Carbon inputs regulate the temperature sensitivity of soil respiration in temperate forests (Postprint)

Authors: LIU Yulin, LI Jiwei, Hai Xuying, WU Jianzhao, DONG Lingbo, PAN Yingjie, Shangguan Zhouping, WANG Kaibo, DENG Lei

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Abstract

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Full Text

Preamble

Carbon inputs regulate the temperature sensitivity of soil respiration in temperate forests

Yulin Liu[12], Jiwei Li[12], Xuying Hai[3], Jianzhao Wu[3], Lingbo Dong[3], Yingjie Pan[12], Zhouping Shangguan[123], Kaibo Wang[4], *Lei Deng*[123]

[1] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling 712100, China

[2] University of Chinese Academy of Sciences, Beijing 100049, China

[3] Institute of Soil and Water Conservation, Northwest Agriculture and Forestry University, Yangling 712100, China

[4] State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710075, China

Abstract

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Keywords: litter biomass; root carbon; soil respiration; temperate forests; Loess Plateau

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1 Introduction

Forest ecosystems are the primary carbon sequestration bodies, accounting for 80% of global soil carbon pools (He et al., 2021). Soil CO_2 efflux represents the largest carbon flux between terrestrial ecosystems and the atmosphere, playing a crucial role in forest ecosystem carbon cycling (Bond-Lamberty and Thomson, 2010; Ballantyne et al., 2015). Annual CO_2 emissions from soils to the atmosphere account for 5%–20% of total greenhouse gas emissions (Wang et al., 2019), representing a key factor driving global warming. The temperature sensitivity (Q_{10}) of soil respiration is commonly used to estimate its feedback strength to temperature increases (Bond-Lamberty et al., 2018; Yan et al., 2019; Ge et al., 2020). Therefore, determining the Q_{10} of soil respiration is essential for predicting soil carbon pools and their potential effects on climate change (Todd-Brown et al., 2013; Bond-Lamberty et al., 2018).

Soil CO_2 emissions derive from the metabolism of plant roots (autotrophic respiration, R_a) and microbial communities (heterotrophic respiration, R_h) (Kukumägi et al., 2017; Zhang et al., 2021). Determining the contribution of each component to soil respiration and its dependence on multiple environmental factors is critical (Wang et al., 2019; Ge et al., 2020). Vegetation controls soil respiration and its components by influencing litter and root biomass, nutrient availability, soil temperature, and soil moisture (Deng et al., 2014a, 2018; Li et al., 2020). At large spatial scales, the length of the plant growing season is a chief driving factor for soil respiration (Davidson et al., 2006; Uri et al., 2012; Varik et al., 2013; Machmuller et al., 2018). Moreover, across various seasonal scales, the Q_{10} of soil respiration shows different influencing factors (Davidson et al., 2006; Ferreira et al., 2016). For example, seasonal changes in root activity trigger environmental factors that considerably affect R_a (Li et al., 2020a), while substrate decomposition by heterotrophic soil organisms varies with substrates (such as litter) and seasonal changes in nutrient availability (Luan et al., 2011; Ma et al., 2014).

Forest type is another important factor leading to changes in the Q_{10} values of R_a and R_h (Wang et al., 2016; Yu et al., 2017). Studies have shown that various forest types have different effects on the Q_{10} values of total soil respiration (R_{total}), R_a, and R_h (Wang et al., 2013), and that the Q_{10} values of both R_a and R_h are significantly positively influenced by forest types (Yu et al., 2017; Li et al., 2020a). However, other studies have reported no significant difference between forest types and the Q_{10} of rhizosphere respiration (Shi et al., 2015). Therefore, no consensus exists on how forest types affect the Q_{10} values of R_{total}, R_a, and R_h. Separately studying the Q_{10} values of R_a and R_h changes is crucial and could enhance our understanding of total soil respiration dynamics (Gaumant-Guay et al., 2009; Chang et al., 2016).

