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Relationships among Soil Properties, CO_2 Emission and Ecosystem Respiration in Dry Dipterocarp Forest, Western Thailand

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ABSTRACT

CO_2 emissions from the forest (ecosystem respiration, R_e) come from both aboveground respiration (plant respiration, R_a) and belowground respiration (soil respiration, R_s). The ratio between R_e and R_s varies in time and space. It is not well understood especially in the tropical forests that how these two components play the roles in controlling the amount of CO_2 emissions, and how they respond to the changes in environmental factors such as precipitation, soil moisture and temperature. Understanding the responses to such environmental factors is fundamental to an accurate prediction of the impacts of climate on carbon cycling processes, i.e. on sources or sink capacity and climate feedbacks. The objectives of the present study are to quantify the contribution of R_s to R_e, and to investigate the relationship between soil properties and CO_2 release in a dry dipterocarp forest in western Thailand.

It was found that the averaged soil respiration (R_s) in 2009 and 2010 were 459.10±162.67 and 404.28±133.31 $mgCO_2m^{-2}hr^{-1}$, respectively. The averaged ecosystem respiration rates during these same years were 497.30±336.12 and 686.32±416.04 $mgCO_2m^{-2}hr^{-1}$, respectively. Annual estimates of soil and ecosystem respiration indicate that the annual R_s/R_e ratio ranged from 0.24-1.20, with a mean of 0.57. R_s/R_e ratio was relatively high in dry season [0.91, during November to April] when compared with during wet season [0.55, during May to October].The relatively high contribution of R_s to R_e is quite unique for this dry dipterocarp forest. Comparing the amount of CO_2 respired during wet and dry seasons, 80% was released during the wet season (April-November) when the monthly average of soil moisture content was above 8% WFPS. High contribution of R_s to R_e during dry season was due to the low aboveground respiration associated with leaf fall in the periods. Analyzing the relationship between soil respiration and ecosystem respiration with soil property factors indicates that unlike in temperate forest, tropical dry dipterocarp forest shows decreasing respiration when soil temperature increases. However, positive correlation between soil respiration and soil moisture was found in both wet and dry seasons.

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1. INTRODUCTION

Forest ecosystems influence the concentrations of atmospheric CO_2 and global carbon cycle because large amounts of carbon are stored in biomass and soil, and these are readily exchangeable. For example, the global soils contain carbon as high as 3150 Pg C, including 450 Pg C in wetlands, 400 Pg C in permanently frozen soils, and 2300 Pg C in other ecosystems (Sabine 2003). Due to its large amount, a small fraction change in soil carbon pool will have significant effects on the concentration of atmospheric CO_2. In the past, release of carbon from forest ecosystem is one of the main causes of increasing concentrations of atmospheric CO_2. Houghton (2003) reported that almost all of the global carbon flux occurs in the tropical regions (2.2 PgC / yr in the 1990), mainly from deforestation. Outside the tropics, the net flux is a small sink (0.2 PgC / yr during the 1990). In forest ecosystem, rapid exchanges of carbon between the atmosphere, terrestrial biota and soil, are the dominant characteristics.

