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Temperature sensitivity of soil respiration in China's forest ecosystems: Patterns and controls

Zhenfeng Xu [a,*], Shishan Tang [a], Li Xiong [a], Wanqin Yang [a,*], Huajun Yin [b], Lihua Tu [c], Fuzhong Wu [a], Lianghua Chen [a], Bo Tan [c]

[a] Key Laboratory of Ecological Forestry Engineering, Institute of Forest & Ecology, Sichuan Agricultural University, Chengdu 611130, China
[b] Chengdu Institute of Biology, Chinese Academy of Sciences, Chengdu 610041, China
[c] College of Forestry, Sichuan Agricultural University, Chengdu 611130, China

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ABSTRACT

Soil respiration, one of the most important carbon fluxes in terrestrial ecosystems, is very sensitive to climate change. Understanding the spatial patterns of temperature sensitivity of soil respiration (Q_{10}) and its controlling factors is very important to quantify the climate–carbon cycle feedback at regional scales. In this study, we conducted a synthesis of 74 field measurements on Q_{10} value across China's forests. Based on the overall data, the Q_{10} values ranged from 1.10 to 5.18, with a mean value of 2.51. Moreover, the largest relative frequency of Q_{10} values was within the range of 2.0–3.0. The Q_{10} value in China's forests was significantly and negatively correlated with mean annual temperature and mean annual precipitation. However, the Q_{10} values increased with latitude and altitude but there was no obvious relationship between Q_{10} and longitude. There were no significant differences in Q_{10} among evergreen coniferous forest, coniferous-broadleaved mixed forest, deciduous broadleaved forest and deciduous coniferous forest. However, the Q_{10} of evergreen broadleaved forest was significantly lower than that of evergreen coniferous forest and deciduous coniferous forest. The findings may advance our understanding on the different environmental controls of Q_{10} of soil respiration and also improve our ability to predict regional-scale soil carbon flux in a changing world.

1. Introduction

Soil-surface CO_2 efflux, commonly referred to as soil respiration, is key carbon cycle process that releases CO_2 from the soil via the metabolic respiration of live roots, associated mycorrhiza, and microbial decomposition of litter and soil organic matter (Fang and Wang, 2007). Global warming is expected to stimulate soil respiration and the increased CO_2 efflux from soils could result in further warming (IPCC, 2007). The temperature sensitivity of soil respiration (often termed as Q_{10} value), the factor by which soil respiration increases by 10 °C increases, is a key parameter to evaluate the feedback intensity between soil C efflux and climate warming (Reichstein et al., 2005; Davidson and Janssens, 2006). Thus, the strength of this feedback is dependent largely on the temperature sensitivity of soil respiration, which has been identified as one of the major sources of uncertainty in model projections of climate change (Friedlingstein et al., 2006).

Previous studies commonly treated Q_{10} as a constant of 2 in many ecosystem models (e.g., Aber et al., 1997; Tian et al., 1999). A slight deviation in Q_{10} might cause a significant bias in the estimate of C budget (Xu and Qi, 2001). A large number of studies have demonstrated that the Q_{10} value is largely regulated by plant species, climate and substrate availability (Raich and Tufekcioglu, 2000; Wang et al., 2010). As well as we known, these factors are spatially heterogeneous. Therefore, Q_{10} value resulted from field measurement may vary with geographic locations. On national or global scale, several studies have reported the effects of climatic factors, measurement methods and vegetation activity on Q_{10} (Chen and Tian, 2005; Wang et al., 2010; Peng et al., 2009). However, a comprehensive understanding of how the spatial variation of Q_{10} value varies with geographic variables still remains unclear. In addition, the rate of climate warming varies in space and time at large (Xia et al., 2014). Thus, knowledge on geographic patterns and controls of Q_{10} value at the large scale is crucial for better understanding of C cycle in a warmer world (Wang et al., 2010).

* Corresponding authors at: Institute of Forest & Ecology, Sichuan Agricultural University, 211#, Huimin Road, Wenjiang, Sichuan 611830, China.
Tel.: +86 28 86291112; fax: +86 28 86290957.
E-mail addresses: xuzf@sicau.edu.cn (Z. Xu), yangwq@163.com (W. Yang).

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China covers tropical, subtropical and temperate climate zones from the south to north, and humid, semi-humid, semi-arid and arid areas from the southeast to northeast (Fang et al., 2010). China has geographic regimes ranging from western high mountains to eastern lowlands (Fang et al., 2001). The different climate gradients and landforms support a series of forest ecosystems ranging from the tropical rain forest and subtropical evergreen broad-leaved forest in the south to the boreal coniferous forest in the north or in the eastern Tibetan Plateau. Such diverse forests, climates and landforms are very helpful for understanding mechanisms of abiotic and biotic controls on the variability of Q_{10} value. Experimental studies of Q_{10} have extensively been performed at many sites across China over the last decades (e.g., Wang et al., 2006; Chen et al., 2010). It is clear that assessing the national C cycle demands an understanding of how Q_{10} value is regulated over broad spatial scales.

As mentioned above, we hypothesized that Q_{10} value should increase with latitude/altitude because temperature, precipitation, and plant productivity decrease from the Equator to the North or from low to high altitude. Here, we constructed a comprehensive database of Q_{10} values estimated from field experiments across China's forests to examine variations of Q_{10} value to geographic variables (latitude, longitude and altitude) and climatic factors (mean annual temperature and mean annual precipitation) from original literatures. Moreover, we explore the variations of Q_{10} value among different forest types. Based on this database, we then tried to seek general patterns of Q_{10} values along environmental variables.

