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Contribution of Root Respiration to Soil Respiration during Rainy Season in Dry Dipterocarp Forest, Northern Thailand

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Abstract

Soil respiration (R_s) plays a key role in regulating the terrestrial carbon cycle. The nature of this role is determined by the different responses of root respiration (R_r) and microbial respiration (Rm) to environmental factors such as precipitation, soil moisture and temperature. Understanding these responses is fundamental to improving our predictions of climate change impacts on carbon cycling processes. In this study, the ratio of root respiration to soil respiration (R_r/R_s) was studied to improve our understanding of soil CO_2 emissions. The study aimed to improve our knowledge of Rr in relation to rainy season soil environmental factors in a dry dipterocarp forest in northern Thailand. With values of R_r ranging from 41.04-61.97 $mgCO_2\ m^{-2}\ h^{-1}$, with a R_r/R_s ratio from 23-48 %, the results suggest that soil moisture was a main driver for emitted CO_2 from Rr while soil temperature was only weakly related with Rr during the rainy season. However, longer-term studies are needed, including measurements of root biomass to improve accuracy and understanding of the dynamics of root respiration and their linkages with CO_2 emissions.

Keywords: Root respiration; Soil respiration; Dry dipterocarp forest

Introduction

Soil respiration (R_s) plays a key role in regulating the terrestrial carbon cycle, and includes respiration by both plant roots and soil microorganisms [1-2]. Root respiration (R_r) is a major contributor to total CO_2 emissions from soil [3]. CO_2 losses from R_r and rhizosphere activities implicate with consumption of organic

compounds supplied by aboveground plant's organ [4]. The separation of these two components of soil respiration helps to improve our understanding of the carbon dynamics and responses to environmental change [5]. Previous studies have reported that the ratio of root respiration to total soil respiration (R_r/R_s) was about 10-90 % depending on its spatial and temporal variation [6]. The results of 39 studies of R_r/R_s in the temperate zone found a wide range in R_r/R_s; the minimum rate was 5 % in a *Fagus* forest [7] with a maximum of 90 % in *Picea mariana* and *Quercus* forests [8-9]. In tropical forest soils, which have been less closely studied, R_r/R_s ranged from 43-55 % [6].

In general, several techniques are available for estimating root respiration, including component integration, root exclusion and isotope method [6]. Component integration involves separation of soil components (i.e. root, sieved soil and litter). The potential limitation of this method is that root respiration is usually measured *in vitro*. Root respiration is directly estimated by measuring R_s with and without the presence of roots. The isotope method can allow partitioning of R_s between root respiration and microbial respiration *in sit*u better than component integration and root exclusion. However, the method is disadvantaged by the complexity of experimental setup and cost of analytical radioactive or stable C isotopes [6].

Tropical forests represent the largest area of global forest biomes (~50 %) and play a vital role in the global carbon cycle [10]. Dry dipterocarp forests are found only in continental Southeast Asia (Vietnam, Laos, Cambodia Thailand, Myanmar, India, and south China) in a region referred to as the Indo-Burma Biodiversity Hotspot [11]. Root respiration studies are crucial to explaining the variability of carbon dynamics. The variation of soil respiration and its components are controlled by environmental factors such as soil temperature and moisture. Temperature regulates substrate transportation and metabolism, while soil moisture influences soil respiration directly though physiological processes of roots and microorganism, and indirectly via diffusion of substrates and O_2 [12]. The study of soil respiration and its components was conducted in Thailand's, such as the Skaerat dry evergreen forest in Nakhonratsrima, Maeklong mixed deciduous forest in Mae Klong, watershed research station, Kanchanaburi and dry dipterocarp forest in Ratchaburi Province [13]. Dry dipterocarp forest is commonly found in Thailand and delivers a range of non-timber benefits to adjacent communities, including wood and charcoal, timber, mushroom and hunting. Though dry dipterocarp forest is typified by rapid carbon turnover in each season, there are few studies of carbon dynamics for this type of forest. A study of R_r/R_s in dry dipterocarp forest was found only for the Ratchaburi site, where Hanpattanakit et al. [13] reported an average R_r/R_s ratio of 29 % during the rainy seasons over a 4-year study period. The authors found that growth of fine roots was strongly correlated with root respiration in the rainy season and soil moisture was closely linked to the R_r/R_s. To improve our understanding on the variability of R_r/R_s in dry dipterocarp forests, the current research aimed to evaluate the contribution of soil respiration by using the trenching method. Trenching involves installation of a barrier to restrict plant root growth and has been widely used to partition soil respiration components [5-6, 13-15]. This method blocks carbon supply from tree to soil [16] and maintains the conditions in study plots in their original state with respect to soil temperature and moisture. Trenching is in-expensive and a generally accepted method for partitioning R_s components [5]. The aim of this study was to investigate environmental factors affecting soil respiration in dry dipterocarp forest during rainy season in dry dipterocarp forest, northern Thailand.

