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Litter production rates and soil moisture influences interannual variability in litter respiration in the semi-arid Loess Plateau, China

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ABSTRACT

A better understanding of the factors affecting interannual variability in litter respiration is critical to precisely understand local carbon cycling, especially under the changing climate. In this study, litter respiration was obtained by subtracting *in situ* soil respiration in a control (LCK) treatment by that in a litter removal (LR) treatment for the period 2009–2013 in a 30-year-old black locust plantation (*Robinia pseudoacacia* L.) on a ridge slope in a small watershed of Loess Plateau, China. Annual cumulative litter respiration ranged from 48 ± 15 to 165 ± 36 g C m^{-2} y^{-1}, with mean value of 113 ± 45 g C m^{-2} y^{-1} and coefficient of variation (CV) of 40%; annual contribution rate of litter respiration to total soil respiration (hereafter refer to as litter contribution rate) also exhibited a similar interannual variability (ranged from 8 ± 3% to 20 ± 7%; mean = 15 ± 5%; CV = 31%). Additionally, annual mean soil moisture was highest in 2010 (53.2 ± 8.4% WFPS) and lowest in 2013 (31.4 ± 9.5% WFPS), with mean value of 41.6 ± 7.9% WFPS and CV of 19%; annual litter production rates also exhibited a similar interannual variability (ranged from 379 ± 34 to 565 ± 69 g m^{-2} y^{-1}; mean = 477 ± 71 g m^{-2} y^{-1}; CV = 15%). Annual mean soil moisture was mainly affected by the frequency and distribution of precipitation, and annual litter production rates varied with summer precipitation. Annual cumulative litter respiration and litter contribution rate increased linearly with both annual litter production rates and mean soil moisture content. The contribution of soil water to litter respiration was larger than that of litter production rates. Therefore, litter production rates and soil moisture resulted from precipitation needs to be taken into account for precisely predicting litter respiration in the dryland ecosystems, especially under the changing climate.

1. Introduction

Soil respiration is a complex process that includes three major sources of CO_2 efflux from soil: root-, soil organic matter (SOM)-, and litter-derived respiration (Kuzyakov, 2006). The annual global CO_2 emission from the decomposition of aboveground and belowground litter is estimated to be 68 Gt, accounting for about 70% of the total annual carbon flux (Raich and Schlesinger, 1992). Aboveground litter respiration (hereafter ‘litter respiration’) is important for soil carbon cycling due to its effect on CO_2 efflux from soil and the buildup of soil organic carbon (SOC) (Prescott, 2010). Litter respiration has been a topic of extensive research (Raich and Nadelhoffer, 1989; Rey et al., 2002; Wang et al., 2009), primarily in the tropical regions (Sayer et al., 2007; Zimmermann et al., 2009), subtropical regions (Deng et al., 2007; Wang et al., 2009; Xiao et al., 2014), cold temperate regions (Kim et al., 2005; Liang et al., 2010), as well as natural forest ecosystems (Bowden et al., 1993; Rey et al., 2002; Sulzman et al., 2005; Zimmermann et al., 2009). Aboveground litter production rates (hereafter ‘litter production rates’) in drylands that cover 41–47% of the terrestrial surface (Reynolds et al., 2007) accounts for about 11% of the global litter production rates (French et al., 1979; Guo et al., 2009). However, litter respiration in dryland plantation remains poorly understood.

There have been a number of studies investigating the seasonal

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variation in litter respiration and its influencing factors at a field scale in the dryland ecosystems over the past years (Bowden et al., 1993; Raich and Nadelhoffer, 1989; Rey et al., 2002; Zhang et al., 2014). Seasonal variation in litter respiration appears to be significantly affected by soil temperature (Aerts, 2006; Zhang et al., 2008; Berryman et al., 2014; Xiao et al., 2014) and water availability (Salamanca et al., 2003; Cisneros-Dozal et al., 2007; Lee et al., 2014), especially in dryland ecosystems (Irvine and Law, 2002; Shen et al., 2008; Talmon et al., 2011). However, the response of litter respiration to soil moisture is complex, as litter respiration is restricted in case of low and high soil moisture content, and the response rate may also be confounded by soil temperature (Zhang et al., 2014). The dryland ecosystems tend to have marked seasonal and interannual fluctuations in water availability due to uneven distribution of rainfall (Solomon et al., 2007; Guo et al., 2012), which can also dramatically influence litter production rates (Xu et al., 2006; Zhou et al., 2009; Travers and Eldridge, 2013). Litter production rates follow a quadratic relationship with mean annual precipitation along the gradient in Southern Great Plains, USA (Zhou et al., 2009). Soil micro-environment and litter production rates can have a significant effect on litter respiration (Prescott, 2010). Litter respiration in China's forest ecosystems increases linearly with litter production rates (Chen et al., 2008). Aboveground litter management practices (removal, addition, etc.) can also influence litter respiration (Rey et al., 2002; Sulzman et al., 2005; Berryman et al., 2013; Zhang et al., 2014). However, to our knowledge, studies for investigating the interannual variation in litter respiration and its influencing factors in the dryland ecosystems are scarce.