Populus davidiana Dode (pioneer) forests and Quercus liaotungensis Mary (climax) forests are typical natural secondary forest species in the Ziwuling forest region on the Chinese Loess Plateau (Deng et al., 2014b). In these two forests, we established four treatments—R_{total}, litter-removed soil respiration (R_{no}-litter), root-removed soil respiration (R_{no}-root), and the decomposition of soil organic matter (i.e., both litter and root removal; R_{SOM})—to observe changes in soil respiration fluxes across different seasonal scales, and then obtained seasonal dynamic changes and influencing factors of the Q_{10} of soil respiration. The objectives of this study were to: (1) classify R_{total}, R_{no}-litter, R_{no}-root, and R_{SOM} to independently quantify the Q_{10} of soil respiration in different seasons in the two forests; (2) explore how the Q_{10} of R_{total}, R_{no}-litter, R_{no}-root, and R_{SOM} vary with forest types; and (3) reveal the main factors affecting changes in the Q_{10} of soil respiration.

2.1 Study area

This study was conducted at the Lianjiabian Forest Farmland (36°00$‘43’‘–36°06’55’‘N, 108°26’23’‘–108°41’10”$ 1371–1453 m a.s.l.) in Heshui County, Gansu Province, China, located in the Ziwuling forest region on the Loess Plateau (Deng et al., 2014b). The study area has a mid-temperate continental monsoon climate, with an annual average temperature of 10°C and average annual precipitation of 587 mm (Liu et al., 2020). The area features typical loess hilly topography. As the main soil type, loessial soil (Calcic Cambisols) has developed from primary or secondary loess parent materials and is distributed evenly at depths of 50–130 m (Wang et al., 2020). Situated in a temperate zone, the area has a forest density of 80%–95% and is suitable for the development of deciduous broadleaved and temperate coniferous forest species such as P. davidiana, Betula platyphylla Suk., and Q. liaotungensis. All these species grow on hilltops with slopes not exceeding 5° (Liu et al., 2020).

According to local forest farm records, vegetation almost disappeared due to human-caused destruction. After local residents moved out around 1860, vegetation on abandoned farmlands naturally recovered, gradually forming secondary deciduous broadleaved forest landscapes. Moreover, a relatively complete succession chronosequence of secondary vegetation developed in this area, including abandoned farmland, herbaceous communities, shrub communities, pioneer forests, and climax communities. We selected P. davidiana forests and Q. liaotungensis forests for this study, which are approximately 110 and 160 years old, respectively (Deng et al., 2018; Wang et al., 2020). The main understory plants associated with P. davidiana included Carex lanceolata Boott, Artemisia campestris L., Ulmus macrocarpa Hance, Acer ginnala Maxim., Armeniaca sibirica (L.) Lam., and B. platyphylla. The understory plants associated with Q. liaotungensis comprised C. lanceolata, A. campestris, P. davidiana, and B. platyphylla.

2.2 Experimental design

Mature P. davidiana forests and Q. liaotungensis forests were selected in 2016. The two forests are situated within 2 km of each other. In October 2016, we performed a series of treatments at three plots (each 30 m × 30 m) in each forest, examining R_{total}, R_{no}-litter, R_{no}-root, and R_{SOM} with five replicates per treatment. Root exclusion was performed using the trench method (Rey et al., 2002). An area of 1 m × 1 m was selected and excavated to a depth of 100 cm to remove root systems. A 100-mesh nylon net was installed around the perimeter, and the excavated soil was then replaced. Soil respiration rate was measured monthly from March to November (spring–autumn) in 2018, with spring defined as March–May, summer as June–August, and autumn as September–November.

2.3 Soil respiration measurements

Soil respiration rate was measured using a soil respiration monitoring system (LI-8100A, Li-COR Inc., Nebraska, USA). From March to November 2018, at the end or beginning of each month, measurements were taken between 09:00 and 14:00 (local standard time) during sunny weather, with 3-minute measurements for each chamber. To eliminate the influence of soil disturbance, weeds were cut one day before each measurement. The LI-8100 temperature and humidity sensor simultaneously measured soil temperature and volumetric water content at a depth of 5 cm.

