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Review

Quantification of soil respiration in forest ecosystems across China

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HIGHLIGHTS

- Mean annual soil respiration rate was 33.65 t CO_2 ha^{-1} $year^{-1}$ across Chinese forest ecosystems.
- Mean Q_{10} value of 1.28 was lower than the world average (1.4–2.0).
- Artificial neural network model may effectively predict Rs across Chinese forest ecosystems.
- Q_{10} values derived from the soil temperature significantly increased with elevation and latitude.

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ABSTRACT

We collected 139 estimates of the annual forest soil CO_2 flux and 173 estimates of the Q_{10} value (the temperature sensitivity) assembled from 90 published studies across Chinese forest ecosystems. We analyzed the annual soil respiration (Rs) rates and the temperature sensitivities of seven forest ecosystems, including evergreen broadleaf forests (EBF), deciduous broadleaf forests (DBF), broadleaf and needleleaf mixed forests (BNMF), evergreen needleleaf forests (ENF), deciduous needleleaf forests (DNF), bamboo forests (BF) and shrubs (SF). The results showed that the mean annual Rs rate was 33.65 t CO_2 ha^{-1} $year^{-1}$ across Chinese forest ecosystems. Rs rates were significantly different ($P < 0.001$) among the seven forest types, and were significantly and positively influenced by mean annual temperature (MAT), mean annual precipitation (MAP), and actual evapotranspiration (AET); but negatively affected by latitude and elevation. The mean Q_{10} value of 1.28 was lower than the world average (1.4–2.0). The Q_{10} values derived from the soil temperature at a depth of 5 cm varied among forest ecosystems by an average of 2.46 and significantly decreased with the MAT but increased with elevation and latitude. Moreover, our results suggested that an artificial neural network (ANN) model can effectively predict Rs across Chinese forest ecosystems. This study contributes to better understanding of Rs across Chinese forest ecosystems and their possible responses to global warming.

1. Introduction

Soil respiration is an important flux of carbon in forest ecosystems and globally (Schlesinger and Bernhardt, 2013). With a total area of 195.45 million hectares, Chinese forests cover 20% of the surface of China (State Forestry Administration, 2011), representing a variety of different conditions across 50 degrees of latitude between 53°N and 3°N. This paper analyzes the available data for soil respiration in Chinese forests, to elucidate patterns with climate, soils, and location, which have proven to be important in other

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recent work (Davidson and Janssens, 2006; Peng et al., 2009; Raich and Schlesinger, 1992; Zheng et al., 2009).

The relationships between either Rs or Q_{10} (the factor by which soil respiration increases upon a 10 °C rise in temperature) and other independent variables are rarely linear in nature. An artificial neural network (ANN) model can be used to overcome the non-linearity problem. The ANN is a form of artificial intelligence that was inspired by the studies of the human neuron and has been used to analyze biophysical data (Hewitson and Crane, 1994; Levine et al., 1996; Wasserman, 1989). The ANN model can auto-analyze the relationships between multi-source inputs (including combinations of qualitative and quantitative data) by self-learning and can produce results without a hypothesis. Several studies have indicated that the ANN model can be used to establish relationships with linear or non-linear mapping equations to a desirable accuracy (Somaratne et al., 2005; Xu and Wu, 2002). Therefore, an ANN model was also applied to analyze the relationships between either soil respiration or Q_{10} and other independent variables in this study.

The objectives of this study were to analyze the patterns of Rs and its temperature sensitivity across various forest types, and identify the key controlling factors including climatic variables, soil quality and topography.

2. Materials and methods

2.1. Data collection

We collected available soil respiration data of Chinese forest ecosystems from publications identified via a keyword search using the terms "soil respiration", "soil CO_2 flux", "soil carbon flux", and "soil carbon emission" from the Web of Science and the China Knowledge Resource Integrated Database. The following criteria were used to ensure data consistency and accuracy: (1) the measurements were collected in the field; (2) the investigation time was not less than 12 months in order that the annual soil respiration rate could be estimated; and (3) the investigation time for Q_{10} was more than 3 months.

