

Soil respiration and soil CO₂ concentration in a tropical forest, Thailand

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This is the peer reviewed version of the following article: [Hashimoto, S., N. Tanaka, M. Suzuki, A. Inoue, H. Takizawa, I. Kosaka, K. Tanaka, C. Tantasirin and N. Tangtham (2004) Soil respiration and soil CO₂ concentration in a tropical forest, Thailand. Journal of Forest Research, 9: 75-79. doi:10.1007/s10310-003-0046-y].

The final publication is available

at Springer via [<http://dx.doi.org/10.1007/s10310-003-0046-y>].

Abstract

Soil respiration and soil carbon dioxide (CO₂) concentration were investigated in a tropical monsoon forest in northern Thailand, from 1998 to 2000. Soil respiration was relatively high during the rainy season and low during the dry season, although inter-annual fluctuations were large. Soil moisture was widely different between the dry and wet seasons, while soil temperature changed little throughout the year. As a result, the rate of soil respiration is determined predominately by soil moisture, not by soil temperature. The roughly estimated annual soil respiration rate was 2560 gCm⁻²yr⁻¹. The soil CO₂ concentration also increased in the rainy season and decreased in the dry season, and showed clearer seasonality than soil respiration did.

KEYWORDS: *soil respiration, soil CO₂ concentration, tropical forest, soil temperature, soil moisture*

Introduction

The concentration of carbon dioxide CO₂ in the atmosphere is rising due to human activity, and scientists have predicted that this increase will cause critical changes in global climate. Forests are considered as one of the carbon (C) sinks, and the CO₂ budgets of forest ecosystems have been investigated (Lafleur et al., 1997; Granier et al., 2000; Schmid et al., 2000). Soil respiration is one of the largest elements of carbon cycling in forests, so the accurate measurements of soil respiration is essential for understanding the carbon cycle in forest ecosystems. There are many factors that influence soil respiration. However, as numerous studies have shown (Schlentner and Van Cleve, 1984; Fang et al., 1998; Goulden et al., 1998; Dong et al., 1998; Ohashi et al., 1999; Londo et al., 1999; Rayment and Jarvis, 2000; Morén and Lindroth, 2000), temperature and soil moisture are two major factors. Soil respiration is affected by temperature and soil moisture more strongly than by any other factors. In general, soil respiration increases with temperature and varies parabolically with soil moisture (Howard and Howard, 1993).

In boreal forests, soil temperature is the main determinant of soil respiration and soil water has little effect (Schlentner and Van Cleve, 1984; Goulden et al., 1998; Rayment and Jarvis, 2000; Morén and Lindroth, 2000). Soil respiration stops during the winter with freezing. In temperate forests, both soil temperature and soil water control soil respiration. Soil respiration changes seasonally with soil temperature and often decreases with decreasing soil water in the summer (Dong et al., 1998; Fang et al., 1998; Londo et al., 1999; Ohashi et al., 1999).

As mentioned above, there are many studies on soil respiration in boreal and temperate forests. However, despite of the large C efflux from soil in tropical forests (Malhi et al., 1999), there are few reports on soil respiration in tropical forests compared to other climate regions (Medina et al., 1980; Keller et al., 1986; McGroddy and Silver, 2000), especially for Southeast Asia. The difficulty of accessing to these regions that have tropical forests is perhaps one of the reasons for the shortage of studies of soil respiration in tropical forests. Most tropical forests exist in developing countries in low latitudes. Then, traffic networks are not yet enough, and neither are observation systems.

