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Partitioning soil respiration in two typical forests in semi-arid regions, North China

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ABSTRACT

This investigation examines the contributions of autotrophic respiration (R_A) and heterotrophic respiration (R_H) to total soil respiration (R_T) in two typical forests (*Armeniaca sibirica* Lam. (AS) and *Vitex negundo* Linn. var. *Heterophylla* (VN)) in semi-arid region of North China. The soil respiration components' responses to changing temperatures were also examined. A similar pattern was identified in the diurnal variation of R_T and R_H; R_A exhibited a different diurnal pattern with nighttime values being greater than daytime values. On the seasonal scale, the variations of R_T, R_H and R_A exhibited a similar and strong single-peak pattern with values peaking in early August for both forest sites. The seasonal variations of R_T, R_A and R_H were strongly affected by soil temperature and moisture, with soil temperature accounting for more variations in soil respiration components at both sites. The contributions of R_A to R_T (R_A/R_T ratio) exhibited remarkable diurnal and seasonal variations. Due to the lag time between photosynthesis and root respiration, diurnal variation of R_A/R_T was lower during the daytime than at night in both AS and VN sites. Meanwhile, under the influence of plant physiology, the seasonal variation of R_A/R_T presented a bimodal curve, with ratios peaking in April and August and bottoming out in October. In addition, due to having higher fine root biomass, VN had a significantly higher annual mean R_A/R_T ratio (24.44%) than AS (17.46%). Regardless of vegetation type, the responses of R_T, R_A and R_H to soil temperature were more sensitive during the dormant season than during the growing season, with their Q_{10} ranked as $R_A > R_T > R_H$. Our results indicate that R_A is more sensitive to temperature variation than R_H, and that the dormant season may have greater soil respiration potential than the growing season in our study areas in the context of increasing global temperatures. The response of R_T, R_A and R_H to soil temperature showed greater sensitivity for VN than for AS during the annual time scale. We can infer that soil respiration under VN may be more sensitive to temperature variations under global warming scenarios.

1. Introduction

Soil respiration (SR), one of the key components of carbon cycle in terrestrial ecosystems, is recognized as the second largest carbon flux from terrestrial ecosystems into the atmosphere (Peng et al., 2008; Bahn et al., 2009). Due to uncertainty (positive and negative) feedback mechanisms associated with the belowground carbon cycle in the process of global warming, there has been a recent increase in investigations into soil respiration (Giardina and Ryan, 2000; Moyano et al., 2007). Soil respiration releases 80.4 Pg C annually to the atmosphere, a volume which is about 10-fold greater than that of fossil fuel combustion and deforestation combined (Raich et al., 2002). Any changes therefore in soil respiration could have a profound influence on atmospheric CO_2 concentrations, and potentially aggravate climate warming induced by greenhouse gases (Kane et al., 2005; Song et al., 2013).

Soil respiration is usually comprised of auto- (R_A; root and rhizosphere) and heterotrophic (R_H; microbes and soil fauna) respiration components (Kuzyakov, 2006; Yi et al., 2007). The contribution of R_A to total soil respiration has been reported to have a wide range (10–90%) with mean values of 45–50% for forest ecosystems (Hanson et al., 2000). Autotrophic respiration is highly dependent on fine root biomass, plant primary productivity, photosynthesis and photosynthate allocation to roots, while heterotrophic respiration is mainly influenced by the carbon substrate availability such as belowground detritus, soil organic carbon and nutrient contents (Tang and Baldocchi, 2005;

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Wang et al., 2006). As different components of soil respiration contain various biological and ecological processes, the responses of each component to environmental changes are also different (Boone et al., 1998; Lee et al., 2003; Lee et al., 2010). Therefore, it is necessary to partition SR into its components, which is benefit to gain a mechanistic understanding of SR and its response to environmental changes, and determine carbon source or sink patterns in terrestrial ecosystems in relation to global climate change (Jia et al., 2006; Luo and Zhou, 2006).

Partitioning the heterotrophic and autotrophic components of SR in situ and determining its driving factors are difficult but very important (Li et al., 2010). Three main methods have been used to distinguish hetero- from autotrophic respiration in field studies, including component integration, root exclusion and isotopic approaches (Hanson et al., 2000; Subke et al., 2006). Among these methods, the trenching method is recognized as a simple but effective root exclusion approach. This method has been applied extensively due to it having little disturbance to remaining trees; being suitable for maintaining most field conditions; and being easy to implement under experimental conditions (Li et al., 2010; Shi et al., 2012). Through this method, Li et al. (2010) found that the R_A/R_T ratio in the growing season was 67.3% in a *Setaria italic* (L.) Beauv. cropland on the Loess Plateau, northern China. Larionova et al. (2006) reported that the R_A/R_T ratios in spring barley, corn and bulk wheat croplands were 37.6, 69.4 and 88.2% in the growing season, respectively. Yi et al. (2007) found that the R_A/R_T ratios in the rainy season and the dry season were in the range of 26.1–35.4 and 18.1–22.1% in subtropical forests, respectively.