2.4 Litter and root measurements

Fine root biomass (RB) was obtained after each soil respiration measurement. In each plot of both forests, the soil surface mulch was cleared, and a 9-cm diameter root auger was used to collect RB at soil depths of 0–10 cm. Five samples were collected diagonally across each plot, and the dry sieve method was employed to extract the root system after mixing. Simultaneously, litter biomass (LB) was collected using 10 randomly placed 1 m × 1 m litter collection frames at each sample site to determine LB. Leaves, fallen branches, fruits, flowers, miscellaneous branches, and miscellaneous materials (including insect and bird droppings and plant debris) were separated and transported to the laboratory. Samples were oven-dried at 80°C to constant weight and then weighed. Litter carbon (LC) and root carbon (RC) were determined through wet digestion using the $K_2Cr_2O_7$ oxidation method (Nelson and Sommers, 1982).

2.5 Data analysis and statistics

The Q_{10} values of soil respiration were evaluated using the following equations (Li et al., 2020b):

$$R_s = a \times e^{bT}$$

$$Q_{10} = e^{10b}$$

where R_s is the measured soil respiration rate (mol/(m^2·s)); T is the measured soil temperature (°C); and a and b are fitted parameters.

Two-way analysis of variance (ANOVA) was used to identify significant differences ($P < 0.05$) among treatments and seasons, followed by least-significant difference (LSD) tests for post hoc comparisons of means. Statistical significance was defined as $P < 0.05$. Linear models were used to analyze the effects of soil temperature and moisture on Q_{10} values, and Pearson correlation analysis determined relationships between Q_{10} values and LB, RB, LC, and RC. Structural equation modeling was performed to identify possible pathways through which variables affect the Q_{10} of soil respiration in the two forests, using Amos 24.0. Other figures were drawn using SigmaPlot 12.5.

3 Results

3.1 Seasonal dynamics of temperature sensitivity (Q_{10}) values under litter and root treatments

For all treatments, summer exhibited the highest Q_{10} values in both P. davidiana and Q. liaotungensis forests (Fig. 1 [Figure 1: see original paper]). Among seasons, Q_{10} values in summer differed considerably from those in spring and autumn ($P < 0.05$; Table 1). No significant differences were observed between spring and autumn Q_{10} values ($P > 0.05$), though spring values were higher than autumn values. Overall, Q_{10} values in P. davidiana forests varied significantly among seasons and treatments ($P < 0.01$), with both seasons and treatments affecting Q_{10} values ($P < 0.05$; Table 1). Q_{10} values ranged from 0.455–3.869 in P. davidiana forests and 0.430–3.861 in Q. liaotungensis forests (Fig. 1).

Fig. 1 Seasonal differences in temperature sensitivity (Q_{10}) of total soil respiration (R_{total}), litter-removed soil respiration (R_{no}-litter), root-removed soil respiration (R_{no}-root), and soil organic matter decomposition (i.e., both litter and root removal; R_{SOM}) in Populus davidiana Dode forests (a) and Quercus liaotungensis Mary forests (b). Lowercase letters indicate variations observed across seasons for the same treatment ($P < 0.05$). Uppercase letters indicate variations observed across treatments within the same season ($P < 0.05$). Bars represent standard errors.

Table 1 Analysis of variance for factors affecting temperature sensitivity (Q_{10}) of soil respiration across seasons and treatments in Populus davidiana Dode forests and Quercus liaotungensis Mary forests

Factor	Degree of freedom	P. davidiana	Q. liaotungensis
Seasons		Mean square: 148.21***	Mean square: 166.89***
Treatments		Mean square: 5.58**	Mean square: 5.96**

Factor	Degree of freedom	P. davidiana	Q. liaotungensis
Seasons × Treatments		Mean square: 2.72*	

Note: , *$P < 0.05$;* **, $P < 0.01$;** , $P < 0.001$.

