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Short Note

Short-Term Effects of Drying and Rewetting on CO_2 and CH_4 Emissions from High-Altitude Peatlands on the Tibetan Plateau

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Abstract: This study used mesocosms to examine the effects of alternate drying and rewetting on CO_2 and CH_4 emissions from high-altitude peatlands on the Tibetan Plateau. The drying and rewetting experiment conducted in this study included three phases: a 10-day predrying phase, a 32-day drying phase, and an 18-day rewetting phase. During the experiment, the water table varied between 0 and 50 cm with respect to the reference peat column where the water table stayed constant at 0 cm. The study found that drying and rewetting had no significant effect on CO_2 emissions from the peatland, while CH_4 emissions decreased. The cumulative CH_4 emissions in the control group was 2.1 times higher than in the drying and rewetting treatment over the study period. Moreover, CO_2 and CH_4 emissions were positively correlated with soil temperature, and the drying process increased the goodness of fit of the regression models predicting the relationships between CO_2 and CH_4 emissions and temperature. These results indicate that small-scale water table variation has a limited effect on CO_2 emissions, but might reduce CH_4 emissions in high-altitude peatlands on the Tibetan Plateau.

Keywords: CO_2; CH_4; peatland; Tibetan Plateau

1. Introduction

Peatlands cover about 3% of the earth's surface, yet they store about 30% of the world's soil carbon stocks [1]. Therefore, they have significant potential to influence the global atmospheric budget of greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) [2]. Peatland ecosystems are expected to be severely affected by future climate change, which may create higher mean annual temperatures and an increased frequency of extreme weather events such as prolonged dry periods and heavy rainfalls, which can lower and raise the water table [3,4]. Changes in water table depth will likely affect carbon release from peatland soils.

Water table and soil moisture are important controls, but their influence on CO_2 production is more complicated [4]. Compared with conditions of soil saturation, CO_2 production typically increases as the soil dries to an optimal moisture content, and then decreases with further drying [5,6]. CO_2 emissions have also been reported to decline as volumetric water content decreases [7]. Higher moisture content has been associated with greater CO_2 emissions in agricultural peatlands [8]. A close relationship also exists between water tables and CH_4 emissions, which typically decreases during drying events [2,4,9]. Under dynamic hydrologic conditions, however, CH_4 emissions are often not clearly related to the position of the water table [4,10].

Until now, the effects of dynamic hydrologic conditions in high-altitude peatlands have not received sufficient attention, and very few studies have reported a clear effect of water table fluctuations between 0–30 cm on CO_2 and CH_4 fluxes within these ecosystems [11]. The Tibetan Plateau is the highest plateau in the world, an area that contains the world's largest extent of high-altitude peatlands. These alpine peatlands contain a large amount of soil organic carbon and play an important role in the carbon budget of peatlands in the world [12]. Drying and rewetting events could be exacerbated in the future as air temperature and precipitation increase on the Tibetan Plateau [13]. However, how CO_2 and CH_4 fluxes are influenced by drying and rewetting is still unknown.

Therefore, the present study investigates the dynamics of CO_2 and CH_4 emissions following drying and rewetting in a high-altitude peatland on the eastern Tibetan Plateau. The experiment also investigates soil temperature as a possible factor in influencing emissions of CO_2 and CH_4 following drying and rewetting.

2. Materials and Methods

The experiment was conducted in Hongyuan County in the eastern Tibetan Plateau (32°59′ N, 103°40′ E), at an altitude of 3500 m. This area has a continental plateau monsoon climate, with a mean average temperature of 1.1 °C, a mean coldest temperature of −10.3 °C in January, and a mean warmest temperature of 10.9 °C in July. Mean annual precipitation is 752 mm, 80% of which falls between May and October [12,14]. Within the study site the mean water table was about 0 cm below soil surface in summer. Vegetation in the alpine peatland is dominated by *Carex muliensis* Hand.-Mazz., accompanied by *Caltha scaposa* Hook. F. and Thoms., *Chamaesium paradoxum* Wolff, and *Sanguisorba filiformis* Hand.-Mazz. The soil at the study site is classified as peat. The concentrations of organic carbon, total N, and total P in the soil are 253.9 $g \cdot kg^{-1}$, 21.3 $g \cdot kg^{-1}$, and 0.9 $g \cdot kg^{-1}$, respectively, and the pH value at the 10 cm depth is 5.3 [12].

