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Effect of nitrogen and acid deposition on soil respiration in a temperate forest in China

Shuai Zheng[a], Hongfeng Bian[a,*], Quan Quan[b], Li Xu[b], Zhi Chen[b], Nianpeng He[b,c,d,e,**]

[a] State Environmental Protection Key Laboratory of Wetland Ecology and Vegetation Restoration, School of Environment, Northeast Normal University, Changchun 130117, China
[b] Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[c] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China
[d] Institute of Grassland Science, Northeast Normal University, Changchun 130024, China
[e] Key Laboratory of Vegetation Ecology, Ministry of Education, Changchun 130024, China

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ABSTRACT

With the rapid development of the economy and society, synchronous increases in atmospheric nitrogen (N) and acid deposition might exert an important effect on the soil respiration of terrestrial ecosystems, simultaneously and interactively. To date, the interactive mechanisms of N and acid deposition on soil respiration (nutrient effect *vs.* acidification effect) remain unclear, because most studies only focused on simulating N deposition. Here, we conducted a field experiment in which simulated atmospheric N and acid deposition in a temperate forest of China, to explore their effects on soil respiration. Our results showed that N deposition reduced the cumulative release of CO_2 by 7.47% during the growing season. Acid deposition and the interaction of N and acid deposition decreased soil respiration rate (R_S) by 0.23% and 1.54%, respectively. Total phospholipid fatty acids (PLFAs) increased by 17.24% with N treatment. The interaction of N and acid deposition reduced total PLFAs by 6.14%. Unexpectedly, all experimental treatments reduced the temperature sensitivity (Q_{10}) of soil respiration to some extent; thus, N and acid deposition might partially weaken the positive effect of warming on CO_2 release from soils under global warming scenarios. The processes and ecological effects of N and acid deposition are simultaneous and inseparable in nature. Therefore, the effects of multi-factor interactions on soil respiration and their regional differences require further investigation.

1. Introduction

Accompanied with economic development in recent decades, the rapid increase in nitrogen (N) deposition from the atmosphere has strongly influenced the global nitrogen cycle and nitrogen balance. Atmospheric N deposition is already serious in East Asia, the United States, and Europe, while the fastest rate of increase is being documented in China (Jia et al., 2016; Zhu et al., 2015). Soil respiration is associated with many components of ecosystem carbon (C) cycles, and plays a key role in regulating atmospheric carbon dioxide (CO_2) concentrations. Some studies have demonstrated the effects of atmospheric N deposition on soil respiration by regulating the amount and time of N addition in different ecosystems (Bowden et al., 2004; Zhu et al., 2013). The responses of soil respiration to stimulating atmospheric N deposition in different forests differs due to differences in vegetation types and soil conditions. The responses are inconsistent, mainly as promotion (Peng et al., 2011; Tu et al., 2011), inhibition (Janssens et al., 2010; Ramirez et al., 2010), and no effect (Allison et al., 2008; Samuelson et al., 2009). Increased N deposition tends to enhance soil N availability and promote the growth of plants and microbes, *i.e.*, the promoting effect. In comparison, soil acidification accompanied with increased N deposition might inhibit soil respiration by altering microbial community structure and reducing microbial activity (Su et al., 2016). To date, it remains unclear how atmospheric N deposition influences soil respiration (nutrient effect *vs.* acidification effect).

There is wide concern that increasing atmospheric acid deposition gives rise to acidification in many terrestrial ecosystems, which is accompanied with atmospheric N deposition (Fig. S1). Although acid

* Correspondence to: H.F. Bian, State Environmental Protection Key Laboratory of Wetland Ecology and Vegetation Restoration, School of Environment, Northeast Normal University, Changchun 130117, China.
** Correspondence to: N.P. He, Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China.
E-mail addresses: bianhf108@nenu.edu.cn (H. Bian), henp@igsnrr.ac.cn (N. He).

