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Original Article

Forest Soil Respirations are More Sensitive to Nighttime Temperature Change in Eastern China

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Abstract

Soil respiration is one of the main fluxes in the global carbon cycle. The effect of temperature on soil respiration is well understood. The response of soil respiration to temperature warming is called apparent temperature sensitivity (Q_{10}) of soil respiration, which is an important parameter in modeling soil CO_2 effluxes under global climate warming. The difference of Q_{10} between daytime and nighttime was hardly reported although attentions are attracted by the differences of temperature change and its effects on vegetation productivity. In this study, we investigated the Q_{10} of soil respiration in daytime and nighttime by modeling empirical functions based on the in situ measurement of soil respiration and temperature in temperate and subtropical forests of eastern China. Our results showed that the Q_{10} of soil respiration is higher in nighttime with the mean value of 2.74 and 2.35 than daytime with the average of 2.49 and 2.18 in all measured months and growing season, respectively. Moreover, the explanatory rate of soil temperature to soil respiration in nighttime is also higher than in daytime in each site in both all measured and growing seasons. The Q_{10} and explanatory rate of soil temperature to soil respiration in nighttime is 1.08 and 1.15 times in daytime in growing season. These findings indicate that soil respiration has a bigger sensitivity to temperature in nighttime than daytime. The change of soil temperature explains more variation of soil respiration in nighttime than daytime.

Keywords: explanatory rate; forest; Q_{10}; soil respiration; temperature

Introduction

The largest C pool is that of the soil, possessing 3.3 times as much C as the atmospheric pool and 4.5 times the C of the biotic pool (Lal, 2004). Small changes to the soil C pool result in large fluctuations in atmospheric CO_2, which will affect the stability of global climate (Friedlingstein *et al.*, 2006). Soil respiration (Rs) is one of the main fluxes in the global carbon cycle, and the second-largest terrestrial carbon flux after gross primary production. Soil respiration has become a central issue in global change ecology because of its controversial role in global warming process (Giardina and Ryan, 2000).

Forest ecosystems, as the main body of the terrestrial ecosystem on earth, are particularly important in the carbon cycle (Luyssaert *et al.*, 2008; Savage *et al.*, 2008; Pan *et al.*, 2011). Of terrestrial ecosystems, forests contain the largest soil C pool, with 73% of the global soil C (Pan *et al.*, 2011), thus playing a critical role in maintaining global C balance and modulating global climate change (Schlesinger and Andrews, 2000). As the one of influencing factors, temperature attracts the most attention (Bond-Lamberty and Thomson, 2010), especially in temperate and subtropical forests (Wang *et al.*, 2006; Xia *et al.*, 2009; Yan *et al.*, 2009; Luan *et al.*, 2013). Moreover, the response of soil respiration to climate warming, which usually is called apparent temperature sensitivity of RS (Q_{10} value) and estimated based on empirical functions, is of importance in predicting the direction and magnitude of terrestrial carbon cycle feedback to climate warming (Davidson *et al.*, 2006; Zhou *et al.*, 2015). Therefore, empirical response functions

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are still a valid method to derive annual estimates of soil respiration based on specific field measurements (Savage *et al.*, 2008). Currently, The Q_{10} of RS has been a focus of RS research and is widely reported in numerous literatures. Most studies of the response of soil respiration to temperature increase and the relationship between soil respiration and temperature, however, ignore this asymmetric forcing effect on soil respiration although temperature is faster warming of the global land surface during the night than during the day (Solomon *et al.*, 2007). Further, A few studies have been carried out to explore the effects of asymmetric warming on ecosystems (Alward *et al.*, 1999; Peng *et al.*, 2004; Beier *et al.*, 2008; Prasad *et al.*, 2008; Wan *et al.*, 2009), which reveal different effects of temperature during daytime and night time on vegetation growth and CO_2 fluxes. Additionally, the Q_{10} of soil respiration also varied with the temporal and spatial changes (Chen *et al.*, 2010; Zhou *et al.*, 2015). Yet the scarcity and short duration of field experiments on soil respiration makes it difficult to assess accurately future soil CO_2 effluxes with climate changes.

Thus, it is important to explore the response of soil respiration to daytime versus nighttime temperature is very necessary for predicting soil carbon fluxes avoiding neglect an essential process by using daily temperature to model global carbon cycle (Peng *et al.*, 2013). In this study, we studied the responses of soil respiration to temperature changes in daytime and nighttime, respectively based on a field in-situ determination of soil respiration and soil temperature in eastern China.

