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Nitrogen addition stimulates different components of soil respiration in a subtropical bamboo ecosystem

Li-hua Tu [a], Ting-xing Hu [a,*], Jian Zhang [a,b], Xian-wei Li [a], Hong-ling Hu [a], Li Liu [c], Yin-long Xiao [a]

[a] College of Forestry, Sichuan Agricultural University, Xingkang Road 46, Ya'an 625014, Sichuan, PR China
[b] Institute of Ecological Forestry, Sichuan Agricultural University Chengdu Campus, Wenjiang District, Chengdu 611130, Sichuan, PR China
[c] Personnel Department, Sichuan Agricultural University, Xingkang Road 46, Ya'an 625014, Sichuan, PR China

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ABSTRACT

Soil respiration is an important carbon (C) flux of global C cycle, and greatly affected by nitrogen (N) addition in the form of deposition or fertilization. However, the effects of N addition on the different components of soil respiration are poorly understood. The aim of this study is to investigate how the components of soil respiration response to N addition and the potential mechanisms in a subtropical bamboo ecosystem. Four N treatment levels (0, 50, 150, 300 kg N ha^{-1} $year^{-1}$) were applied monthly in a *Pleioblastus amarus* bamboo plantation since November 2007. Total soil respiration (RS_T) and soil respiration derived from litter layer (RS_L), root-free soil (RS_S), and plant roots (RS_R) were measured for one year (February 2010 to January 2011). The results showed that the mean rate of RS_T was 428 ± 11 g C m^{-2} $year^{-1}$, and RS_L, RS_S, RS_R contributed (30.2 ± 0.7)%, (20.7 ± 0.9)%, and (49.1 ± 0.7)%, respectively. The temperature coefficients (Q_{10}) of RS_T, RS_L, RS_S, and RS_R were 2.87, 2.28, 3.09, and 3.19, respectively, in control plots. Nitrogen additions significantly increased RS_T and its three components. RS_R was stimulated by N additions through increasing fine root biomass and root metabolic rate. The positive effects of N additions on soil fertility, microbial activity, and the quality and amount of aboveground litterfall also stimulated other CO_2 production processes. In the background of increased N input, response of RS_T and components of RS_T are primarily due to the positive response of plant growth in this bamboo ecosystem.

1. Introduction

Since the Industrial Revolution, human activities, such as food and energy production, have greatly accelerated the formation and deposition of reactive forms of nitrogen (N) (Vitousek et al., 1997; Galloway et al., 2004). Nitrogen deposition will increase in the next decades, especially in East and South Asia (Galloway et al., 2004; Denman et al., 2007). In the context of global warming, one of the major scientific challenges regarding increased N deposition is to understand how it alters carbon (C) cycling and storage. In general, net primary productivity in terrestrial ecosystems is often N limited (Vitousek and Howarth, 1991; LeBauer and Treseder, 2008). Therefore, increased N deposition has the potential to alter the balance between primary productivity and decomposition. Numerous studies have reported that the response of plant growth in terrestrial ecosystems is generally positive (Högberg, 2007; Hyvönen et al., 2008; LeBauer and Treseder, 2008). Whereas, in some N saturated ecosystems, chronic N additions inhibited plant growth and stimulated N leaching (Magill et al., 2004). Ecosystem C balance is determined by the processes regarding C fixations (e.g. plant growth) and C emissions (e.g. soil respiration). Therefore, effects of N deposition on C emissions greatly affect the direction and extent of C balance response.

