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Soil Respiration in Different Ages of Teak Plantations in Thailand

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Abstract

Soil respiration is a crucial carbon flux for determining carbon balance in the forest ecosystem. In Kanchanaburi, western Thailand, we measured soil respiration at different stand ages (1, 6 and 21 year-old) of teak (*Tectona grandis*) plantations. There were no significant differences in soil respiration among plots of different ages. Soil respiration rates showed a clear seasonal pattern of a high rate in the rainy season from April to November and a low rate in the dry season from December to March. The contribution of organic layer, roots and soil to total soil respiration was 17, 15 and 68%, respectively, in the 6 year-old teak plantation (T-Y plot). Total soil respiration rate was significantly correlated with soil water content in the 0–30 cm layer. The annual amount of CO_2 efflux from the forest floor was estimated to be 1,062–1,154 gC m^{-2} y^{-1} in the teak plantations in 1997. In 1998, annual CO_2 efflux declined to 80% of that in 1997 in the T-Y plot, probably due to low rainfall.

Discipline: Forestry and forest products
Additional key words: carbon cycling, root respiration, soil CO_2 efflux, soil moisture, tropical seasonal forest

Introduction

Forest growth is of great interest because of its effectiveness in mitigating the increase in carbon dioxide in the atmosphere. In fact, increases in tree biomass are the visible effect of fixing carbon in the ecosystem[10]. However, soil carbon dynamics should also be identified because changes in soil carbon stock, which is the biggest carbon pool in the terrestrial ecosystem, might significantly affect CO_2 concentration[9,11,13]. Therefore, soil respiration, i.e., CO_2 flux from the forest floor, is a key parameter for determining carbon balance in the forest ecosystem[14].

For plantation forestry, teak (*Tectona grandis*) is a popular species in tropical countries[12]. In Thailand, teak is an indigenous species and has a relatively fast growth rate with a straight stem, which is a desirable characteristic in the commercial market. In addition, the fast growth rate of teak may promote carbon accumulation in the soil as well as in tree biomass. However, carbon dynamics and soil respiration in teak plantations have not been studied in Thailand. Located in monsoon Asia, Thailand has a seasonal climate pattern that includes a rainy season and a dry season[1]. Following the seasonality, soil respiration has a pattern of high soil respiration in the rainy season and low respiration in the dry season, which is mostly controlled by the soil moisture regime[7].

Soil respiration is composed of heterotrophic respiration by soil biota and autotrophic respiration by roots. Separation of heterotrophic and autotrophic respiration is important for evaluating carbon balance in the soil[5,14,18]. Contribution of root respiration to total respiration was reviewed and found to range from 10 to 90%, although there are methodological difficulties in measuring root respira-

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tion in the field[6]. One common method for estimating root respiration is to make a trench to exclude roots around the chamber[14,24], although there is a possibility that trenching will produce some artificial effects on root decomposition and soil moisture.

The objective of this study was to compare i) soil respiration at different stand ages of teak plantations, and ii) separation of CO_2 sources, i.e., organic layer, roots, and soil, in total soil respiration by eliminating these CO_2 sources. We also analyzed the controlling factors for soil respiration and estimated the annual CO_2 efflux from the forest floor at the study sites in Kanchanaburi, western Thailand.

Materials and methods

1. Sites

The study was conducted at the Mae Klong Watershed Research Station (14˚35'N, 98˚52'E), Thong Pha Phum, Kanchanaburi Province, Thailand (Fig. 1). Annual mean air temperature at the station is about 25°C, ranging from 9.3°C to 42.2°C, and the annual mean precipitation is 1,650 mm, most of which falls during the rainy season from April to October[20]. Figure 2 shows monthly rainfall and air temperature measured at the station office from 1997 to 1999. The amounts of annual rainfall during the study period were 1,927 mm in 1997, 1,243 mm in 1998, and 1,733 mm in 1999. Altitude at the study site ranged from 150 to 200 m asl. Soil is classified as Alfisols[19] derived from sedimentary rock, gneiss and limestone. Undergrowth bamboo also influences surface soil conditions at the sites[22]. Soil properties in the teak plantation (T-Y plot, see below) are shown in Table 1. The plantation area had been used as cultivated land. Forest vegetation in the watershed is described in Marod et al.[15].

