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Short communication

Meta-analyses of the effects of major global change drivers on soil respiration across China

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HIGHLIGHTS

- Simulated acid rain significantly decreased soil respiration (*Rs*) across China.
- Warming, N addition and precipitation increase significantly increased *Rs*.
- The responses of *Rs* varied with ecosystem types and experimental treatments.
- The responses of *Rs* under global change in China are similar to those in the global.

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ABSTRACT

Soil respiration (*Rs*) is affected largely by major global change drivers, global meta-analysis studies have synthesized the available information to determine how *Rs* responds to these drivers. However, little is known about the effects of these drivers on *Rs* across China. Here, we conducted a meta-analysis to synthesize 80 studies published in the literature with 301 paired comparisons to quantify the responses of *Rs* to simulated warming, nitrogen addition, precipitation increase and acid rain across Chinese terrestrial ecosystem. Results showed that global change drivers significantly changed *Rs* across Chinese ecosystems. Warming, nitrogen addition, and precipitation increase significantly increased *Rs* by 9.08%, 5.21%, 31.68%, respectively, while simulated acid rain decreased *Rs* by 7.06%. The responses of *Rs* to warming, nitrogen addition, and precipitation increase are similar in both direction and magnitude to those reported in global syntheses, except for higher response ratio under precipitation increase in China. In addition, the responses of *Rs* were different among ecosystem types, and among experimental treatments. Warming significantly increased *Rs* in croplands but did not change in forests and grasslands. The effect magnitude of N addition on *Rs* in grasslands and croplands was much higher than those in other ecosystems. In general, precipitation increase stimulated *Rs* in different ecosystems, and its effect magnitudes increased with changed precipitation levels. However, acid rain inhibited *Rs* in different biomes and intensities of acid rain. Our findings contribute to better understanding of how *Rs* will change under global change, and provide important parameters for carbon cycle model at the regional scale.

1. Introduction

Soil respiration (*Rs*) represents CO_2 release through the soil surface from autotrophic root respiration and heterotrophic respiration which is associated with the decomposition of litter, roots and soil organic matter (Boone et al., 1998; Kuzyakov, 2006; Schindlbacher et al., 2009). As one of the largest fluxes in the global carbon cycle (Raich and Schlesinger, 1992; Bond-Lamberty and Thomson, 2010), *Rs* plays a vitally important role in regulating atmospheric CO_2 concentration and climatic dynamics in the Earth system (Davidson et al., 2002; Luo and Zhou, 2006). The rate of *Rs* is affected largely by global change drivers, including climate warming, increased nitrogen (N) deposition, elevated CO_2 concentration and altered precipitation pattern, etc. (Bowden et al.,

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2004; Cardon et al., 2001; Deng et al., 2010). Therefore, understanding the regulations of *Rs* by multiple global change drivers is necessary to project global carbon cycling in the future (Deng et al., 2010). Several global meta-analysis studies have synthesized the available information to determine how *Rs* responds to these drivers. Their results showed that at the global scale, warming (Wu et al., 2011; Lu et al., 2013; Wang et al., 2014), N addition (Lu et al., 2011; Zhou et al., 2014), and increased precipitation (Wu et al., 2011; Liu et al., 2016) significantly stimulated *Rs*, while decreased precipitation reduced *Rs* (Lu et al., 2011; Liu et al., 2016). However, the impacts of these drivers on *Rs* were different, depending on ecosystem types and experimental treatments (e.g. N addition level, N form, etc.). These studies have greatly improved our understanding of global *Rs* response in a changing world; however, regional or local responses of *Rs* can be different.

As the most populous country and the second largest economy in the world, China's rapid economic development, population growth and anthropogenic activities have accelerated the changes in climate and ecosystem processes, and have caused some serious environmental issues (Chapin et al., 2011; Chen et al., 2015a). The latest data show that the annual average air temperature in China has increased by 0.9–1.5 °C during 1909–2011 and will rise continuously. By the end of this century, annual air temperature in China would increase by 1.3–5.0 °C, which is higher than that in global with the average value of 1–3.7 °C (TNRCC, 2015). In the past 100 years, the annual precipitation in China didn't show a significant change trend, but had obvious regional differentiation of precipitation distribution, with increasing precipitation in semiarid and arid areas during the past 30 years (TNRCC, 2015). The averaged N deposition in China had increased sharply between 1980s (13.2 kg N ha^{-1}) and 2000s (21.1 kg N ha^{-1}), and is projected to increase in the coming decades (Liu et al., 2013). Moreover, southern China has become the third largest area affected by acid rain, following Europe and the United States (Wang and Xu, 2009). Hence, the potential effects of these climate and environmental changes on the *Rs* should be different in Chinese terrestrial ecosystem, and need to be evaluated quantitatively.