Materials and methods

1) Site descriptions

The study was carried out in a dry dipterocarp forest at Phayao Province, northern Thailand (Figure 1a). The site was located in Dry Dipterocarp Forest Flux Phayao Site Thailand (DPT) (Latitude: 19° 02' 14.38" N, Longitude: 99° 54' 10.96" E, altitude 512 m). The topography was sloping, and dominant species were *Shorea obtusa*, *S. siamensis*, *Dipterocarpus tuberculatus* and *D. obtusifolius*. Based on tree density observation, standing trees were mainly found in the forest, with relatively fewer saplings (182,100 and 60,000 tree km^2, respectively) [17] (Figure 1b). This forest has been previously regenerated through forestry concessions to generate secondary forest [18]. In 2015, the age of trees was 15-20 years old. The site has a tropical monsoon climate with 936 mm of average annual precipitation and mean air temperatures of 18.64 to 31.62 °C. Soil temperature ranged from 19.07-31.86 °C, while soil moisture ranged from 11.84-30.82 % WFPS (measured in 2013-2016 at DPT station). The main texture of topsoil was sandy loam (0-10 cm depth) and sandy clay loam in lower layers. Soil bulk density ranged from 1.40 to 1.89 g cm^{-3}, and organic carbon content ranged from 0.67 to 3.89 % [17].

2) Soil respiration (R_s) and root respiration (R_r)

Soil respiration was measured by closed chamber technique during June to October 2016. The measuring system contains a analysis and recording system and chamber (Figure 2a). R_s and its components was measured at 10 minute intervals in each chamber and analyzed by infrared gas analyzer (Li-820, Licor Corporation, Lincoin, Nebraska, USA). Data were stored in a data logger (CR1000, Campbell Scientific, Logan, Utah, USA). The chamber had two parts (cover and base), constructed from polyvinylchloride (PVC), with base diameter of 21.5 cm and height of 22.0 cm (Figure 2b). Nine chambers of R_s were installed into the soil to a depth of 7 cm. R_r was evaluated from the difference of total soil respiration and microbial respiration (Eq. 1). The separation between microbial respiration and root respiration was performed by trenching method (Figure 2c). For this method, roots were exposed by digging a trench into the soil about 100 cm around study plot size 100 cm x 100 cm [12, 16] and inserting a polycarbonate sheet as a barrier to prevent further root growth. Nine chambers of microbial respiration were installed as the R_s. Chamber temperature was measured at 0, 5 and 10 minutes. In addition to these measurements, soil and air temperature, rainfall and soil moisture were continuously measured. Soil temperature and soil moisture were measured at a depth of 5 cm using a thermocouple and CS616 model (Campbell, Scientific, Logan, Utah, USA), respectively. Air temperature and rainfall were measured by WXT520 (Campbell Scientific, Logan, Utah, USA).

$$R_r = R_s - R_m \quad \text{(Eq. 1)}$$

Where R_r, R_s and R_m are the value of root respiration, soil respiration and microbial respiration, respectively.

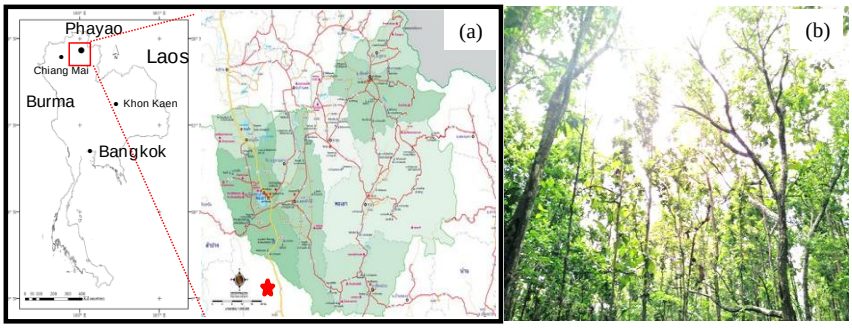

Figure 1 (a) Dry dipterocarp forest flux Phayao Site, Thailand and (b) dry dipterocarp forest.

