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Research Paper

Will nitrogen deposition mitigate warming-increased soil respiration in a young subtropical plantation?

Xiaofei Liu[a], Zhijie Yang[a], Chengfang Lin[a], Christian P. Giardina[b], Decheng Xiong[a], Weisheng Lin[a], Shidong Chen[a], Chao Xu[a], Guangshui Chen[a], Jinsheng Xie[a], Yiqing Li[a,c,*], Yusheng Yang[a,**]

[a] *Key Laboratory for Subtropical Mountain Ecology, School of Geographical Science, Fujian Normal University, Fuzhou 350007, China*
[b] *Institute for Pacific Islands Forestry, USDA Forest Service, Hilo, HI 96720, USA*
[c] *College of Agriculture, Forestry and Natural Resource Management, University of Hawaii, Hilo, HI 96720, USA*

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ABSTRACT

Global change such as climate warming and nitrogen (N) deposition is likely to alter terrestrial carbon (C) cycling, including soil respiration (Rs), the largest CO_2 source from soils to the atmosphere. To examine the effects of warming, N addition and their interactions on Rs, we conducted a two-way factorial soil warming (control, 5 °C warming) and N addition (control, 40 and 80 kg N ha^{-1} yr^{-1}) mesocosm experiment in subtropical China. We measured Rs and nutrient availability. We found warming alone increased Rs by 15%, but warming plus high N addition treatment appeared to have offsetting effects as these plots were not significantly different from unheated and unfertilized controls. Warming alone increased soil available phosphorus (P) but availability declined in response to warming plus N additions. N additions alone had no effect on Rs in this study. Our results suggest that future increases in N deposition could mitigate warming-increased Rs in P-limited and relatively N-saturated subtropical forest ecosystems.

1. Introduction

Climate change models predict that atmospheric temperature and N deposition will continue to increase within sub-tropical regions (Kanakidou et al., 2016 Knutti and Sedláček, 2013; Reay et al., 2008). It is estimated that air temperature in subtropical regions will increase by 1.3–5.0 °C within the next 100 years, which is greater than the global average of 1–3.7 °C (Field et al., 2014; The Committee of China's National Assessment Report on Climate Change, 2015). In the coming 20 years, worldwide N deposition is anticipated to increase by between 50% and 100% by 2030 relative to 2000, with the largest absolute increases occurring over East and South Asia (Reay et al., 2008). Atmospheric wet/bulk N deposition in subtropical China ranges from 26 to 55 kg N ha^{-1} yr^{-1} (Du et al., 2016; Shen et al., 2013). It is widely appreciated that increasing temperature and N deposition have major impacts on C process rates in the tropics and subtropics (Lu et al., 2013; Luo, 2007; Reay et al., 2008). Tropical forests store approximately 25% of all terrestrial C, support one-third of the terrestrial biosphere's net primary productivity, and may play an important role in mitigating future global warming (Bonan, 2008). The extent to which tropical forests might mitigate future warming is uncertain, however, because the independent and interactive effects of warming and nutrient additions on C process rates are poorly understood.

While there have been many manipulative warming experiments in the mid to high latitudes (Aguilos et al., 2011; Luo et al., 2001; Noh et al., 2016; Schindlbacher et al., 2009; Suseela and Dukes, 2013), few studies have tackled the effects of rising temperature on tropical and subtropical forests (Giardina et al., 2014; Wu et al., 2016). This lack of detailed information about tropical and subtropical forest response to warming points to an urgent need for warming experiments in the tropics and subtropics (Cavaleri et al., 2015 Zuidema et al., 2013).