The Loess Plateau is located in the northwest of China and covers a total area of 640,000 km^2. This region is particularly susceptible to soil erosion due to fractured and steep terrain and improper land use such as cultivating in steep slopes and destruction of vegetation, and so on. The drought-resistant black locust (*Robinia pseudoacacia* L.) has been widely planted in this region since 1980s to control soil erosion, and now it is estimated to cover approximately 70, 000 ha. Aboveground litter as an important input of soil carbon plays an important role in controlling soil erosion, increasing SOC storage, and improving the ecological conditions in the erosion-degraded dryland ecosystems (Xu et al., 2013; Li et al., 2014). However, aboveground litter is often collected by local inhabitants as domestic fuel, or destroyed due to serious soil erosion in the loess regions (Xu et al., 2013; Li et al., 2014), both of which will significantly influence regional soil carbon storage (Prescott, 2010). The optimal strategy to sequester more carbon in soil is to have more litter transformed into humic substances and then chemically or physically protected in the mineral soil (Prescott, 2010). Therefore, a better understanding of long-term variation in litter respiration and its influencing factors is important to evaluate local carbon cycling.

The objectives of this study were to investigate (1) the interannual variation in litter respiration and litter contribution rate; (2) the effect of annual mean soil moisture content and annual mean litter production rates on litter respiration and litter contribution rate. To these ends, we monitored soil respiration, soil temperature, soil moisture, and litter production rates for the period 2009–2013 in control (LCK) and litter removal (LR) treatments in a 30-year-old black locust plantation in Loess Plateau, China.

2. Materials and methods

2.1. Site description

The study was conducted in Changwu State Key Agro-Ecological Experimental Station of Chinese Academy of Sciences located in the southern Loess Plateau in Wangdonggou watershed, Changwu, Shaanxi, China (35°13′ N, 107°40′ E; 1095 m a.s.l.). The study site has a continental monsoon climate with a mean annual rainfall of 580 mm and a mean annual air temperature of 9.4 °C for the period 1984–2013 (Guo et al., 2012). However, rainfall varies seasonally and annually, and more than 50% of rainfall falls in summer from June to August. Air temperature also varies seasonally, and the monthly mean temperature is much higher in summer than in other seasons (21.0 vs. 6.4 °C).

The soils in the study area are derived from wind-deposited loess and classified as the loessial soils according to the soil classification system of FAO-UNESCO. The soil parent material is calcareous loess, which is relatively uniform and dominated by loam. Soils collected in 2009 at a depth of 0–20 cm were characterized by pH 8.3, clay content (<0.002 mm) 24%, field capacity 22.4%, permanent wilting point 9.0%, SOC 6.80 g kg^{-1}, total nitrogen (TN) 0.66 g kg^{-1}, and initial $NaHCO_3$-extractable soil phosphorus content 5 mg P kg^{-1} (Zhou et al., 2012; Zhang et al., 2014).

2.2. Plantation description

The black locust plantation was established in the 1980s to control soil erosion, improve soil physical and chemical properties, and increase the soil carbon storage of this region. About 64% (0.68 ha), 24%, and 12% of the study site was covered by trees with a density of 1213 stems ha^{-1}, shrubs, and grasses or bare soil, respectively. The study site was located on a ridge with a gentle slope (<15°). Tree canopy height (H) and diameter at breast height (DBH, 1.3 m above the ground) were recorded for trees with DBH>1 cm. Mean H was 6.8 ± 1.6 m, mean DBH was 6.4 ± 2.6 cm, and canopy area was 55%. The main understory shrub was *Rubus parvifolius* L. (mean H = 62.8 ± 11.8 cm; canopy area = 55%); and the main understory herb was *Bothriochloa ischaemum* (L.) Keng (mean H = 42.5 ± 11.9 cm; canopy area = 75%) (Zhang et al., 2014).

2.3. Experimental design

The tillage was converted into woodland with the implementation of integrated management of small watersheds in the 1980s for the control of soil erosion. In March 2008, a relatively homogeneous black locust plantation was randomly selected as the study site, and two treatments (1.5 m^2, three plots per treatment) were established at random locations within the site. Normal litter inputs were allowed in the LCK plots, whereas aboveground litter inputs were removed in the LR plots using 1-mm^2 mesh screens (Yan et al., 2013). Three pieces of nylon mesh (1 m^2; mesh size = 1 mm^2) were placed in the plantation throughout the experimental period (2009–2013) to collect aboveground litter. Litter production rates adjacent to each litter fall collector were measured every three months or seasonally on an occasional basis. Aboveground litter was washed with distilled water, oven dried at 70 °C for 72 h, and weighed on a digital balance (Valentini et al., 2008). Litter production rates were expressed as the dry mass per unit ground area over a period of one year (g m^{-2} y^{-1}).

2.4. Measurements of soil respiration, soil temperature and soil moisture

Soil respiration was measured using an automated closed soil CO_2 flux system equipped with a portable chamber (20 cm in diameter; Li-8100, Lincoln, NE, USA). A polyvinyl chloride collar (20 cm in diameter and 12 cm in height) was inserted 2 cm into the soil in each plot one day before the first measurement, and left in place throughout the experimental period (2009–2013). All visible living flora and fauna were removed before measurements were taken. If necessary, one or more additional measurements