Carbon enters terrestrial ecosystems through a single process, photosynthesis, but is returned through a variety of processes, collectively referred to as respiration. Functionally, respiration is divided into CO_2 released by living plant leaves, stems and roots (autotrophic respiration), and CO_2 released during decomposition of nonliving organic matter (heterotrophic respiration). Soil respiration (R_s) is the important pathway of carbon dioxide (CO_2) exchanges between forest and the atmosphere, accounting for 40-90% of total ecosystem respiration (R_e) [Schesinger 2000]. CO_2 release from soil surface is a result of both microbial (microbial respiration, R_m) and root (root respiration, R_b) activities, which may respond differently to environmental factors such as precipitation, soil moisture and temperature. The wide range of R_s/R_e ratio of forests available in the literatures suggests differences in controlling factors and responses for both R_s and R_e. Typically, the annual R_s/R_e ratio was 0.68 in temperate hardwood forest in Massachusetts, USA (Goulden 1996); 0.76 in a mixed-age ponderosa pine forest in Oregon, USA (Law 1999); 0.48-0.71 among coniferous boreal forests of central Canada (Lavinge 1997); 0.73 in a boreal aspen forest in Saskatchewan, Canada (Griffis 2004); 0.38-0.99 among Euroflux forested study sites (Janssens 2001); 0.38 in a mature evergreen forest in the central Amazon Basin (Chambers 2004); and 0.31 in a mature evergreen forest of the eastern Amazon Basin (Saleska 2003). Moreover, Davidson (2006) studied the seasonal pattern of the ratio of soil respiration in a spruce-dominated forest, USA. They found that R_s/R_e ratio reached a minimum of about 0.45 in the early spring, gradually increased through the late spring and early summer, leveled off at about 0.65 for the summer, and then increased again to about 0.8 in the autumn. The seasonal change of R_s/R_e was controlled by soil environmental factors such as soil temperature and soil moisture. In addition, it was related to phenology of growth of aboveground and belowground plant tissues also. However, the research on temporal variations of these ratios across seasons in the tropical forest types are quite scare. Studies in the past indicate that the R_s/R_e ratio might vary seasonally and that understanding this could provide insight into ecosystem responses to varying weather and climate. The objectives of the present study are to investigate seasonal variations of the R_s/R_e ratio in a dry diptercarp forest and its responses to soil environmental factors as soil temperature and soil moisture.

2. METHODOLOGY

2.1 Site description

This study was carried out at King Mongkut’s University of Technology Thonburi, Ratchaburi Campus in Ban Ranbua, Tambon Rangbua, Chombung District, Ratchaburi province (13^o 35’ 13.3’’ N, 99^o 30’ 3.9” E, elevation of 110 m above mean sea level). The total area of dipterocarp forest used in this study covers 187.2 ha. This area has been kept as the dipterocarp forest for approximately (more than) 50 years. Communities around this forest have utilized it for energy (wood and charcoal), timber, and other products such as mushrooms and local hunting. As a result, most of the trees are those from the re-generated ones after being cleared occasionally by villagers. In 2009, aboveground trees were 6-7 years old with the average height and perimeter of 5 m and 16 cm, respectively. This forest ecosystem has been preserved and protected, and cutting of trees is no longer permitted, allowing forest to grow and recover towards becoming an undisturbed ecosystem. According to Phiancharoen (2008), there are about 77 tree species found in this study area. The main species are *Dipterocarpus intricatus, D. obtusifolius, D. tuberculatus*, *Shorea obtuse and S. siamensis* (Dipterocarpaceae). This forest ecosystem is unique that while the aboveground biomass is periodically cut by villagers, the belowground biomass stays intact. Therefore, the aboveground to belowground biomass ratio for most of dominant species is less than one.

The mean soil temperature and soil moisture at 0.05 m depth were not quite different in both 2009 and 2010 (Fig. 2a). The mean soil temperatures during 2009-2010 were 26.19 and 26.82 ^oC, and soil moisture were 14.87 and 13.67 % water fill pore space (%WFPS), respectively. The annual average of precipitation, air temperatures, and soil moisture for wet season (during May – October, 2009), and dry season (during November, 2009 – April, 2010) were 194.62 mm/month, 10.47 %WPFS, 27.38 ^oC, and 11.32 mm/month, 4.14 %WPFS, 29.62 ^oC, respectively. This indicated the distinct difference of climate condition between wet season and dry season in dry diptercarp forest. In addition, soil pH at the site was acidic with pH value around 5 throughout the 1 meter profile. Soil bulk density ranged from 1.3 - 1.4 g cm^{-3}. The organic carbon content was 0.3-0.5%. The soil texture for the top to 1 meter depth was loamy sand, with sand particle content of more than 70% and very small fraction of clay content.