Materials and Methods

Site description and experimental design

The study includes five sites across temperature and subtropical forests of eastern China: Labagoumen, Laojun Mountain, Dalaoling Mountain, Tiantong Mountain, and Wutong Mountain. The detailed site information including forestry types, latitude and longitude, elevation, slope and dominant tree species in each site is provided in Table 1.

One typical forest types were selected at each site (Table 1). One plot of 50 m × 50 m was set for each forest type with three random subplots of 10 m × 10 m, and three permanent soil respiratory collars were inserted in each plot (Fig. 1). Soil respiration and soil temperature at 5 cm depth were measured once per month.

Measurement of soil respiration and environmental factors

Soil respiratory measured collars (314.2 cm^2 in area and 8 cm in height) were permanently inserted 5-6 cm into the soil at the center of each subplot. To eliminate aboveground plant respiration, small living plants inside the soil collars were clipped at the soil surface at least 24 hrs before the measurement. The soil respiration was measured between 9:00 and 15:00 on sunny or cloudy days with a Li-8100-103 portable CO_2 infrared gas analyzer (IRGA) (Li-Cor Inc, Lincoln, NE, USA). Three observations (replicates) were measured and the averaged Rs were used for further analysis. From July to October in 2009 and March to October in 2010, respectively, soil respiration was measured in Labagoumen.

Laojun mountain, Dalaoling mountain, Tiantong mountain, and Wutong mountain were measured from August to October in 2009, January and from April to October in 2010, respectively.

Soil temperature was monitored simultaneously with ST measurement using a constant thermocouple penetration probe (Li-8100, Li-Cor Inc), inserted in the soil to a depth of 5 cm in the vicinity of the chamber.

Calculation of Q_{10} of soil respiration

An exponential function was used to describe relationship between SR and ST at 5 cm depth:

$$R_s = a \cdot e^{b \cdot ST} \quad (1)$$

where *a* and *b* are fitting parameters, *a* is the base SR and *b* is related to Q_{10}, which describes the change of Rs per increasing 10 °C in soil temperature, by

$$Q_{10} = e^{10b} \quad (2)$$

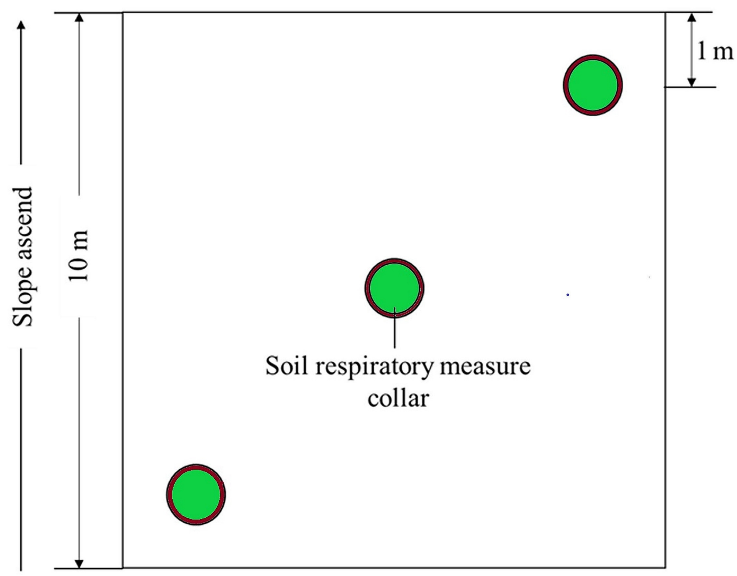

Fig. 1. Distribution sketch of soil respiratory measure collars in each subplot

Table 1. The descriptions of detailed characteristics of studied sites in temperate and subtropical forest ecosystems in eastern China

Sites	Forestry type	Latitude	Longitude	Elevation (m)	Slope	Dominant tree species
Labagoumen (LB)	warm-temperate deciduous broad- leaved forest	40°52′7″ N	116°33′43″ E	1901-1912	10-15°	*Quercus mongolica*
Laojun Mountain (LJS)	warm-temperate subalpine subtropical evergreen mixed conifer and broad- leaved forest	33°43′46″ N	111°38′46″ E	1890-1908	>20°	*Pinus armandii, Abies fargesii, Betula chinensis*
Dalaoling Mountain (DLL)	North subtropical evergreen deciduous broadleaved mixed forests	31°5′3″ N	110°55′49″ E	1647-1654	<10°	*Cyclobalanopsis fulvisericeus, Cyclobalanopsis glauca, Quercus engleriana, Sycopsis sinensis, Castanea mollissima*
Tiantong Mountain (TT)	subtropical ever- green broad leaved forest	29°48′08″ N	121°47′17″ E	152-155	<10°	*Schima superba*
Wutong Mountain (WT)	south subtropical evergreen broad leaved forest	22°34′58″ N	114°10′53″ E	194-198	<10°	*Schefflera octophylla, Pinus massoniana, Aquilaria sinensis*

Data analysis

The temperature sensitivity of mean Rs to soil temperature in each site was assessed by exponential functions (1) and (2) from individual subplots. The significance of the effects of regression coefficients *a* and *b* among the sites was examined. The statistical analyses were performed in SPSS 11.0 for windows (SPSS Inc., Chicago, IL, USA, 2001).

