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Debris manipulation alters soil CO_2 efflux in a subtropical plantation forest

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ABSTRACT

Potential changes in the quality and quantity of C inputs in soil during environmental changes may affect soil CO_2 efflux in forest ecosystems. Therefore, a field debris exclusion experiment and a laboratory debris addition experiment were conducted to assess the response of soil CO_2 efflux to C input manipulation. Our experiments were the first to be conducted in a subtropical Chinese fir (*Cunninghamia lanceolata*) plantation. The field debris exclusion experiment included the following treatments: leaf litter exclusion (NL), leaf litter and root exclusion (NLR), and control (CT). In the laboratory experiment, leaf litter and fine and coarse roots were added to soils collected from the same site and incubated for 100 days at 15.0 °C using the isotopic partitioning approach to determine the priming effect on soil C. The field-experimental results showed that soil CO_2 efflux decreased significantly by 22.9% and 49.1% in the NL and NLR plots, respectively, compared with the CT plots. However, debris exclusion did not affect the diurnal and seasonal patterns of soil CO_2 efflux. The contributions of leaf litter and roots to total soil CO_2 efflux were 22.9% and 26.2%, respectively, which were positively related to soil temperature and moisture. In the laboratory experiment, the cumulative amount of soil CO_2 efflux increased 1.25, 0.51, and 0.43 times in the soils with leaf litter, fine root, and coarse root additions, respectively, compared with the control soil (without debris addition) at the end of the incubation period. The amount of CO_2 derived from leaf litter, fine root, and coarse root additions accounted for 44.0%, 31.1%, and 27.9% of the total amount of soil CO_2 efflux, respectively. During the experimental period, the priming effect induced by fast-decomposing leaf litter (25.9%) was significantly higher than the priming effect induced by slow-decomposing fine roots (3.8%) and coarse roots (2.9%). The priming effect was negatively correlated with the initial lignin content and the lignin:N ratios of the added debris. The similar contributions of leaf litter and roots to soil CO_2 efflux from the field experiment and the greater contributions of the priming of leaf litters to the fluxes from the laboratory experiment suggest that root inputs are more important than litter inputs in regulating soil C storage in Chinese fir forests.

1. Introduction

Soil, a major global carbon (C) pool, contains more than three-fourths of the earth's terrestrial C, and contains as much as 3.3 times the atmospheric C pool (Lal, 2004). Currently, the soil CO_2 efflux is 76.5 Pg Cy^{-1}, approximately 10 times greater than that of fossil fuel combustion and deforestation sources combined (Schimel et al., 2000), even though soil CO_2 efflux is not an annual net input to the atmosphere. Therefore, even small changes in the processes governing soil C cycling may induce the release of large amounts of CO_2 and would have significant effects on the global C cycle. Plant productivity may increase with increase in atmospheric CO_2 concentrations in forest ecosystems. The increase in plant productivity may result in an increase in litterfall (Crow et al., 2009; Liu et al., 2005; Raich et al., 2006). Moreover, some free-air carbon dioxide enrichment studies have shown that fine-root turnover increases under elevated CO_2 (De Graaff et al., 2006; Pregitzer et al., 1995), which leads to higher production of root-derived CO_2 from soil (Martens et al., 2009). Therefore, in the context of climate change, the input of leaf litter and roots to soil is important in the regulation of soil CO_2 efflux and C storage.

Large amounts of C are released into the atmosphere as CO_2 during the decomposition of litter added to the soil (Bowden et al., 1993; Raich, 2000; Rubino et al., 2010). For example, 30% of the total litter C was lost as CO_2 in one year in a coppice poplar (*Populus nigra*) plantation (Rubino et al., 2010). Leaf litter and roots have important effects on soil C dynamics because the contribution of litter to annual CO_2 efflux ranges from 20% to 37% in many forest ecosystems (Hanson et al., 2000; Rey et al., 2002; Rubino et al., 2010; Sulzman et al., 2005; Zimmermann et al., 2009), and that of the roots ranges

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from 23% to 70% (Li et al., 2004; Lin et al., 1999; Subke et al., 2006; Sulzman et al., 2005).

Debris manipulation affects different components of total soil CO_2 efflux in forest ecosystems (Lin et al., 1999; Sulzman et al., 2005; Tang et al., 2005; Wang et al., 2009). In a 1-year litter-manipulation experiment conducted in a mature oak forest (*Quercus petraea*), Chemidlin Prévost-Bouré et al. (2010) noted that soil CO_2 efflux was reduced by 25% to 45% in the litter-exclusion plots and increased by 60% to 120% in the litter addition plots. In the H.J. Andrews Experimental Forest, Crow et al. (2009) found that soil CO_2 efflux in the no-litter plots and no-root plots were 21% and 34% less than that in the control plot, respectively. However, the aforementioned studies were conducted in temperate and tropical forest ecosystems. Wang et al. (2009) reported the effect of leaf litter removal on soil CO_2 efflux in a subtropical pine (*Pinus massoniana*) plantation, but did not include root exclusion. Therefore, the effect of debris manipulation on soil CO_2 efflux in subtropical forests has not yet been fully understood.

Priming effect is defined as a change in the native soil organic C decomposition rate after the addition of exogenous substances to the soil (Blagodatskaya and Kuzyakov, 2008; Neill and Guenet, 2010). Although the process has been described as early as 1926 by Löhnis (1926), it has not yet been fully understood. Many studies have demonstrated that substrate addition can have either positive or negative priming effects (Falchini et al., 2003; Guenet et al., 2010; Kuzyakov and Bol, 2006). However, previous experiments have been conducted through the addition of easily available organic substrates (e.g., glucose and fructose) under controlled laboratory conditions (Ganjegunte et al., 2006; Hamer and Marschner, 2005; Kuzyakov and Bol, 2006). For a given soil, the priming effect depends on the quantity and quality of the organic substance added (Hamer and Marschner, 2005). Little information is available on the priming effect of plant debris on soil C in subtropical forest ecosystems, although some studies have reported on the priming effect of plant residues in temperate forest soils (Nottingham et al., 2009; Rasmussen et al., 2007) and grassland soils (Fontaine et al., 2007).