Six intact peat columns referred to as "mesocosms", were collected in early May 2014 at the study site. The peat column (width 70 cm, height 70 cm) was excavated using pickaxes and a stainless-steel cuboid corer, 60 cm in width and 60 cm in height, was then used to cut the peat column and it was immediately transferred to a stainless steel container sealed at the bottom (width 60 cm, height 65 cm) with as little disturbance to the soil as possible. The vegetation was kept intact during the collection process. All peat columns were transported to the research station and incubated at natural air temperature under a rain shelter in the field. The water table in each mesocosm was monitored with piezometers, and irrigation quantities were adjusted to maintain a stable water table at the soil surface until the experiment began. The six mesocosms were randomly divided into two groups; one group was kept wet at a constantly high water table ("CW") during the experiment, while the other was subjected to a drying and rewetting process ("DW"). We monitored the mesocosms during an initial wet phase ("predrying"), a drying phase ("drying"), and a rewetted phase ("rewetting"). Prior to drying, 10 days with a constant water table at the soil surface were regarded as the "predrying" phase. Once the experiment began irrigation was stopped for 32 days (drying); finally, the columns were rewetted by raising the water table to the soil surface and maintaining it for 18 days ("rewetting") (Figure 1).

Emissions of CO_2 and CH_4 were measured every two days throughout the study period using the static chamber method. The chambers (length 40 cm, width 40 cm, height 40 cm) were made of stainless steel and covered with insulating Styrofoam to prevent rapid increases in air temperature inside the chambers during sampling. Chambers were fixed on chamber base collars made of stainless steel inserted to a depth of 10 cm in the center of each field plot during flux measurement. All chamber base collars were left in place throughout the study period. For CO_2 and CH_4 determinations, air samples were collected between 9 and 11 a.m. according to Wang and Wang [14]. Before sampling, the chambers were closed for 10 min to establish an equilibrium state. At 10, 20, 30 and 40 min intervals, 10 mL headspace samples were extracted into a crimped, pre-evacuated glass vial. After sampling was finished for all replicates, the chamber was immediately removed from the base collars to minimize its effects on soil conditions and plant growth, and the gas samples brought to the laboratory. CO_2 and CH_4 concentrations within the samples were analyzed using an Agilent 7890A gas chromatograph.

The gas chromatography was equipped with a flame ionization detector for CO_2 and CH_4 and analysis. The gas chromatography configurations for analyzing concentrations of CO_2 and CH_4 as described by Wang and Wang [15]. CO_2 and CH_4 fluxes were calculated based on the rate of change in their concentrations within the chamber, which was estimated as the slope of linear regression between concentration and time.

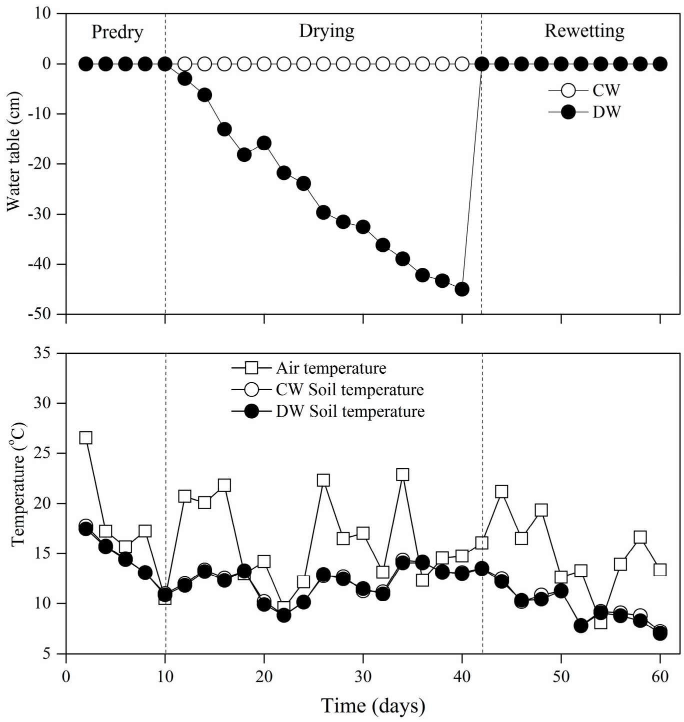

Figure 1. Water table, air temperature, and soil temperature at 10 cm depth. CW and DW represent constantly high water table and a drying and rewetting process, respectively.

On each sample date, the air temperature and soil temperature at 10 cm depth were measured in each mesocosm using a digital thermometer (JM624, Tianjin Jinming Instrument Co. Ltd., Tianjin, China).

