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The effect of water table decline on soil CO_2 emission of Zoige peatland on eastern Tibetan Plateau: A four-year *in situ* experimental drainage

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ABSTRACT

Water table decline is a major threat to soil organic carbon in peatlands worldwide principally because it may largely increase soil CO_2 emission (SCE). This study is to determine the response of SCE to water table decline in the Zoige peatland of Tibetan Plateau, which has experienced rapid decline of water table due to climate change and anthropogenic drainage. We conducted a field *in situ* drainage experiment consisting of low (plots surrounded by 50 cm deep ditches), intermediate (20 cm deep) and high (intact) water table levels. The experiment lasted for about four years, during which we measured SCE rate and associated variables including soil temperature and moisture with a higher frequency in the growing season (May–September) than the non-growing season (October–April). Experimental drainage decreased water table height by *ca.* 12 cm and 15 cm (relative to the intact) and soil moisture (at 5 cm soil) by 6% and 12% (relative to 45% in the intact) on average in intermediate and low water table treatments, respectively, but it did not affect soil temperature during the experimental years.

The effect of drainage on SCE varied with season. In the non-growing season, the drainage effect was nonsignificant in each measurement possibly because the low-temperature effect overrode the drainage effect on SCE. In the growing season, the drainage mostly increased the emission except for several cases, in which a negative effect was observed. The negative effect of drainage could be due to the low soil moisture ($<$ 25%) in the drained treatments. Provided that the magnitude and the duration of the SCE increase were greater than those of the decrease, it can be estimated that drainage increased SCE by 17% and 20% on average in the low and the intermediate water table treatments, respectively, over the experimental years. Our results suggest that water table decline may facilitate net carbon emission and hence decrease soil carbon storage in the Zoige peatland. We call for artificial filling of the ditches that were historically created by both human beings and storm waters to increase water table in the Zoige peatland.

1. Introduction

The Zoige peatland on the eastern Tibet Plateau, covering 4605 km^2 in area, has the largest peat deposition among Chinse peatlands (Fei et al., 2006) and among the alpine peatlands worldwide (Xiang et al., 2009). The estimated soil organic carbon (SOC) is 0.48 Pg in the Zoige peatland (Chen et al., 2014), accounting for 6.2% of SOC storage in China and 1‰ in the world (Cui et al., 2015). Thus, exploring the response of this peatland to environmental changes is of significance to regional and global carbon dynamics.

The Zoige peatland is now experiencing unprecedented water table decline, as confronted by many large peatlands in the world (Kettridge et al., 2015). On one hand, in the past 40 years, the temperature has increased by 0.4 °C per decade and precipitation has decreased by 22 mm per decade (Yang et al., 2013). Such a climatic change must have decreased water storage in the peatland. Consistently, hydrological records at the two most important rivers, the White River and the Black River, show that the mean annual runoff from the peatland has decreased by about 28% and 35%, respectively, from 1957 to 2010 (Li et al., 2014). On the other hand, the Zoige peatland has ever been largely drained to enlarge the area of rangelands from the 1970s to the 1990s. As a result, nearly 1 000 artificial drainage channels, with a total length of 2864 km, have drained nearly 41% of the total area of the Zoige peatland (Dong et al., 2010). Although drainage has been banned since the 2000s, many channels are still in function, thereby increasing water output from the Zoige peatland (Dong et al., 2010). The climatic

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Abbreviations: SCE, soil CO_2 emission; SOC, soil organic carbon; PVC, polyvinyl chloride
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change and human activities have collectively decreased water table by 5–15 cm from the 1970s to the 2000s in the Zoige peatland (Xiang et al., 2009).

High water table is crucial to maintain high SOC storage in peatlands (Hayward and Clymo, 1983). However, water table decline may facilitate oxygen diffusion and hence increase soil aeration, which would enhance the decomposition rate of SOC and soil CO_2 emission (SCE) (Moore and Knowles, 1989; NykäNen et al., 1998). Moreover, water table decline may facilitate the invasion of soil animals into peatlands and improve microbial activities (Hribljan et al., 2014; Laiho et al., 2001; Mäkiranta et al., 2009; Schmidt et al., 2016), which further increases the decomposition rate of SOC and SCE (Wu et al., 2017). Thus, studying the response of SCE to water table decline is of significance to predicting peatland SOC dynamics under global climate change and human activities.

Several studies have attempted to explore the effect of water table on SCEs in wetlands including the Zoige peatland (Gao et al., 2011; Moore and Dalva, 1993; Wang et al., 2017). The most commonly used methodology is to maintain a constant water table level for peatland soil cores (Wang et al., 2014a). This methodology is advantageous in that water table can be accurately controlled. However, water table cannot be at a constant level in nature. For example, assuming that water table of the Zioge peatland decreases in future, we may expect that the water table should vary with rainfall timing and intensity. Thus, the experiments that can reflect the natural fluctuations of water table should be conducted to accurately estimate the SCE response to water table decline in peatlands.

In this study we employed the methodology of artificial drainage and conducted an *in situ* field experiment consisting of three water table level treatments. We recorded water table, soil moisture, soil temperature and SCE rate for four consecutive years. The objective of our study was to determine to what extent experimental drainage increased SCE rate in the Zoige peatland. Our results indicate that water table decline may have contrast effects on SCE, showing a context-dependent pattern in the peatland.

