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Tree species diversity promotes soil carbon stability by depressing the temperature sensitivity of soil respiration in temperate forests

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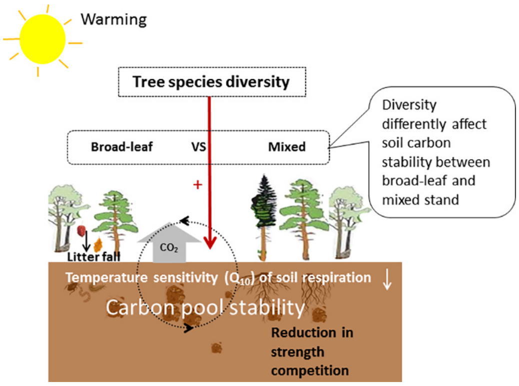
HIGHLIGHTS

- Tree species diversity affects the temperature sensitivity of soil respiration.
- Higher species diversity leads to lower Q_{10} for both broad-leaf and mixed stands.
- Spatial variation of soil respiration is independent of tree species diversity.
- Diversity affects soil C stability differently in broad-leaf and mixed stands.

GRAPHICAL ABSTRACT



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ABSTRACT

The diversity-stability interrelationship suggests that high diversity can buffer fluctuations in environmental conditions such as temperature; we thus hypothesize that tree species diversity will lower the temperature sensitivity of soil respiration (R_s), known as Q_{10} value. Our hypothesis was tested in a deciduous broad-leaf and a coniferous-broad-leaf mixedwood stand in the warm temperate region in China. We measured soil respiration and indices of tree species diversity including species richness (S), the Berger-Parker index (d), the Simpson index (λ), the Shannon index (H_e'), and the Pielou evenness index (J_e). Our results generally confirm our hypothesis that Q_{10} was positively correlated to λ, but negatively related to H_e', d, and J_e, and independent of S, in both stands. However, R_s was independent of the diversity indices. These findings imply that tree species diversity promotes soil carbon stability by depressing the Q_{10}. Furthermore, different biotic and abiotic variables explained the variations of species diversity and Q_{10} in the broad-leaf and mixedwood forests, suggesting that the mechanisms underlining the effects of tree species diversity on Q_{10} are different between the two forest types. We conclude that sustainable forest management that improves tree species diversity will increase soil carbon stability and benefit our efforts to mitigate climate change.

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1. Introduction

Rapid species loss worldwide (Rockstrom et al., 2009) and its potential effects on ecosystem services stimulate the study of relationships between biodiversity and ecosystem function (Loreau et al., 2001; Tilman et al., 2014). Evidence shows that biodiversity increases ecosystem stability in a changing environment (Tilman et al., 2006; Jiang and Pu, 2009; Hector et al., 2010), while the mechanisms that underlie this effect are still poorly understood (Loreau and de Mazancourt, 2013). As one of the most important functions of ecosystems, soil carbon (C) sequestration has been widely studied (Trumbore et al., 1996; Lal, 2004; Davidson and Janssens, 2006). The change in vegetation composition or biodiversity degradation has been also demonstrated to exert a significant impact on both short-term C fluxes (Ward et al., 2009) and long-term soil C storage (Augé, 2001; Norby and Zak, 2011; Lange et al., 2015). Thus, studies on the relationship between soil processes and biodiversity (Nielsen et al., 2011; Bardgett and van der Putten, 2014), and the connections among plants, soil biota and soil C storage (Averill et al., 2014; Lange et al., 2015) have been explored to some extent. However, the linkage between species diversity and the stability of soil carbon has been rarely documented.

Soil CO_2 efflux, also known as soil respiration (R_s), the second largest terrestrial carbon flux (Raich and Potter, 1995), was related to species diversity in grasslands (Stocker et al., 1999; Wardle et al., 1999; Dias et al., 2010). In temperate and boreal forests, tree species are believed to influence the size of soil carbon stocks (Vesterdal et al., 2013), and the effect of tree species diversity on R_s has been tested in monocultural and mixed species stands (Murphy et al., 2008). The temperature dependence of R_s, known as Q_{10} value (Van't Hoff, 1898), has been widely used to address the sensitivity of soil CO_2 flux to temperature variation (Davidson et al., 2006). Large variability of Q_{10} values has been reported between ecosystems (Fierer et al., 2005; Peng et al., 2009), interannually (Xu and Qi, 2001; Chen et al., 2010), and spatially within stands (Tang and Baldocchi, 2005; Khomik et al., 2006; Metcalfe et al., 2008; Luan et al., 2013). Due to the complexity of factors affecting soil CO_2 flux, contradictory relationships between Q_{10} and the quality of soil organic carbon have been reported, where similar (Fang et al., 2005; Reichstein et al., 2005a, 2005b) or different (Fierer et al., 2005; Conant et al., 2008; Hartley and Ineson, 2008) temperature sensitivities of soil organic matter with a different quality have been debatable. Our previous work illustrated that the spatial variation of Q_{10} values can be partially attributed to the lability of soil organic carbon (Luan et al., 2013). Given that Q_{10} value is a comprehensive parameter that reflects the soil CO_2 flux, it is an important soil property to predict possible feedbacks between the global carbon cycle and the climate system (Davidson et al., 2006). In this study, we aim at answering if there is a linkage between tree species diversity and soil carbon stability, by evaluating how R_s responds to temperature change.