An exponential equation (Eq. (1)) was used to describe the relationship between the soil respiration rate and soil temperature.

$$\mathrm{Rs} = \alpha e^{\beta T} \tag{1}$$

where Rs is the soil respiration rate, T is the soil temperature at different depths, and α and β are fitted parameters. The Q_{10} values were calculated using the following equation:

$$Q_{10} = e^{10\beta} \tag{2}$$

Within these constraints, 139 estimates of the annual forest soil CO_2 flux and 173 estimates of the Q_{10} value were assembled from 90 published studies across China (Fig. 1, Table S1). These Q_{10} values were calculated based on the soil temperature at four different depths (ST5, soil temperature at 5 cm; ST10, soil temperature at 10 cm; ST15, soil temperature at 15 cm; and ST20, soil temperature at 20 cm). The 173 Q_{10} value estimates consisted of 107 estimates derived by ST5, 47 by ST10, 15 by ST15, and 4 by ST20.

2.2. Statistical analysis

Based on the forest types reported in these publications, the estimates were divided into seven groups, including (1) evergreen broadleaf forests (EBF), (2) deciduous broadleaf forests (DBF), (3) broadleaf and needleleaf mixed forests (BNMF), (4) evergreen needleleaf forests (ENF), (5) deciduous needleleaf forests (DNF), (6) bamboo forests (BF) and (7) shrubs (SF). Total 139 estimates of the annual forest soil CO_2 flux were mostly dominated by the EBF, DBF and ENF ecosystems (Fig. 2). For each study site, the supporting information, including the forest type, soil organic C (SOC) at a depth of 20 cm, annual litterfall, latitude and longitude, elevation, and methods of measuring soil respiration and climatic factors was recorded. Climatic factors include the mean annual temperature (MAT), mean annual precipitation (MAP), although another

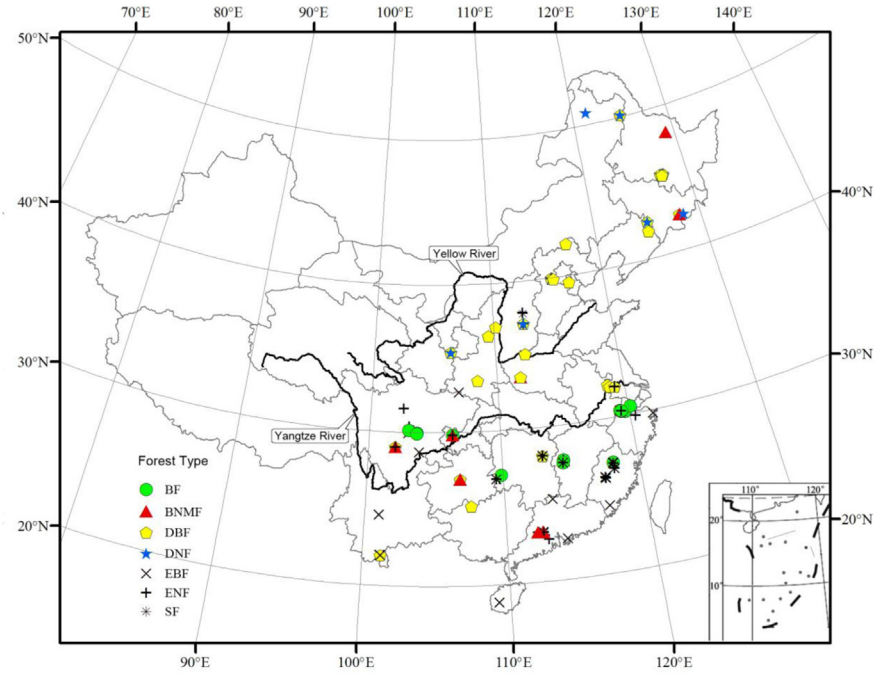

Fig. 1. The site distribution of the soil respiration studies across Chinese forest ecosystems. The DBF, DNF, EBF, ENF, BNMF, BF, and SF represent deciduous broadleaf forests, deciduous needleleaf forests, evergreen broadleaf forests, evergreen needleleaf forests, broadleaf and needleleaf mixed forests, bamboo forests, and shrubs, respectively.