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Simulated rain addition modifies diurnal patterns and temperature sensitivities of autotrophic and heterotrophic soil respiration in an arid desert ecosystem

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ABSTRACT

The timing and magnitude of rainfall events in arid and semiarid regions are expected to change dramatically in future decades, which will likely greatly affect regional carbon cycles. To understand how increases in rainfall affect the diurnal patterns and temperature sensitivities (Q_{10}) of soil respiration (R_S) and its key components (i.e. heterotrophic respiration (R_H) and autotrophic respiration (R_A)), we conducted a manipulative field experiment in a desert ecosystem of Northwest China. We simulated five different scenarios of future rain regimes (0%, 25%, 50%, 75% and 100% increase over local annual mean precipitation) each month from May to September in 2009. We measured R_S and R_H every three hours on 6 and 16 days after the rain addition, and estimated R_A by calculating the difference between R_S and R_H. We found that rain addition significantly increased the daily mean R_S and its components on the two measurement days during the growing season. However, the diurnal pattern was different between the two respiration components. Rain addition significantly increased the daily Q_{10} value of R_H but suppressed that of R_A on Day 6. Rain addition had no influence on daily Q_{10} value of both respiration components on Day 16 when soil moisture was lower. In addition, we observed significantly higher daily Q_{10} of R_H than R_A under all five rain addition treatments, indicating that microbial respiration is more temperature sensitive than root respiration in a short-time scale in this desert ecosystem. Thus, partitioning soil respiration into its two components, and analyzing the differential responses of R_H and R_A to future climate changes should be considered for more accurate predictions of soil respiration and regional carbon cycle in these arid and semiarid regions.

1. Introduction

Arid and semiarid areas are among Earth's most widespread ecosystems, and store 15.5% of the world's total soil organic carbon (SOC) (Lal, 2009). In China, due to severe desertification caused by climatic variability (especially rainfall) and land use change associated with unsustainable human activities, the extensive desert areas comprise more than 30% of the country's total land area. Although the rate of carbon fluxes is not high in desert areas, their large land mass bestows them an important role in global carbon storage and cycling. Global climate models predict that the arid and semiarid areas of China will undergo more extreme climate changes characterized by increasing amount of total precipitation and higher frequency of extreme rainfall events for the 21st century (IPCC, 2007; Gao et al., 2012; Chen, 2013), although for both southern (Kalahari and Namibia) and northern (Sahara/Sahel) Africa the prediction is for higher temperatures and less rainfall – thus greatly increased aridity (IPCC, 2007). In addition, the precipitation data from the northwest regions of China for the past 40 years showed an obvious trend of increasing precipitation delivered by heavy rainfall events (Liu et al., 2005). Given that water is

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the primary driver of biological activity in arid and semiarid ecosystems, such alterations in the hydrological cycle will affect carbon cycling (Noy-Meir, 1973).

As the primary contributor to carbon fluxes from terrestrial ecosystems to the atmosphere, soil respiration has received widespread attention in recent years due to its vulnerability to the climate change (Valentini et al., 2000; Luo et al., 2001; Davidson et al., 2006). Soil respiration consists of two components: the autotrophic respiration (R_A) of roots and the associated rhizosphere community, and the heterotrophic respiration (R_H) from the decomposition process of soil microbes (Raich and Tufekcioglu, 2000; Ryan and law, 2005; Kuzyakov, 2006). Numerous studies have investigated the responses of soil respiration and its components (i.e., R_H and R_A) to simulated rain addition in arid and semiarid ecosystems (Liu et al., 2002; Sponseller, 2007; Cable et al., 2008; McCrackin et al., 2008; Thomas et al., 2008; Chen et al., 2009; Jin et al., 2009; Zhang et al., 2010; Barron-Gafford et al., 2011; Su et al., 2012; Qi et al., 2014). However, the effects of simulated rain addition on soil respiration remain unclear due to the differences in regions, environmental conditions and experimental methods. In addition, such studies in arid and semiarid ecosystems were mainly focused on pulse-driven responses of soil respiration in a short time scale (hour to week) (Liu et al., 2002; Sponseller, 2007; Cable et al., 2008; Chen et al., 2009; Jin et al., 2009; Su et al., 2012; Qi et al., 2014). Research concerning the diurnal dynamics of soil respiration *in situ* during rain pulses over the growing season is still rare (Barron-Gafford et al., 2011; Thomas et al., 2011; Ma et al., 2012) and represents a gap in our knowledge of soil respiration during rain pulses. When "rain" is applied, three major areas are expected to be changed, which have the potential to influence the course of soil respiration and its components at diurnal scale. First, given that arid and semiarid ecosystems are often characterized by extremes in temperature and soil water availability, increase in rainfall may eliminate environment stress and provide a favorable (cool, wet) microclimate for microbial activity at diurnal scale (Hou et al., 2013). Second, previous studies have shown that the diurnal dynamic of R_A is strongly linked to recent photosynthesis (Kuzyakov and Cheng, 2001; Tang et al., 2005; Bahn et al., 2009). Enhanced photosynthesis under increased rainfall may modify the diurnal transport of recent photosynthetic substrates belowground and their metabolism in roots and the associated rhizosphere community. Finally, the effect of increased rainfall on the rate of soil respiration may depend not only on the rain amount and timing, but also on the different response time and duration of the two respiration components (Illeris et al., 2003; Huxman et al., 2004; Chen et al., 2009). For example, in a semiarid steppe, Chen et al. (2009) found that the response of R_H to rain addition was quicker than that of R_A, and did not last as long as that of R_A. This implied that the diurnal response of R_H differ from that of R_A after a rainfall event. Therefore, it is necessary to accurately measure the diurnal responses of soil respiration and its components to rain addition in order to accurately predict soil C loss in future climate scenarios.

