Response of soil N\textsubscript{2}O emissions to precipitation pulses under different nitrogen availabilities in a semiarid temperate steppe of Inner Mongolia, China

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Abstract: Short-term nitrous oxide (N\textsubscript{2}O) pulse emissions caused by precipitation account for a considerable portion of the annual N\textsubscript{2}O emissions and are greatly influenced by soil nitrogen (N) dynamics. However, in Chinese semiarid temperate steppes, the response of N\textsubscript{2}O emissions to the coupling changes of precipitation and soil N availability is not yet fully understood. In this study, we conducted two 7-day field experiments in a semiarid temperate typical steppe of Inner Mongolia, China, to investigate the N\textsubscript{2}O emission pulses resulting from artificial precipitation events (approximately equivalent to 10.0 mm rainfall) under four N addition levels (0, 5, 10 and 20 g N/(m\textsuperscript{2}·a)) using the static opaque chamber technique. The results show that the simulated rainfall during the dry period in 2010 caused greater short-term emission bursts than that during the relatively rainy observation period in 2011 (\(P<0.05\)). No significant increase was observed for either the N\textsubscript{2}O peak effluxes or the weekly cumulative emissions (\(P>0.05\)) with single water addition. The peak values of N\textsubscript{2}O efflux increased with the increasing N input. Only the treatments with water and medium (WN10) or high N addition (WN20) significantly increased the cumulative N\textsubscript{2}O emissions (\(P<0.01\)) in both experimental periods. Under drought condition, the variations in soil N\textsubscript{2}O effuxes were positively correlated with the soil NH\textsubscript{4}-N concentrations in the three N input treatments (WN5, WN10, and WN20). Besides, the soil moisture and temperature also greatly influenced the N\textsubscript{2}O pulse emissions, particularly the N\textsubscript{2}O pulse under the relatively rainy soil condition or in the treatments without N addition (ZN and ZWN). The responses of the plant metabolism to the varying precipitation distribution and the length of drought period prior to rainfall could greatly affect the soil N dynamics and N\textsubscript{2}O emission pulses in semiarid grasslands.

Keywords: temperate semiarid steppe; nitrous oxide; nitrogen availability; precipitation

Citation: XinChao LIU, YuChun QI, YunShe DONG, Qin PENG, YaTing HE, LiangJie SUN, JunQiang JIA, CongCong CAO. 2014. Response of soil N\textsubscript{2}O emissions to precipitation pulses under different nitrogen availabilities in a semiarid temperate steppe of Inner Mongolia, China. Journal of Arid Land, 6(4): 410–422. doi: 10.1007/s40333-013-0211-x

Nitrous Oxide (N\textsubscript{2}O) is one of the most important global greenhouse gases (Wuebbles, 2009). In contrast to other greenhouse gases, N\textsubscript{2}O is often released instantaneously and circumstantially from the soils, particularly after precipitation during drought season (Priemé and Christensen, 2001; Freibauer and Kaltenschmitt, 2003; Yao et al., 2010; Harrison-Kirk et al., 2013). By experiments Birch et al. (1964) found that the soil drying and wetting cycles caused by precipitation stimulated the mineralization of soil organic matter, resulting in rapid soil carbon losses; such phenomenon was called the “Birch effect”. By following Birch’s experiment, several studies (Priemé and Christensen, 2001; Haren et al., 2005; Muhr et al., 2006; Li et al., 2006; Li et al., 2007; Li et al., 2008; Li et al., 2009; Li et al., 2010; Li et al., 2011; Li et al., 2012; Li et al., 2013).
2008; Kim et al., 2010; Trost et al., 2013) have proven that precipitation also triggers a considerable N\textsubscript{2}O emission pulse. Haren et al. (2005) found that the first rainfall after a drought period triggered an N\textsubscript{2}O pulse for several hours in Brazilian tropical forests. This pulse accounted for approximately 25% of the drought-associated reduced N\textsubscript{2}O efflux and for 1.3%±0.4% of the annual N\textsubscript{2}O emissions. Meanwhile, as the intermediate product or by-product of soil nitrification and denitrification, soil mineral N concentrations greatly influenced the amplitude of N\textsubscript{2}O emissions from the soil (Weier et al., 1993; Doobie et al., 2003; Peng et al., 2011; Rafique et al., 2011). Burger et al. (2005) indicated that the greatest N\textsubscript{2}O effluxes occurred immediately after the application of N fertilizer during the drying and wetting cycles in the agricultural soils in the California Central Valley. In addition, plants and microbes have different sensitivities to water pulses. The variations in precipitation distribution affect the biological activity of microbes and plants, thereby affecting the soil N dynamics and the corresponding soil N\textsubscript{2}O effluxes (Austin et al., 2004; Barton et al., 2008; Austin 2011; Dijkstra et al., 2012; Song et al., 2012). Furthermore, the N\textsubscript{2}O emission pulses induced by water pulses substantially vary among different ecosystems and under different soil N conditions (Rudaz et al., 1991; Davidson et al., 1992a, b, 1993; Priemé and Christensen, 2001; Huxman et al., 2004a; Burger et al., 2005; Barton et al., 2008; Yao et al., 2010; Li et al., 2011; Xu et al., 2012; Harrison-Kirk et al., 2013).

