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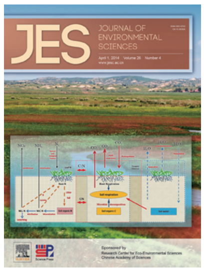

Differential responses of short-term soil respiration dynamics to the experimental addition of nitrogen and water in the temperate semi-arid steppe of Inner Mongolia, China

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ABSTRACT

We examined the effects of simulated rainfall and increasing N supply of different levels on CO_2 pulse emission from typical Inner Mongolian steppe soil using the static opaque chamber technique, respectively in a dry June and a rainy August. The treatments included NH_4NO_3 additions at rates of 0, 5, 10, and 20 g N/(m^2·year) with or without water. Immediately after the experimental simulated rainfall events, the CO_2 effluxes in the watering plots without N addition (WCK) increased greatly and reached the maximum value at 2 hr. However, the efflux level reverted to the background level within 48 hr. The cumulative CO_2 effluxes in the soil ranged from 5.60 to 6.49 g C/m^2 over 48 hr after a single water application, thus showing an increase of approximately 148.64% and 48.36% in the effluxes during both observation periods. By contrast, the addition of different N levels without water addition did not result in a significant change in soil respiration in the short term. Two-way ANOVA showed that the effects of the interaction between water and N addition were insignificant in short-term soil CO_2 effluxes in the soil. The cumulative soil CO_2 fluxes of different treatments over 48 hr accounted for approximately 5.34% to 6.91% and 2.36% to 2.93% of annual C emission in both experimental periods. These results stress the need for improving the sampling frequency after rainfall in future studies to ensure more accurate evaluation of the grassland C emission contribution.

Introduction

Soil respiration is one of the major processes that control the carbon (C) budget of terrestrial ecosystems and the largest fluxes in the global C cycle (Schlesinger and Andrews, 2000). Worldwide concerns about the C cycle and its effects on the environment have emphasized the need for an improved understanding and quantification of soil respiration processes (Mariko et al., 2007).

The production and emission of carbon dioxide (CO_2) in soil is a complicated biological process and is influenced jointly by various biotic and abiotic factors (Bowden et al., 2004; Harper et al., 2005, Li et al., 2011). In semi-arid and arid ecosystems, water and soil nutrient availability are considered the most important limiting factors in the primary production of ecosystems (Belnap, 2001; Austin et al., 2004; Guo et al., 2006; Zhao et al., 2009) and the mineralization of soil organic matter, because soil moisture and nutrients affect the supply of C substrates to plant roots and soil microorganisms (Illeris et al., 2003; Xiang et al., 2008; Ouyang et al., 2008).

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perate zones has been estimated to enhance C storage by 0.3 to 0.5 Pg C/year (Bowden et al., 2004). Several published field and laboratory studies have examined the response of soil CO_2 effluxes to changes in N availability. However, the results obtained have often been controversial. For example, some studies (Craine et al., 2001; Xu and Wan, 2008) found that an increased N input stimulated soil respiration, whereas other studies either did not find any effects (Raich and Tufekcioglu, 2000; Micks et al., 2004) or discovered negative effects (Burton et al., 2004; Mo et al., 2008). Bowden et al. (2004) and Peng et al. (2011) found an immediate change in soil respiration following the addition of N in the initial stage of their studies; however, the respiration rates of fertilized plots did not differ from those of the control with continuous N addition. The effects of N addition on soil respiration changed over time.

In addition, alterations in the amount and timing of rainfall events in arid and semi-arid ecosystems because of global changes also are likely to have important effects on the C balance of the entire ecosystem (Sponseller, 2007). Fluctuations in water availability, particularly the rapid increase in water potential after dry soil rewetting in grasslands or other water-limited soil, often result in an intense C emission pulse, and the CO_2 often increases by as much as 500% (Fierer and Schimel, 2003). By contrast, Bouma and Bryla (2000) indicated that heavy rainfall events might temporarily suppress soil respiration because of the reduced diffusion in fine-textured soil with high numbers of water-filled pore spaces. The responses of soil CO_2 emission to changes in either N availability or precipitation are complex and remain debatable. Furthermore, information on grassland ecosystems is limited, particularly on the temperate steppes of China.

Increasing anthropogenic N deposition and shifting precipitation regimes have become a global change phenomenon (Galloway and Cowling, 2002; IPCC, 2007). Anthropogenic N deposition, mainly originating from fertilizer application, fossil fuel combustion, and legume cultivation, has increased from less than 1 Tg N/year in the 1860s to 25 Tg N/year around the year 2000 (Matson et al., 2002; Lu et al., 2012). Given the increasing N concentration in the atmosphere, the global N deposition level is expected to double in the next 25 years (Moore et al., 2009). Liu et al. (2013) reported that the bulk N deposition in China increased significantly over time ($P <$ 0.001) with an average annual increase of 0.41 kg N/ha between 1980 and 2010. China has become the region with the third highest N deposition rate after America and Europe (Zhang et al., 2008). In addition, the anticipated global increase in precipitation per decade in this century is approximately 0.5% to 1% (IPCC, 2001). The precipitation in North China is expected to increase by 14 to 155 mm at the end of the 21st century according to the simulations of 13 IPCC global climate models (Jiang et al., 2008). The significant changes in precipitation and N input may affect greenhouse gas effluxes and result in feedback on global climate change (Liu et al., 2008). Therefore, further research on the effect of altered N and water availability on soil C emission in the arid or semi-arid regions of Northern China is important to the accurate prediction of the C budget of the ecosystem in future climate change scenarios. Several studies on arid and semi-arid regions have shown a close relationship between N and water availability in the regulation of the ecosystem primary production (Zhang and Zak, 1998; Rao and Allen, 2010; Ronnenberg and Wesche, 2011). However, little information has been provided on the interactive effects of water and N on soil CO_2 emission. The short-term effects induced by water or N pulse inputs have often been ignored in previous research. Thus, a comprehensive study on the differential responses of grassland soil respiration to water and N availability, as well as the synthetic effects of water and N at different time scales, is important.

Grassland is the largest terrestrial ecosystem in China, covering an area of approximately 4×10^6 km^2 or 40% of the land area of China (Chen and Wang, 2000). Approximately 78% of the grasslands in China are located in the temperate arid and semi-arid regions. A fragile eco-environment increases the sensitivity of grasslands to environmental change compared with other ecosystems (Warren et al., 1996; Wen, 1996). To the best of our knowledge, few studies have explored the short-term response of soil CO_2 fluxes to the coupled changes in water and N availability in the semi-arid region of China. Given the limited studies in this field, a temperate typical steppe in Inner Mongolia, China was investigated. The long-term and short-term responses of soil respiration to changes in the water and N availability were systematically studied. This current study, focused on the short-term effect of elevated N and water availability on soil respiration, was part of a long-term research study. The objectives of this study were as follows: (1) identify the short-term differential responses of soil respiration to the increased N and water availability and their coupled variations, as well as explore the intrinsic mechanisms; (2) characterize the contribution of short-term CO_2 pulses to annual C emission after the episodic addition of water and N.

1 Materials and methods

1.1 Site description

The experiment site was located in the Xilin River Basin of Inner Mongolia, China (43°26′N to 44°39′N, 115°32′E to 117°12′E) and in the vicinity of the Inner Mongolian Grassland Ecosystem Research Station, Chinese Academy of Sciences (**Fig. 1**). The Xilin River Basin is situated in the core area of the Northeast China Transect (NECT) for