Soil carbon storage in arid and semiarid regions is important for global carbon storage and easing atmospheric CO_2 concentration enrichment, therefore making these regions increasingly important in the global carbon cycle (Gaumont-Guay et al., 2006; Xu et al., 2011). Mount Taihang, located in the lithoid hilly area of North China, has a thin soil layer with high gravel content. Soil water content in this region is the main limiting factor for vegetation growth. Although some investigations have been conducted on environmental factors such as vegetation type, soil temperature and moisture effecting soil respiration in this area (Shen et al., 2014; Zeng et al., 2014), little research has been undertaken on soil respiration partitioning and their response to environment factors. Partitioning soil respiration components and studying their driving factors will deepen our understanding of soil respiration processes and their mechanisms, and it will also provide a reference for accurate evaluation of regional carbon sources and sinks in the view of global climate change.

Two typical vegetation types were selected for our study (artificial plantation: *Armeniaca sibirica*; deciduous shrub: *Vitex negundo*) in the hilly region of Mount Taihang to separate soil respiration components using the trenching method. We aimed to (1) study the diurnal and seasonal variations of soil respiration components of different vegetation types; (2) quantify and compare the contribution of autotrophic respiration to total soil respiration at diurnal and seasonal scales; and (3) compare the responses of soil respiration and its components to environmental factors within and between vegetation types.

2. Materials and methods

2.1. Site description

This study was conducted at the Hilly Ecology Experimentation Station (114°13′–16′E, 37°53′–56′N, 350 m a.s.l) of the Chinese Academy of Sciences, which is located in the hilly region of Mount Taihang, China (Fig. 1). The area has a semi-arid continental climate with an annual average air temperature of 13.2 °C and a mean annual precipitation of 570 mm. The minimum mean air temperature is −1.6 °C in January, and the maximum mean air temperature is 26.3 °C in July. The soil parent material is mainly granitic gneiss with relatively small amounts of shale and limestone. The soil is classified as Cinnamon soil in the Chinese soil classification (State Soil Survey Service of China, 1998), equivalent to Ustalf in the USDA Soil Taxonomy (Soil Survey Staff, 1999). The average < 0.01 mm soil particle fraction for Cinnamon soil is 28.1%; this soil is classified as a loam with a textural composition of 51.5% sand, 34.5% silt and 14.0% clay (Zhou and Zhang, 2012). Vegetation at the site is currently composed of secondary forest, artificial plantations, deciduous shrubs and herbs, these accounting for 10, 15, 45 and 20% of the study area, respectively. *Armeniaca sibirica* (AS) and *Vitex negundo* are two typical vegetation types in this area, which are representative of the artificial plantations and deciduous shrubs (VN), respectively. The stand characteristics and soil properties of the experimental sites are shown in Table 1.

2.2. Partitioning soil respiration

A trenching method was used to partition autotrophic respiration (R_A) and heterotrophic respiration (R_H) from total soil respiration (R_T). In October 2012, six 1 m × 1 m permanent plots were set up in each vegetation site (three plots for trenching and three plots as controls). The trenching plots were established adjacent to the control plots (Fig. 1). Trenches of 0.2 m wide and 0.8 m deep (approximately the bottom of the root zone) were excavated around the trenching plots. In order to prevent root growth into the trenched plots, we lined the trench with polyethylene nets of 0.037 mm mesh size, and then refilled the soil back into the trench according to its original soil profiles. A polyvinyl chloride (PVC) collar (20 cm inside diameter × 10 cm height) was inserted 3 cm deep into the soil in each plot for soil respiration measurement. The seeding and herbaceous vegetation within the plots were regularly clipped at ground level during the measurements. It was assumed that the CO_2 efflux measured in the trenching plot was composed of R_H, while that in the control plot was composed of R_H and R_A. Differences between the control plots and corresponding trenching plots were used to determine R_A.

2.3. Field measurements and laboratory analysis

An automated soil CO_2 flux system (LI-8100, LI-COR, USA) equipped with a portable chamber (Model 8100-103) was used to measure soil respiration from January to December, 2013. Soil respiration was measured twice a month during the growing season (May–September) and once a month during the dormant season (January–April and October–December). Measurements were made between 09:00 and 13:00 local time on each sampling day. Continuous measurements were made on July 25–28 and September 25–28 to monitor diurnal variation in total soil respiration and its components. These measurements were made every 2 h from 08:00 to 08:00 the next day. Soil temperature (ST) at 10 cm depth and soil moisture (SM) at 5 cm depth were monitored simultaneously near the PVC collars using a temperature sensor and a moisture sensor attached to a LI-8100, as per the method of Song et al. (2013).

Soil samples were collected once a month from July to October using 5-cm diameter tube auger at depth intervals of 0–10, 10–20, 20–40 and 40–60 cm depths near the PVC collars. Twelve soil samples from the same soil layer in each plot were combined to form a composite sample. After excluding gravel, roots and clutter, the soil samples were air-dried and crushed before being passed through a 0.25 mm soil sieve. Soil organic carbon (SOC) was measured by Walkley-Black's method (Walkley and Black, 1934), and soil total nitrogen (STN) was measured by the Semimicro-Kjeldahl method (Bremner and Mulvaney, 1982).

Fine root biomass was determined according to the method described by Shi et al. (2009). Soil samples were collected in the vicinity of the soil collars every month from July to October. A soil auger (5 cm in diameter) with a sharpened edge was used to collect the soil material for this analysis. Twelve soil cores from the same soil layer in each plot were randomly collected and combined to form a composite soil sample. Soil samples were then placed into a metal screen of 0.1 mm mesh size, soaked and washed with tap water. Fine roots were then