3.2 Relationships of Q_{10} values with soil temperature and moisture under litter and root treatments

In all treatments, soil respiration rate and soil temperature showed a trend of first increasing then decreasing, with maximum values for both occurring in July during summer, while soil moisture was relatively lower in July (Fig. 2 [Figure 2: see original paper]). Q_{10} values were driven by both soil moisture and temperature (Fig. 3 [Figure 3: see original paper]; Table 2). The combined effect of soil temperature and moisture showed an extremely significant correlation with Q_{10} values ($P < 0.001$; Fig. 3; Table 2). Regardless of season, soil temperature showed a positive response to Q_{10} values in both forest types, with coefficients of determination (R^2) above 0.80, and the promoting effect of soil temperature on Q_{10} values was more pronounced in summer (Fig. 4a [Figure 4: see original paper] and b). Overall, soil moisture showed a negative response to Q_{10} values (Fig. 4c and d).

Fig. 2 Seasonal changes in soil respiration rate, soil temperature, and soil moisture in P. davidiana forests (a, c, e) and Q. liaotungensis forests (b, d, f). Bars represent standard errors.

Fig. 3 Responses of Q_{10} of soil respiration to the combination of soil temperature (T) and soil moisture (M) with a bivariate non-linear model ($Q_{10} = a \times M \times T + b \times M + c \times T + d$, where a, b, and c represent coefficients of soil temperature and moisture, and d represents the constant) in P. davidiana forests (a, c, e) and Q. liaotungensis forests (b, d, f). Specific fitting equations are shown in Table 2.

Table 2 Equations for Q_{10} of soil respiration with soil temperature (T) and soil moisture (M) in P. davidiana forests and Q. liaotungensis forests

Forests	Season	Equation	R^2
P. davidiana	Spring	$Q_{10} = 0.01 \times M \times T - 0.21 \times M - 0.03 \times T + 1.41$	0.86***
	Summer	$Q_{10} = -0.01 \times M \times T + 0.38 \times M + 0.66 \times T - 14.56$	0.81***
	Autumn	$Q_{10} = 0.005 \times M \times T - 0.07 \times M + 0.05 \times T + 0.07$	0.92***

Forests	Season	Equation	R^2
Q. liaotungensis	Spring	$Q_{10} = -0.02 \times M \times T + 0.33 \times M + 0.30 \times T - 4.57$	0.83***
	Summer	$Q_{10} = -0.02 \times M \times T + 0.37 \times M + 0.49 \times T - 9.83$	0.81***
	Autumn	$Q_{10} = -0.001 \times M \times T + 0.02 \times M + 0.11 \times T - 0.81$	0.95***

Note: ***, $P < 0.001$.

3.3 Relationships of Q_{10} values with litter biomass (LB), fine root biomass (RB), litter carbon (LC), and root carbon (RC) under litter and root treatments

LB in Q. liaotungensis forests was significantly higher than in P. davidiana forests ($P < 0.05$), while LC in P. davidiana forests was significantly higher than in Q. liaotungensis forests ($P < 0.05$; Table 3). RB and RC in P. davidiana forests peaked in autumn, while RB in Q. liaotungensis forests was highest in summer. No significant differences were observed in RB and RC between P. davidiana and Q. liaotungensis forests within the same season or across different seasons ($P > 0.05$; Table 3).

Table 3 Litter biomass, litter carbon, fine root biomass, and root carbon in P. davidiana forests and Q. liaotungensis forests

Forests	Litter biomass (g/m^2)	Litter carbon (g/kg)	Fine root biomass (g/m^2)	Root carbon (g/kg)
P. davidiana	`$±$8.33b`	`$±$3.51a`	Spring `$±$16.60Ba`	Summer `$±$10.86Bb`
Q. liaotungensis	`$±$10.89a`	`$±$11.95b`	`$±$20.00Aa`	`$±$20.32Aa`

Note: Uppercase letters indicate significant differences among seasons ($P < 0.05$) and lowercase letters indicate significant differences between forests ($P < 0.05$).