The distributions of CO_2 and CH_4 fluxes and environmental parameters were tested for normality with the Shapiroe Wilk test. The effects of dry/wet treatments on the rates of CO_2 and CH_4 fluxes during each phase of the experiment were analyzed using repeated measures ANOVA with sample dates. Mann–Whitney U tests were used to evaluate differences in cumulative CO_2/CH_4 emission between dry/wet treatments. Regression analysis was used to analyze the relationships between CO_2/CH_4 emission and the measured environmental variables. All analyses were carried out by SPSS Version 16 for Windows.

3. Results and Discussion

During the experiment, both air temperature and soil temperature at a 5 cm depth declined (Figure 1). Air temperature ranged from 8 °C to 27 °C, with an average of 16 °C. The soil temperature ranged between 7 °C and 18 °C, with little variation between the two treatment groups: CW mesocosms averaged 11.9 °C and DW mesocosms averaged 11.7 °C (Figure 1).

The rate of CO_2 emissions for CW and DW groups followed a similar downward trend, varying from 443.0 to 5.0 mg CO_2-C m^{-2} h^{-1} (Figure 2). Between day 10 and 60, the CH_4 flux was significantly higher in the CW group than in the DW group (Figure 2). The cumulative CO_2 emissions in the CW group were 235.2 g CO_2-C m^{-2}, very close to the 209.7 g CO_2-C m^{-2} in the DW group, while the cumulative CH_4 emissions in the CW group throughout the experiment were 1.79 g CH_4-C m^{-2}, 2.1 times higher than the 0.86 g CH_4-C m^{-2} in the DW group (Figure 3).

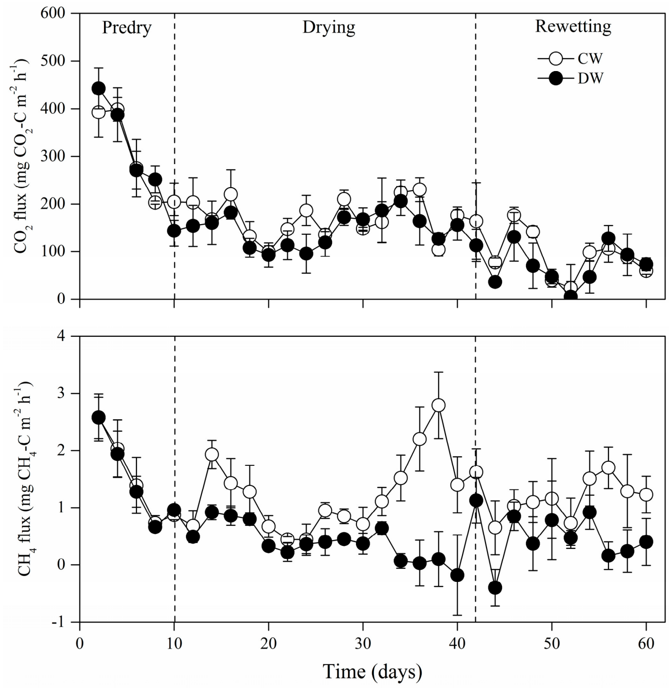

Figure 2. CO_2 and CH_4 emissions during drying and rewetting in high-altitude peat core. Vertical bars indicate standard errors of three replications.

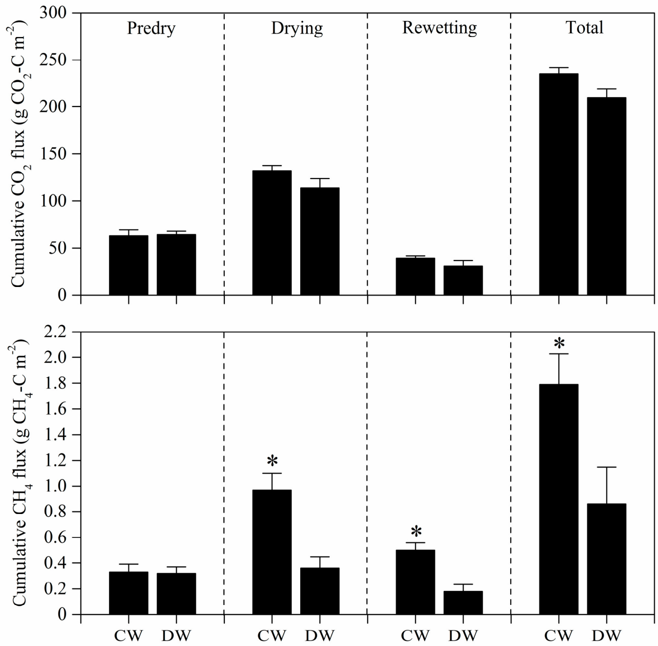

Figure 3. Cumulative CO_2 and CH_4 emissions during drying and rewetting in high-altitude peat core. Vertical bars indicate standard errors of three replications. Asterisks represent significant difference between the treatments at the 0.05 level.

