Soil respiration in tropical seasonal rain forest in Xishuangbanna, SW China

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Received July 14, 2004; revised January 31, 2005

Abstract With the static opaque chamber and gas chromatography technique, from January 2003 to January 2004 soil respiration was investigated in a tropical seasonal rain forest in Xishuangbanna, SW China. In this study three treatments were applied, each with three replicates: A (bare soil), B (soil+litter), and C (soil+litter+seedling). The results showed that soil respiration varied seasonally, low from December 2003 to February 2004, and high from June to July 2004. The annual average values of CO_2 efflux from soil respiration differed among the treatments at 1% level, with the rank of C (14642 $mgCO_2 \cdot m^{-2} \cdot h^{-1}$)>B (12807 $mgCO_2 \cdot m^{-2} \cdot h^{-1}$)> A (9532 $mgCO_2 \cdot m^{-2} \cdot h^{-1}$). Diurnal variation in soil respiration was not apparent due to little diurnal temperate change in Xishuangbanna. There was a parabola relationship between soil respiration and soil moisture at 1% level. Soil respiration rates were higher when soil moisture ranged from 35% to 45%. There was an exponential relationship between soil respiration and soil temperature (at a depth of 5cm in mineral soil) at 1% level. The calculated Q_{10} values in this study, ranging from 2.03 to 2.36, were very near to those of tropical soil reported. The CO_2 efflux in 2003 was 5.34 $kgCO_2 \cdot m^{-2} \cdot a^{-1}$ from soil plus litter plus seedling, of them 3.48 $kgCO_2 \cdot m^{-2} \cdot a^{-1}$ from soil (accounting for 62.5%), 1.19 $kgCO_2 \cdot m^{-2} \cdot a^{-1}$ from litter (22.3%) and 0.67 $kgCO_2 \cdot m^{-2} \cdot a^{-1}$ from seedling (12.5%).

Keywords: seasonal rain forest, soil respiration, CO_2 efflux, Q_{10}, Xishuangbanna.

DOI: 10.1360/05zd0019

Since the industrial revolution human activities have greatly affected the natural ecosystems in regional and even in global scale. The greenhouse gas concentration in the atmosphere is increasing due to fossil fuel combustion, land use/cover change, especially deforestation. Scientists predicted that this increase will cause critical changes in global climate[1—3]. The increase in CO_2 concentration from about 315 ppmv to about 368 ppmv was measured over 40 years at Mauna Loa in Hawaii[4]. It was estimated that the preindustrial CO_2 level was 243—290 ppmv[5,6]. The data from ice cores in the South Pole showed that since the middle of the 18th century CO_2 concentration in the atmosphere has increased by 25%, and is continuing to increase exponentially[7]. The cause of the long-term CO_2 increase is mainly due to the burning of fossil fuels and land use change[8]. If the effluxes of greenhouse gases keep increasing at the present rates, the atmosphere temperature on the surface of the earth may rise by 0.2℃ every 10 years. CO_2-induced climatic change is a major environmental problem, threatening human beings in many aspects, such as rising sea level, change of rainfall pattern and vegetation distribution, decrease of productivity, etc. Annual input of CO_2 to the atmosphere by human activities was about 6.0 PgC[4,9—11], of which about 3.36 PgC remained in the atmosphere[12], another 2 PgC was absorbed by oceans[13,14]. But so far scientists are not clear yet where the left 2 PgC had gone. This missing sink, mainly due to the net absorption effect of biosphere, especially the absorption of forest and soil[19], may exist in the mid-latitude regions of the Northern Hemisphere[13,15—18]. Recent research showed that tropical area is possibly a big carbon sink[20—23].

Forest is an important component in global carbon cycle. The amount of carbon restored in forest is about three times that in the atmosphere[24]. The carbon stored in forest accounts for about 90% of that in the terrestrial living biomass, and the NPP of forest accounts for about 60% of the terrestrial vegetation. The global forest covers an area of 34.17×10^9 km^2, accounting for about 26% of the land of the earth. The global evergreen broad-leaved forest covers (1.6—2) $\times10^8$ km^2, beneath which soil contains 43% of the global soil carbon. The conversion from forest to farming land will release great amounts of carbon into the atmosphere, with the burning of forest, decomposition of plant residuals, change of soil moisture, temperature and aeration[25]. From 1980 to 1989 the annual average value of CO_2 input to the atmosphere was 2.6—6 PgC because of landuse change and deforestation. In most of the terrestrial ecosystems carbon flux of soil respiration is only smaller than that of photosynthesis[26]. Small change of soil respiration caused by global climatic change will greatly increase the CO_2 concentration in the atmosphere, and this increase can compete to the value of CO_2 released from the burning of fossil fuels[27,28]. There are many reports at home and abroad on carbon sequestration by forest and effects of landuse change on carbon cycle[17,29-31].

Soil respiration is one of the key processes in the carbon cycle. Research on soil respiration in tropical forest ecosystem is of importance in understanding global carbon cycle. There are many studies on soil respiration in boreal, temperate and subtropical forests. However, there are few reports on soil respiration in tropical forests, especially in Southeast Asia compared with other climate regions[32].