2.2. Instrument setup

We use automated - chamber for measuring R_s and tower-based eddy covariance for measuring R_e. Comparisons with estimates of R_e derived by scaling and summing chamber measurement of soil, foliar, and bole respiration or derived from eddy covariance measurements have indicated that the sum of chamber measurements often higher than the eddy covariance estimates (Goulden 1996; Lavinge 1997; chambers 2004; Griffis 2004). These authors have discussed the numerous uncertainties in both methodological approaches, which we do not pursue further here. However, we do address several possible sources of error and bias that are specific to calculation R_s/R_e ratio.

Automated-chamber measurements of R_s

Soil respiration was measured by automated-chamber technique during 2009-2010. The measuring system consisted of a chamber operation system and data-storing unit (data logger). The chamber had two parts; the cover and base. The cover was made of acrylic of 0.3 m width x 0.3 m length x 0.3 m height and the base was made of stainless steel with dimension of 0.3 m width x 0.3 m length x 0.15 m height. The base was permanently inserted into the soil where gas sampling was conducted. To monitor the net CO_2 exchange through soil respiration and to prevent the effects of photosynthesis, the opaque chamber was used and installed in the area without plant.

The chambers were closed and opened by a hydraulic system which was controlled by a program on a data logger (CR10x, Campbell Scientific, Logan, Utah, USA) and a two-way solenoid valve. At any given time, CR10x commanded the two-way solenoid valve to close the chamber lid, and another one way solenoid valve was set open. Then, air sample inside the chamber was pumped (1.0 L min^{-1}) into the measurement unit where CO_2 concentration was determined by infrared gas analyzer (Licor-820, Licor Corporation, Lincoln, Nebraska, USA). The data generated were stored in the datalogger and downloaded manually. After analysis of CO_2 concentrations, the air sample was channeled back to the chamber through one way solenoid valve**.** One sampling cycle took about 7 minutes. In the present study, soil respiration was measured hourly during 2009-2010. Thus, for each replication (there were 3 replications), respiration was measured 24 times per day, or about 17,520 times during the whole study period of 24 months. During the course of measurement, CO_2 in ambient air was also measured hourly. The system was calibrated with standard CO_2 gas regularly (monthly). In addition to these measurements, soil and air temperatures and soil water content were continuously measured. Soil temperature was measured at a depth of 0.05 m with two Averaging Soil Thermocouple Probes (TCAC, Campbell Scientific, Inc. Logan, Utah, USA). Soil water content was measured at 0.05 m depth with two water content reflectometers (CS615, Campbell Scientific, Inc., Logan, Utah, USA).

Eddy covariance measurements of R_e

The eddy covariance method was used to measure the CO_2 exchange between the atmosphere and forest ecosystems that were measured directly on the real time (Kato 2004; Macmillan 2008; Saigusa 2008). For this study, the eddy covariance flux measurements system was used to study carbon exchange in the forest. It was established on the dry dipterocarp forest flux Ratchaburi tower since 2009. Fluxes have been measured at a height of 11 meter on the soil surface and control systems were automated that used three data logger. Carbon dioxide and water vapor densities were measured with an open-path infrared CO_2/H_2O analyzer at 4 Hz (LI-7500, LI-COR, Lincoln, Nebraska 68504 USA). Wind velocity and the speed of sound was measured with three-dimensional sonic anemometer-thermometer (Campbell CSAT3). Temperature and humidity were measured by Vaisala sensor (Vaisala Inc. Model HMP45C).

2.3. CO_2 flux calculations and statistical analysis

Soil respiration rates (R_s) were calculated using the linear portion of the gas concentration change over the chamber closing period as mentioned above. Only data showing a significant correlation of the measurement points (Pearson correlation coefficient of concentration data versus time was significantly >0 at the $p \leq 0.05$) were taken into account to calculate the CO_2 flux. Correlation and regression analysis were used to test the relationship between of respiration from R_s and R_e with environmental factors as soil temperature and soil moisture.