Also, there are so many types of tropical forests; various structures, diversities of species and climate (Whitmore, 1990), compared with boreal and temperate forests. Thus, the more studies of soil respiration in tropical forests are needed. Additionally, the soil CO₂ concentration is of interest. The soil CO₂ concentration reflects biological activity in soil, and a high soil CO₂ concentration affects plant growth (Burton et al., 1997). Moreover, the soil CO₂ concentration is essential for identifying the depth at which CO₂ is produced in the soil (Campbell and

Frascarelli, 1981; Davidson and Trumbore, 1995). Carbon dioxide from soil surface is produced in soil and transported to soil surface. Compared with soil respiration (soil surface CO₂ flux), observations of CO₂ concentration in soil are rather rare. Observations of both soil respiration and soil CO₂ concentration are important for the understanding the mechanism of soil respiration.

In this study, we investigated seasonal changes in soil respiration and soil CO₂ concentration in an undisturbed, hillside, evergreen forest, under a tropical monsoon climate in Southeast Asia.

Materials and Methods

Study area

The study area, the Kog-Ma Experimental Watershed of Kasetsart University, is situated near the city of Chiang-Mai in northern Thailand, located at 18°48'N, 98°54'E, at an altitude of about 1300 m (Fig. 1). Thai researchers have conducted many ecological and hydrological studies in this experimental watershed since 1965. Thai and Japanese hydrologists began cooperative research in 1997, to estimate energy and water budgets in hillside evergreen forests as a part of GAME (GEWEX-related Asia Monsoon Experiment). Soil respiration and soil CO₂ carbon dioxide concentration have been measured, together with soil temperature and soil moisture.

The Kog-Ma Experimental Watershed is covered by dense evergreen forest, mainly dominated by *Castanopsis*, *Lithocarpus*, and *Quercus sp.*. The mean annual precipitation between 1966 and 1980 was 2084.1 mm (Chunkao et al., 1981). The rainy season usually starts in April and lasts through November, whereas the dry season occurs from December to March. January and February usually experience no rainfall. Six months of the dry season receive <100 mm of precipitation (November to April between 1966 and 1980, Chunkao et al., 1981). The mean annual temperature at the site is 20 °C. This kind of tropical forest, so called hill evergreen forest, is characterized by comparatively long dry season and low temperature (Whitmore, 1990). The average annual litter fall between 1968 and 1972 was 6.88 ton ha⁻¹y⁻¹ (dry weight, Boonyawat and Ngampongsai, 1974; Thaiutsa et al., 1979). Monthly litter fall is generally largest in February and smallest in August (Boonyawat and Ngampongsai, 1974).

Figure 1

Methods

We visited Thailand, stayed for about two weeks and carried out various microclimatic observations. Soil respiration was measured in a day without rain during the stay. Soil respiration was measured at three sampling points (A, B, and C) at 3-month intervals beginning in July 1998. The three sampling points were distributed with a distance of about 30 m. Point A was located at the base of the watershed, and points B and C were halfway up the watershed.

The closed-chamber method was used with a portable chamber (Hanson et al., 1993; Sellers et al., 1997; Striegl and Wickland, 1998). The portable chamber was about 0.00155 m³ (0.135 m in diameter, 0.105 m high). When measuring a soil respiration, we pressed the chamber on the soil surface firmly, but not so firmly

that we disturbed the soil surface structure. The chamber edge was not pushed into the soil surface but was on the soil surface (Hanson et al., 1993; Sellers et al., 1997; Striegl and Wickland, 1998).

The CO₂ concentration in the chamber was measured with a CO₂ analyzer (Model LI6252 or Model LI6262, LI-COR), and was recorded at 10-s intervals for several minutes. The flow rate of the circulation pump was approximately 0.017 L/s. At each point (A, B and C), one plot (0.3 m × 0.3 m) was set up. Measurements were taken two to three times in each plot. The place we put on the chamber was changed every measurement in each plot.

All instruments were transported from Japan on each occasion, except for the chamber. The calibration of the CO₂ analyzer was conducted in Japan before leaving Japan.

