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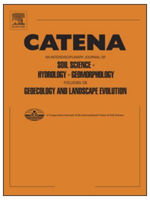

Rainfall pulses modify soil carbon emission in a semiarid desert

Zhen Liu, Yuqing Zhang *, Keyu Fa, Shugao Qin, Weiwei She

Yanchi Research Station, School of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, PR China

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ABSTRACT

Modifications of rainfall patterns are expected to accompany global climate changes. It has been suggested that in dry regions changes in soil carbon emission induced by precipitation will affect soil carbon storage and atmospheric CO_2 concentration. However, our understanding of the responses of soil carbon emission [often as soil respiration (R_S)] to rainfall pulses is still limited regarding changes in soil respiration components [heterotrophic respiration (R_H) and autotrophic respiration (R_A)] and under different precipitation patterns in arid and semiarid ecosystems. To evaluate the variations in soil carbon emission in response to rainfall pulses, we measured R_S and its components in situ before/after precipitation in the Mu Us Desert, China. Rates of R_S and its components were significantly enhanced by rainfall pulses, but gradually reverted thereafter. Moreover, the magnitudes of diel hysteresis for R_S, R_H, and R_A with respect to soil temperature (T_S) were modified by precipitation, and the effects of rainfall pulses on R_S were influenced by antecedent soil water availability. In addition, the ratio of respiration components was changed by individual precipitation events, with an increase in the amount of each rainfall pulse causing a decrease in the proportion of R_H to R_S. Our results indicate that rainfall pulses in desert ecosystems have a major impact on soil carbon emission via changes in the magnitude and ratio of respiration components. We accordingly suggest that greater carbon emission and alterations in respiration components may occur with more extreme precipitation in desert ecosystems.

1. Introduction

On the basis of observations and global climate models, total precipitation amounts and annual extremes in drylands, such as those of central America and northwest China (Chen, 2013; Irmak et al., 2012), are projected to constantly increase in the future (Donat et al., 2016). Changes in precipitation patterns are considered to affect productivity, matter cycles (Jongen et al., 2013), and particularly the carbon budget of the terrestrial biosphere (Zhang et al., 2015). As drylands are widespread in terrestrial ecosystems and store 15.5% of the world's total soil organic carbon (Lal, 2009), the CO_2 released from drylands to the atmosphere via soil respiration (R_S) plays a large role in global carbon storage and cycling. Thus, an understanding of the responses of terrestrial carbon dynamics to changing precipitation patterns in drylands is of fundamental importance for assessing the magnitude of terrestrial CO_2 emission feedbacks to the atmosphere (Straaten et al., 2010).

R_S, often as soil CO_2 flux, represents CO_2 release through the soil surface. R_S mainly includes autotrophic respiration (R_A) and heterotrophic respiration (R_H). Of these, R_A is mainly derived from live roots and associated rhizosphere communities, whereas R_H originates from organic matter and litter decomposition (Luo and Zhou, 2006). Given that water is the main driver of biological activities in arid and semiarid ecosystems, many studies have focused on the response of R_S to precipitation through simulative rain treatments (addition or reduction) and tracing natural rainfall pulses in dry regions. (Cable et al., 2008; Chen et al., 2008; Huang et al., 2015; Ma et al., 2012; Sponseller, 2007; Wang et al., 2014; Zhao et al., 2009). Rainfall pulses significantly affect R_S (Ma et al., 2012), and its components respond differently to precipitation. For example, R_H responds more sensitively to rainfall events than does R_A, although the response is not as prolonged (Austin et al., 2004; Chen et al., 2009). Heavy precipitation favors both R_H and R_A, whereas light precipitation only triggers microbial activities in the surface soil (Austin et al., 2004) or shows no effect on R_S (Cable et al., 2008). In addition, precipitation can also change the diurnal scale of R_S, R_H, and R_A and the hysteresis of R_S, R_H, and R_A with respective to temperature (Ma et al., 2012; Song et al., 2015b). Moreover, the carbon release induced by rainfall pulses has been shown to be positively correlated with the amount of precipitation (Cable et al., 2008; Ma et al., 2012). Interestingly, sandy soils even have the ability to absorb CO_2 following precipitation (Fa et al., 2015). When precipitation occurs, the potential change in processes such as provision of a favorable microclimate for soil microorganisms, enhancement of photosynthate transport, and changes in heat transport and CO_2 diffusion (Sponseller, 2007; Fa et al., 2015), could influence the dynamics of R_S and its components. However, the effects of precipitation on R_S and its components remain unclear, owing to differences among regions, environmental conditions,