3. RESULT AND DISCUSSION

3.1 Seasonal variations of R_s and R_e

CO_2 produced in soil by roots and microorganisms is transferred through soil profiles to the soil surface. At the soil surface, CO_2 is released into the air by both diffusion and air turbulence. The released CO_2 is then mixed in plant canopy, partly absorbed by photosynthesis during daytime, and mostly released to the atmosphere through a planetary boundary layer. The belowground respiration (R_s) represents 40-90% of the forest ecosystem respiration (Schlesinger 2000). Thus, soil activity in forests plays an important role in the carbon exchange of the forest ecosystem.

The seasonal pattern for R_s and R_e in dry dipterocarp forest (DDF) during 2009 - 2010 is shown in figure 1. The mean soil respiration during 2009 – 2010 were 459.10 ± 162.67 and 404.28 ± 133.31 $mgCO_2m^{-2}hr^{-1}$, and average ecosystem respiration during the same year were 497.30 ± 336.12 and 686.32 ± 416.04 $mgCO_2m^{-2}hr^{-1}$, respectively. Normally, both of R_s and R_e increase in beginning of wet season and remained high until beginning of dry season (April - November). The CO_2 released during this period was 80% of total CO_2 emission during the year. The result indicate that the seasonal variations in R_s and R_e were closely related to soil water content and soil temperature. R_s was positively correlated with soil water content and negatively with soil temperature (Fig. 3). Moreover, during the dry period (November - April), when soil water content was low, all CO_2 releasing were also low. In contrast, CO_2 emission in DDF increased during the wet season (May - October). This well-known effect is a result of the stimulation of biological activity in the soil (Borken 2003; Lee 2003; Liu 2002). After rain coming during the beginning wet season, the soil activities were possibly enhanced. Yi (2007) studied about the root and microbial activity between wet and dry season in evergreen broad-leaf forest and pine forest, South of China. They found that fine root biomass and microbial biomass differed significantly between wet and dry season. During wet season, the plants grew faster and higher root biomasses while the litter biomass on the soil surface is decomposed by microbial and soil animal such as termite and earthworm. It was related to CO_2 production from root respiration and microbial respiration. Adachi (2006) also found that soil respiration increased with fine root biomass (size < 2 mm) and with microbial biomass in the tropical forests. The results suggested that the temporal change in soil respiration was resulted from the growth of plant and microbial in soil, which in turn affected by soil property as soil temperature and soil moisture.

The aboveground respiration is combining between leaf respiration and wood respiration. It was reported that up to 35% of the total carbon assimilated may be lost CO_2 by leaf respiration (Athin 1998). Plant respiration varies between species (Reich 1992; 1998, Wright 2001; Turnbull 1990) and leaf respiration accounts for approximately half of the whole plant respiration (Poorter 1990).

Davison (2006) explained about an increase in aboveground respiration in wet season that this may rely on mobilization of stored carbohydrates, as is the case for springtime upward sapflow. Activation of aboveground respiration, as buds first begin to swell, could be a phonological response to increased day length, soil temperature and soil moisture. Interactions between soil property as high soil moisture and decreasing soil temperature in wet season at dry diptercarp forest may also enhance aboveground respiration quickly. Moreover, the plant physiology also affects to aboveground respiration. For example, leaf age effects to respiration rate. Villar (1995) studied the relationship between age and leaf respiration rate of *Heteromeles arbutifolia* in evergreen forest and *Lepechinia fragans* in deciduous forest. They found that both leaf respirations of both plants decreased significantly with increasing leaf age. Our results of aboveground respiration had shown the gradual decrease towards the ending wet season until beginning dry season (October to December). Normally, foliage and litter fall in dry dipterocarp forest was concentrated during the cool and dry period (January to March). The foliage fall on the surface implies the decrease in aboveground respiration. Curtis (2005) studied the relationship between R_s and R_e in an aspen-dominated mixed hardwood forest in Michigan from 1999 to 2003. They found that the average contribution of R_s is 71% of R_e. However, the relative contribution of R_s to R_e varies considerably in a year. R_s contributes nearly 100% of R_e for most of the winter; the contribution drops to about 60% during the period of fast last leaf expansion and then gradually increases during the growing season as soil warms, reaching about 75% at the time of leaf abscission in the autumn (Curtis 2005). Typically, R_s contributes 30-80% of R_e in forests.

