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Seasonal variations of Q_{10} soil respiration and its components in the temperate forest ecosystems, northeastern China

Mengguang Han, Guangze Jin*

Center for Ecological Research, Northeast Forestry University, Harbin 150040, China

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ABSTRACT

Understanding the temperature sensitivity (Q_{10}) of soil respiration (R_S) and corresponding controlling factors is crucial for estimating the feedback of soil carbon pool to future climatic changes. In this study, trenching method was used to separate R_H and R_A. Simultaneous measurements of soil respiration and soil microclimate were conducted within two temperate forests (a birch forest and a spruce fir forest). We aimed to analyze the seasonal variations of the Q_{10} of R_S and its two components (heterotrophic [R_H] and autotrophic [R_A]) and to find relevant influencing factors. The Q_{10} values ranged from 0.3 to 5.4, and exhibited strong seasonal variation. The regression analysis showed a negative relationship between Q_{10} and soil temperature in the two forests. Additionally, the Q_{10} values of R_H were also negatively correlated with soil microbial biomass carbon. Positive relationships were found between the temperature dependency of R_H and soil organic carbon and C:N only in birch forest, and the seasonal dynamics for Q_{10} of R_A was more dependent on fine root biomass compared to soil temperature in this forest. Soil moisture had no effects on the seasonal changes of Q_{10} due to its slight fluctuation throughout the growing season. The Q_{10} value of long-term was a little higher compared to that of short-term. These results emphasize the importance of independently exploring the short-term Q_{10} of R_H and R_A; and a single apparent Q_{10} should be used with caution in estimating soil CO_2 emission under global warming.

1. Introduction

As a major process controlling carbon loss from terrestrial ecosystems, soil respiration (R_S) was estimated to release 75–100 Pg C yr^{-1} on global scale [1]. Accordingly, even small changes in the magnitude of R_S in response to minor variations in climate could have a large impact on the concentration of CO_2 in the atmosphere. Gaining more insight in which the factors influencing R_S is therefore important. Generally, R_S has an obvious seasonal variation in temperate region. For the terrestrial ecosystems without drought stress, soil temperature is usually the most important factor determining the seasonal variation of R_S [1,2]. Numerous studies have focused on the responses of R_S to soil temperature, and an exponential correlation has been developed and commonly applied to simulate the temperature sensitivity (Q_{10}) of R_S [2–4]. Generally, the Q_{10} value is expected to be identical within a year when modeling the annual budgets of soil carbon, however, an increasing evidence has been found indicating that the Q_{10} values of soil respiration rates are not constant throughout the year [2,3,5], as the response of R_S to temperature depending on many other biotic and abiotic factors change with season, including climate events, vegetation cover, hydrological regime and soil properties, etc [2,6,7]. It has been generally acknowledged that Q_{10} decreases with temperature increament, but tends to decrease with decreasing soil moisture [3,5], as the moisture limitation can suppress microbial activity and root growth [6]. On the other hand, few studies have incorporated other seasonal fluctuating factors such as the quantity and availability of substrates, litter inputs, microbial biomass and populations and root activity and biomass when estimated the temporal dynamics of Q_{10} of R_S [3,8], as these factors confound the response of R_S to soil temperature *per se* [7–9]. Furthermore, seasonal changes of these factors are directly linked to the temporal dynamics of the two processes comprising R_S, that is the decomposition of substrate by heterotrophic soil organisms (R_H) and the respiration of root-rhizosphere (R_A). For instance, the microbial community composition and exo-enzyme production vary with seasonal changes in substrate and nutrient availability (e.g. litterfall variation) [2]. Seasonal changes in root activity and environmental triggers on physiology of plant has an important effect on R_A, especially for deciduous tree species [9]. Simultaneously, R_H could also be affected by root activity through variation in release of root exudates and a corresponding important process “rhizosphere priming effect” [10–12]. Consequently, the responses of R_H and R_A to temperature over growing season could be confounded by changes in these soil and plant

* Corresponding author.
E-mail address: taxus@126.com (G. Jin).

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characteristics.

Most of the previous studies on the temporal changes of Q_{10} of soil CO_2 efflux are mainly focused on R_S [3,8]. To date there are already lots of studies concerning the Q_{10} of R_H and R_A separately associated with relevant influencing factors mentioned earlier, such as the quantity and quality of substrate [13,14], microbial organisms and enzymes kinetics [15,16], photosynthesis and fine root biomass [7]. However, there is still a paucity of knowledge about the temporal dynamics of Q_{10} of these two components in field. As the individual and combined effects of those biotic and abiotic factors, R_H and R_A may exhibit different values of apparent Q_{10} [17,18], and may change over time (from diurnal to interannual and even longer timescale) [19]. It has been suggested that a minor deviation of Q_{10} value may cause a significant bias in modeling the carbon loss from soil due to soil respiration [3]. The use of a constant, as in most field observations of soil CO_2 efflux, a single apparent Q_{10} value of R_S, R_H and R_A in models without considering its temporal variability may result in significant errors in prediction of future soil CO_2 emission [3]. In this study, R_S, R_H and R_A were measured using a trenching method in two temperate forests in Northeastern China; simultaneously, soil microclimate, soil properties and fine root biomass were measured during the growing season. Our main objectives were to (1) examine the seasonal variations in Q_{10} of R_S, R_H and R_A; (2) investigate the biotic and abiotic factors that influencing the short-term Q_{10} of R_H and R_A in temperate forests.

