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Temperature sensitivity of soil carbon dioxide and nitrous oxide emissions in mountain forest and meadow ecosystems in China

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HIGHLIGHTS

- CO_2 emissions were higher in forests than meadow and greater in broadleaf forest.
- N_2O emissions showed small variation under different temperatures.
- A positive correlation was found between CO_2 and N_2O emission rates.
- Q_{10} values for CO_2 increased with temperature but changed slightly for N_2O.

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ABSTRACT

An incubation experiment was conducted at three temperature levels (8, 18 and 28 °C) to quantify the response of soil CO_2 and N_2O emissions to temperature in three ecosystems (pine forest, oak forest, and meadow) located in the Qinling Mountains of China, which are considered to be susceptible to disturbance and climate changes, especially global warming. The soil CO_2 emission rates increased with temperature and decreased with soil depth; they were the highest in the oak forest (broadleaf forest) and were lower in the pine forest (coniferous forest) and the meadow ecosystem. However, there was no significant difference in the soil N_2O emission rates among the three ecosystems. The temperature sensitivity of CO_2 and N_2O was higher in the forest than in the meadow ecosystem. The Q_{10} values (temperature sensitivity coefficient) for CO_2 and N_2O were 1.07–2.25 and 0.82–1.22, respectively, for the three ecosystems. There was also evidence that the CO_2 and N_2O emission rates were positively correlated. The soil characteristics exhibited different effects on CO_2 and N_2O emissions among different ecosystems at the three temperature levels. Moreover, the soil dissolved organic carbon (DOC), specific ultraviolet absorbance (SUVA) and nitrate (NO_3^-) were important factors for CO_2 emissions, whereas the soil ammonium (NH_4^+) and pH were the major controllers of N_2O emissions. Unexpectedly, our results indicated that CO_2 emissions are more sensitive to increasing temperature than N_2O, noting the different feedback of CO_2 and N_2O emissions to global warming in this region. The different responses of greenhouse gas emissions in different forest types and a meadow ecosystem suggest that it is critical to conduct a comprehensive investigation of the complex mountain forest and meadow ecosystem in the transitional climate zone under global warming. Our research results provide new insight and advanced understanding of the variations in major greenhouse gas emissions (CO_2 and N_2O) and soil characteristics in response to warming.

1. Introduction

Carbon dioxide (CO_2) and nitrous oxide (N_2O) are two important greenhouse gases that contribute to global warming (Parry et al.,

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2007). Climate change due to greenhouse gas emissions is predicted to raise the mean global temperature by 1.0–3.5 °C over the next 50–100 years (Rustad et al., 2001). Soils are the main sources of CO_2 and N_2O (Luo et al., 2012). Carbon dioxide emissions from soil are ten times greater than those from fossil fuel combustion (Chang et al., 2008). The global warming potential of N_2O is approximately 298 times higher than that of CO_2 (Parry et al., 2007). Therefore, terrestrial ecosystems are expected to be very sensitive to changes in global warming because temperature is considered a key factor in terrestrial biogeochemical processes.

The production of CO_2 in soils occurs primarily from autotrophic and heterotrophic respiration, in which temperature plays an important role (Wu et al., 2010). Soil temperature and CO_2 emissions exhibit a positive correlation when other factors are not limited (Meiner, 2006). Other researchers have found that soil CO_2 emissions decreased with temperature due to reduced soil organic carbon content (Fang et al., 2010). Thus, it is important to know how soil characteristics change with temperature. With respect to N_2O, there is a positive correlation between N_2O emissions and soil temperature (Cantarel et al., 2011). The main environmental factors such as soil temperature, soil nitrogen (N) content (NH_4^+ and NO_3^-) and moisture have a profound influence on N_2O emissions (Butterbach-Bahl and Kiese, 2005). In addition, previous work has suggested that net N_2O emissions will increase over the next several years because of elevated CO_2 and temperature (Tian et al., 2012). Moreover, the recent study has demonstrated that variation in temperature can influence the soil respiration, N decomposition, nitrification and denitrification, which ultimately affect the production of CO_2 and N_2O (Luo et al., 2012).