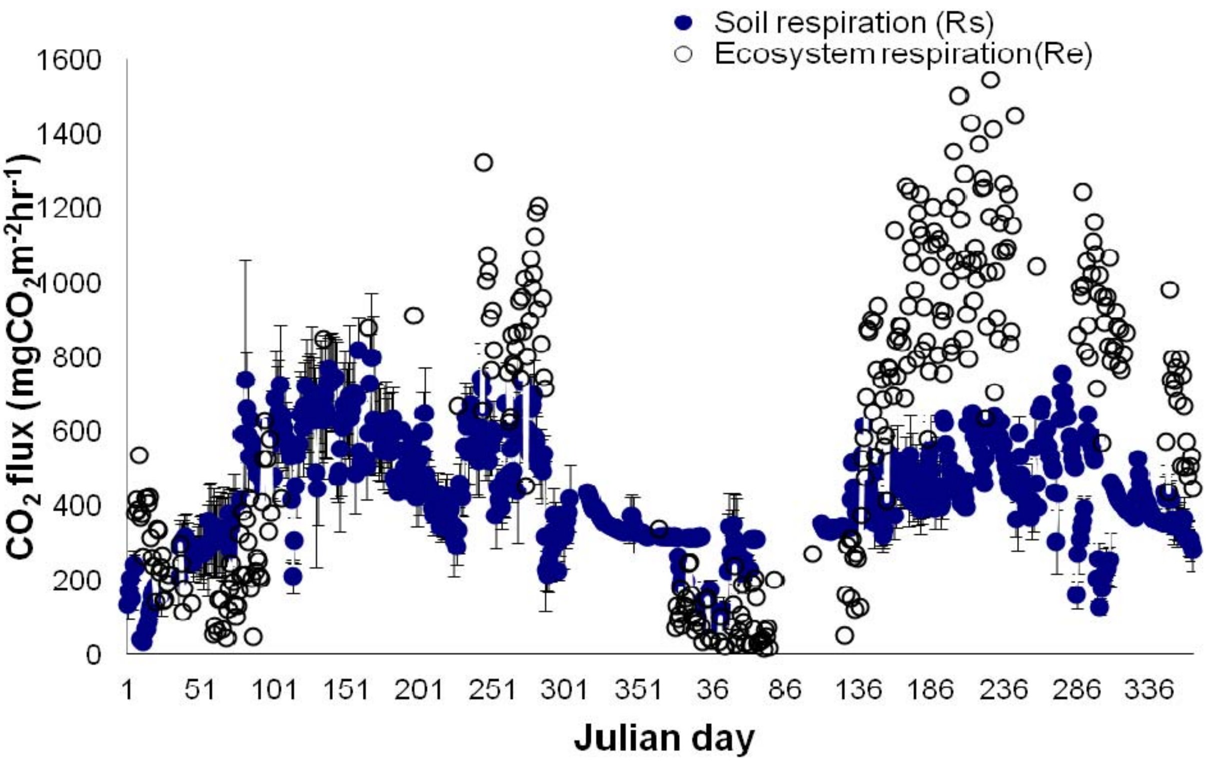


Fig. 1 Seasonal variation of mean soil respiration and ecosystem respiration at Dry Dipterocarp Forest Flux Ratchaburi site, Western Thailand during 2009 – 2010 were observed.