Under different treatments, Q_{10} values in P. davidiana forests were positively correlated with RB ($P < 0.05$; Fig. 5 [Figure 5: see original paper]), while Q_{10}

values in Q. liaotungensis forests were only negatively correlated with LC for R_{total} and R_{no}-litter treatments ($P < 0.05$; Fig. 5b). Q_{10} values in P. davidiana forests were negatively correlated with LB in summer ($P < 0.05$; Fig. 5c), and Q_{10} values in Q. liaotungensis forests showed significant correlations with RB and LC in spring ($P < 0.05$; Fig. 5d).

3.4 Contribution of LB, RB, LC, and RC as well as soil temperature and moisture to Q_{10} values

Structural equation modeling revealed strong relationships among soil temperature, soil moisture, and Q_{10} values in both forests (Fig. 6 [Figure 6: see original paper]). Among examined plant characteristics, RB and LC effectively predicted Q_{10} values in P. davidiana forests (Fig. 6a and c). Additionally, RB and LC had the greatest influence on predicting Q_{10} values in Q. liaotungensis forests (Fig. 6b and d).

Fig. 5 Pearson correlation of Q_{10} of soil respiration with litter biomass (LB), fine root biomass (RB), litter carbon (LC), and root carbon (RC) under different treatments and seasons. (a and b) Correlations across different treatments with LB, RB, LC, and RC; (c and d) correlations across different seasons with LB, RB, LC, and RC. *, $P < 0.05$.

Fig. 6 Structural equation model evaluating direct and indirect effects of T, M, LB, RB, LC, and RC on Q_{10} of soil respiration and standardized total effects in P. davidiana forests (a and c) and Q. liaotungensis forests (b and d). Black and grey lines indicate significant and non-significant correlations, respectively; dashed and solid lines represent negative and positive correlations, respectively ($P = 0.05$); line thickness represents the magnitude of path coefficients. CFI, comparative fit index; RMSEA, root mean square error of approximation. *, P < 0.05;* ***, P < 0.01;*** , $P < 0.001$.

4 Discussion

4.1 Effects of soil temperature and moisture on seasonal dynamics of Q_{10} of soil respiration

The Q_{10} of soil respiration showed strong seasonality (Fig. 1; Table 1). In both forests, the highest Q_{10} values occurred in summer, while the lowest values appeared in spring and autumn (Fig. 1). Higher Q_{10} values at higher temperature ranges occurred primarily because the Q_{10} of unstable carbon mineralization increased with temperature, and the metabolic efficiency of the microbial community was high (Wang et al., 2013). In spring and autumn, when temperatures were low, litter, root, and microbial respiration activities were weak, and the Q_{10} of soil respiration was mainly restricted by biochemical reactions (Wang et al., 2018). Therefore, soil respiration rate was more sensitive to temperature in summer than in spring and autumn, indicating that temperature increases lead to enhanced carbon emissions.

No significant difference in Q_{10} of soil respiration existed between the two forests ($P > 0.05$; Fig. 1). The Q_{10} values were not significantly different due to similar soil temperature and respiration rates (Kim et al., 2010). The insignificant differences also resulted from subtle changes in plant variables (root biomass and carbon content) between forests (Yan et al., 2013). In this study, differences in plant characteristics were small, and most variations between forests were not obvious (Table 3). Therefore, these factors may be responsible for the insignificant difference in Q_{10} values between P. davidiana and Q. liaotungensis forests.