Results

The Q_{10} of soil respiration is higher in nighttime than in daytime in both all measured seasons among all 5 sites in temperate and subtropical forests in eastern China (Figs. 2 and 3). The Q_{10} varied from 2.30 in Wutong Mountain to 2.95 in Labagoumen with the mean of 2.48 in all measure seasons. The average of Q_{10} is significant higher in nighttime with tha value of 2.73 than daytime. When each site was considered, Q_{10} markedly increased in night in all sites but Tiantong Mountain in all measured seasons (Fig. 2). Further, the Q_{10} was analysed in growing seasons, which presented the same trend with the determination in all measured seasons (Fig. 3). The mean Q_{10} was also significant higher in nighttime than daytime. At the same time, the ratio of Q_{10} of soil respiration in day and nighttime in all measured and growing seasons were counted (Fig. 4), which varied from 1.01 to 1.16 with the mean of 1.10 in all measure season and from 1.01 to 1.19 with the average of 1.08 in growing seasons.

From the Q_{10} values in daytime and nighttime, we supposed that the temperature would be more account for the variation of soil respiration in nighttime than daytime. Therefore, we counted the explanatory rate of soil temperature to soil respiration in all measured and growing seasons (Figs. 5 and 6). The results supported our hypothesis that the soil respiration is more sensitive to temperature change in nighttime than in daytime. Whether in all measured seasons or in growing seasons, the explanatory rate of soil temperature to soil respiration presented the increasing trends in nighttime comparing to that in daytime. The ratio of explanatory rate of soil temperature to soil respiration in night to day-time in all measured and growing season were further analysed (Fig. 7). The ratio also more than 1 in each site although the variation are obvious in growing seasons.

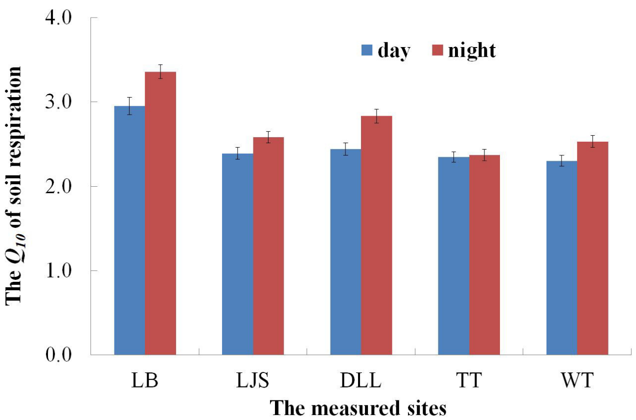

Fig. 2. The temperature sensitivity (Q_{10}) of soil respiration in day and night-time in all measured seasons

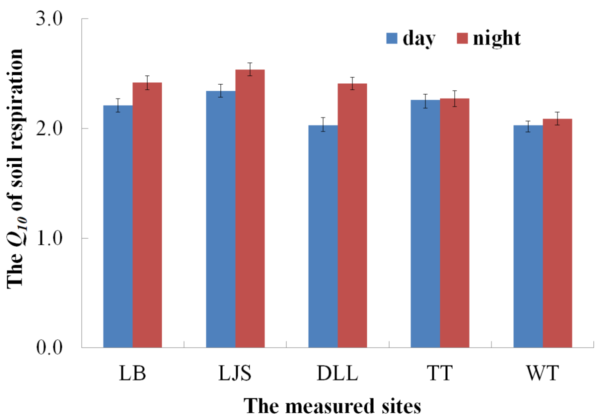

Fig. 3. The temperature sensitivity (Q_{10}) of soil respiration in day and night-time in growing season