2. Plots for measuring soil respiration

Soil respiration was compared in 1997 for teak plan-

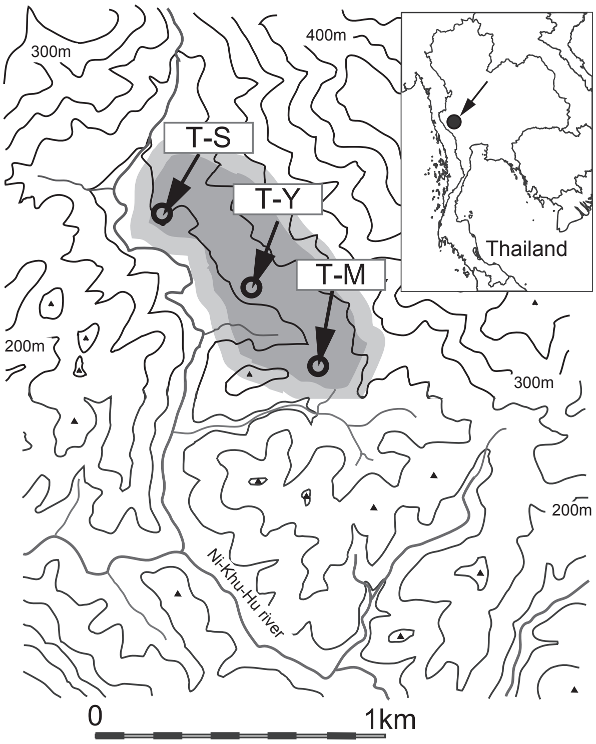

Fig. 1. Location map of study sites in Kanchanaburi, Thailand

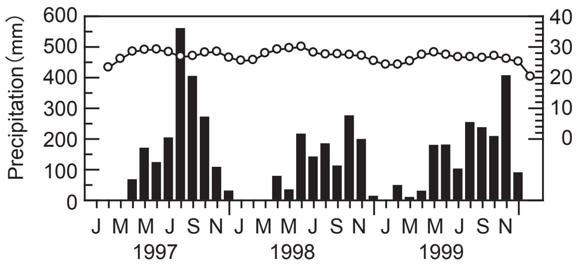

Fig. 2. Monthly precipitation and monthly mean air temperature at the Mae Klong Watershed Research Station, Kanchanaburi, Thailand

Table 1. Soil properties in the plot of T-Y in the Mae Klong Watershed Station

Horizon	Depth	C	N	C/N	pH(H_2O)	pH(KCl)	CEC	Exchangeable				BS[1)]	Texture
								Ca	Mg	K	Na		
	(cm)	g kg^{-1}	g kg^{-1}				cmol$_c$ kg^{-1}	cmol$_c$ kg^{-1}				%	
Ap	13	19.00	1.20	15.8	7.11	6.32	10.29	5.78	1.37	0.54	0.06	75.3	SL
Bw	52	8.64	0.61	14.2	7.13	6.13	7.47	3.48	0.63	0.20	0.30	61.7	SL
Bt1	84	5.84	0.47	12.5	6.56	5.78	7.99	2.08	0.81	0.18	0.39	43.2	SCL
Bt2	130	3.59	0.35	10.4	6.38	5.42	12.38	1.28	0.38	0.20	0.26	17.1	L
BC	160	3.08	0.32	9.8	n.d.[2)]	n.d.[2)]	5.83	1.42	0.35	0.26	0.95	51.1	n.d.[2)]

1): Percentage of base saturation.
2): Not determined.

tation plots of different ages, i.e., just after planting seedlings (T-S), 6 year-old (T-Y) and 21 year-old (T-M). In T-S, teak seedlings were planted at a spacing of 4 × 4 m in 1997. T-Y, planted in 1992, had a density of 530 trees ha^{-1}. Average height and diameter at breast height (DBH) in 1996 were 11.3 m and 11.4 cm, respectively, in T-Y. In T-M, tree height was 17 m and DBH was 23.2 cm on average in 1996. These plantations were located on the bottom of wide valleys (Fig. 1). In 1997, soil respiration was measured monthly. From 1998, only the T-Y plot was measured bimonthly to monitor interannual fluctuation.