Recently, two meta-analyses related to *Rs* responses to major global change drivers across Chinese ecosystems have been conducted at the regional scale. Fu et al. (2015) found that precipitation increase significantly increased *Rs*, while N addition and warming did not affect *Rs*. However, Chen et al. (2015a) showed negative effect of N addition on *Rs*. To some extent, these findings can help us understand how *Rs* respond to N addition, warming and precipitation increase at the national scale. However, their results on N addition were inconsistent, and the effect of acid rain on *Rs* hasn't been evaluated yet. Moreover, China has diverse ecosystems types and vegetation communities. Therefore, the response of *Rs* may differ among ecosystems in direction or magnitude. Unfortunately, how *Rs* respond to global change drivers among ecosystem types, and among experimental treatments across China remains lacking.

In this study, we used a meta-analysis approach to synthesize all available data relating to *Rs* responses to these drivers across Chinese terrestrial ecosystem. Our main objectives were to: (1) quantify the responses of *Rs* to major global change factors; (2) examine whether ecosystem types and experimental treatments influence the responses of *Rs*; (3) compare the responses of Chinese terrestrial ecosystem with those from previous global meta-analyses.

2. Materials and methods

2.1. Data collection

Peer-reviewed journal articles and theses published before 10 March 2016 were searched using Web of Science (Thomson Reuters, New York, NY, USA) and the China Knowledge Resource Integrated Database (CNKI, available online: http://epub.cnki.net). The searches looked for relevant papers whose title, abstract, or keywords referred to: soil respiration, soil carbon flux/efflux/emission, root/autotrophic respiration, microbial/heterotrophic respiration; warming, elevated/increasing temperature, nitrogen (N) addition/deposition/fertilization/input/enrichment/application, urea; simulated acid rain, acid rain simulation/deposition; increase/decrease precipitation (rain), enhance/exclude/reduce precipitation (rain), water add, watering, alter/changing precipitation (rain); elevated/increased CO_2, CO_2 enrichment; global change experiment, China. The detailed keywords and search term combinations were listed in Supplementary Information Table S1. All field studies evaluating the effects of simulated global change drivers on *Rs* conducted in China were selected following the criteria as described in some meta-analyses (Zhou et al., 2014; Fu et al., 2015; Chen et al., 2015a; Yue et al., 2016). To avoid the influence of short-term noise, we only selected experiments where the duration of *Rs* measurements was longer than one growing season. We only compiled databases for studies related to warming, N addition, precipitation increase and simulated acid rain because of data limitations for elevated CO_2 and precipitation decrease experiments in China. Our search criteria lead to 301 paired comparisons from 80 published papers, with 49 warming treatments, 136 N addition treatments, 49 precipitation increase treatments, and 67 treatments that simulated acid rain (Supplementary Information Table S2). The distribution of selected field experiments was shown in Fig. 1.

2.2. Meta-analysis

The data were analyzed using the meta-analysis methods described by Hedges et al. (1999), Luo and Zhou (2006), and Liao et al. (2008). A response ratio (*RR*, natural log of the ratio of the mean value of *Rs* in treatment plot to that in control) was used to estimate the effect magnitude for each individual observation; *RR* and its variance (v) were calculated as:

$$RR = \ln\left(\overline{X_t}/\overline{X_c}\right) = \ln\left(\overline{X_t}\right) - \ln\left(\overline{X_c}\right) \quad (1)$$

$$v = \frac{S_t^2}{n_t\overline{X_t}^2} + \frac{S_c^2}{n_c\overline{X_c}^2} \quad (2)$$

where and $\overline{X_c}$, S_c, and n_c represent the mean, standard deviation, and sample size of *Rs* in the control group, respectively; $\overline{X_t}$, S_t, and n_t represent the mean, standard deviation, and sample size of *Rs* in the treatment group, respectively (Hedges et al., 1999). The reciprocal of its variance ($1/v$) was considered as the weight of each *RR*, and the weighted response ratio (RR_{++}) was calculated from *RR* of individual pairwise comparison between control and treatment.

To test whether the experimental conditions alter the response magnitude to the four simulated drivers, each treatment (e.g. N form) was further categorized into 2–4 groups (Table 1) based on previous studies (Lu et al., 2013; Liang et al., 2013; Chen et al., 2015a; Fu et al., 2015). RR_{++} and its related 95% confidence interval (CI) were calculated using meta-analytical software MetaWin 2.1 (Sinauer Associates Sunderland, MA, USA). And we conducted our calculation using random-effects model because of high heterogeneity from individual studies in our database, which can partly eliminate heterogeneity effects. If the 95% CI did not overlap with zero, the effect on *Rs* was considered significant. We also used *t*-test to test whether the response ratio in treatment was