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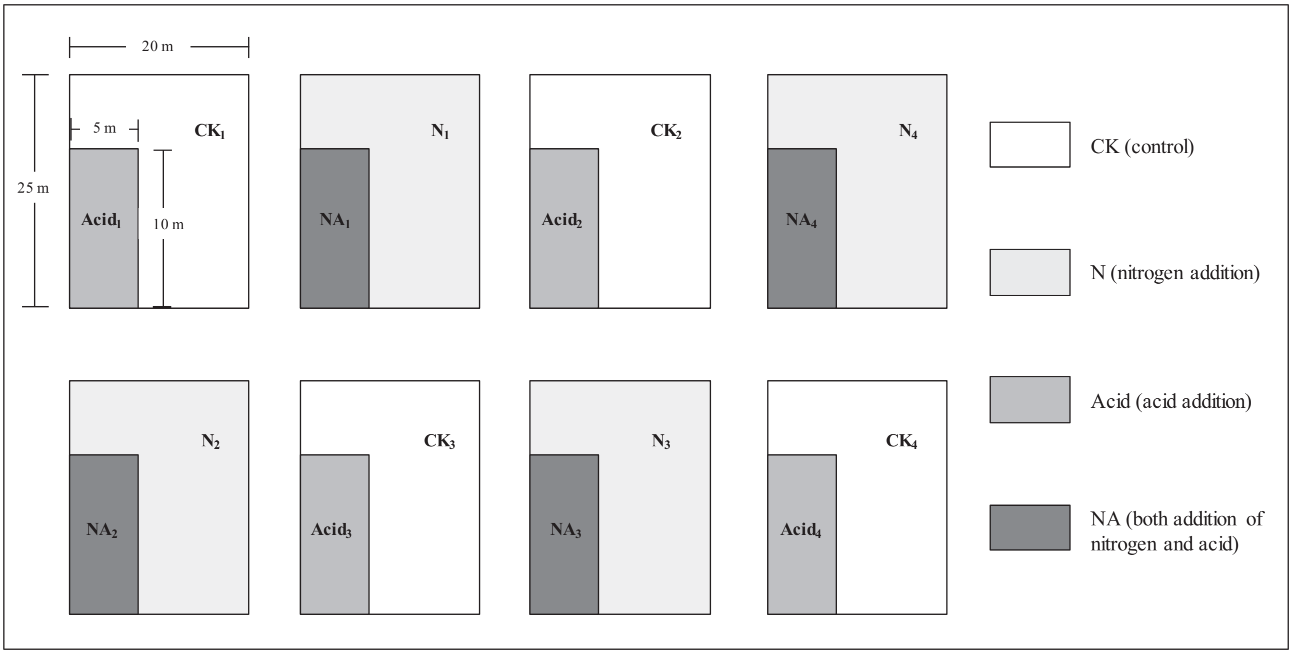

Fig. 1. Diagram of the experimental plots used to simulate atmospheric nitrogen and acid deposition. The addition of nitrogen (N) was achieved using ammonium nitrate (NH_4NO_3) at 10 g N m^{-2} a^{-1}. Acid addition (Acid) was 98% concentrated sulfuric acid diluted to 1% at the rate of 0.92 mol H^+ m^{-2} a^{-1}, and evenly sprayed onto the corresponding plots each month. Each experimental treatment had four replicates.

deposition has declined in developed countries recently, it is continuously increasing in developing regions and countries, particularly China (Wang and Xu, 2009; Yu et al., 2017). $SO_4{}^{2-}$, $NO_3{}^{-}$, and other acidic substances directly damage plant organs and their physiological function through precipitation on the surface of leaves. A large amount of H^+ in precipitation falls onto the soils, disrupting the soil ion balance, leading to run off containing more active K^+, Ca^{2+}, Na^+, Mg^{2+} and other base ions. When precipitation exceeds evaporation, these base ions in soils are lost through leaching processes, resulting in soil acidification and alteration in soil microbial community composition and activity (Driscoll et al., 2003; Singh and Agrawal, 2008). Vanhala et al. (1996) found that strong acid rain depressed the soil respiration rate (R_S) by 20% after 8-years simulating acid rain in the sub-frigid forests of Finland.