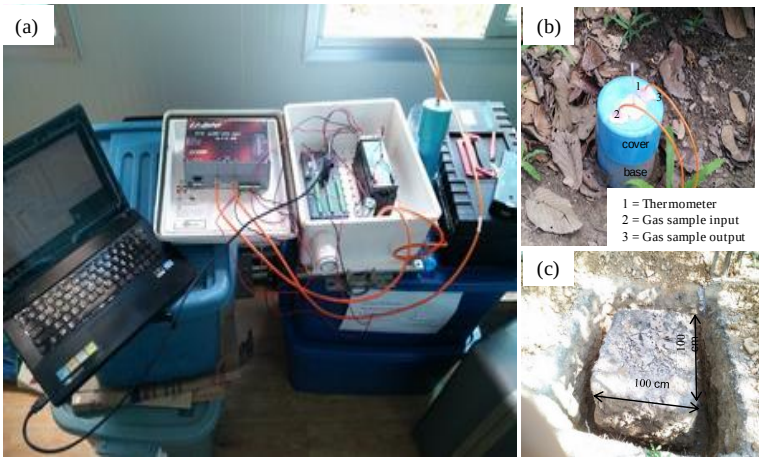

Figure 2 Picture of (a) Soil respiration measurement system, (b) closed chamber and (c) Trenching method.

3) Soil CO_2 flux calculation

Soil respiration rate were calculated using the linear portion of gas concentration change during chamber closing time. Only data showing a significant correlation of the measurement points were taken into account to calculate the CO_2 flux followed by equations 2 and 3 [16]. Correlation and regression analysis were used to test the relationship between R_r and soil environmental factors (soil moisture and soil temperature).

$$C_i = \frac{qiMP}{RT} \qquad \text{(Eq. 2)}$$

Where *Ci* is mass per volume concentration (gCO_2 m^{-3}), *qi* is volume per volume concentration (m^3 m^{-3}), *M* is molecular weight of CO_2 (44 g mol^{-1}), *P* is atmospheric pressure (1 atm), *R* is the gas constant (8.2058 x 10^{-5} m^3 atm K^{-1} mol^{-1}), *T* is the average temperature inside the chamber (K).

$$F = \frac{dC_i V}{d_t A} \qquad \text{(Eq. 3)}$$

Where *F* is flux on the aerial basis (g m^{-2} min^{-1}), *V* is volume of the chamber's headspace (m^3), *A* is area of soil enclosed by the chamber (m^2) and dc_i/d_t is rate constants of CO_2 concentration increase with time (gCO_2 m^{-3} min^{-1})

Results and discussion

1) Meteorological data

Meteorological measurement during June to October 2016 included all information on air temperature, rainfall, soil temperature and soil moisture at 5 cm depth (% water filled pore space; % WFPS). Mean air temperature ranged from 24.9-25.9 °C, with the highest in June and lowest in October. Mean soil temperature at 5 cm depth ranged from 25.4-26.4 °C (Figure 3a) while average soil moisture during the same period was 24.67, 24.33, 25.34, 30.97 and 30.82

% WFPS, respectively (Figure 3b). The seasonal variation of the soil moisture at a depth of 5 cm depth was a response to the rainfall pattern during the year. Total precipitation (June - October) was 733.3 mm.

2) Total soil respiration (R_s) and root respiration (R_r)