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* Corresponding author at: School of Soil and Water Conservation, Beijing Forestry University, (No.) 35 Qinghua East Road, Haidian District, Beijing 100083, PR China.
E-mail address: zhangyq@bjfu.edu.cn (Y. Zhang).

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and experimental methods (Tang et al., 2005; Song et al., 2015b). In addition, the dynamics of respiration components in situ during rainfall pulses over the growing season have not been thoroughly investigated (Ma et al., 2012), and this represents an important gap in our knowledge of soil carbon emission during precipitation. Therefore, it is important to gain an understanding of the responses of R_S and its components to alterations in such hydrological cycles in semiarid regions.

In the present study, conducted in the Mu Us Desert, China, continuous soil CO_2 flux was measured in situ and a trenching method was used to separate R_H and R_A from R_S during the 2015 growing season. The main objectives of this study were to investigate the variations in respiration components induced by rainfall pulses in the Mu Us Desert, and evaluate the effect of rainfall pulses on soil C emission.

2. Materials and methods

2.1. Site description

The research site is located on the southwestern fringe of the Mu Us Desert, north of Yanchi County, Ningxia Province, China (37°42′N, 107°13′E; 1509 m above sea level). The region has a typical temperate continental climate, with a mean annual temperature of 7.6 °C and a frost-free period of approximately 128 days. Mean annual precipitation is 275 mm (for the years 1954 to 2013), which occurs mainly in August–September, and annual potential evaporation is 2024 mm. The main soil type is Aripsamment. The vegetation at the site is dominated by *Artemisia ordosica*, with sparse coverage of *Hedysarum mongolicum*, *Salix psammophila*, *Caragana korshinskii*, and *Agropyron cristatum* (vegetation coverage approximates to 30%).

2.2. Experimental design

In April 2015, early in the growing season, a 50 m × 50 m *A. ordosica* sample plot was fenced. To measure R_S, three polyvinyl chloride (PVC) collars (20 cm internal diameter, 11 cm height) were randomly installed into soil near the shrubs. To measure R_H, a trenching method was used to cut the carbon supply from the plants. In brief, a further three collars (20 cm internal diameter, 60 cm height) were separately installed close to the collars used to measure R_S, inserting 57 cm of the collar into the soil to physically cut roots. Further details are shown in Fig. 1. Our early research showed that the vast majority of *A. ordosica* roots are distributed in the depth range 0–60 cm (Lai et al., 2016); therefore, the depths to which we inserted the PVC collars were appropriate to cut root growth. We also installed PVC collars of the same length close to (<1 m) the R_H monitoring points, in which sensors were embedded for measuring soil temperature (T_S) and volumetric water content (*VWC*) (Fig. 1, unfilled black circles).