The soil CO₂ concentration was measured at the sampling point B, at depths of 0.1, 0.2, 0.4, and 0.6 m at 1-week intervals, beginning in February 1998. Soil air collection probes were installed at each depth. One hundred milliliter of soil air was directly extracted from the probes using gas detector tubes with a gas-sampling pump (GV-100S, Gastec, Japan). The length of the color-changed zone in the gas detector tube indicated the CO₂ concentration in soil air after a few minutes. This method is widely used in Japan (Hamada and Tanaka, 2001).

The soil temperature was measured at the sampling point B, at depths of 0.02, 0.1, and 0.3 m using thermistor (CT-UU-A10-2A, Grant Ltd) with a logger (SQ1259, Grant. Ltd). The soil water content was measured at sampling point B, at depths of 0.1, 0.2, 0.3, 0.4, and 0.5 m using TDR sensors (CS615, Campbell Sci. Co.) with a logger (CR10X, Campbell Sci. Co.).

Results and Discussion

Seasonal changes in precipitation, soil water content, air and soil temperature are shown in Figures 2a, 2b, and 2c, respectively. The average annual precipitation and air temperature from 1998 to 2000 were 1657 mm and about 19 °C, respectively. The rainy season started in April and lasted through November. During the dry season, the area received very little rain. Corresponding to the patterns of precipitation, the soil moisture content was high from April to November and low from January to March. Soil temperature was high in the rainy season and low in the dry season. During the 8-month rainy season, soil temperature changed little. The air temperature and soil temperature in the 1998 rainy season were slightly higher than in 1999 and 2000. The precipitation in the 1998 rainy season was less than in a normal year.

Figure 2

Soil respiration

Soil respiration and the soil CO₂ concentration are shown in Figures. 2d and 2e, respectively. Soil respiration rates ranged from 0.94×10^{-7} to 6.2×10^{-7} kg CO₂ m⁻²s⁻¹. Soil respiration was comparatively high from August to September, and was comparatively low between December and February. The rates of soil respiration were relatively high in 1999 and low in 1998, 2000. The rates of soil respiration were relatively high in the rainy season and low in the dry season; however, the fluctuations among the years and among the sampling points were large, and there

was no clear difference in soil respiration between the dry and rainy seasons (Table 1).

Table 1

Figure 3

Figure 3 shows the relationship between soil respiration and soil water content. Soil respiration increased with increasing soil moisture. This agrees with other studies (Bowden et al., 1998; Zak et al., 1999). Soil water content measured in soil respiration measurements ranged between 0.15 and 0.35. In some studies, decreases of soil respiration were observed when soil was rather wet. In this study, the decrease was not observed. The saturated soil water content in this forest was reported to be about 0.5-0.6 (Udomchock et al., 1983). The maximum soil water content that was observed in our soil respiration measurements was about 0.35. We could not obtain data of soil respiration when soil was rather wetter. It is unknown if soil respiration in this site decreases or not when soil is rather wet. This is one of the subjects for our future study.

Figure 4

Figure 4 shows the relationship between soil respiration and soil temperature. Soil temperature was relatively constant. The narrow temperature range is due to both the limited number of observations, and the small variation in temperature during the rainy season. No clear relationship between soil respiration and soil temperature was found. Except for the hot rainy season in 1998 and a very cold day in the winter of 1999, the soil temperature at 0.1 m deep ranged from 15 to 20 °C, and the temperature range was much smaller during the rainy season. In this region, the seasonal variation in soil moisture is large, while that of soil temperature is small. Therefore, in this region, soil moisture plays a greater role in governing soil respiration than soil temperature. Generally, soil respiration increases exponentially with temperature. In boreal and temperate forests, there is a wide range of seasonal temperatures and large seasonality (Malhi et al., 1999). Therefore, soil respiration also shows large seasonality in boreal and temperate forests. By contrast, the relationship between soil respiration and soil moisture is parabolic (Bowden et al., 1998; Zak et al., 1999) or linear (Leirós et al., 1999). Hence, it is reasonable to expect the seasonality of soil respiration, which is limited by soil moisture, to be small in tropical regions. To compare annual soil respiration rate with other studies, the annual soil respiration rate was roughly estimated using the average value of soil respiration at sampling points A, B, and C,

