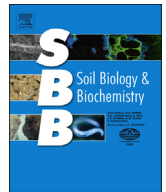




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Effects of simulated nitrogen deposition on soil respiration components and their temperature sensitivities in a semiarid grassland

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ABSTRACT

Nitrogen (N) deposition to semiarid ecosystems is increasing globally, yet few studies have investigated the ecological consequences of N enrichment in these ecosystems. Furthermore, soil CO₂ flux – including plant root and microbial respiration – is a key feedback to ecosystem carbon (C) cycling that links ecosystem processes to climate, yet few studies have investigated the effects of N enrichment on belowground processes in water-limited ecosystems. In this study, we conducted two-level N addition experiments to investigate the effects of N enrichment on microbial and root respiration in a grassland ecosystem on the Loess Plateau in northwestern China. Two years of high N additions (9.2 g N m⁻² y⁻¹) significantly increased soil CO₂ flux, including both microbial and root respiration, particularly during the warm growing season. Low N additions (2.3 g N m⁻² y⁻¹) increased microbial respiration during the growing season only, but had no significant effects on root respiration. The annual temperature coefficients (Q₁₀) of soil respiration and microbial respiration ranged from 1.86 to 3.00 and 1.86 to 2.72 respectively, and there was a significant decrease in Q₁₀ between the control and the N treatments during the non-growing season but no difference was found during the growing season. Following nitrogen additions, elevated rates of root respiration were significantly and positively related to root N concentrations and biomass, while elevated rates of microbial respiration were related to soil microbial biomass C (SMBC). The microbial respiration tended to respond more sensitively to N addition, while the root respiration did not have similar response. The different mechanisms of N addition impacts on soil respiration and its components and their sensitivity to temperature identified in this study may facilitate the simulation and prediction of C cycling and storage in semiarid grasslands under future scenarios of global change.

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1. Introduction

Human activities such as fossil fuel combustion, forest disturbance, and land conversion have elevated atmospheric concentrations of carbon dioxide (CO₂) and deposition of nitrogen (N) to the biosphere (Matson et al., 2002). Indeed, Earth's land surface has experienced an approximate doubling of reactive N input during the industrial era (Gruber and Galloway, 2008). Furthermore,

atmospheric N deposition is projected to increase by a factor of 2.5 from current levels by the end of this century (Lamarque, 2005). In the context of global climate change, one of the major scientific challenges regarding increased N deposition is to understand how it alters Carbon (C) cycling and storage (Tu et al., 2013). Given widespread N limitation of terrestrial primary productivity (Elser et al., 2007), changes in N enrichment may influence global C cycling profoundly with consequent feedbacks of the biosphere to climate change.

Most previous studies on the responses of ecosystem C cycling to N enrichment have focused on gross primary productivity (GPP) and net primary productivity (NPP, Elser et al., 2007). N enrichment usually increases GPP and NPP by stimulating plant growth and

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biomass production (Xia and Wan, 2008). Nevertheless, the majority of ecosystem C uptake through plant photosynthesis is eventually emitted back into the atmosphere via ecosystem respiration (ER), which itself can also be stimulated by N enrichment (Cleveland and Townsend, 2006; Xu and Wan, 2008). Ecosystem respiration is responsible to large annual CO₂ flux to the atmosphere, with soil respiration contributing ~50% of this flux across ecosystems (Schlesinger, 1997). However, large variations and inconsistencies in the responses of soil respiration to N addition have been found in the literature in different ecosystems and regions (Lee and Jose, 2003; Xu and Wan, 2008; Janssens et al., 2010; Liu et al., 2010). N additions have been shown to cause simultaneous changes to a suite of biotic and abiotic drivers of soil respiration, including litter quality and quantity, soil moisture, soil temperature, etc. Therefore, the effects of N deposition on soil C cycling require more detailed studies in different ecosystems.

One key factor contributing to the variability of past studies in N deposition effects on soil respiration is the fact that soil respiration consists of two components: one being root respiration from plant roots, mycorrhizal fungi, and other associated microorganisms (rhizosphere microorganisms) that use C that has been recently fixed by plant photosynthesis and the other being microbial respiration from decomposition of plant residues and soil organic matter (SOM, Ryan and Law, 2005). And the responses of root and microbial respiration to N addition were not consistent, perhaps because N deposition could either change the activity of soil microorganisms (Margesin et al., 2007; Allison et al., 2009) and/or change the community composition of soil microorganisms (Zhang et al., 2005). Moreover, N addition could either increase root biomass (Cleveland and Townsend, 2006) or decrease C allocation to belowground biomass (Giardina et al., 2004), resulting in corresponding changes in root respiration. Changes in the relative contribution of root respiration to soil respiration (root respiration ratio) could also be important in interpreting different responses of soil respiration to N addition among different ecosystem types (Yan et al., 2009). For example, Hanson et al. (2000) reported that root respiration ratio might vary among different ecosystems, ranging from 10% to 90%, likely due to considerable spatial and temporal variation of the supply of carbohydrates to root from aboveground photosynthesis (Zhou et al., 2007; Li et al., 2010), which, in turn, could be affected by N deposition. Thus, further investigation of the differential responses of root respiration and microbial respiration to N addition may be the key in achieving a more comprehensive understanding of the impacts of increasing N enrichment on soil respiration and C cycling.