Researchers have drawn different conclusions about the effects of alternate drying and rewetting on CO_2 release from the soil in wetlands. Some studies suggested that alternate drying and rewetting can stimulate CO_2 release from peatlands as a result of increased substrate availability to microbes from the release of osmolytes accumulated during the drying phase, as well as cell lysis and the breakdown of aggregates that release previously protected organic matter [4,16]. In our study, alternate drying and rewetting had little impact on CO_2 release. A similar lack of effect from drying and rewetting has been found in northern [10] and German peatlands [17]. The drop in the water table did not affect CO_2 emissions from the soil, possibly because labile organic matter was primarily distributed in surface soils [17] rather than in deeper soils [17,18]. Moreover, soil respiration occurring in peatland ecosystems includes both autotrophic and heterotrophic respiration. A decline in the water table may increase heterotrophic respiration and reduce autotrophic respiration, such that the total respiration may ultimately be unaffected [11].

Peatlands are commonly a source of CH_4 when organic matter is degraded anaerobically [19]. Several bacteria species that degrade organic material via a complex food web are needed to perform these processes. The final step is performed by methanogens, methane-producing archaea. All of these processes are affected by peat soil water conditions. It is acknowledged that a decline in the water table can reduce the emission of CH_4 from peatlands [20]. In our experiment the water table decline during the drying phase caused a decrease in CH_4 emissions, consistent with results from previous research. After the water table declined, the peatland soil was exposed to oxygen, resulting in an aerobic soil environment. On the one hand, the aerobic environment inhibited the activity of methanogens, causing a decrease in CH_4 production. On the other hand, aerobic conditions increased CH_4 consumption by promoting the growth of methanotrophs. As a result, CH_4 emissions from the peatland decreased after the water table dropped.

In this study, the period following the rewetting phase saw no increase in CH_4 emissions. This finding contradicts previous research on peatlands [16], but is consistent with the findings of Bubier et al. [21]. Currently, no study has reached a clear conclusion about how rewetting affects CH_4 emissions. Deppe et al. [11] proposed that rewetting does not affect CH_4 production in peatlands, possibly because the anaerobic structures in the peat help methanogens adapt to the rewetting-induced changes in oxygen concentration in the peat. Additionally, some plant species growing in peatlands may also serve as regulators of CH_4 emissions.

During the drying phase, no obvious correlation was detected between the DW group's CO_2 flux and water table (Figure 4); however, this group's CH_4 flux was positively correlated with the water table depth ($p < 0.01$) (Figure 4). Throughout our experiment, the CO_2 flux was strongly correlated with both air temperature ($p < 0.05$) and soil temperature ($p < 0.01$) (Figure 4) in both control and treatment groups. In comparison, CH_4 flux showed a remarkable correlation with air temperature ($p < 0.05$) throughout the experiment only in the DW group (Figure 4). Both CO_2 and CH_4 fluxes were positively correlated with soil temperature in the two treatment groups ($p < 0.01$).

Soil temperature is another important environmental factor that affects CO_2 flux in peatlands. A rise in soil temperature can usually facilitate CO_2 release from the soil [12,22]. This experiment established a positive correlation between soil temperature and CO_2 emissions in high-altitude peatlands. A rise in soil temperature can stimulate microbial activity and accelerate the breakdown of organic matter, thereby increasing CO_2 emissions [21].

The current study's results suggest that increased temperatures promote CH_4 release, as shown previously by Gao et al. [12] and Schütz et al. [23]. Rising temperatures can increase CH_4 emissions in three ways. First, assuming there is no interference from other environmental factors, the activity of methanogens tends to grow as the soil temperature rises if the original temperature is below the optimal level for the methanogens. This enhanced methanogen activity can increase oxygen consumption and lower electric potential (Eh) across the soil by boosting zymolysis of organic substances in the soil. The resulting soil conditions are favorable for methanogens, ultimately increasing CH_4 emissions [2,4]. Second, a rise in temperature can promote plant growth and accelerate plant respiration and transpiration, thus increasing the rate of CH_4 release from plants to the air [15]. Third, a temperature increase can speed up the diffusion of CH_4 through water layers. This, combined with the fact that CH_4 can easily bubble up to the water surface, can reduce the long-term retention of CH_4 in the aerobic zone, thereby obstructing further oxidation of the gas [2,11].