In our study, annual estimates of soil and ecosystem respiration indicate that the annual R_s/R_e ratio ranges from 0.24-1.20, with mean of 0.57. R_s/R_e ratio was relatively high in dry season dry [0.91, during November to April] when compared with during wet season [0.55, during May to October] (Fig. 2b). The ratios vary widely and only part of this variation can be attributed to the seasonal patterns. Remaining variation may include responses to synoptic weather patterns, spatial and temporal mismatches between R_s and R_e measurements, and measurement errors (Davidson 2006). These results indicate about the factors controlling the R_s/R_e were temperature and moisture in soil. In our study, the ratios were increased and decreased with soil temperatures (Fig 2a). In addition, high contribution of R_s to R_e during dry season was due to the low aboveground respiration associated with leaf fall in the periods. Thus, the major CO_2 releasing in the forest during dry season was soil respiration. The R_s /R_e ratio was gradually decreasing during wet season because of aboveground respiration from leaf as mentioned above.

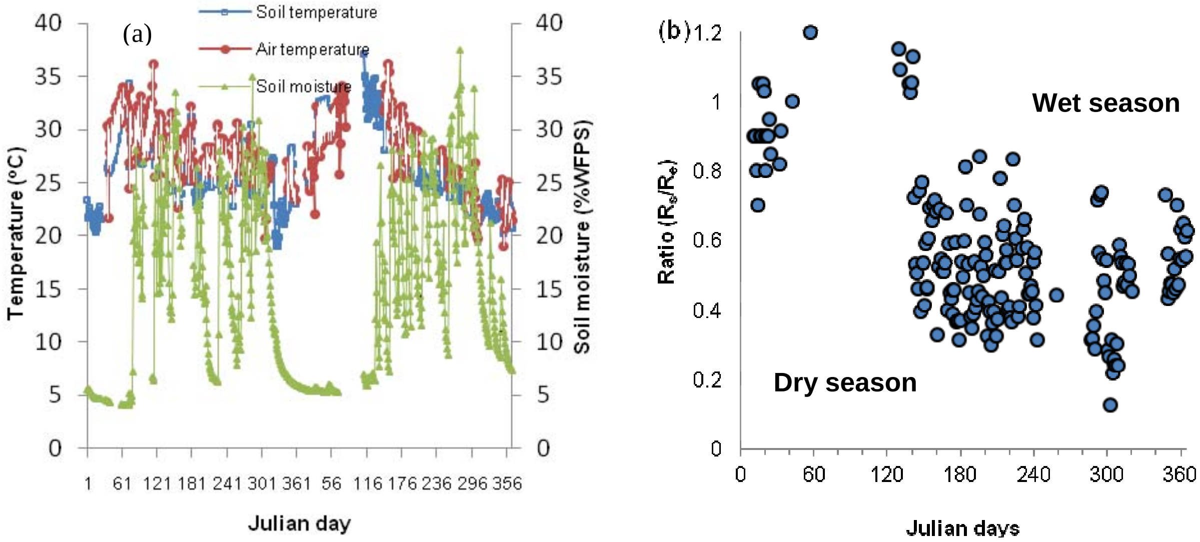
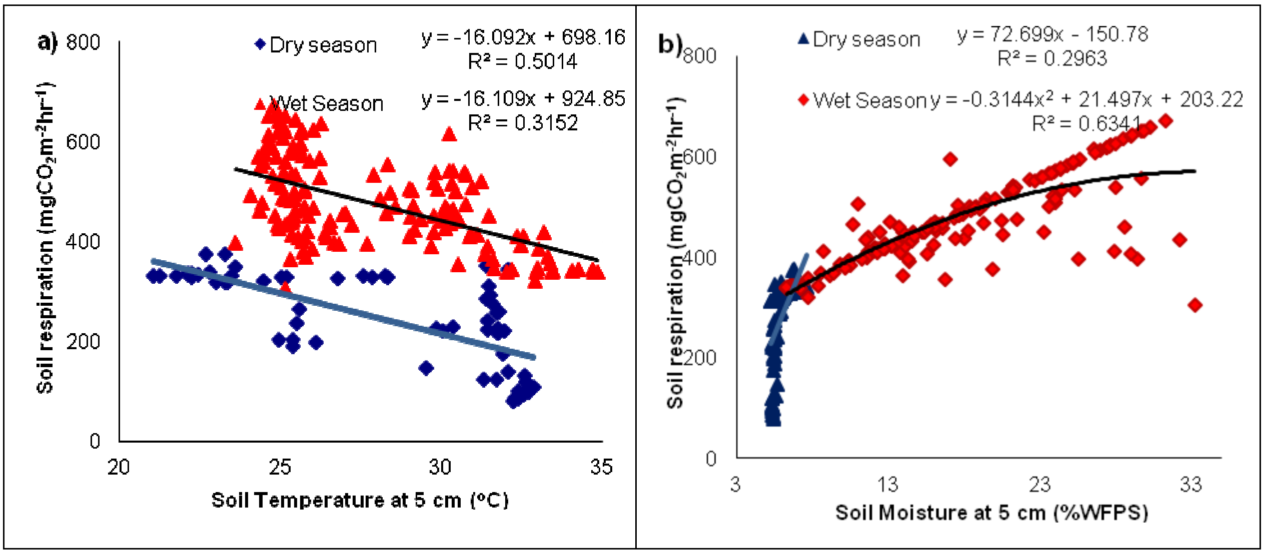