2.3. Measurement of soil respiration, soil properties, and meteorological parameters

During the 2015 growing season on days of the year (DOY) 177–280, soil respiration was continuously monitored at hourly intervals using a Li-8100A Automated Soil CO_2 Flux System & Li-8150 Multiplexer (LI-COR Inc., Lincoln, NE, USA) with six Li-8100-104 Long-Term Chambers. Three of these chambers were used to monitor R_S, and the other three were used to monitor R_H. To eliminate deviations caused by measurement, the monitoring sequence was set as follows: $R_S \rightarrow R_H \rightarrow R_S \rightarrow R_H \rightarrow R_S \rightarrow R_H$. Measurements were conducted for 1.5 min, with a 1.5-min interval between each measurement. The dead band was 15 s. The time of both pre-purge and post-purge was 30 s. Measurements of T_S and *VWC* were conducted at a depth of 10 cm using the ECH$_2$O system (LI-COR Inc., Lincoln, NE, USA) equipped with Em50R sensors placed near the R_S monitoring points and in the PVC collars near the R_H monitoring points. In late August, three soil cores were collected near each PVC collar to a depth of 0–10 cm using a soil auger (2.5 cm in diameter). These cores were pooled to provide one composite sample, which was then sieved using a 2-mm mesh and divided into two sub-samples. One sub-sample was air-dried for the analysis of soil organic carbon (*SOC*), total nitrogen (*TN*), total phosphorus (*TP*), and soil *pH*. *SOC*, *TN*, and *TP* were analyzed using the potassium dichromate oxidation, micro-Kjeldahl, and Mo-Sb Anti spectrophotometer methods, respectively. Soil *pH* was measured from a soil:water (w:v, 1:2.5) mixture using a *pH* meter (PHS-3C, Zhiguang Instruments, Shanghai). Soil particle size was determined using a Mastersizer 2000 particle size analyzer (Malvern Instruments, Malvern, England) and classified based on clay (<0.002 mm), silt (0.002–0.05 mm), and sand (0.05–2.00 mm) in accordance with the U.S. Department of Agriculture. The second sub-sample was maintained in its original state to assess soil dissolved nitrogen (*DN*), microbial biomass carbon (*MBC*), and microbial biomass nitrogen (*MBN*). *DN* was extracted with 1 mol/L KCl and determined using the alkaline potassium persulfate digestion-UV spectrophotometric method, whereas *MBC* and *MBN* were determined using a fumigation-extraction method (Brookes et al., 1985). Meteorological parameters, including photosynthetically active radiation (*PAR*), air temperature, and precipitation, were monitored using an InteliMet Advantage Weather Station (Dynamax Inc., USA), which was located at a distance of 200 m from the research site.

2.4. Data analysis

Autotrophic respiration (R_A) was determined by the difference between R_S and R_H.

$$R_A = R_S - R_H. \tag{1}$$

This method may underestimate the contribution of R_A because of the decomposition of cut roots in the collars used for R_H measurement. However, considering the different partitioning methods mentioned by Sun et al. (2014) and Song et al. (2015a and b), the trenching method we used appeared to be more suitable for separating R_H and R_A in the semiarid desert.

The dependence of R_S and its components on T_S was expressed by the following linear model:

$$R = a \times T + b, \tag{2}$$

where R is the R_S and its components (R_H, R_A), T is the temperature (T_{10}), and a, b are the equation parameters.

The response of daily R_S and its components during the days after rainfall pulses was determined using the following equation:

$$R_t = a \times e^{(b \times t)} + c, \tag{3}$$

where R_t is the daily R_S, R_H, and R_A, t is the days after rainfall pulses, and a, b, and c are the equation parameters.

The relative increment in carbon release in R_S, R_H, and R_A induced by rainfall pulses during each whole rainfall pulse-influenced period was determined as follows:

$$\Delta R = \sum (R_i - R_0), \tag{4}$$

where ΔR is the relative increment in carbon release in R_S, R_H, and R_A ($\Delta R_S, \Delta R_H, \text{and} \Delta R_A$) during each whole period, R_i is the i day's daily total amount of R_S, R_H, and R_A during each whole rainfall pulse-influenced period with $i = (1, 2, \ldots)$, and R_0 is the daily total amount of R_S, R_H, and R_A 1 day before a rainfall pulse. Each whole rainfall pulse-influenced period (the lasting time) was defined as days of the stimulatory effect of precipitation on R_S, which persisted until the daily mean R_S was approximately equal to that of the day before a rainfall pulse.

The proportion of the relative increment in carbon release in R_H (PR_H) induced by rainfall pulses during each whole rainfall pulse-