Plants and soils contain the most C in terrestrial ecosystems. Resent studies show that the C stored in global plants and soils are 560 Pg (Forster et al., 2007) and >3300 Pg (Tarnocai et al., 2009), respectively. Soil respiration is the primary process through which carbon dioxide (CO_2) returns to the atmosphere (Schlesinger and Andrews, 2000). Eddy covariance studies have shown that on average approximately 80% of the gross primary productivity (GPP) in terrestrial ecosystems will return to atmosphere through ecosystem respiration (Law et al., 2002), and approximately 70% of that ecosystem respiration is from soil (Goulden et al., 1996; Law et al., 1999; Janssens et al., 2001). Global CO_2 flux through soil respiration is 68–98 Pg C yr^{-1}(Raich and Schlesinger, 1992; Schlesinger and Andrews, 2000; Bond-Lamberty and Thomson, 2010), which is 10 times greater than the annual CO_2 emission from fossil fuel combustion (Boden et al., 2009).

* Corresponding author. Tel.: +86 835 2882215.
E-mail address: hutx001@yahoo.com.cn (T.-x. Hu).

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Nitrogen additions to forest soils have shown variable effects on soil respiration, including increases (Bowden et al., 2004; Cleveland and Townsend, 2006), decreases (Bowden et al., 2004; Olsson et al., 2005; Mo et al., 2007; Jia et al., 2010), or unchanged rates (Allison et al., 2008; Samuelson et al., 2009). However, there are many different sources of total soil respiration. Kuzyakov (2006) distinguished five main biogenic sources of CO_2 efflux from soils. Because the turnover rates of the C pools are very different, without separation of SOM (soil organic matter) – derived CO_2 from plant-derived CO_2, measurements of total soil respiration have very limited value for evaluation of the soil as a source or sink of atmospheric CO_2 and for interpreting the fate of C within soils and ecosystems (Kuzyakov, 2006). The potential effects and mechanisms of N additions on soil respiration components may different because the main controllers of different components of soil respiration are variable. The effects of N additions on decomposition depend on its stage: generally, decomposition rates of light soil C fractions/fresh litter are accelerated but decomposition rates of heavier soil C fractions/humified organic matter are suppressed (Neff et al., 2002). An incubation experiment (Ramirez et al., 2010) demonstrated that N fertilization inhibits soil microbial respiration regardless of the form of N applied. Jia et al. (2010) found N fertilization increased fine root respiration in two temperate forests through incubating soil cores. However, the underlying mechanisms of chronic N deposition in influencing different components of soil respiration are still not well understood.

It should also be noted that most studies regarding the effects of N addition on soil respiration have been conducted in coniferous, broad-leaved forests. Bamboo forest is one of the most important forest types in the world, accounting for 2.94% of the forest area in China (FAO, 2010). Bamboo forests contribute about 10% of the C stocks in the living biomass of forests in China (Chen et al., 2009). Therefore, bamboo forests play an important role in regional, even global, C cycling. Bamboo forests/plantations are mainly distributed in the southern provinces in China where the background N deposition is among the highest in the world (Fang et al., 2011). Therefore, it is critical to address the effects of increased N deposition on the key processes regarding C cycling in the forest ecosystems, especially the bamboo forest/plantation ecosystems in this region. In our previous study, N additions stimulated soil respiration in the first two years (Tu et al., 2011a). The purpose of this study is to investigate how the components of soil respiration respond to N additions and the potential mechanisms.

2. Materials and methods

2.1. Site description

The study was conducted in Liujiang, Sichuan, China (29° 42′ N, 103° 14′ E, about 600 m a.s.l.), the heart of the rainy zone of SW China. The study area is a large scale, complicated ecotone located west of Sichuan basin, ranging 50–70 km east to west and 400–450 km north to south with an area of about 25,000 km^2 (Zhuang and Gao, 2002). The region has a mid-subtropical, humid, mountainous climate (Zhuang and Gao, 2002). The annual mean relative humidity is 86%, and the monthly mean temperature is 6.6 °C in January and 25.7 °C in July. The mean annual precipitation from 1980 to 2000 was 1490 mm. The background wet N deposition measured in 2008 and 2009 was 82 and 113 kg N ha^{-1} $year^{-1}$, respectively (Tu et al., 2011b). The site (10 ha) was converted from cropland to a *Pleioblastus amarus* plantation in 2000 as part of the National Project of Converting Farmland to Forests (NPCFF). At the time of our study, the plant density was 52,000 trees ha^{-1}, and the mean diameter at breast height was 2.3 cm. The aboveground dry biomass was 25.4 kg m^{-2} in November 2007 (Tu et al., 2011a). The soil at the site is Dystric Purpli-Orthic Primosols and is derived from purple sandstone and shale (Zhu and Li, 1989). The average soil depth to bedrock was approximately 1 m, and the thickness of the surface organic layer was approximately 1 cm before the experimental treatments began. The surface soil horizon (0–20 cm) contained 8.9 mg g^{-1} C and 0.81 mg g^{-1} N (soil C/N ratio = 11). There was very little shrub or herb in the understory at the time of the experiment.