According to the stabilization effects of biodiversity on ecosystem characteristics, we hypothesize that tree species diversity can be a buffer against fluctuations in environmental conditions, such as temperature, on R_s, and high tree species diversity will decrease the Q_{10}, which means that greater tree species diversity will reduce the sensitivity of soil CO_2 efflux to climate warming. Taking advantage of a large dataset on calculated Q_{10} values based on field measurements and the associated tree species diversity data of forest stands, we tested our hypothesis in a regenerated oak forest (deciduous broad-leaf trees, hereafter referred to as a broad-leaf stand) and a pine plantation with some broadleaf species voluntarily regenerated due to the lack of management (coniferous and broad-leaf mixed species trees, hereafter referred to as a mixed stand) in a warm temperate region in China. This study intends to provide important implications of sustainable forest management in terms of soil carbon stability.

2. Materials and methods

2.1. Study site and experimental design

The study site was located at the Forest Ecological Research Station in Baotianman Natural Reserve (111°47′–112°04′E, 33°20′–33°36′N), Henan Province, China. The study site has an annual mean precipitation of 900 mm and air temperature of 15.1 °C. Upland soils are dominated by Haplic luvisol (FAO) developed on granite. In this study, a regenerated oak stand (a broad-leaf stand, 40–50 years old) and a nearby pine plantation without intensive management for about 40 years (mixed stand) were used to test our hypothesis. The broad-leaf stand was dominated by *Quercus aliena* Bl. var. *acuteserrata* Maxim. ex Wenz., which accounts for 33% of the trees, with other tree species including *Carpinus cordata* Bl., *Cornus controversa* Hemsl., *Tilia tuan* Szyszyl., and *Carpinus turczaninowii* Hance. The mixed stand was dominated by *Pinus armandii* Franch, but some broadleaf species were also voluntarily regenerated due to the lack of management; such species include *Quercus aliena* var. *acuteserrata*. The sub-canopy contained 22 woody species, of which *Dendrobenthamia japonica* var. *chinensis* Fang, *Lindera obtusiloba* Bl., *Carpinus cordata* Bl., and *turczaninowii* Hance were the most common. International Code of Nomenclature for the species was used in this paper.

One 60 × 80 m block was delineated in each stand. Within each block, 10 × 10 m square grids were systematically laid out and 35 subplots (1 × 1 m) were set up at the intersections of these grids for measuring R_s. Tree species was identified and each tree with a diameter at breast height (DBH) larger than 1 cm was recorded and with its location in the plot mapped to calculate the indices of tree species diversity.

2.2. R_s, microclimate measurements, and Q_{10} calculation

We installed PVC collars (19.6 cm inside diameter) in each subplot in September 2008 and the PVC collars were kept on the site throughout the study. Soil respiration measurements were conducted for a total of 12 and 13 measurement campaigns for the broad-leaf and mixed stands, respectively, using a Li-8100 soil CO_2 flux system (LI-COR Inc., Lincoln, NE, USA), from October 2008 to October 2009, in the snow-free period. Sampling was performed between 9:00 and 15:00 (GMT + 8:00). Soil temperature at the 5 cm depth (T_5) was measured adjacent to each respiration collar with a portable temperature probe that is attached to the Li-8100.

An exponential equation was used to describe the temporal relationship between R_S and T_5 for each subplot:

$$R_S = ae^{bT_5} \tag{1}$$

Table 1
Descriptive statistics for tree species diversity indices (within 5 m of measurement points) and soil respiration.

	Broad-leaf stand			Mixed stand		
	Mean	S.D.	Range	Mean	S.D.	Range
R_s (μmol m^{-2} s^{-1})[a]	2.12	0.58	1.16–4.17	2.01	0.44	1.07–3.16
Q_{10}[a]	3.8	0.95	1.7–5.12	4.25	0.81	2.30–6.21
d	2.54	1.07	1.05–6.00	2.49	0.86	1.17–4.75
λ	0.28	0.19	0.00–0.90	0.27	0.14	0.06–0.73
H_e'	1.34	0.42	0.20–2.03	1.42	0.43	0.51–2.33
J_e	0.82	0.15	0.29–1.00	0.82	0.09	0.46–0.94
S	5.23	1.68	2.00–9.00	6.03	2.31	2.00–12.0

[a] Data from Luan et al. (2012).