3. Soil respiration rate

In T-Y, we estimated the contribution of CO_2 sources, i.e., soil, roots and organic layer, to total soil respiration. Estimation was done by comparing total soil respiration and respiration whereby CO_2 from the organic layer and roots was eliminated. The calculation method is shown below.

Soil respiration rate was measured using the closed chamber method. The size of the steel chamber used was 30 cm in diameter and 30 cm in height. The bottom rim of the chamber was inserted 3–5 cm into the surface soil. About 20 min after the cover was sealed, CO_2 concentration in the headspace of the chamber was determined using an IRGA (ZFP5, Fuji Electronics Co., Ltd., Japan). Soil respiration rate was calculated using a linear model of increasing CO_2 concentration. Temperature correction was applied.

4. Separation of CO_2 sources

One chamber (Chamber A) was set on the forest floor for measuring total soil respiration as described above. Another chamber (Chamber B), in which the surface organic layer was removed from the soil in the chamber, was installed a meter away from Chamber A, and was expected to have no CO_2 emissions from organic layers. A third chamber, Chamber C, was installed 1.5 m away from Chamber A, in the opposite direction to Chamber B. A 60 cm square trench was dug 30 cm deep around Chamber C to cut the roots in the soil. Plastic boards were vertically inserted into the trench to prevent root invasion, and then the soil was replaced. The organic layer was also removed from Chamber C. This treatment was expected to eliminate both root respiration and organic layer respiration. At the study sites, there were no roots in the organic layers. This treatment was performed one month before measurement.

Total soil respiration (Rt) was determined by the CO_2 flux in Chamber A (RA), which consisted of CO_2 respired from the soil (Rs), from the organic layer (Ro), and from the roots (Rr). Thus,

$$RA = Rt = Rs + Ro + Rr \quad (1)$$

Respiration in Chamber B (RB) is given by:

$$RB = Rs + Rr = Rs + Rr1 + Rr2 \quad (2)$$

where Rr1 is respiration from the roots in the 0–30 cm soil layer in the trench and Rr2 is respiration from roots more than 30 cm deep. Respiration in Chamber C (RC) is

$$RC = Rs + Rr2 \quad (3)$$

Organic layer respiration is given by:

$$Ro = RA - RB = Rt - (Rs + Rr1 + Rr2) \quad (4)$$

Root respiration is given by:

$$Rr = Rt - (Rs + Ro + Rr1 + Rr2) \quad (5)$$

If we assumed that root respiration per unit of root biomass was constant throughout the soil layer, the following formula is derived:

$$Rr = Rr1 + Rr2 = aB1 + aB2 \quad (6)$$

where B1 is root biomass 0–30 cm in depth, B2 is root biomass more than 30 cm deep up to the rooting zone and "a" is a specific root respiration rate per unit root biomass.

$$Rr1 = RB - RC = aB1 \quad (7)$$

$$Rr = (RB - RC)(1 + B2/B1) \quad (8)$$

In this study, we assumed that the rooting zone was 1.2 m deep and that the root biomass contributing to root respiration was limited to fine roots with a diameter smaller than 3 mm.

For replication, four sets of Chambers A, B and C were installed in T-Y. In T-S and T-M, four units of Chamber A were installed for measuring total soil respiration only.

When soil respiration was measured, soil (0–5 cm) and organic layer samples around the chambers were collected to determine moisture content. The samples were oven-dried at 105°C. Soil moisture in the 0–15 and 15–30 cm layers was monitored using TDR sensors (Moisture Point™ Model MP-917, Environmental Sensors, Canada) during the period of soil respiration measurement. The measurement interval was one to three days in 1997 and 1998, but the equipment frequently broke down for long periods in 1999.