As shown in Fig. S1, scientists are not able to analyze the ecological effects of atmospheric N deposition and atmospheric acid deposition separately, because they occur synchronously and interact with each other in atmospheric and soil processes. Acid deposition through precipitation contains H^+, sulfate ($SO_4{}^{2-}$) and nitrate ($NO_3{}^{-}$), which directly reduce soil pH. Similarly, $NO_3{}^{-}$ input to the soil through N deposition leads to soil acidification and the loss of base cations after a series of cation exchanges in soils (Bowman et al., 2008). All evidence supports that the processes and ecological effects of atmospheric N deposition and atmospheric acid deposition interact with each other and should not be separated (Fig. S1). Both processes potentially exacerbate soil acidification, influencing soil respiration through regulating vegetation types, above- and below-ground biomass, and microbial activity (Allison et al., 2008; Craine et al., 2001; Magill and Aber, 1998). Yet, few studies have explored the interacting mechanisms of N deposition and acid deposition on soil respiration in terrestrial ecosystems (Chen et al., 2016; Li et al., 2018).

In this study, we conducted a field experiment to simulate atmospheric N and acid deposition in a typical temperate forest of China, to explore their effects on soil respiration. In practice, we measured monthly soil respiration rates (R_S), soil temperature (T), soil water content (SWC), soil pH, oxidation-reduction potential (ORP), and phospholipid fatty acid (PLFAs). The main objectives of this study were to: (1) investigate how soil respiration responds to N deposition and acid deposition; and (2) explore how soil environmental and biotic factors control the responses of soil respiration to N deposition and acid deposition. Our results are expected to provide novel insights on how N deposition and acid deposition interact to regulate soil respiration, and emphasize the importance of evaluating these two processes in combination in the future.

2. Methods

2.1. Site description

This experiment was conducted in a typical temperate forest near to Beijing, China. The study area has high temperature and rain in summer, but is cold and dry in winter. The mean annual temperature is approximately 6.3 °C, with the maximum and minimum temperatures occurring in July and January, respectively. The mean annual precipitation is about 612 mm, with 74% of precipitation occurring between June and August. The soil type in the area is mainly brown and cinnamon soil (Wang et al., 2016; Quan et al., 2015). The initial basic soil characteristics are as follows: soil pH: 6.58 ± 0.49; soil organic matter: 6.90 ± 0.81%; soil total nitrogen: 0.30 ± 0.05%; C/N ratio of soil: 13.73 ± 1.73; $NH_4{}^{+}$: 9.42 ± 0.44 mg kg^{-1}; $NO_3{}^{-}$: 6.42 ± 1.10 mg kg^{-1} (Quan et al., 2014; Liu et al., 2017). Due to long term lumbering since the 1950s, artificial afforestation (*Pinus tabulaeformis* Carr.) is widespread, existing vegetation being dominated by an artificial coniferous forest (Quan et al., 2014). Pine forests in the area are relatively stable after 60 years of growth, providing suitable natural plots for this study.

P. tabulaeformis forests are the most widely distributed temperate coniferous forests in China, especially in North China, and this species is unique to China (Li et al., 2014). We set the experimental plots in a *P. tabulaeformis* forest, which are administrated by the Beijing Forest Ecosystem Research Station, CAS (39°58′ N, 115°25′ E, 1278 m altitude). The dominant species in these forests are *P. tabulaeformis*, *Q. wutaishanica* Mary, and *Ulmus davidiana* Planch. A few shrubs and herbaceous plants are present in the understory. As reported by previous studies (Jia et al., 2016; Zhu et al., 2015; Yu et al., 2016), this region has been subjected to serious atmospheric N and atmospheric

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