Accumulative R_s in rainy season was 0.11 $kgCO_2$ m^{-2} $month^{-1}$. The annual average of R_s during June to October 2016 was 121.72±91.65 171.41±65.91 147.54±67.65 178.39±140.34 and 138.72±79.64 $mgCO_2$ m^{-2} h^{-1}, respectively. Estimated R_m values during June to October 2016 were 63.32±35.60, 118.55±51.22, 85.57± 22.02, 137.35±110.56 and 92.97±47.74 $mgCO_2$ m^{-2} h^{-1}, while, accumulated R_r was 0.038 $kgCO_2$ m^{-2} $month^{-1}$. The means of R_r for five months were 58.40±56.06 52.86±14.69 61.97±45.63 41.04±29.78 and 45.74±31.90 $mgCO_2$ m^{-2} h^{-1}, respectively (Figure 4a). The average ratio of R_r/R_s was 35 % or between 23-48 % (Figure 4b). Compared with Ratchaburi site, root respiration of the dry dipterocarp forest during the wet seasons of 2008-2011 in Ratchaburi ranged between 112-205 $mgCO_2$ m^{-2} h^{-1}, and the ratio of R_r/R_s was about 21-33 % [13]. The ratio of R_r/R_s was similar with our study. Although the trees at Ratchaburi site were younger than at the Phayao site [19]. However, Hanpattanakit [13] suggested that dry dipterocarp forest at Ratchaburi may have adapted to actively transport the majority of fixed carbon to aboveground biomass instead of the roots after past invasion. Age of trees have affect to respiration from root activity directly [20]. However, when we compared the R_r/R_s with older forests. Example, R_r/R_s of needle leaf mixed forest at Chongqing was 26.75 % [21], evergreen broadleaf forest, pine forest and broadleaf mixed forest at Guangdong ranged 26-35 % [22], and old-growth subtropical evergreen forest at Yunnan was approximately 16 % [23]. These results presented that our R_r/R_s was nearly with the ratio of the forests, although age of our forest had younger age due to the difference of plant community's activities. Moreover, the previous study about the R_r/R_s of other forest types found 50-93 %, 62-89 %, 33-50 % and 35-62 % in arctic tundra, boreal forests, broadleaved forests and pines forests, respectively [3]. For this reason, the different types of forest and climate conditions, especially soil temperature and moisture were affect to CO_2 emission from root activity [24].

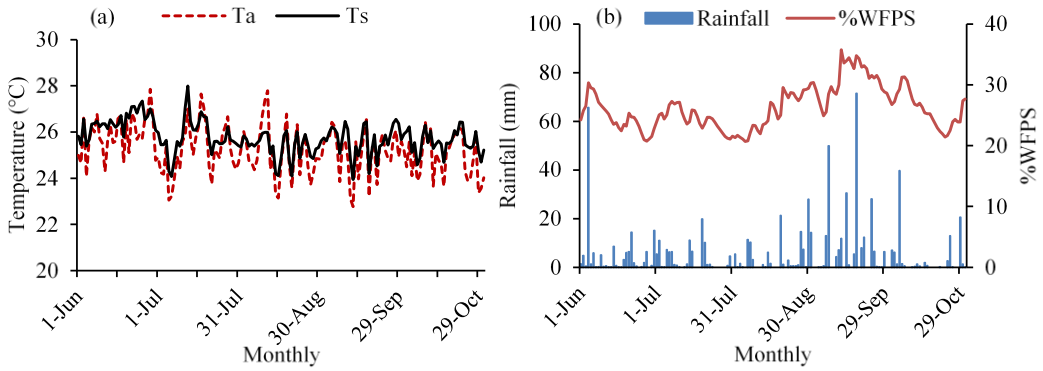

Figure 3 Graphs of (a) Air temperature (Ta), soil temperature (Ts) and (b) total monthly rainfall and soil moisture from June to October 2016.

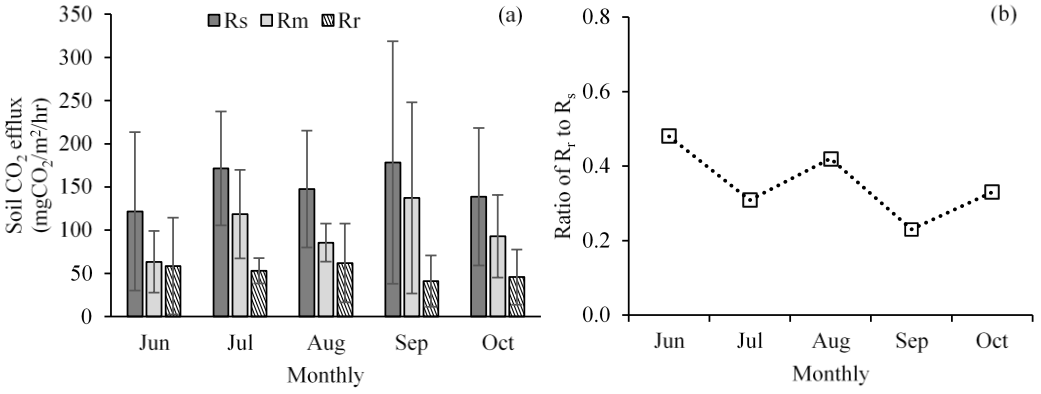

Figure 4 Graphs of (a) soil, microbial and root respiration and (b) the ratio of root respiration to soil respiration during June to October 2016.