5. Root biomass and carbon stock in soil and organic layer

Root biomass (< 10 mm) was measured using a soil column with an area of 15 × 15 cm at a depth of 0–15, 15–30, 30–60, 60–90, and 90–120 cm. Triplicate sampling was done in November 1998. Dead roots were eliminated by visible inspection. Roots were separated according to their diameter, and washed and weighed after being oven-dried at 70°C. Carbon stock in the soil in T-Y and T-M was determined from bulk fine soil (< 2 mm) density measured by soil cylinder core (400 mL, 100 cm^2 × 4 cm) and carbon content in fine soil. Carbon content was analyzed using an NC analyzer (Shimadzu Co., Kyoto, Japan). We did not measure soil carbon stock in T-S. Dry weight of organic layer, mostly relatively fresh litter, was measured in T-Y in December 1998.

6. Statistics

Differences in soil respiration and related parameters among plots were tested by repeated-measures ANOVA. All statistics were calculated using STATISTICA software (StatSoft Japan Inc.).

Results

1. Soil respiration at different stand ages of teak plantations

The seasonal patterns of total soil respiration in teak plantations were similar among plots of different stand ages (Fig. 3). In 1997, soil respiration was quite low during the middle of the dry season from January to March and then increased from April with the highest peaks in September. In 1998, a similar seasonal pattern of low respiration in the dry season and high in the rainy season with a peak in the late rainy season was observed in the T-Y.

The T-S plot showed the highest soil temperature but the lowest water content, while the T-M plot showed the lowest soil temperature and highest soil water content (Table 2). Although tree biomass and site environment differed greatly among plots, total soil respiration rates did not differ significantly among the plots (ANOVA, $p = 0.698$).

Soil carbon stock (kgC m^{-2}) was larger in the T-M plots than in the T-Y plots for surface (0–0.3 m) and all soil layers (0–1.2 m) (Table 3). Mass of organic layer measured in T-Y was 0.247 kg m^{-2} in December 1998.

2. Separation of CO_2 sources

In T-Y, mean biomass (s.e. n = 3) of total roots (< 2 cm) was 2.34 (1.20) kg m^{-2} and that of fine roots (< 3 mm) was 0.27 (0.03) kg m^{-2} at a depth of 0–1.2 m. In the 0–0.3 m surface soil layer, fine root biomass was 0.07 (0.01) kg

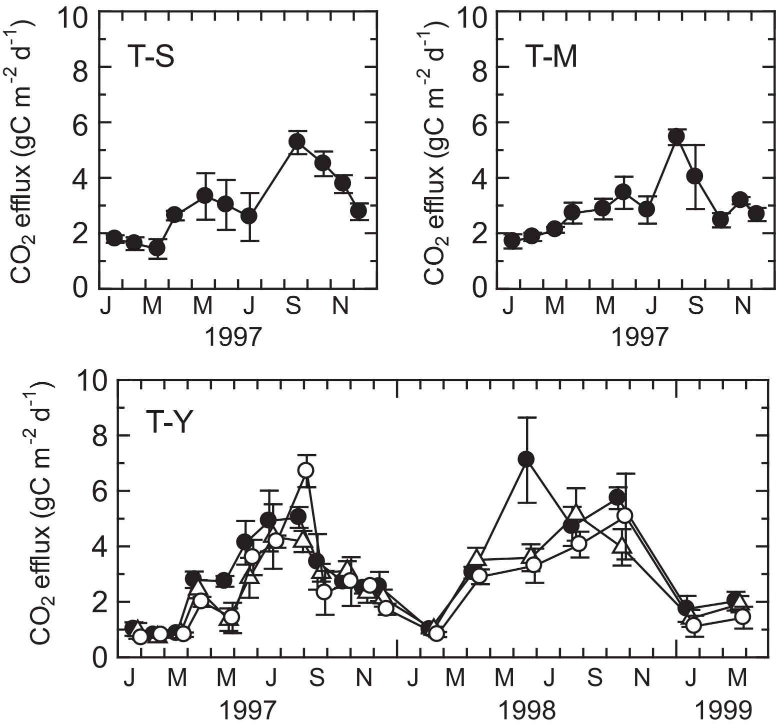

Fig. 3. CO_2 effluxes from the forest floor in 1 year-old (T-S), 6 year-old (T-Y) and 21 year-old (T-M) teak plantations

In the T-Y plot, the effluxes in Chambers A (dot, total soil respiration), B (open triangle, soil respiration without organic layer) and C (circle, soil respiration without organic layer and roots) are depicted. Mean efflux and standard error (vertical bar, n = 4) are shown.