4.2 Effects of litter and root on seasonal dynamics of Q_{10} of soil respiration

The Q_{10} of soil respiration increased when litter was included in soil respiration (especially in summer), as Q_{10} values of R_{total} were significantly higher than those of R_{no}-litter. Additionally, Q_{10} values of R_{no}-root were higher than those of R_{total} and R_{no}-litter (Figs. 1 and 2), further indicating that litter enhanced the sensitivity of soil respiration to temperature increases (Li et al., 2020, 2020c). Some studies have shown that litter presence increases substrate input, which enhances microbial respiration and substrates available for microorganisms (Li et al., 2016; Qu et al., 2018; Goncharova et al., 2020). Other studies have demonstrated different Q_{10} values for R_a and R_h (Wang et al., 2017; Hu et al., 2018; Zeng et al., 2018). Interactions between litter decomposition and root activity significantly impact soil respiration (Subke et al., 2011; Wu et al., 2014), and the mechanism linking litter, root, and soil respiration may involve microbial activities (Subke et al., 2011; Xiao et al., 2017). Due to variations in the availability of litter and root substrates, microbial decomposition activities led to differences in soil respiration activities among various R_a and R_h components (D'Acunto et al., 2018; Yan et al., 2018). Therefore, different major drivers of R_{no}-litter, R_{no}-root, and R_{SOM}, as well as asynchronous effects of these factors, may cause variations in Q_{10} of soil respiration (Wang et al., 2018; Li et al., 2020a, 2020c).

Due to environmental factors, root and microbial activities were weak in spring and autumn (Wang et al., 2018), resulting in low Q_{10} values. In summer, R_{no}-litter exhibited lower Q_{10} values compared to other treatments ($P < 0.05$; Fig. 1b), indicating that litter removal strongly affected Q_{10} values (Kukumägi et al., 2017). SEM results supported this finding (Fig. 6). Results from R_{no}-root and R_{SOM} treatments are consistent with the temperature-quality hypothesis reported in literature (Suseela et al., 2013; Wu et al., 2014). Although missing root exudates and readily decomposable carbon sources for microbes can influence soil respiration by affecting decomposition of highly recalcitrant litter and soil organic matter (Wu et al., 2014; Kukumägi et al., 2017), long-term trenching experiments can alter soil conditions and microbial biomass and activity in trenched plots (Kukumägi et al., 2017). Thus, these factors can affect Q_{10} values among respiratory components. Additionally, studies have reported similar variations in Q_{10} values (Jones et al., 2005; Wu et al., 2014), consistent with R_{no}-litter results. Opposite results for R_{no}-root and R_{no}-litter may be explained by labile carbon dynamics (Jones et al., 2005; Li et al., 2021). The R_{no}-litter treatment allowed root rhizosphere activity, permitting labile carbon input into soil through photosynthesis (Wu et al., 2014). The R_{no}-root treatment allowed litter input; however, minimal labile carbon entered soil because trenching prevented root decomposition (Wu et al., 2014; Li et al., 2020b). Significant differences between R_{no}-litter and R_{total} resulted from strong responses of carbon input, microbial activities, and soil respiration under coexisting litter and root conditions (Li et al., 2021). Therefore, the difference between R_{no}-litter and R_{total} was large, particularly in long trenching experiments (Jones et al., 2005; Li et al., 2020a). Lower Q_{10} values for R_{no}-litter treatment in summer (Fig. 1) indicated that root activity reduced Q_{10} values (Subke et al., 2011; Wu et al., 2014; Li et al., 2020b).

4.3 Driving factors of variations in Q_{10} of soil respiration

Soil moisture directly and indirectly affected both autotrophic and heterotrophic respiration through microbial and root physiological processes and oxygen and substrate diffusion (Aaltonen et al., 2017). In this study, soil moisture decreased during the rainy season (Fig. 2), leading to significant increases in R_{total}, R_{no}-litter, R_{no}-root, and R_{SOM} (Aaltonen et al., 2017; Chen et al., 2019). Decreased soil moisture improved soil oxygen utilization rates (Aaltonen et al., 2017), promoting better plant growth and providing more carbon substrates for root respiration (Chen et al., 2019). Soil moisture exhibited similar effects on Q_{10} of soil respiration, with higher substrate utilization leading to higher Q_{10} values (Brunner et al., 2015; Ferreira et al., 2016). When soil moisture decreased in summer, levels approached the optimal range required for microbial and root activities, potentially increasing Q_{10} of soil respiration and its components (Ferreira et al., 2016; Chen et al., 2019).