3) Soil factors and root respiration

Normally, soil moisture and soil temperature are influential factors in the CO_2 efflux of forest ecosystems, especially through their mediation of soil respiration and its components. In our study, both factors influenced CO_2 emissions from soil microbial and root respiration. Soil moisture and R_r were negatively correlated, though the relationship was not statistically significant (Figure 5a). High soil moisture reduced CO_2 emission through root respiration due to the prevailing anaerobic conditions in the soil pores. However, Bryla et al. [25] reported that R_r rate in wet soils was higher than at high temperatures under dry soil conditions, while R_s ($R^2 = 0.17$, $p < 0.05$) and R_m ($R^2 = 0.29$, $p < 0.01$) were positively correlated with soil moisture. This was explained by the presence of several groups of soil microorganisms adapted to the changing environment. Microorganisms represent the main source of CO_2 release in this dry dipterocarp forest (67-79 %). The relationship between soil temperature and R_s showed weak positive correlation and no significantly (R^2 = 0.11). While, relationship between soil temperature and soil respiration components (R_m and R_r) found weak positive correlation significantly in Rm ($R^2 = 0.12$, $p < 0.05$) and no significant in R_r ($R^2 = 0.09$, $p < 0.05$). Generally, temperature affects the increase of root respiration [12]. The relationship of R_r in this study has similar with previous studies. For example, the R_r and temperature in a secondary forest of Japan was no significant correlation [26]. R_r of old-growth Ailaoshan subtropical forest in Yunnan, broadleaf and needle leaf mixed forest and bamboo forest in Chongqing was least sensitive to temperature [21, 23]. However, the increase of R_r with soil temperature was exponential but it increase only takes a short time [27-28]. Hanpattnakit [16] presented soil respiration and its components in dry dipterocarp forest can response well in soil temperature less than 26 °C. At the temperature over 35 °C, it may affect to protoplasm system to break down [12]. In addition, the direct factor affect to R_r is photosynthesis which is an important to root growth and synthesis of new tissue [29-30] and the indirect factors are salinity, water stress, nutrient supply and pH value [29]. Thus, further studies should be observed continuous for increase our understanding about the response of R_r to soil temperature, and conducted root biomass and other factors for accuracy of the information.

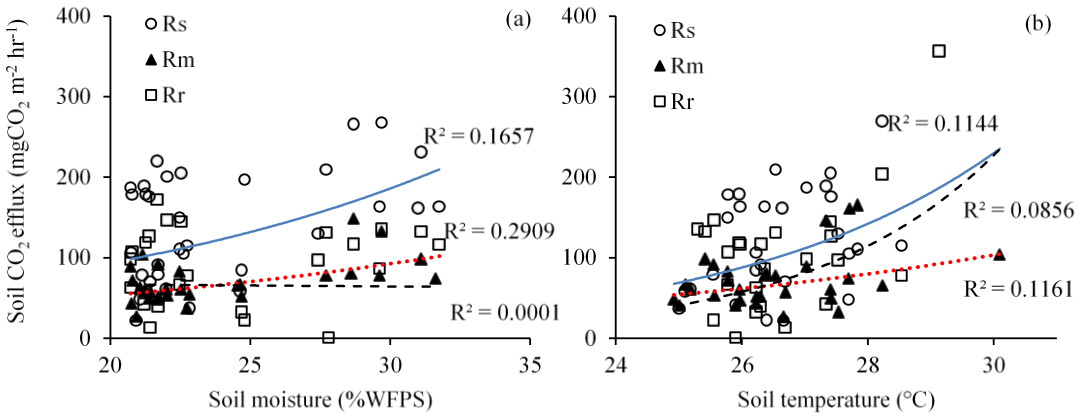

Figure 5 Relationships between (a) soil moisture and (b) soil temperature with soil respiration and its components.

Conclusion

Soil CO_2 emissions from root respiration, measured during June to October 2016 in dry dipterocarp forest, northern Thailand was recorded at 0.038 $kgCO_2$ m^{-2} $month^{-1}$ with a range of 41.04-61.97 $mgCO_2$ m^{-2} h^{-1}. Soil respiration accounted for 23-48 % of the total, with soil temperature as the main factor determining root respiration rate during the rainy season. R_s and R_m were positively correlated with soil temperature and soil moisture. However, further study on soil respiration and root biomass is needed. The results of this study can be used to explain the mechanism of soil carbon cycling and CO_2 emission transport from root to atmosphere. Additionally, the obtained data can be also used to support the mechanism of carbon stock and the initiative program on Reducing Emission from Deforestation and Forest Degradation in Developing Countries (REDD+) in the future.

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