Grassland soil N\textsubscript{2}O emission is an important part of the global N\textsubscript{2}O budget and accounts for approximately 14% of the global annual anthropogenic N\textsubscript{2}O emissions (Zhang et al., 2010). In China, grasslands comprise the largest terrestrial ecosystems, covering approximately 3.93×10\textsuperscript{8} hm\textsuperscript{2} or 41.7% of the national land area (Fan et al., 2008). The reported value of N\textsubscript{2}O emissions from grasslands in China is 76.5±12.8 Gg N/a (Mummey et al., 2000; Zhang et al., 2010). Most of the grassland ecosystems in China are distributed in arid and semiarid regions. The precipitation in arid and semiarid areas causes rapid transitions between the drought and wet conditions in soil, resulting in marked changes in the soil N cycle (Austin et al., 2004; Saetre and Stark, 2005; Borken and Matzner, 2009; Dijkstra et al., 2012; Zhang et al., 2013). Several previous studies (e.g. Du et al., 2006; Liu et al., 2010; Peng et al., 2011) have explained the relationship between N\textsubscript{2}O effluxes and soil water availability. The response of soil N\textsubscript{2}O effluxes to the available soil N concentrations in Chinese semiarid grasslands has also been explored (Peng et al., 2011). However, few studies have focused on the short-term pulse dynamic of soil N\textsubscript{2}O after precipitation in temperate semiarid grasslands in China (Yao et al., 2010). Moreover, the differences in the N\textsubscript{2}O emission pulses caused by precipitation among different soil N availabilities have seldom been discussed previously. Thus, we investigated the effects of simulated rainfall on the N\textsubscript{2}O pulse emissions under four different N addition levels, respectively during drought and rainy periods by performing two 7-day field experiments in a typical semiarid temperate steppe in Inner Mongolia. The objectives of this study were (1) to quantify the N\textsubscript{2}O emission pulses triggered by precipitation in temperate grassland soils, (2) to explore the responses of major environmental factors to different water and N addition levels, as well as their effects on N\textsubscript{2}O emission pulses, and (3) to evaluate the effects of different soil available N concentrations on short-term N\textsubscript{2}O losses during rainfall events.

1 Materials and methods

1.1 Study area

The experimental plots were built at a Leymus chinensis steppe in the Bainxile Pasture, Xilin River Basin, Inner Mongolia, China, which is located at 43°26′N to 44°39′N, 115°32′E to 117°12′E, 1,265 m asl. The annual mean temperature in this area is −0.4°C, whereas the mean month temperature ranges from −21.41°C (January) to 18.53°C (July). The mean annual precipitation approximately ranges from 350 to 450 mm, 70% of which falls between June and September (Peng et al., 2011). The soil is classified as chestnut soil under Chinese soil classification or as calcic-orthic Aridisol under soil taxonomic classification. The soil texture consists of 60% sand, 21% clay and 19% silt. The soil depth changes between 100 and 150 cm and horizon A is ap-