Although elevated N deposition is likely to have broad-reaching effects on ecosystem properties and processes, these outcomes are likely to co-occur with other atmospheric changes associated with climate, including elevated temperatures and concentrations of CO₂. Both rates of soil respiration and NPP are strongly associated with temperature, and climate change is predicted to have large effects on the terrestrial C budget (Davidson and Janssens, 2006; Davidson et al., 2006). While numerous studies have examined the individual effects of these global change components on soil respiration (e.g. effects of soil moisture, see Sponseller, 2007; effects of soil temperature, see Wan et al., 2007), few have examined the interactions between these components. For example, few studies have examined if levels of N deposition to ecosystems might influence the temperature dependence of soil respiration (Mo et al., 2007), especially in semiarid grassland (e.g. Jia et al., 2012).

To evaluate the effects of N deposition on soil respiration and its components, we conducted an experiment that simulated elevated atmospheric N deposition in a semiarid grassland of the Loess Plateau. The Loess Plateau occupies a total area of 628,000 km² in

northern China and is mainly characterized by an arid and semiarid climate. It is known for its serious soil erosion. Meanwhile, its ecosystem is being exposed to increasing deposition of atmospheric N (Wei et al., 2011). We hypothesized that (1) N addition would stimulate soil respiration and its components, because N addition is known to stimulate plant growth, litter decomposition, root and microbial activity and respiration in other studies (Xu and Wan, 2008); (2) The root respiration and microbial respiration may respond differently to N addition; (3) N addition may affect the dependence of soil respiration on temperature (Q₁₀). Our main objectives were to explore the difference of soil respiration and its components between nitrogen addition treatments and to elucidate the factors influencing soil respiration and its components.

2. Materials and methods

2.1. Site description

Our experiment was conducted in a fenced (since 2005) grassland at the Semi-Arid Climate and Environment Observatory of Lanzhou University (SACOL) (35°57'N, 104°09'E; altitude 1966 m), about 40 km southeast of Lanzhou city, China. The grassland was established after cessation of a long-term farming operation in 1986. The region belongs to the continental semiarid climate with mean annual air temperature of 6.7 °C and mean annual precipitation of ~382 mm. The soil is classified as Calcaric Cambisol according to FAO/ISRIC/ISSS Soil Taxonomy, and the dominant plant species were *Stipa bungeana*, *Artemisia frigida* and *Tripolium vulgare* Ness. Plants begin to turn green in later March and wilt in end of October in this ecosystem.

2.2. Experimental design

The experiment used a complete block design with nine blocks (Fig. 1a). Each block consisted of one 4 m × 5 m whole-soil plot and three 0.5 m × 0.5 m root-free plots (these were placed at about 0.5-m intervals adjacent to the whole-soil plots, Fig. 1b), blocks were separated by at least 0.5-m walkways (Fig. 1a). Root-free plots were established in order to estimate microbial respiration. Each block was then assigned randomly to one of the following treatments: control (CK), low nitrogen addition (LN), and high nitrogen addition (HN).

Nitrogen additions were initiated in May 2009 and repeated twice annually in late May and late June of each year. Application timing was chosen according to the rainfall events of this area (the rain season begins in May, data not show). Nitrogen was added in the form of urea (CO (NH₂)₂) in water at the rate of 2.3 and 9.2 g N m⁻² y⁻¹ in the LN and HN treatments, respectively (each application was 1.15 g N m⁻² and 4.6 g N m⁻² in LN and HN treatment, respectively). The low rate of N addition was chosen to represent the highest rate of atmospheric N deposition at this site which estimated at about 0.2–2.2 g N m⁻² y⁻¹ and average 0.8 g N m⁻² y⁻¹ (Lü and Tian, 2007). In each application, the fertilizer was weighed, dissolved in 10 L of water, and applied to the plots using a portable sprayer. The control plot received 10 L of water without fertilizer.

In early May 2010, trenches (0.1 m wide and 0.5 m deep) were excavated around each plot that was identified to become root-free. Trench were lined with nylon mesh (0.038 mm mesh size) to prevent root growth into the plots but allow the movement of water, bacteria, organic matter, and minerals (this is the reason that root-free plots were smaller than whole-soil plots) (Moyano et al., 2007), the trench was then refilled with soil. The root-free plots were then kept free of vegetation by cutting the plants regrowth manually throughout the study period, additional care was given to minimize

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