On a diurnal, seasonal and annual scale, soil temperature is now widely recognized as a pivotal factor affecting soil respiration, and the relationship between soil respiration and temperature is commonly expressed by the Q_{10} relationship (Lloyd and Taylor, 1994; Davidson et al., 1998; Curiel Yuste et al., 2004). Currently, most ecosystem models consider the Q_{10} value as globally invariant when simulating global soil respiration. However, evidence suggests that Q_{10} value varies in space and time (Raich and Schlesinger, 1992; Xu and Qi, 2001; Davidson et al., 2006; Chen et al., 2010) because Q_{10} is regulated by various abiotic and biotic factors, such as soil moisture and plant physiological activity (Boone et al., 1998; Davidson et al., 1998; Xu and Qi, 2001; Jia and Zhou, 2009; Subke and Bahn, 2010). Thus, the increased rainfall in arid and semiarid regions in northwestern China under future climate scenarios is expected to modify the Q_{10} value (Curiel Yuste et al., 2003; Lellei-Kovacs et al., 2011; Jiang et al., 2013). Many experimental studies have investigated the response of daily Q_{10} to rainfall variability (Liu et al., 2008; Zhang et al., 2010; Bowling et al., 2011; Li et al., 2011; Thomas et al., 2011; Shi et al., 2012; Vargas et al., 2012). However, we are not aware of any studies which distinguished the differential responses of daily Q_{10} of R_H and R_A to rain change.

To evaluate the effects of altered precipitation on the diurnal patterns and daily Q_{10} values of soil respiration and its components, we conducted a manipulative field experiment in a desert ecosystem of northwestern China dominated by the shrub species *Nitraria tangutorum*. Different amounts of water, simulating five scenarios of future rain regimes (0%, 25%, 50%, 75% and 100% increase over local annual mean precipitation) were applied equally each month from May to September 2009. The main objectives of this study were to evaluate: (1) How do diurnal patterns of soil respiration and its components respond to gradients of rain addition? and (2) What are the roles of rain addition in driving the daily Q_{10} values of soil respiration and its components? We hypothesized that the responses of diurnal pattern and the relative Q_{10} value to artificial rain addition treatments would differ significantly between the two respiration components, because of the differential response mechanisms of microbes and roots to rain pulse.

2. Materials and methods

2.1. Site description

The experimental site (38° 34′ N, 102° 58′ E) was located in a sandy land area between Badain Jaran Desert and Tengger Desert in Minqin County, Gansu province, China. This area has a temperate arid continental climate with a mean annual temperature of 7.8 °C, and −9.6 °C and 23.2 °C mean temperatures during the coldest and warmest months, respectively. Mean annual precipitation is 115 mm mainly from July to September. The dominant soil type is aeolian sandy soil (Entisols in the USDA soil taxonomy system), and the dominant species is *N. tangutorum Bobr*. Vegetation cover was approximately 35% at the entire study site.

The experiment was conducted in a patched landscape with *N. tangutorum* interspersed with sand dune, orientated northwest-southeast, and composed of two distinct types of soil cover. The northwest slope of the sand dunes was covered with *N. tangutorum* plants while the southeast was bare soil. The mean height and size of the dunes were 0.9 m and 14.2 m^2, respectively.

2.2. Experimental design

A completely random design was used with five rain addition treatments and four replicates for each treatment (113 m^2 per plot, 20 plots in total). Five rain addition treatments were designed to simulate a rain increase of 0% (CK), 25% (+25%PPT), 50% (+50%PPT), 75% (+75%PPT) and 100% (+100%PPT) over long-term (1978–2008) average annual precipitation (115 mm) at the study site, respectively. During the growing season (from May to September) of 2009, the rain addition was applied equally every month, and the additional rain amounts were 0, 5.8, 11.5, 17.3 and 23.0 mm each time for the five addition treatments, respectively. Water was pumped into a tank from a well near the plots and used to irrigate the plots via a system composed of a water-pump, water meter and spraying arms. The irrigation systems were installed on the top of a sand dune and could sprinkle simulated rain over the treatment area uniformly. The rainfall intensity of the rain addition systems was about 25.2 mm h^{-1}, which was almost the maximum single rainfall intensity in this region. As shown in our previous paper