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Research Paper

Impacts of warming and nitrogen addition on soil autotrophic and heterotrophic respiration in a semi-arid environment

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ABSTRACT

Evaluating the responses of soil respiration and its components to global environmental change is crucial for predicting future terrestrial carbon cycle. However, the effects of warming and nitrogen (N) addition on them remain unclear. A field manipulative experiment was conducted in a semi-arid grassland on the Loess Plateau to evaluate the responses of soil total respiration (Rt), autotrophic respiration (Ra) and heterotrophic respiration (Rh) to warming and N addition from April 2015 to December 2016. Open-top chambers were used to elevate temperature and N was added as NH_4NO_3 at a rate of 4.42 g N m^{-2} yr^{-1}. Warming significantly decreased Rt and Rh by 7.4% and 9.5%, respectively, but had no significant effect on Ra. N addition significantly stimulated Ra by 34%, whereas it inhibited Rh by 11% and had no significant effect on Rt. The maximum N-inducing stimulation of Rt and Ra were observed in the month with the most rainfall events in 2015. N addition significantly increased the contribution of Ra to Rt by 10%. Warming decreased the Q10 values of Rt and Rh but had no significant effect on Q10 values of Ra. N addition significantly increased the Q10 values of Rt and Rh, whereas it decreased the Q10 values of Ra. The combination of warming and N addition had a synergistic effect on the cumulant of Rh, whereas it had an antagonistic effect on Ra. No interactive effect between warming and N addition was observed on Rt. Our results emphasized that Ra and Rh responded differently to warming and/or N addition, and the extreme rainfall frequency influenced the responses of Rt and its components to N addition. Our findings suggested that Rt has the potential to resist climate warming and increasing N deposition by differentiating the responses of its inherent components.

1. Introduction

The global mean air temperature has increased approximately 0.85 °C since the industrial revolution and is projected to increase by 0.9 °C–5.4 °C at the end of this century (IPCC, 2013). In addition, reactive nitrogen (Nr) continues to deposit into the biosphere due to intensified human activities, such as fertilization and fossil fuel combustion (McPhee et al., 2015; Morillas et al., 2015). Nitrogen deposition has increased three- to five-fold in the past century and is likely to increase in the near future (Galloway et al., 2008; Basto et al., 2015). Both temperature and nitrogen (N) deposition can substantially influence the CO_2 exchange between the biosphere and atmosphere, thereby potentially causing positive or negative feedbacks to future climate (Luo et al., 2001; Rustad et al., 2001; Melillo et al., 2002; Janssens et al., 2010; Niu et al., 2010). Soil respiration represents the largest potential source of atmospheric carbon, and thus small fluctuations in soil total respiration (Rt) can reduce or accelerate the elevation of atmospheric CO_2 (Schimel, 1995; Luo et al., 2009; Tu et al., 2010; Wang et al., 2014; Zhou et al., 2016). Numerous modeling and experimental studies over the past two decades suggest that the responses of Rt to both warming and N addition in grassland ecosystems are highly variable and complex. Warming was found to persistently increase Rt (Xu et al., 2015), increase Rt for a short-term (Rustad et al., 2001) and have no (Li et al., 2013) or negative (Reynolds et al., 2015) effect on Rt in different grassland ecosystems. Similarly, N addition was found to significantly and continuously increase Rt (Zhang et al., 2014; Fang et al., 2017), increase Rt in the first year and then decrease (Ren et al., 2016) and decrease Rt (Chen et al., 2016a) in various grassland ecosytems. Although the single factor effect of warming or N addition on soil respiration has been widely studied, the impacts of concurrent increases in temperature and N loading on Rt is less studied, especially on the Loess Plateau where our study was conducted.

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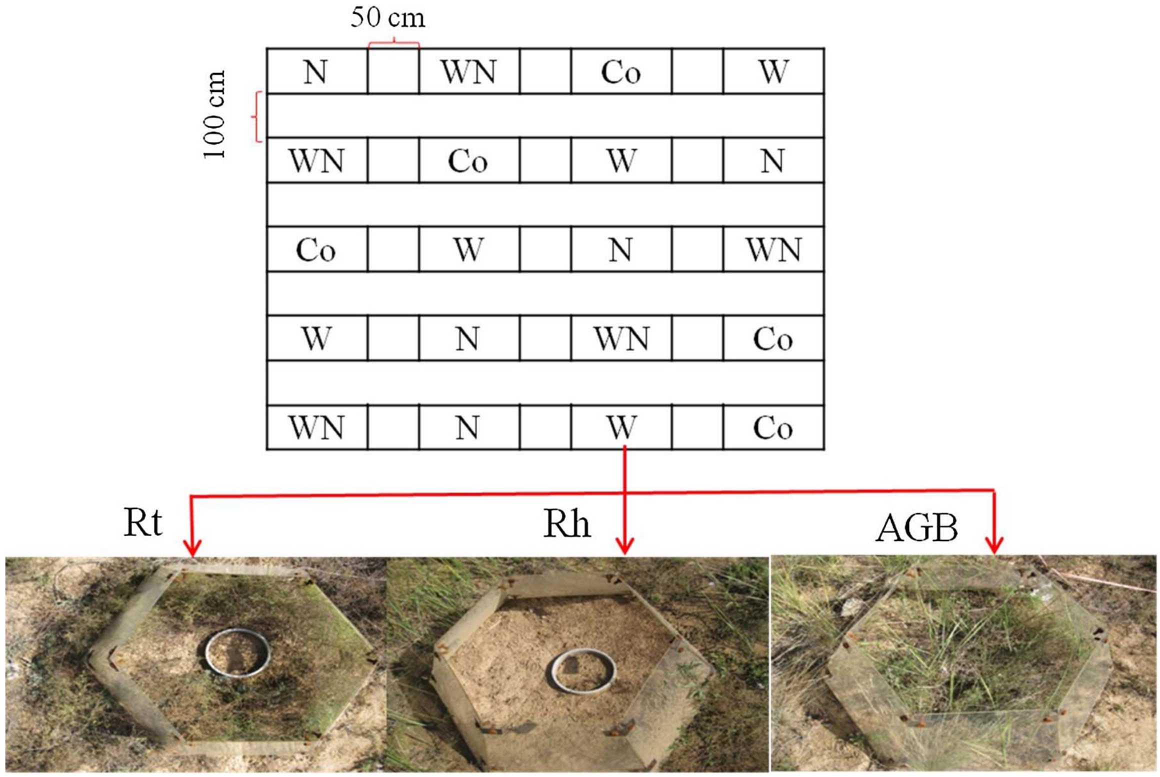