Vegetation types also have a prominent influence on the production of CO_2 (Peng et al., 2009) and N_2O (Lin et al., 2010). In forest soil, pine forests exhibit higher CO_2 efflux than oak forests due to the higher soil organic carbon contents in the uppermost mineral layer (Díaz-Pinés et al., 2014). Soil N_2O emissions are slightly higher in deciduous forests than in coniferous forests because of differences in soil and litter properties between the two forest types (Pilegaard et al., 2006). It has been shown that the soil CO_2 and N_2O emissions in forest soils differ from those of meadow soils because of the varying soil characteristics (Lang et al., 2011). Therefore, soil characteristics are also influential in greenhouse gas emissions in forest and meadow ecosystems under global warming conditions. Several studies have examined CO_2 and N_2O emissions (Bai et al., 2014; Horváth et al., 2010; Kitzler et al., 2006). Because mountains are important components of the climate system (Beniston et al., 1997), studies have focused on greenhouse gas emissions in either mountain forests or meadow ecosystems (Jiang et al., 2010; Kanerva et al., 2007; Yan et al., 2014). Moreover, studies of CO_2 and N_2O emissions in complex ecosystems have primarily been conducted on the forest-tundra and forest-peatland, as well as mountain forest-wetland (Flessa et al., 2008; Hartshorn et al., 2003; Stine et al., 2011). However, studies on the complex mountain forest-meadow ecosystem in climate-sensitive zone are very limited (Kao and Chang, 2009). Little is known about the temperature sensitivity of CO_2 and N_2O emissions under different temperature ranges in the complex mountain forests and meadow ecosystems along the climate transition zone in China.

The Qinling Mountains are located in a special site that forms the boundary between a warm temperate and subtropical climate in China (Zhao et al., 2014). This region is considered to be fragile, sensitive to ecosystem disturbances and susceptible to climate changes, especially global warming. The transition zone has unique characteristics because of the interactions between adjacent environmental systems and potentially transitional vegetation characteristics (Di Castri and Hansen, 1992). Therefore, minor fluctuations in the general circulation can lead to large changes (Giorgi and Lionello, 2008; Thuiller et al., 2005). In addition, most studies are based on a large ecological scale, where it is difficult to overcome the impacts of climate, soil types and forest age (Cheng et al., 2013). The complex mountain forest-meadow ecosystem (coniferous, deciduous forest and subalpine meadow) in the Qinling Mountains along an altitudinal gradient over a short distance offers a great opportunity to advance our understanding of the variations in major greenhouse gas emissions (CO_2 and N_2O) and soil characteristics in response to warming. It has been demonstrated that the terrestrial ecosystems in China have been a large carbon sink in recent decades; however, it is uncertain whether the CO_2 sink can serve to mitigate climate warming because the CH_4 and N_2O emissions are relatively high (Piao et al., 2009; Huang et al., 2010; Zou et al., 2010). More site-level studies on the emissions of multiple greenhouse gases and their interactions are needed to validate process-based model results and understand their underlying mechanisms over wider ranges (Tian et al., 2011). A recent study showed that the temperature in the Qinling Mountains will continue to increase, whereas precipitation will decline, over the next several years (Yan and Yan, 2009). A change in temperature may move the climatic boundary, which affects vegetation characteristics (Liu, 1981). Moreover, the mean temperature in the growing season is the primary factor controlling the elevational distribution of the vegetation types in the Qinling Mountains (Tang and Fang, 2006). Such changes in this complex ecosystem may alter the variation in major greenhouse gas emissions (CO_2 and N_2O) and soil characteristics. It has been recognized that mountains are an important component of the global environment, and subtle shifts in the environment can greatly affect land-use dynamics (Beniston, 2003; Camarero et al., 2006; Houet et al., 2010). Therefore, it is important to understand the response of the Qinling Mountains forest-meadow ecosystem to further climate change.

Because climate factors vary with ecosystem type, lab incubation can facilitate comparisons of the potential effects of temperature on greenhouse gas emissions (Schaufler et al., 2010). Moreover, temporal changes in soil substrate availability to microbes can be evaluated through lab incubation (Chen and Stark, 2000). To obtain a better understanding of the dynamics of soil CO_2 and N_2O emissions and the influence of soil characteristics, we incubated soils from a pine forest, an oak forest and a subalpine meadow for 50 days at three temperatures and examined the CO_2 and N_2O emissions under the different temperature conditions. Our objectives were to (1) investigate the response of CO_2 and N_2O emissions to different temperatures and (2) quantify the influence of temperature change on soil characteristics related to CO_2 and N_2O emissions in the Qinling Mountains forest-meadow ecosystem located the climate transition zone.

2. Materials and methods

2.1. Site description

The study site is located at the National Field Station of the Qinling forest ecosystem in Shaanxi (33°18′-33°28′ N, 108°21′-108°39′ E). The station is positioned on the south slope of the mountain that ranges in elevation from 826 to 2500 m. The area has a warm temperate humid climate with a mean annual temperature that varies from 8 to 12 °C. The mean annual precipitation is 1130 mm, most of which occurs from July to September. The main soil type in the region is brown forest soil, with some yellow brown soil and dark brown forest soil. The average total thickness of the organic layer and the underlying mineral layer is 50 cm. The dominant species in this zone are *Pinus armandii, Pinus tabulaeformis, Quercus aliena var. acuteserrata*, and *Betula albo-sinensis*.