and Waddington, 2007). Climate change scenarios forecast an increase in mean temperature and a decrease in regional precipitation during the summer in the northern hemisphere (IPCC, 2007). This highlights the need to explore how changes in the water table level and soil warming will interact to influence CH_4 emission.

The Zoige Plateau is located in the southeastern part of the Qinghai-Tibetan Plateau. Anoxia, low temperature and low pH conditions (Fenner and Freeman, 2011; Gorham, 1991; Laiho, 2006) resulted in the development of 4605 km^2 peatlands and an accumulation of approximately 0.48 Pg C (Chen et al., 2014). These peat areas are quite sensitive to climate change because they depend on the specific cool and humid climatic conditions (Essl et al., 2012). However, the region has been warming by 0.4 °C per decade over the past 40 years, based on data from the Chinese National Meteorological Information Center. C dynamics in this region continue to attract increasing interest from researchers interested in greenhouse gas flux in grasslands, permafrost degradation and carbon loss, and soil organic carbon density in degraded wetlands (Chen et al., 2013; Wang et al., 2008; Huo et al., 2013; Kato et al., 2004; Zhu et al., 2012). However, little is known about how CH_4 emissions from the Zoige peatlands are changing as a result of climate change. Therefore the present study aimed to examine (1) how soil warming and rainfall reduction affect CH_4 emissions from the Zoige peatlands, and 2) whether these effects vary with water table levels of peatlands.

2. Materials and methods

2.1. Study area and experimental design

2.1.1. Study area

Field experiments were undertaken in a fen during 2009–2010 in Hongyuan County town (3600 m a.s.l.), located in the upper reaches of the Yellow River in the southeastern part of the Qinghai-Tibetan Plateau. Mean annual temperature for the period 1961–1991 was 1.4 °C, with the warmest monthly temperature (11 °C) recorded in July and the coldest (−10.1 °C) in January. Mean annual precipitation is 650–749 mm (Hongyuan, 1996), with 811 mm of annual precipitation in 2009 and 788 mm in 2010, based on data from the Chinese National Meteorological Information Center (www.nmic.gov.cn). Because the site is located in a transition zone between semi-humid subalpine and semi-humid temperate climates, the region is strongly influenced by the southwest monsoon from the Indian Ocean, and is therefore particularly sensitive to climatic variation. During the past four decades, the Zoige Plateau has experienced significant and universal warming, with the temperature increasing by 0.4 °C per decade since 1970, based on data from the National Meteorological Information Center (Fig. 1). In parallel with rising temperature, precipitation has decreased an average of 22 mm per decade over the last several decades.

Peatlands in this region have a depth of 0.3–10 m and a mean dry mass accumulation rate of 0.03 g m^{-2} yr^{-1} (Chen et al., 2010; Sun, 1992); an average pH of 6.6–7.0 (Tian et al., 2012); an average TC of 58.6 mg L^{-1}; TN of 1.4 mg L^{-1} and pore water DOC concentration is 25.7 mg L^{-1}. Water table fluctuates seasonally, approximately −11 cm when excavated peat core in May 2009. The dominant plant species is *Carex muliensis*, and other abundant plant species include *Caltha palustris*, *Gentiana formosa*, and *Trollius farreri*.

2.1.2. Experimental design

A complete factorial experimental design was used, comprising six water table levels (0, −10, −20, −30, −40, −50 cm), two temperatures [passive warming with open-top chambers (OTCs), ambient temperature], and two precipitation levels (ambient rainfall, 20% reduction in rainfall). Experiments were performed in triplicate for every possible combination of water table level, temperature and precipitation. A total of 72 mesocosms were established in four subplots (Fig. 2). The subplots were designated as follows: A: water table experiment without changes in other climate factors, B: water table experiment with soil warming, C: water table experiment with precipitation change (20% rainfall reduction), and D: water table experiment with combined soil warming and precipitation change.

Peat cores were collected from an open fen near Hongyuan County town using a stainless steel, cylindrical corer with a diameter of 25 cm and a height of 60 cm. After cutting the peat with the corer, the core was dug out with the vegetation of the peat surface

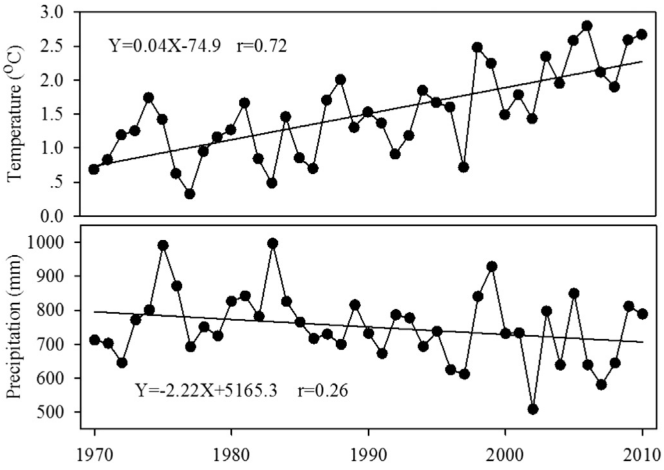

Fig. 1. Temperature and precipitation data for the study area. Climate data from Hongyuan were acquired from the Chinese National Meteorological Information Center (http://www.nmic.gov.cn/). Precipitation data included monthly accumulation of rain and snowfall.