Fig. 1. Layout of the experiment design. WN, combined warming and nitrogen addtion treatment; W, warming treatment; N, nitrogen addition treatment; Co, control treatment. Rt, soil total respiration; Rh, heterotrophic respiration; AGB, aboveground biomass.

Soil respiration is a combination of soil autotrophic respiration (Ra) and heterotrophic respiration (Rh) and they might respond differently to environmental changes, which increases the difficulty to evaluate the role of soil respiration in global C cycling under global change. Simulated warming in a meadow grassland reduced Rh but had no effect on Ra (Chen et al., 2016b), while in an alpine meadow ecosystem, it enhanced rates of both Rh and Ra (Peng et al., 2015). Differential responses for Rh and Ra were also reported for N experiments. A meta-analysis suggested that N deposition stimulated Ra but inhibited Rh in global grasslands (Zhou et al., 2014). Understanding how each component, Rh and Ra, responds to environmental drivers is essential in order to evaluate the role of Rt in the global C cycle under global change.

Different response mechanisms govern the behavior of Rh and Ra to environmental drivers. Ra is highly dependent on roots and associated rhizosphere, whereas Rh results from the decomposition of litter and soil organic matter by soil microbes (Hanson et al., 2000; Kuzyakov, 2002; Wan and Luo, 2003; Li et al., 2010). Other studies of the effects of soil warming have shown that Ra is mainly coupled to plant composition and the responses of productivity, photosynthesis and soil temperature (Lin et al., 2011; Li et al., 2013; Xu et al., 2015), whereas Rh is associated with the depletion of microbial biomass carbon, labile carbon, and soil temperature and water (Tucker et al., 2013; McDaniel et al., 2014; Hicks Pries et al., 2015; Chen et al., 2016b). N addition may increase soil microbial biomass and activity or decrease enzyme activity and soil organic matter (SOM) decomposability, resulting in corresponding changes of Rh (Janssens et al., 2010; Chen et al., 2017a; Wang et al., 2017). Likewise, N application may stimulate Ra due to increased plant growth or suppress Ra by reducing belowground carbon (C) allocation (Giardina et al., 2004; Zhang et al., 2014; Zhong et al., 2016b; Chen et al., 2017b; Wang et al., 2017).

To investigate the response of Rt and its components to warming and N addition, we measured Rt, Rh and Ra by using root exclusion method in a semi-arid grassland during both the growing and non-growing seasons for two years. Our objectives were to (i) examine whether the components of Rt responded differently to the concurrent increases in temperature and nitrogen loading and (ii) quantify the effects of warming and/or nitrogen addition on the relative contributions of Rh and Ra to Rt.

2. Materials and methods

2.1. Study area

The experiment was conducted from 2015 to 2016 in the Semiarid Ecosystem Research Station (Lanzhou University) on the Loess Plateau (36°02′N, 104°25′E, 2400 m above sea level). The area has a medium-temperate semi-arid climate where according to the meteorological record from 1955 to 2013, the mean annual air temperature is 6.5 °C and the mean growing (April to October) and non-growing (November to March) season temperatures are 11.7 °C and −5.3 °C, respectively. The mean annual precipitation was 305 mm with the 80% of the annual rainfall occurring during the growing season. The mean annual pan evaporation is roughly 1300 mm. The soil is Heima soil (Calcic Kastanozem, FAO Taxonomy) with high percentage of silt (around 76%). The study area was sown with *Melilotus suaveolens* L. (a biennial herb) in April 2003 to facilitate the revegetation of degraded land for improving the vegetation cover and reduce soil erosion. The plant community at the study site is dominated by *Heteropappus altaicus Novopokr.*, *Stipa breviflora Griseb.*, and *Artemisia capillaris* during the experimental period.

2.2. Experimental design

To evaluate the effect of warming and N addition on soil respiration, a random blocking design with five blocks as replicates was used in the experiment (Fig. 1). Four treatments in each block were included: control (Co), nitrogen addition (N), warming (W) and combined