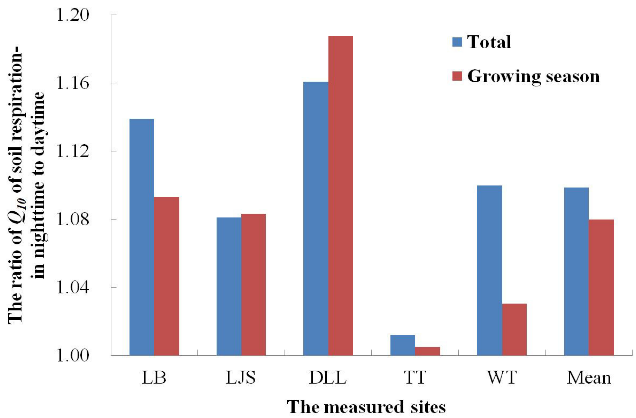

Fig. 4. The ratio of temperature sensitivity (Q_{10}) of soil respiration in day and night-time in all measured and growing season

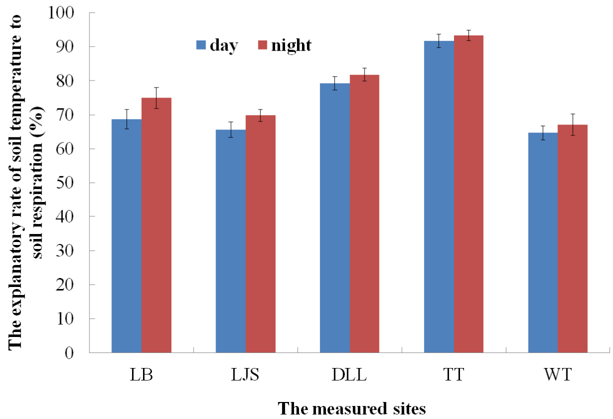

Fig. 5. The explanatory rate of soil temperature to soil respiration in day and night-time in all measured seasons

Discussion

The Q_{10} value of soil respiration is a key parameter in modeling effects of global warming on ecosystem carbon release, which reflects the response of soil Rs to temperature changes. Although many studies have focused on the Q_{10} (Peng *et al.*, 2009; Bond-Lamberty and Thomson, 2010; Wang *et al.*, 2010), there was few report on their difference between daytime and nighttime. In this study, the Q_{10} is higher in nighttime than in daytime in all measured and growing seasons. Hu *et al.* (2012) showed Q_{10} were lower in nighttime (3.74) than in daytime (3.90) estimated during their whole measurement period from April to November in subalpine meadow. Our finding showed that the change of temperature caused the more variation of soil respiration in nighttime than in daytime, which was possible caused by many reasons. First is the more sensitive night temperature comparing to day temperature in the conditions of climate warming (Solomon *et al.*, 2007). Second is different of the plant response to the temperature change in day and nighttime because the variation of vegetation productivity presented the different trend due to the temperature increasing in daytime and nighttime (Peng *et al.*, 2013). Third is the more temperature influence on soil respiration in nighttime than daytime (Figs. 5 and 6), which can be supported by warming experiment in a temperate steppe made by Xia *et al.* (2009). Their finding revealed that day warming had no effect on soil respiration, whereas night warming significantly increased soil respiration.

In this study, our estimates of Q_{10} changed from 2.30 to 2.95 and from 2.37 to 3.36 based on all measured months, and from 2.03 to 2.34 and 2.09 to 2.54 based on growing season in daytime and nighttime, respectively. These values are higher than the value of global vegetation (1.5) calculated based on atmospheric temperature (Bond-Lamberty and Thomson, 2010). This result may be due to two reasons: (1) The Q_{10} value of Rs calculated with atmospheric temperature is significantly lower than that estimated by soil temperature at the depths of 5 cm in global forests (Wang *et al.*, 2010), and (2) Their vegetation types also include other ecosystems (e.g. grassland) in addition to

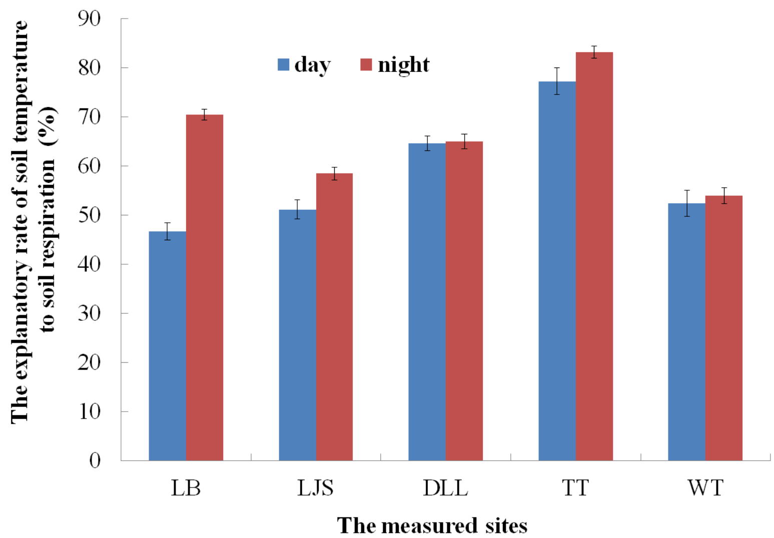

Fig. 6. The explanatory rate of soil temperature to soil respiration in day and night-time in growing seasons