2. Materials and methods

2.1. Study site

This study was conducted in Hongyuan County, Sichuan Province, Southwest China (32°48′N, 102°33′E), on the eastern part of the Tibet Plateau. Situated at an altitude of *ca.* 3500 m above sea level, the area has a climate characterized by short, cool summers and long, cold winters. The mean annual temperature is 0.9 °C, the maximum average monthly temperature is 10.9 °C (July), and the minimum average monthly temperature is −10.3 °C (January). The mean annual precipitation is 744 mm, most of which occurs between May and August (Zhao et al., 2014).

The Zoige peatland consists of lakes, river wide valleys, and marshy meadows (river terrace marshes), among which marshy meadows occupy a percentage of 67.2% of the total peatland area (Lang et al., 1999). Marshy meadows are a primary type of peatland in Hongyuan County, occupying about 492 km^2 (Lang et al., 1999). This peatland is mostly waterlogged in early summer, and its peat depth in this region ranges from 0.3 to 10 m, having a mean dry mass accumulation rate of 0.03 $g\ m^{-2}\ yr^{-1}$. The soil pH is 6.6–7.0, and the soil carbon and N concentrations are on average 58.6 $mg\ L^{-1}$ and 1.4 $mg\ L^{-1}$, respectively (Wu et al., 2017; Yang et al., 2014).

The vegetation coverage in the study meadow is over 90% and consists mostly of sedge species including *Carex muliensis, Kobresia humilis*, *Scirpus pumilus*, *Blysmus sinocompressus*, *Kobresia setchwanensis* and *Kobresia pygmaea*. Rushes (*Juncus leucanthus* and *Juncus allioides*) are common but with relatively low abundance. Grasses, including *Poa pratensis*, *Deschampsia caespitosa* and *Agrostis matsumurae*, and forb species, including *Chamaesium paradoxum* and *Anemone trullifolia* var. *linearis*, are also abundant. Bryophyte is not apparent in our study site.

2.2. Experimental setting

Experiments were set up as the one-factor, three-level block design, and each block involving the high, intermediate, and low water table treatments. Each treatment was replicated six times, resulting in a total of 18 plots.

The water table was manipulated by ditching in the homogeneous peatland. In April of 2013, we dug a 240 m long, 0.5 m wide, and 1 m deep drainage ditch (called the major ditch thereafter) in a fenced, flat area of 150 × 150 m. The major ditch was connected to a small river. Eighteen 6 × 6 m quadrate plots were deployed (with regular intervals of 30 m between two adjacent plots) approximately 30 m away from the major ditch, with 9 plots distributed along each side of the major ditch. Six plots were drained by a 50 cm deep ditch, 6 plots by a 20 cm deep ditch, and 6 plots were kept intact, which served as low, intermediate, and high water table treatments, respectively (see Fig. S1).

We installed one polyvinyl chloride (PVC) pipe (1.5 m in length and 5 cm in diameter respectively) vertically in each plot. The bottom of the pipe was covered by a piece of steel sheet with a mesh size of 0.5 mm to prevent large soil particles entering the pipe. A ruler that was 1.5 m in length and 2.5 cm in width was used to record the water table every three to ten days during the experiment except for the freezing period (from November to March). While measuring the water table depth, we inserted the ruler along the inner side to the bottom of the PVC pipe, and the distance from the ground to the position of the water surface was recorded as the depth of the water table. The mean annual water table was about 11–22 cm and 9–16 cm lower in the low and intermediate treatments than that in undrained plots from 2013 to 2016 (Fig. S2). We also measured soil moisture (Water Scout SM100-6460-20) and temperature (Temp-3667-20) 5 cm below the ground surface in the center of the plots every 30 min over four years using data loggers (Watchdog 2000, Spectrum Technologies, Inc., USA). Average daily soil moisture was 10–21% and 4–14% lower in the low and intermediate treatments than that in undrained plots from 2013 to 2016 (Fig. S3), whereas there was no systematic and significant difference in soil temperature (Fig. S3).

2.3. SCE rate measurement

We employed a non-steady-state and automated soil CO_2 flux system (LI-8100, LI-COR Biosciences, Lincoln, NE, USA) with a survey chamber of 10 cm in diameter (835.2 cm^3 for chamber volume) to measure the SCE rates. The measurements were conducted for all plots one to three times per month in the growing season (May–September) and once per two months in the non-growing season (November–April) from 2013 to 2016. The measurements were conducted on a sunny day at least two days after a heavy rain (if any). For each measurement, the CO_2 emission rate was estimated using the initial slope of a fitted exponential curve at the ambient CO_2 concentration. All live aboveground plant tissues within the measured site were clipped and removed 24 h prior to each measurement and then a PVC collar (10.4 cm in diameter and 5 cm in height) was installed into the soil to a depth of 2 cm at the center of each plot. While measuring CO_2 emission rates, we measured the soil temperature using a T-handled type E thermocouple (p/n 8100-201 temperature probe) and moisture using TDR 300 (Spectrum, USA) 5 cm below ground surface at the site adjacent to PVC soil collars.

2.4. Data analyses

Shapiro-Wilk normality tests were used to check for normality distribution of the residuals. A linear mixed model (LMM) with water table as fixed factor, block and monitoring date as random factors, was used to determine the effect of water table on SCE rates for each year. When we evaluated water table and season effects on SCE rates, we firstly