2.2. Experimental design

Twelve plots were established within the study site in October 2007, each measuring 3 × 3 m at about 5 m intervals. The individual plots were separated from each other by impermeable plastic covers at 0–1 m soil depth. Plots were divided into four treatments (3 plots per treatment) as follows: (1) control (no N added), (2) low-N (50 kg N ha^{-1} $year^{-1}$), (3) medium-N (150 kg N ha^{-1} $year^{-1}$), and (4) high-N (300 kg N ha^{-1} $year^{-1}$). Three replicates were performed for each treatment, and plots were randomly selected to receive treatments. Nitrogen additions were initiated in November 2007. Ammonium nitrate (NH_4NO_3) was applied monthly in twelve equal applications. In each application, the fertilizer was weighed, dissolved in 1 L of water, and applied to each plot using a portable sprayer. The control plot received 1 L water without fertilizer.

In November 2009 (after two years of N additions), each 3 × 3 m plot was further divided into 9 sub-plots (each measured 1 × 1 m). Sub-plots were randomly divided into three treatments (3 sub-plots per treatment): intact (IT), no litter (NL), and no root & litter (NRL) (Fig. 1).

(1) IT. Kept in the natural state of the sub-plot. The CO_2 efflux measured in IT sub-plots was the total soil respiration (RS_T).
(2) NL. The litter layer on soil surface was removed within the sub-plot. To prevent the input of fresh fallen litter, a litter trap (100 cm × 100 cm × 80 cm) with a 1-mm mesh nylon netting bag (about 30 cm deep) was placed just above the sub-plot. The materials in the litter trap were cleared every two weeks. The CO_2 efflux in NL (RS_{NL}) treatment was RS_T without soil respiration derived from the litter layer (RS_L), therefore, $RS_L = RS_T - RS_{NL}$.
(3) NRL. First, the surface litter layer was removed within the sub-plot. Then, a soil column (35 cm in diameter, 30 cm in depth) in the center of NRL sub-plot was removed in the order of 0–10 cm, 10–20 cm, and 20–30 cm. Each layer of soil was placed separately on plastic sheeting. The visible roots were removed with tweezers. In order to prevent intrusion of new fine roots and keep the water and air circulation, a layer of 0.1 mm nylon mesh was placed around the inside edge of pit. The soil was backfilled at the layers close to the original soil

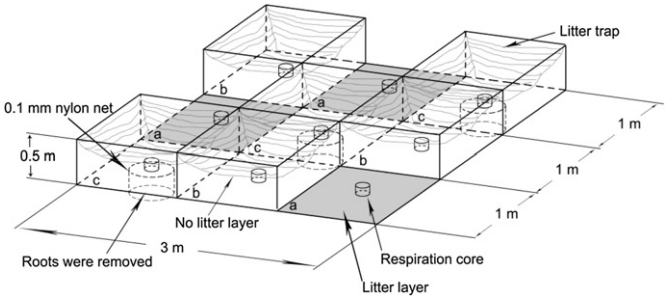

Fig. 1. Schematic diagram of experimental design (one of the twelve plots). a, intact; b, no root & litter (NRL); c, no litter (NL).