Moreover, soil temperature strongly affected seasonal variations in Q_{10} of soil respiration, with seasonal Q_{10} variation synchronizing with soil temperature (Figs. 2 and 4). The correlation between soil temperature and Q_{10} of soil respiration was stronger than that between soil moisture and Q_{10} (Figs. 4 and 5). Soil temperature may be more important than soil moisture in influencing Q_{10} of soil respiration in temperate forests (Xu et al., 2015). Additionally, higher Q_{10} values in summer than in spring and autumn indicated that soil respiration was more sensitive to temperature increases in warmer summers than in cooler spring and autumn periods (Fig. 2c and d). Q_{10} values increased with temperature, confirmed by strong positive correlations between Q_{10} of soil respiration and soil temperature (Figs. 4 and 5). This strong positive correlation can be explained by increased enzyme activity with rising soil temperature (Kunito et al., 2018). Seasonal adaptation of soil enzyme activity resulted from changes in isoenzymes that adapt to corresponding environmental temperature conditions

(Di Nardo et al., 2004; Tucker et al., 2017; Guan et al., 2021). Thus, more relevant biological and biochemical activities were observed in summer (Qin et al., 2013).

Comparing different litter and root treatments, Q_{10} of soil respiration could be enhanced without litter removal (Fig. 1). LC exhibited higher predictive capacity in both P. davidiana and Q. liaotungensis forests (Fig. 6a and b). Changes in LC affected substrate availability for soil respiration, thereby influencing Q_{10} of soil respiration (Meyer et al., 2018a; Yan et al., 2019). Litter decomposition can provide easily decomposable carbon for microorganisms (Xu et al., 2018). However, litter quantity and quality varied with forest type, further affecting soil carbon distribution and substrate quality for microbial respiration; consequently, LC exhibited different effects on Q_{10} values in the two forests (Liu et al., 2017). Simultaneously, other plant characteristics influenced different Q_{10} values of respiration components across forests. Among these, RB showed strong predictive capacity for Q_{10} values in both forests (Fig. 6) due to the extended seasonal duration (spring to autumn) of root metabolism (Li et al., 2020b). Moreover, interactions between root activity and soil organic matter may affect Q_{10} variations (Li et al., 2020a). With increased root death due to trenching treatment, respiration from root fragment decomposition increased, potentially persisting until the second year (October 2016 to November 2018) and leading to increased root respiration proportion (Wu et al., 2014; Kukumägi et al., 2017). Furthermore, main predictors of Q_{10} of soil respiration varied with seasons across different forests due to variations in tree species, ecosystem types, and experimental operation modes (Hu et al., 2016; Meyer et al., 2018b; Chen et al., 2019). Therefore, Q_{10} variations were affected by both biological and abiotic factors (Hu et al., 2016).

5 Conclusions

The Q_{10} of soil respiration shows considerable seasonality in temperate forests, with the highest values reached in summer. Among different soil respiration components, litter enhances soil respiration temperature sensitivity more than roots do. Additionally, P. davidiana and Q. liaotungensis forests exhibit similar Q_{10} values for soil respiration. The interactions and synergistic effects of soil temperature, soil moisture, litter biomass, and fine root biomass play important roles in influencing Q_{10} of soil respiration in both forests. These results explain how soil temperature, moisture, litter biomass, fine root biomass, litter carbon, and root carbon influence Q_{10} of soil respiration and improve our understanding of how temperate forest systems respond to long-term climate dynamics.

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Note: Figure translations are in progress. See original paper for figures.