Fig. 2 Seasonal variation of air temperature (0.15 m above the soil surface) and soil temperature and moisture (0.05 m depth) (a) and the ratios of R_s/R_e during wet and dry season at Dry Dipterocarp Forest Flux Ratchaburi site, Western Thailand (b).

3.2 Soil factors controlling R_s and R_e

Normally, soil moisture and soil temperature were strongly affect to CO_2 releasing in forest ecosystems. However, the relative importance in arid and semiarid ecosystem is still controversial (Huxman 2004). In these ecosystems, soil moisture is the main factor limiting soil respiration. Thus, seasonal patterns of soil respiration closely follow dynamics of soil moisture (Davidson 2000). In the Amazon basin, where the seasonal variation in temperature is not large, while variation in soil water content is substantial, soil respiration in pastures and forests correlates significantly with water-filled pore space in soil (Salimon 2004). In Mediterranean climate regimes with cold, wet winters and hot, dry summers, water usually constrains biological activity in summer. Seasonal patterns of soil respiration and ecosystem respiration are largely determined by soil water availability. Soil respiration rates correlate positively with soil water content and negatively with soil temperature in sandstone and serpentine grasslands (Xu 2001). It has been reported that the relationship between soil respiration and soil moisture can be fitted by several functions including linear, exponential and logarithmic, asymptotic and polynomial functions (Chen. 2008). Upon comparison of different functions, linear functions were applied to the datasets of soil respiration with soil temperature both wet and dry season in this study. The negative relationship between soil respiration rate and soil temperature suggests that soil temperature was a limiting factor in biotic activity in the forest. Moreover, the positive relationship between soil respiration rate and soil moisture suggests that soil moisture was a limiting factor in carbon decomposition and root activity in both seasons (Fig. 3 a-b). For the correlation between ecosystem respiration with soil moisture and soil temperature were similar to the relationships of soil respiration and soil property but with different correlation functions (Fig. 3 c-d).