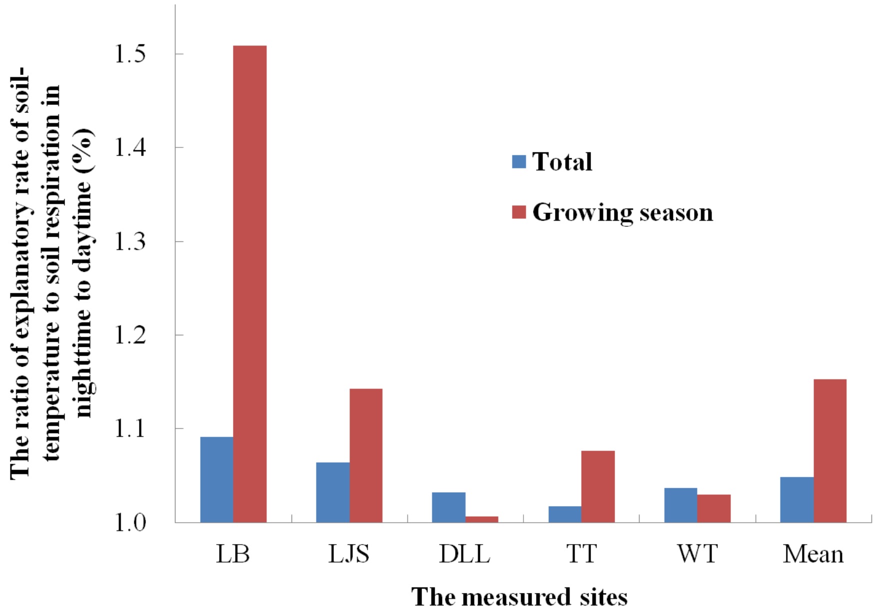

Fig. 7. The ratio of explanatory rate of soil temperature to soil respiration in night to day -time in all measured and growing season

forests. Meanwhile, the Q_{10} value of forest ecosystems is higher than that of grass ecosystem (Peng *et al.*, 2009; Wang *et al.*, 2010). Moreover, our Q_{10} value was roughly consistent with many results obtained from forests. Wang *et al.* (2010) calculated the Q_{10} based soil temperature at 5 cm depth in global forest and showed that the Q_{10} are 1.98±0.12 and 2.79±0.14 in deciduous broadleaf forest and evergreen broadleaf forest, respectively. Peng *et al.* (2009) showed Q_{10} are 2.25±0.28 and 1.81±0.43 in deciduous broadleaf forest and evergreen broadleaf forest in China. When sites were considered, our results are also similar with previous studies in the same forest types. For example, Q_{10} of Laojunshan (2.34-2.58) based on all measured and growing season was similar to that of Baotianma (2.30-2.44) (Chang *et al.* 2007). Q_{10} of Wutongshan is also similar to the site of Tinghushan of subtropical forests with the value from 2.25 to 3.37 that were reported by Yan *et al.* (2009).

As to the explanatory rate of soil temperature to soil respiration were consistent with numerous studies in temperate and subtropical forest (Yan *et al.*, 2009; Wang *et al.*, 2006), which revealed the vital function of soil temperature to soil respiration. The different of explanatory rate of soil temperature to soil respiration and the ratios of Q_{10} and explanatory rate of soil temperature to soil respiration in daytime and nighttime needed to be further studied for understanding their mechanisms.

This study revealed the differences of Q_{10} and explanatory rate of soil temperature to soil respiration between daytime and nighttime, which showed that the response of soil CO_2 effluxes to temperature changes are not equivalent in daytime and nighttime. The finding indicated that the incorporate differential responses of day and night of temperature to soil respiration is necessary on assessing the soil CO_2 effluxes by Q_{10} under global climate warming in the future. Moreover, Temperature warming of the global land surface is faster during the night than during the day in over the past five decades (Solomon *et al.*, 2007).

Conclusions

The Q_{10} of soil respiration is higher in nighttime than that in daytime in all measured months and growing season. The change of soil temperature is more account for variation of soil respiration in nighttime than daytime.

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