2. Materials and methods

2.1. Study site

This study was conducted at the Heilongjiang Liangshui National Nature Reserve, located in the southern part of the Xiaoxing'an Mountains (128°53′20″ E, 47° 10′ 50″ N). It belongs to a typical hilly landscape. Climate in the region is classified as continental monsoon, with mean annual temperature of −0.3 °C, and mean annual precipitation of 676 mm, of which occurred primarily in the summer (June–August). The soil is dark-brown forest soil by the Chinese soil classfication, which is equivalent to Luvisols based on the World Reference Base of Soil Resources [20].

The experiment was conducted in a coniferous spruce fir forest (SFF) and a broadleaved secondary birch forest (SBF). As an important component of dark coniferous forests which are widely distributed in temperate zones, the spruce fir forest is the virgin non-zonal climax forest, with elevation ranging from 339 to 350 m and the slope is almost flat. The spruce fir forest is sensitive to global warming, as melting of the island permafrost has altered the habitat of the forest and lead to its natural southern boundary will move northward [21]. Therefore, changing hydrothermal conditions and relevant other environmental changes may strongly impact the dynamics of soil carbon pool in this forest. The secondary birch forest which regenerated naturally following harvest of primary forest in 1953, is a deciduous temperate forest located close to spruce fir forest in this region, with elevation ranging from 378 to 510 m and slopes ranging from 10° to 15° [22,23]. Over last few decades, large tracts of primary forest in northeastern China have been harvested and subsequently transformed into secondary forest and planations due to human interference or management. The birch forest is a forest type widely distributed in northeastern China. Table 1 gives the information of the stand and soil characteristics of these two forests.

2.2. Soil respiration measurements

Three 30 × 20 m permanent plots were established in each forest, with tens to hundreds meters buffer zone. Eight polyvinyl choride (PVC) collars (10.4 cm inside diameter, 6 cm height) were randomly inserted into the surface soil of 2–3 cm depth. To minimise the effect of disturbance on soil, the first measurement was conducted 1 week later.

Table 1
Soil and stand characteristics of the two forests.

Properties	Secondary birch forest	Spruce fir forest
Soil properties		
Bulk density (g cm^{-3})	0.53 (0.03)	0.48 (0.04)
pH	4.9 (0.1)	4.8 (0.1)
Organic carbon (g kg^{-1})	66.8 (5.6)	90.1 (11.2)
Total N (g kg^{-1})	9.9 (1.5)	7.5 (0.7)
Stand characteristics		
Tree density (trees ha^{-1})	2475 (316)	1900 (404)
Basal area (m^2 ha^{-1})	23.2 (2.2)	27.2 (2.1)
Mean DBH (cm)	8.4 (1.8)	14.1 (2.0)
Primary species composition	*Betula latyphylla, Larix gmelinii, Picea koraiensis*	*Picea koraiensis, Abies nephrolepis*

DBH: Diameter at breast hight of tree. Values in parentheses are standard errors.

R_S was measured approximately once every two weeks using a soil CO_2 flux system (LI-6400, LI-COR Inc., Lincoln, NE, USA) during the 2013–2014 growing seasons (from early May to early October). The measurements were conducted from 10:00 to 16:00 to minimise the effect of daytime soil temperature fluctuations. Furthermore, all measurements were conducted within rainless days. Meanwhile, soil temperature at a depth of 5 cm below the ground surface next to each collar was recorded using the portable temperature probe connected to the LI-6400; and soil moisture at a depth of 5 cm was measured using a time-domain reflectometry probe (IMKO, Ettlingen, Germany).

Trenching method was used to distinguish R_H and R_A. Four subplots (2 × 2 m) were randomly selected around each plot in October 2009. Trenches were dug on the outside edges of the subplots to bedrock or below, where few roots existed. Then they were lined with double-layer nylon mesh (pore size: 37.4 μm) to enable lateral water movement but inhibit root ingrowth, then refilled carefully with the excavated soil. Therefore, we were able to separate R_A (i.e. respiration of roots, mycorrhizal and associated bacteria) from R_H but not able to exclude ectomycorrhizal mycelia respiration with this set up. However, this should be of minor concern within our trenching treatment, as there was a buffer zone (10–20 cm) existed between the root exclusion nylon-mesh and the measurement collar for soil respiration. Lateral CO_2 diffusion and ingrowth of mycorrhiza mycelia into the collar should have been diminished, as not all mycorrhizal fungi species form far-reaching mycelia [24]. Three PVC collars were installed in each subplot. The plants growing in the trenched plots and inside the collars were clipped two days before each measurement. Soil respiration rate in the trenched subplot was considered as R_H, which was measured simultaneously with R_S using the gas analyzer mentioned above. Actually, we recorded the respiration data from 2010, but in order to minimise the influence of residual root decomposition on R_H, we conducted the study from 2013 and implemented measurements of relevant soil properties and fine root biomass throughout the growing season in this study.

2.3. Soil properties and fine root biomass

Four samples of topsoil (0–10 cm) were collected using a soil core (5 cm inside diameter) from May through October 2013 at each plot of the two forests. The samples were passed through 2 mm sieves and pooled as one sample every time, then refrigerated at 4 °C until to analyze soil microbial biomass (MBC) within one week after sampling. In addition, some soil samples were air dried to analyze the chemical properties. MBC was determined using the chloroform fumigation extraction method [25], and calculated using the following equation:

$$MBC = EC/0.45 \quad (1)$$

where EC was the difference in organic carbon between fumigated and non-fumigated extracts, and 0.45 is the correction coefficient. The