The objectives of this study are to quantify the contributions of leaf litter and roots to the total soil CO_2 efflux in a subtropical coniferous forest and to determine whether the magnitudes of priming effects depend on the quality of C inputs. A debris exclusion experiment was conducted to partition soil CO_2 efflux into mineral soil (R_s), leaf litter (R_l), and root (R_r) CO_2 flux in a 16-year old Chinese fir (*Cunninghamia lanceolata*) plantation in a subtropical region of China. C isotopic-labeling technique was used to assess the priming effects on soil C following additions of leaf litter and fine and coarse roots in a controlled laboratory experiment.

2. Materials and methods

2.1. Study site

The study area is located at the Huitong Natural Research Station of Forest Ecosystem (26° 40′ to 27° 09′ N and 109° 26′ to 110° 08′ E) in Hunan Province, subtropical China. The study area has a humid mid-subtropical monsoon climate. The site receives an average annual precipitation of 1200 mm and an annual mean temperature of 16.5 °C. The Chinese fir plantation was established on a clear-cutting Chinese fir site in 1990. The plantation density was 2500 trees/ha during its planting and was approximately 1500 trees/ha in 2004, after undergoing thinning twice. The understory vegetation is dominated by *Maesa japonica*, *Lophatherum gracile*, *Microlepia marginata*, *Dryopteris fuscipes*, and *Parathelypteris glanduligera*. The soil is approximately 80 cm deep and is classified as an oxisol based on US soil taxonomy (Soil Survey Staff, 1999). The soil is medium-clayey loam (sand, 32%; silt, 22%; and clay, 46%). The stand characteristics and some properties of the surface soil (from 0 cm to 20 cm) have been described by Wang et al. (2007).

2.2. Debris exclusion experiment

The experiment was conducted from June 2005 to August 2006 in a 16-year old Chinese fir plantation. Five blocks were arranged into a 0.25 ha square plot in June 2005. The size of each block was 20 m × 20 m. Three treatments (leaf litter exclusion, leaf litter and root exclusion, and the control) were established in each block. Within each treatment, three permanent sampling locations for measuring soil CO_2 efflux were randomly selected, and the mean of the three values was considered an independent replicate for the treatment. Each treatment had five replicates to minimize the innate variability in the study. Although soil CO_2 efflux was not measured before the treatments, we assumed no significant difference because soil total N (1.38 $g \cdot kg^{-1}$) and P (0.136 $g \cdot kg^{-1}$) were not significantly different between the plots ($P > 0.05$). The leaf litter exclusion treatment (NL) was implemented by building a 4 m × 4 m tent (1 m above the ground surface) using a 2 mm mesh screen. The ground litter was removed when the tents were installed. To exclude the roots, the soil was trenched 60 cm deep along the four sides of the plot (about 4 m × 4 m). A plastic trap sheet was then buried in the soil to prevent the roots of the Chinese firs from growing into the plots. The understory vegetation was removed by hand. The leaf litter and root exclusion treatment (NLR) was similarly implemented by building a tent and burying a plastic trap sheet. The control treatment (CT) received normal litter inputs. The measurement of soil CO_2 efflux was conducted three months after root trenching to reduce effects of dead root decomposition and soil disturbance on soil CO_2 efflux. The soil CO_2 efflux was determined monthly from September 2005 to August 2006. The soil CO_2 efflux was measured using a CO_2 infrared gas analyzer (Model CI-301, CID, Inc.) equipped with a soil respiration chamber (Khomik et al., 2006). Measurements were taken at the middle of each month. Four days without rain passed before measurements were taken, and measurements were finished in one day. During each CO_2 flux measurement, soil temperature was measured using copper-constant thermocouples at a depth of 5 cm, and soil moisture was measured using a handheld time-domain reflectometer at a location outside each soil collar. Moreover, soil CO_2 efflux was also measured at 00:00, 03:00, 06:00, 09:00, 11:00, 13:00, 15:00, 17:00, 19:00, and 21:00 within 1 day in December 2005 and in April and August 2006 to estimate the diurnal pattern of soil CO_2 efflux. Ground litter was not removed when soil CO_2 efflux was measured in the control plots.

2.3. Chinese fir labeling

A controlled growth chamber (180 cm deep, 160 cm wide, and 200 cm high) was designed in the laboratory to allow the labeling of Chinese fir seedlings. The chamber was made of glass and was regulated using a temperature and humidity control system. The temperature and humidity were regulated at 30 °C and 80% during ^{13}C labeling, respectively. A 2-year-old Chinese fir seedling was planted in a container (35 cm upper diameter and 30 cm height). Plants with high $\delta^{13}C$ values relative to the soil were labeled. Sixteen individual seedlings were labeled during the growing season. $^{13}CO_2$ gas with 99.9% abundance was used for the labeling. The total CO_2 concentration in the growth chamber was monitored continuously using an infrared gas analyzer. The concentration ranged from 300 ppm to 400 ppm during the labeling from May to October. After labeling, all the seedlings were harvested and divided into leaves, fine roots (diameter < 2 mm), coarse roots (diameter > 2 mm), and other parts, which were then air-dried for the incubation experiment. The chemical properties of the labeled litters are shown in Table 1.