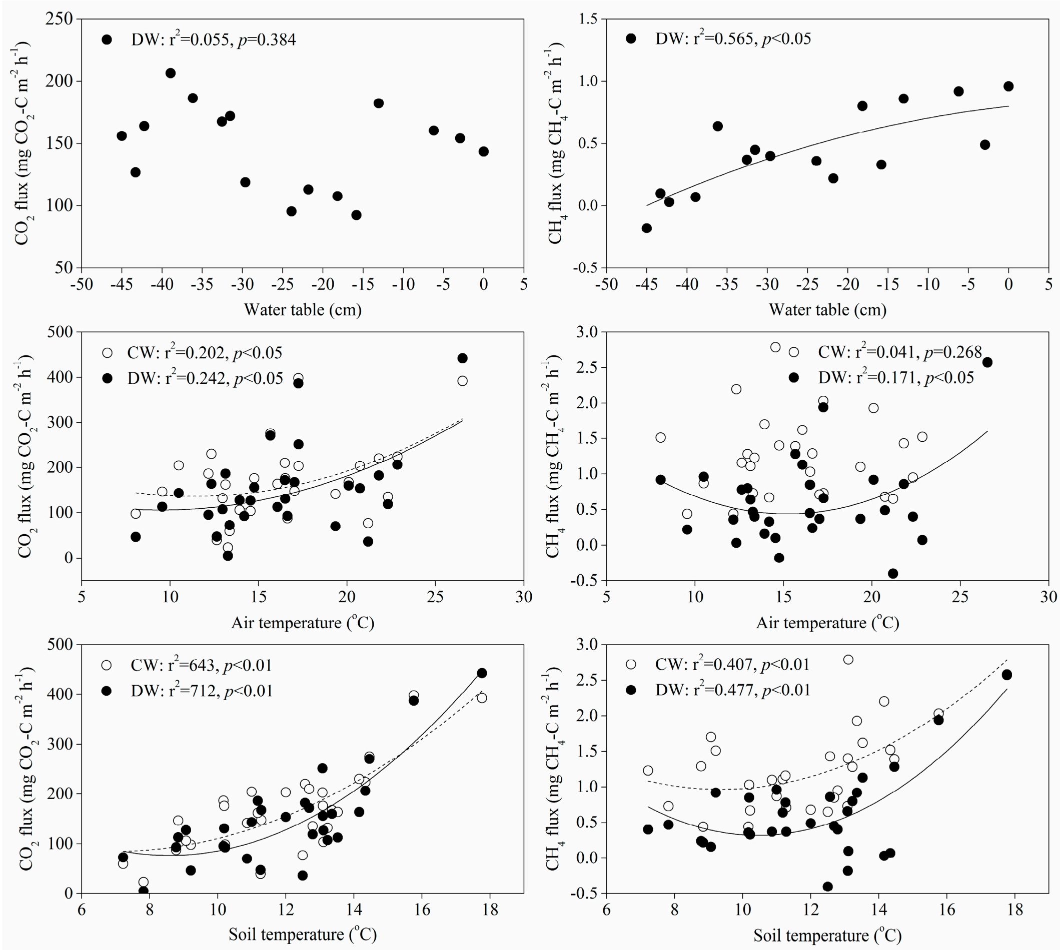

Figure 4. Relationships between CO_2 and CH_4 fluxes and water table, air temperature, and 10 cm soil temperature in high-altitude peat core.

4. Conclusions

We found that alternate drying and rewetting had no significant effect on CO_2 emissions from high-altitude peatlands on the Tibetan Plateau, but it decreased CH_4 emissions. This finding indicates that alternate drying and rewetting may reduce the contributions of carbon gas emissions from high-altitude peatlands to the atmosphere and decrease global warming potential. Further research is needed to investigate how alternate drying and rewetting at different frequencies and intensities affects fluxes of CO_2 and CH_4 emitted from high-altitude peatlands.

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Author Contributions: Xiaoyang Zeng collected air samples and wrote the manuscript; Yongheng Gao designed the research and conducted the CO_2 and CH_4 measurement.

Conflicts of Interest: The authors declare no conflict of interest.

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