$$SR = (\sum^n Y_i \times 10^3 \times 12/44 \times 3600 \times 24 \times 365) / n$$

where SR is the average soil respiration ($\text{gCm}^{-2}\text{yr}^{-1}$), Y_i is the measured soil respiration ($\text{kg CO}_2 \text{ m}^{-2}\text{s}^{-1}$), and n is the number of measurements, although the estimated value using this simple equation and the limited number of data perhaps has some uncertainty. The estimated value was $2560 \text{ gCm}^{-2}\text{yr}^{-1}$; Raich and Schlesinger (1992) reviewed the measured rate of soil respiration in terrestrial and wetland ecosystems, and the value reported here is as high as the highest they reported. They proposed a simple model describing the relationship between annual soil respiration rate (SR , $\text{gCm}^{-2}\text{yr}^{-1}$) and two climate variables, mean annual temperature (T , °C) and mean annual precipitation (P , mm): $SR = 9.88T + 0.0344P + 0.0112TP + 268$. Using this relationship, the estimated annual soil

respiration of the Kog-Ma watershed would be $870 \text{ gCm}^{-2}\text{yr}^{-1}$. The value estimated in our study is about three times as large. However, a similar value was reported in a study of the Amazon (Davidson et al., 2000), which also pointed out that soil respiration might have been underestimated in old reports based on soda lime techniques.

Soil CO₂ concentration

The CO₂ concentration in soil increased with increasing depth and exhibited a distinct seasonal trend. The CO₂ concentration in soil ranged from 10,000 to 40,000 m³/m³ at a depth of 0.6 m, and ranged from 2000 to 12,000 m³/m³ at a depth of 0.1 m. The highest soil CO₂ concentrations were recorded from August to September, and the lowest values were recorded from December to February. The soil CO₂ concentrations were similar to values reported in other studies (Kursar, 1989; Davidson and Trumbore, 1995).

CO₂ concentration profile in soil results from CO₂ production in soil and its transport. Which depth CO₂ is mostly produced at is very important information to understand the mechanism of soil respiration and predict the impact of global warming on soil respiration. Analyzing CO₂ profile in soil will show vertical distributions of CO₂ production rate (Davidson and Trumbore, 1995). It is also the subject of our future study.

Acknowledgement

This research was carried out as one of the GAME-Tropics activities funded by the Japanese Ministry of Education, Culture, Sports, Science and Technology, Grant-in-Aid for Scientific Research (#07041106 and #10041219, Leader: Prof. K. Musiaka, The University of Tokyo) with cooperation from the National Research Council of Thailand.

The author acknowledges the input of two anonymous reviewers, whose comments improved the quality of this paper.

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Figure 1: Kog-Ma experimental watershed of Kasetsart University, situated near the city of Chiang-Mai in northern Thailand.

Figure 2: Seasonal variations of precipitation (a), soil temperature (b), soil water content (c), soil respiration rate (d, bars indicate standard deviation) and soil CO₂ concentration (e).

Figure 3: The relationships between soil water content and soil respiration rate (bars indicate standard deviation).

Figure 4: The relationships between soil temperature and soil respiration rate (bars indicate standard deviation).

Table 1: Average soil respiration with standard deviation in parentheses.
There were no significant differences between proximate dry and rainy seasons ($P < 0.05$).

Period for average	Soil respiration ($\times 10^{-7}$ kg CO ₂ m ⁻² s ⁻¹)
Rainy season 1998 (May, Sep., Nov.)	2.96 (1.11)
Dry season 1999 (March)	2.40 (0.91)
Rainy season 1999 (May, Sep. Nov.)	3.45 (1.66)
Dry season 2000 (March)	2.88 (0.94)
Rainy season 2000 (May, Sep., Nov.)	2.45 (1.36)

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