Compared with wide-spread N limitations to forest productivity in temperate regions, nutrient limitations to productivity in older soils of tropical and subtropical regions are typically driven by P (Cleveland and Townsend, 2006; Cleveland et al., 2002). Thus, effects of high rates of N deposition on ecosystem processes in the tropical and subtropical regions may be expressed very differently than in temperate regions. Many studies have examined the effects of elevated N deposition on soil C cycles of forest ecosystems in tropical and subtropical forests (Gao et al., 2014; Mo et al., 2008; Ramirez et al., 2012). Some studies

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* Corresponding author at: Key Laboratory for Subtropical Mountain Ecology, School of Geographical Science, Fujian Normal University, Fuzhou 350007, China.
** Corresponding author.
E-mail addresses: yiqing@hawaii.edu (Y. Li), geoyys@fjnu.edu.cn (Y. Yang).

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indicate that responses of soil C cycles of tropical and subtropical forests to N deposition are significantly different between N-enriched and N-limited forests (Gao et al., 2014; Mo et al., 2008). There is little information on the effects of N deposition on subtropical forests in southeastern China.

Soil respiration (Rs) is the largest source of CO_2 from terrestrial ecosystems to the atmosphere (Metcalfe et al., 2011). Many studies indicate that both increased temperature and N deposition have major impacts on Rs (Melillo et al., 2011; Noh et al., 2016; Schindlbacher et al., 2009; Sun et al., 2014; Suseela and Dukes, 2013). In addition, warming often stimulates forest net N mineralization and thus increases N availability in soils (Butler et al., 2012; Melillo et al., 2011), which in turn can affect Rs rates through altered plant allocation schemes, changes to plant litter decomposition, or reduced mycorrhizal colonization rates (Giardina et al., 2004; Giardina et al., 2003).

The independent effects of warming and N deposition on Rs have been studied across a diversity of forest types, but few studies have examined both independent and interactive effects and underlying mechanisms of warming and N deposition on Rs (Contosta et al., 2011; Graham et al., 2014). Research in tropical and subtropical regions is largely absent despite the fact that these regions are facing substantial increases in both temperature and N deposition (Field et al., 2014; Kanakidou et al., 2016). These knowledge gaps are important because for larger areas of the terrestrial biosphere, both temperature and N deposition are increasing, the tropics and subtropics account for a large fraction of the Earth's primary productivity, and their interactive effects cannot be fully understood from single factor experiments (Bonan, 2008; Cavaleri et al., 2015; Zhou et al., 2013; Zuidema et al., 2013).

China's forests represent an important sink for atmospheric C, storing 4.75 Pg C per year (Fang et al., 2001) and taking up 0.19–0.26 Pg C per year (Piao et al., 2009). Approximately 65% of Chinese forests and associated C occur in the southeastern subtropical provinces of Fujian, Hunan and Zhejiang (Piao et al., 2009). More than 32% of these forests are plantations, the dominant species being Chinese fir (*Cunninghamia lanceolata*), which accounts for most commercial plantations with respect to acreage and timber production (Lu et al., 2015; SFA, 2009). We used Chinese fir plantation as a model system to understand Rs responses to the independent and combined effects of artificial soil warming and N enrichment through fertilization. A thorough understanding of Rs responses of Chinese fir to both warming and N enrichment and their interactions is critical for accurately predicting belowground C dynamics of subtropical forest ecosystems with future climate change. Our multi-factorial experiment allowed us to quantify the effects of soil warming, N addition and their interactions on Rs.

We used our experimental design to address the following questions: (1) how do soil warming and N addition affect Rs of a subtropical plantation? (2) will temperature sensitivity of Rs change with warming and N addition? and (3) how will soil warming interact with N addition in affecting Rs?