Table 2. Comparison of mean soil temperature, soil water content, organic layer moisture, and total soil respiration in teak plantations by ANOVA

	Plots			
	T-S	T-Y	T-M	*p*
Soil temperature (ºC) 1)	26.9	25.7	24.5	0.040
Soil water content (v/v) 2)	0.174	0.182	0.280	0.056
Organic layer moisture (w/w)	0.228	0.222	0.241	0.982
Soil respiration rate (gC m^{-2} d^{-1})	3.002	2.618	2.770	0.698

1): Temperature at 10 cm in depth.
2): Volumetric water content of soil in the 0–15 cm layer measured by TDR sensor.

Table 3. Carbon stocks (kgC m^{-2}) in soil in 0-0.3 m, and soil in 0-1.2 m in T-Y and T-M plots

Plot	Surface soil (0-0.3 m)	Soil (0-1.2 m)
T-Y	5.05	11.74
T-M	5.60	13.82

m^{-2}. The teak plantation (T-Y) had a low proportion of fine root biomass to total roots, and fine roots were sparse in the surface layer.

Total soil respiration (Chamber A) was usually highest, followed by that from the chamber without organic layer (Chamber B), and then that from the chamber without organic layer and root respiration (Chamber C). However, the difference was small in T-Y in the teak plantation (Fig. 3). Although poor separation of CO_2 sources occurred in some measurements, the average contribution of CO_2 sources was calculated. In the teak plantation, the contribution of root respiration was 14.6% and that of organic matter was 17.2%; therefore, that of soil respiration was 68.2%.

3. Factors controlling soil respiration and estimation of annual CO_2 efflux from forest floor

We examined the relationship between total soil respiration rate and soil temperature at a depth of 10 cm, water content in organic layer, and water content in 0–30 cm soil layer, which was the average of 0–15 and 15–30 cm layers determined by TDR sensor (Table 4). Variation in soil temperature was largest in T-S, ranging from 22.8 to 31.9ºC. Water content of organic layer varied largely even in the rainy season. Accordingly, these parameters had a low correlation with soil respiration, except for the T-Y plot. The only factor strongly correlated with total soil respiration was water content in the 0–30 cm soil layer.

For estimating the annual CO_2 efflux from the forest floor in the plots, i.e. annual amount of CO_2 emitted by total soil respiration, the following equation was used: $Rt = a \times WC^b$, where Rt is total soil respiration (gC m^{-2} d^{-1}), WC is water content at 0–30 cm (v/v), and a and b are constants[4], at each site (Fig. 4). The coefficient of determination, R^2, ranged from 0.497 to 0.701. The response of total soil respiration to soil water content was relatively weak in the T-M plot. Using the monitoring data on soil water content measured by TDR and the above equations, annual CO_2 efflux by soil respiration was estimated (Table 5). The teak plantation released 1,062–1,154 gCO_2-C by soil respiration in 1997. Although stand age ranged from 1 to 21 years old, annual CO_2 efflux was similar. For interannual variation in the T-Y plot, annual CO_2 efflux in 1998 was reduced to 79.6% of the efflux in 1997.

Table 4. Correlation coefficients (r) between total soil respiration and water content in soil layer 0–30 cm, water content in organic layer, and soil temperature at 10 cm deep

Plot	Water content in soil 0 – 30 cm layer (v/v)	Water content in organic layer (w/w)	Soil temperature (ºC) at 10 cm in depth
T-S	0.725***	0.119	0.092
T-Y	0.696**	0.468*	0.081
T-M	0.626**	0.104	0.366