2. Materials and methods

2.1. Data extraction

We collected data (publication before 2014) on Q_{10} values of soil respiration in China's forest ecosystems from published literatures for example Yan et al. (2006), Fang et al. (2009), and Chen et al. (2010). To avoid bias in publication selection, we select the literatures that satisfy the following 5 criteria. (1) The Q_{10} value of soil respiration was derived from longer than six months of measurements; (2) to ensure the comparability of environmental variables among studies, the experiments conducted in laboratory were excluded; (3) soil respiration were measured using closed dynamic chamber method; (4) the Q_{10} values were inferred from soil temperature of 5 cm depth; (5) the Q_{10} values were estimated using van't Hoff equation (Van's Hoff, 1898).

$$SR = \alpha \times \exp(\beta \times T)$$

where SR is measured soil CO_2 efflux and T is the measured temperature. Coefficient α is the intercept of soil respiration when temperature is zero and coefficient β represents the temperature sensitivity of soil respiration. The Q_{10} values are calculated as:

$$Q_{10} = \exp(10 \times \beta)$$

Within these constraints, we obtained 145 datasets from 74 published studies available for analysis (Fig. 1). In most of publications, the Q_{10} values and coefficient of determination (R^2) of the model were presented and we incorporated them into our database directly. We recalculated the Q_{10} values according to the available information in several publications that Q_{10} values were not provided directly. In addition, to explore the controlling factors of Q_{10} value, we also recorded other information including geographic variables (latitude, longitude and altitude), climatic factors (mean annual temperature, MAT and mean annual precipitation, MAP), and forest type from original literatures. In order to estimate the role of biome, we classified forest types into evergreen broadleaved forest (EBF), evergreen coniferous forest (ECF), broadleaved and coniferous mixed forest (MF), deciduous broadleaved forest (DBF) and deciduous coniferous forest (DCF) according to the vegetation descriptions in the quoted papers. Site latitude ranges from 20 to 51N; longitude ranges from 100 to 130E; altitude noted in this study ranges from 30 to 3242 m. Most of the

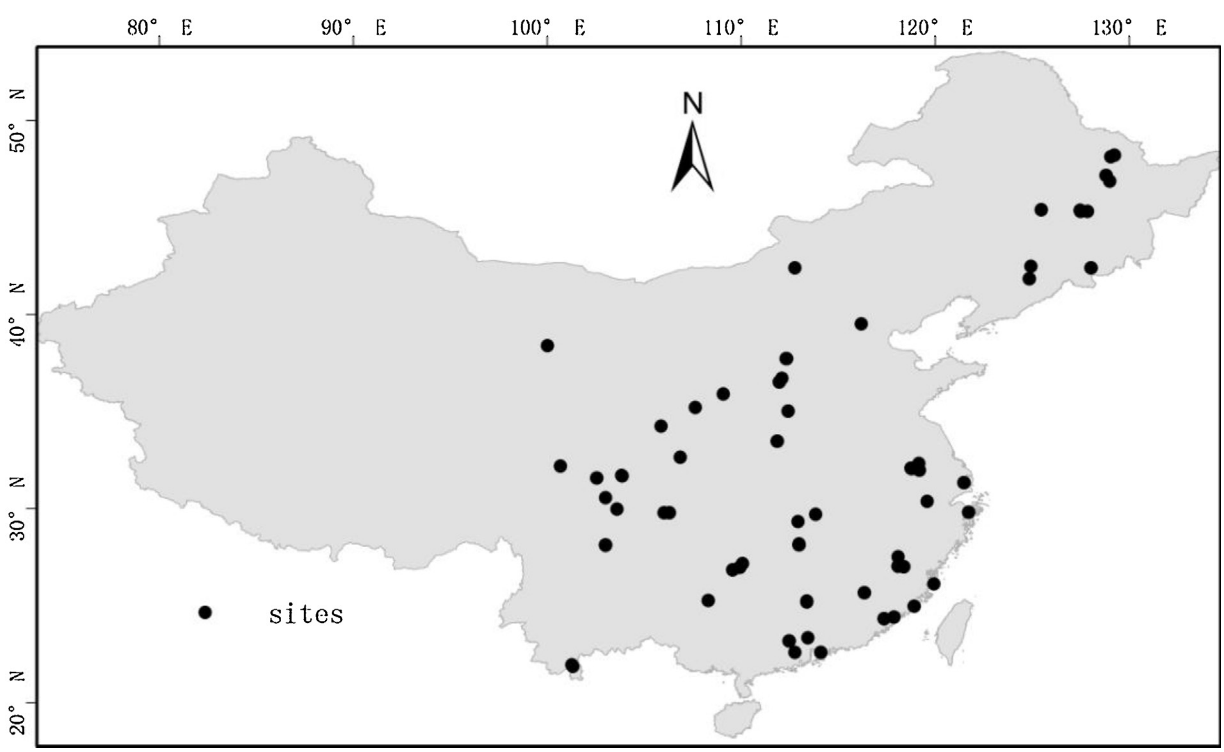

Fig. 1. Locations of soil respiration studies across China's forests.