2. Materials and methods

2.1. Study area

The study was conducted in the Chenda Observation Study Site (26° 19′55″ N, 117° 36′53″ E, 300 m a.s.l.) of Sanming Forest Ecosystem and Global Change Research Station in Fujian Province, China. This study site borders the Daiyun Mountains on the south-east and the Wuyi Mountains on the northwest. This area is 10 km northwest of the small industrial city of Sanming. Average annual wet N deposition (NO_3^- plus NH_4^+) from precipitation in Sanming region is 36.3 kg N m^{-2} yr^{-1} (Zhang, 2013). The study site is characterized by a typical maritime subtropical monsoon climate. The mean annual temperature (MAT) is 19.1 °C with low temperatures occurring in January and high temperatures occurring in July. Mean annual relative humidity is 81% and the mean annual precipitation (MAP) is 1750 mm. Approximately 75% of total precipitation occurs from March to August. The mean annual potential evapotranspiration is 1585 mm. The soil at the study site is sandy in texture and granite in parent material. It is classified as red soil from the China soil classification systems, and is equivalent to Oxisol in the USDA Soil Taxonomy (State Soil Survey Service of China, 1998; Soil Survey Staff of USDA, 2014).

2.2. Experimental design

In this experiment, a randomized block design was used with soil warming and N addition as the main treatments. There were five blocks and each block included control (CT), soil warming (W), low N addition (LN, 40 kg N ha^{-1} yr^{-1}), soil warming plus low N addition (WLN), high N addition (HN, 80 kg N ha^{-1} yr^{-1}), and soil warming plus high N addition (WHN). This experimental design resulted in a total of 30 plots and each plot had a size of 2 m × 2 m. The plots were separated with PVC boards inserting into soils at a depth of 0.7 m. Each plot was divided into four 1 m × 1 m subplots and one-year-old Chinese-fir seedling was planted in each subplot. The seedlings were selected from a local nursery to be uniform in plant height, basal diameter and fresh weight. The average plant height and basal diameter of the seedlings were 25.7 ± 2.5 cm and 3.4 ± 0.4 mm, respectively. In November 2013, four healthy seedlings were randomly selected and transplanted into the center of each subplot.

Soil temperatures in the warmed plots (W, WLN and WHN) were maintained at a constant 5 °C above the ambient temperature of the unwarmed control plots. The warming treatment was conducted by using buried heating cables placed 10 cm below the soil surface with an interval of 20 cm. The heating cables (TXLP/1, Nexans, Norway) contained a resistance wire with an output of 17 w m^{-1} at 230 V. The heating cables were installed in August 2013 and soil warming started on 1 March 2014, approximately 4 months after planting. We used "disturbance control" in this study (i.e., with cables buried but no heating). The temperature sensors (T109 from Campbell Scientific Inc., Logan, UT, USA) were placed between two cable lines in the soils at a depth of 10 cm. Three temperature sensors were installed in each warming plot and two in each control plot. Soil moisture in each plot was measured by using 2 ECH_2O-5 soil moisture probes (Decagon, Pullman, Washington, USA) placed between two cable lines in the soils at a depth of 10 cm.

2.3. Nitrogen addition

Nitrogen additions began at the time of the warming treatments in March 2014 and were applied monthly using an aqueous solution of NH_4NO_3 to achieve a total application rate of 40 and 80 kg N ha^{-1} yr^{-1} for the low N (LN and WLN) and high N (HN and WHN) treatments, respectively. The solutions were mixed with 800 mL of deionized water and applied evenly to each subplot of each treated plot using a watering can. The control and warming plots received 800 mL of deionized water without N. Nitrogen addition rate was only slightly higher than the local N deposition rate which averages 36.3 kg N ha^{-1} yr^{-1} (Zhang et al., 2013).

2.4. Rs measurements

Two PVC collars (20 cm in diameter) were installed at a soil depth of 5 cm for Rs measurements at the center of two seedlings in each plot. Rs measurements started in March 2014. Rs was measured biweekly using two automatic soil CO_2 flux systems (Li-8100A, LI-COR, USA) from 09:00 to 12:00 a.m. Soil temperatures were measured at 5-cm depth using a hand-held probe (Model SK-250WP, Sato Keiryoki Mfg. Co. Ltd, Tokyo, Japan) and soil moisture at 0–12 cm depth using time domain reflectometry (TDR 300 Soil Moisture Meter, Spectrum, USA). Measurements continued for one year until February 2015.