Many reports studied correlation and regression of soil property as soil temperature and soil moisture with R_s and R_e in different place with different ecosystems (Davison 2006; Gu 2008; Malcoln 2009). These studies generally suggest a positive relationship between soil temperature and soil respiration or ecosystem respiration. However, our study was unable to reach such a conclusion (Fig 3 a,c). Similar results were also reported recently (Xu 2008; Shi 2011). This might be attributed to three main causes. Firstly, our research station lies within the semiarid forest transition zone. As water plays an important role in the transient response of the ecosystem carbon balance, a change in soil temperature may not have a significant effect relative to the effect of the water element. Secondly, the soil temperatures at the site are relatively high when compared to other reports, especially in the afternoon of both wet and dry season. Thus, it was also possible that soil respiration was partially suppressed. Thirdly, the soil contains sand particle more than 70% with very small fraction of clay content. It might be possible that the water in soil space was easy evaporated when soil temperature was increased. The high soil temperature could stimulate water evaporation in soil lead to low soil moisture (Xu and Wan, 2008). These conditions are not appropriate for biotic activity and CO_2 emission from both root and microbial respiration.



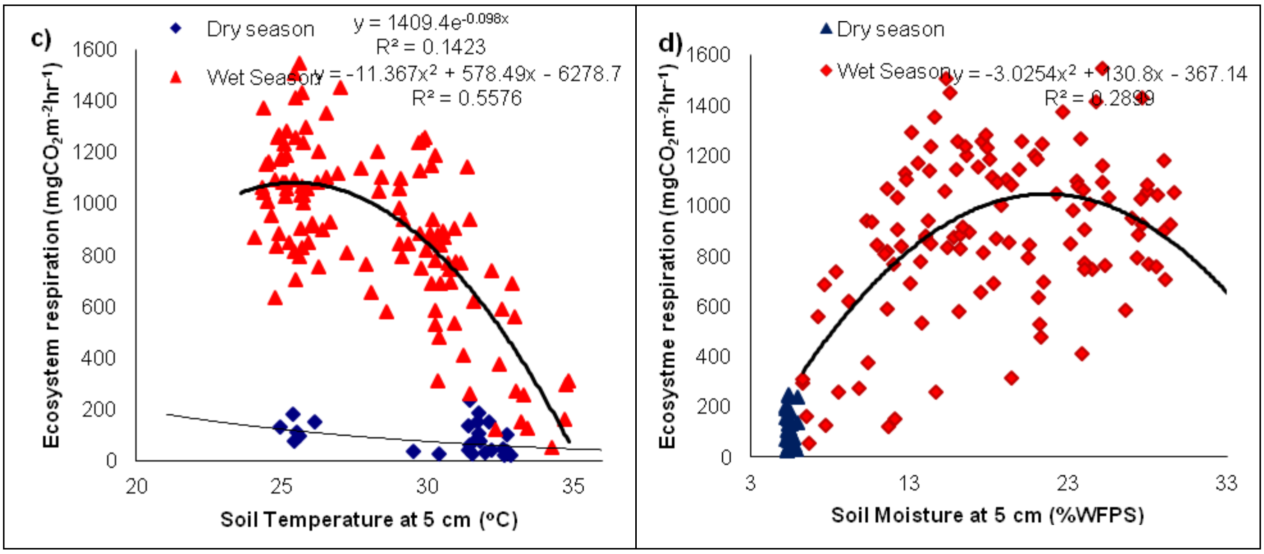


Fig. 3 Soil temperature and soil moisture response curves of soil respiration (a, b) and ecosystem respiration (c, d) during wet and dry season in dry dipterocarp forest.

4. CONCLUSION

The present study demonstrates that R_s/R_e ratios varied widely within a forest ecosystem, being high in dry season [0.91] and low during wet season [0.55]. However, only part of this variation can be attributed to the environmental patterns as biotic and abiotic factors. The main abiotic factors controlling the variations pattern of R_s/R_e in dry dipterocarp forest were soil moisture and soil temperature. R_s and R_e were negatively related with soil temperature and positively correlated with moisture in both seasons. These relationships were different from those found in the temperate forests, possibly due to the location of forest was located in dry area. Thus, seasonal pattern of CO_2 flux is controlled by soil moisture.

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