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

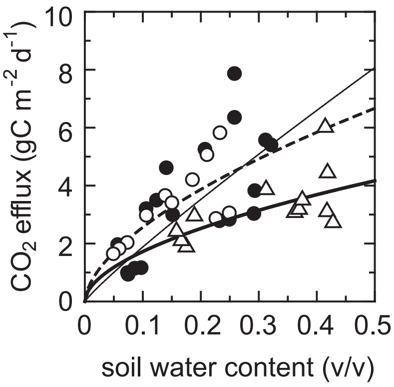

Fig. 4. Relationships between soil respiration (CO_2 efflux) and soil water content in T-S, T-Y and T-M plots
○ - - : T-S, $Y=0.650\times^{0.593}$ (R^2=0.701)
● — : T-Y, $Y=0.235\times^{0.904}$ (R^2=0.602)
△ ▬ : T-M, $Y=0.486\times^{0.549}$ (R^2=0.497)

Discussion

We assumed that varying tree biomass in different

Table 5. Annual CO_2 effluxes (gC m^{-2} y^{-1}) from the forest floor in the plots in 1997 and 1998

Plot	Year 1997	Year 1998
	Annual CO_2 efflux (gC m^{-2} y^{-1})	
T-S	1,082	n.d.[1)]
T-Y	1,154	919
T-M	1,062	n.d.[1)]

1): Soil respiration was not measured.

ages of teak plantations would change the soil respiration rate and proportion of CO_2 sources. However, no clear difference was found in soil respiration. Small fine-root biomass in teak and low contribution of root respiration may be a cause of the weak response of soil respiration to stand ages. For soil carbon, Suzuki et al.[21] found that soil organic matter did not increase with stand age of teak plantations in Myanmar due to frequent combustion of organic layer as we also observed in the study watershed. In addition, sheet erosion of top soil under the teak plantation[23] seems to be responsible for preventing the accumulation of organic carbon in the soil as well. These degrading processes of surface soil might be a reason for weak response of soil respiration to variation of soil water content in the T-M plot (Fig. 4).

In addition to forest fire and top soil erosion, low fine-root densities in the surface soil were not likely to contribute to accumulate soil organic matter through root litter deposition. Although soil carbon stock was 10% larger in T-M compared to T-Y (Table 3), we are not certain that the effects of plantation growth was responsible for this carbon because if leaf and root litterfall contributed to the accumulation of carbon stock in soil, the proportion of surface soil to total soil in T-M should have increased. Detailed monitoring of carbon balance, including the effects of forest fire and soil erosion as we discussed above, would be needed to reach a conclusion about the effect of plantation on soil carbon accumulation.

Soil respiration rate was lower than those in the adjacent natural forests (4.93 gC m^{-2} d^{-1}, annual average, unpublished data) and annual amounts of soil CO_2 efflux in the teak plantations were also lower than that estimated for natural forests (2,560 gCm^{-2} y^{-1}) in northern Thailand[7]. This might be due to the land-use history where the teak plantations are located. The plantation in the watershed had been used as agricultural land, which may have resulted in lower soil respiration by consumption of labile soil organic matter as often found in shifting cultivation sites[3].

Raich et al.[17] reviewed that interannual variability of soil CO_2 effluxes correlated with interannual differences in precipitation in seasonally dry climate biome like our sites. Reduction of annual CO_2 efflux in 1998 in T-Y plot was probably due to low annual rainfall (1,927 mm in 1997 and 1,243 mm in 1998). As Hashimoto[8] suggested that forest soils in Thailand responded to soil temperature by soil incubation experiments, a temperature parameter[4] also may improve the estimation of annual CO_2 efflux to some extent. Moreover, seasonal variation in CO_2 sources should be studied in future because respiration of soil microbes and that of plant roots respond differently to seasonal environment[2,18].

In conclusion, carbon dynamics in the soil under teak plantations in western Thailand were determined by the soil moisture regime, which is controlled by seasonal rainfall pattern and annual rainfall. Temperature did not significantly influence soil respiration due to small variation. Soil respiration in teak plantations had no clear difference between different stand ages. Annual CO_2 efflux from the forest floor in the Mae Klong watershed ranged from 919 to 1,154 gC m^{-2} y^{-1} in 1997 and 1998. The CO_2 efflux fluctuated probably due to changes in soil moisture controlled by rainfall events.

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