There is no report on soil respiration in tropical forest in China except in Hainan Province. In this paper two issues will be discussed: the soil respiration of tropical seasonal rain forest in Xishuangbanna and its relationship with main environmental factors, such as temperature and moisture. In this study the data in soil respiration of tropical forest were provided with the estimation of the effects of changing environmental factors on carbon efflux based on the model formulated.

1 Materials and methods

1.1 Study site

The study site is located near the permanent plot of Xishuangbanna Station for Tropical Rain Forest Ecosystem Studies, Chinese Ecosystem Research Network (CERN), at an elevation of 720 m, about 5 km away from Menglun township (21°56′N, 101°16′E), Mengla County. The annual mean air temperature is 21.4℃ and the annual mean precipitation is 1557 mm, but 1355 mm of which (accounting for 87%) occurs in rainy season (from May to October), 202 mm (13%) in dry season (from November to April of next year). The annual mean relative humidity is 86%. Soil is an oxisol derived from sandstone, with a 2 to 5cm depth litter layer and a 1 to 3 cm depth humus layer. The organic matter content at the depth of 0 to 20 cm in the mineral soil is about 20 $g\cdot kg^{-1}$. In a hectare plot 119 tree species (DBH>10 cm) were recorded. The dominant species were *Pometia tomentosa*, *Terminalia myriocarpa*, *Myristica yunnanensis*, *Horsfieldia tetratepala*, *Homalium laoticum*, *Barringtonia macrostachya*, etc. The community was 48 m high and 200 years old[35—37].

1.2 Experiment facilities

The static opaque chamber technique was used. A square collar (50 cm×50 cm) made of stainless steel was installed in soil, and a chamber (50 cm×50 cm×50 cm) could fit it closely, in which two electric fans, a temperature sensor and gas sampling tube were installed.

Three treatments were applied with three replicates. Treatment A: in the square collar litter was removed and seedlings were cleared. Treatment B: in the collar seedlings cleared but litter remained. Treatment C: litter and seedlings remained in the collar.

1.3 Sampling

Sampling was done on every Monday morning during 09:00 to 11:00. Four gas samples were collected in 100 mL plastic syringes after 0, 10, 20 and 30 min respectively after the chamber was covered on the collar. Open air temperature, air temperature in the chamber, temperature on soil surface and at a depth of 5 cm were recorded. Soil moisture at a depth of about 7 cm was measured by using TDR sensor. Gas samples were analyzed in the laboratory of Xishuangbanna Station for Tropical Rain Forest Ecosystem Studies. The seedling biomass in the collars was estimated in four different seasons based on a model from similar seedlings outside of the collars.

Diurnal change of soil respiration was measured in three different seasons. Samples were collected at every 3 to 4 h in 24 h when it was sunny. Temperature and moisture were observed at the sampling time. Data of air temperature, soil temperature, precipitation, etc. were recorded automatically by the weather station in the 72-m-tower near the permanent plot of CERN.

1.4 CO_2 analysis

Samples were analyzed by a gas chromatography (4890D GC, Agilent Co. Produced), with an auto-sampling which could be used to measure CH_4, CO_2 and N_2O concentration simultaneously[38,39].

1.5 CO_2 efflux calculation

$$F=\frac{M}{V_0}\frac{P}{P_0}\frac{T_0}{T}H\frac{dc}{dt}, \qquad (1)$$

where F was flux ($mg \cdot m^{-2} \cdot h^{-1}$), M is mass per mole ($44\ g \cdot mol^{-1}$ for CO_2), P_0 and T_0 air pressure and temperature of ideal gas in standard conditions (1013.25 hPa and 273.15 K, respectively), V_0 gas volume per mole in standard conditions ($22.4\ L \cdot mol^{-1}$), H the height (in meter) of the chamber, P and T air pressure and air temperature respectively inside the chamber when samples were collected, dc/dt the slope of regression equation between measured gas concentration and time.

2 Research results

2.1 Seasonal change in soil respiration

Seasonal changes in soil respiration, precipitation, and soil temperature are shown in fig. 1(a), (b), and (c), respectively. Soil respiration rates were relatively high during the periods of March—April, June—July, and September—October, in accordance with the fluctuation of temperature and precipitation. From February to May, soil respiration began to increase with rising temperature, but did not arrive at the peak due to few precipitation and low soil moisture. Soil respiration rates reached the highest from June to July because of high temperature and soil moisture. Around August soil respiration dropped, for heavy precipitation caused temperature dropping slightly and soil aeration decreasing greatly. After October soil respiration kept dropping gradually with precipitation and temperature decreasing. There were differences at 1% level within the three treatments, with the rank of C (14642 $mgCO_2 \cdot m^{-2} \cdot h^{-1}$) > B (12807 $mgCO_2 \cdot m^{-2} \cdot h^{-1}$) > A (9532 $mgCO_2 \cdot m^{-2} \cdot h^{-1}$).

2.2 Diurnal change in soil respiration

Diurnal change in soil respiration is shown in fig. 2. No significant diurnal change was found in soil respiration based on measurements in March, May and August, for the difference between maximum and minimum soil temperature was normally smaller than 2℃. It was also found that soil respiration rate during the period of 09:00—11:00 a.m. was equal to the mean value in whole day.

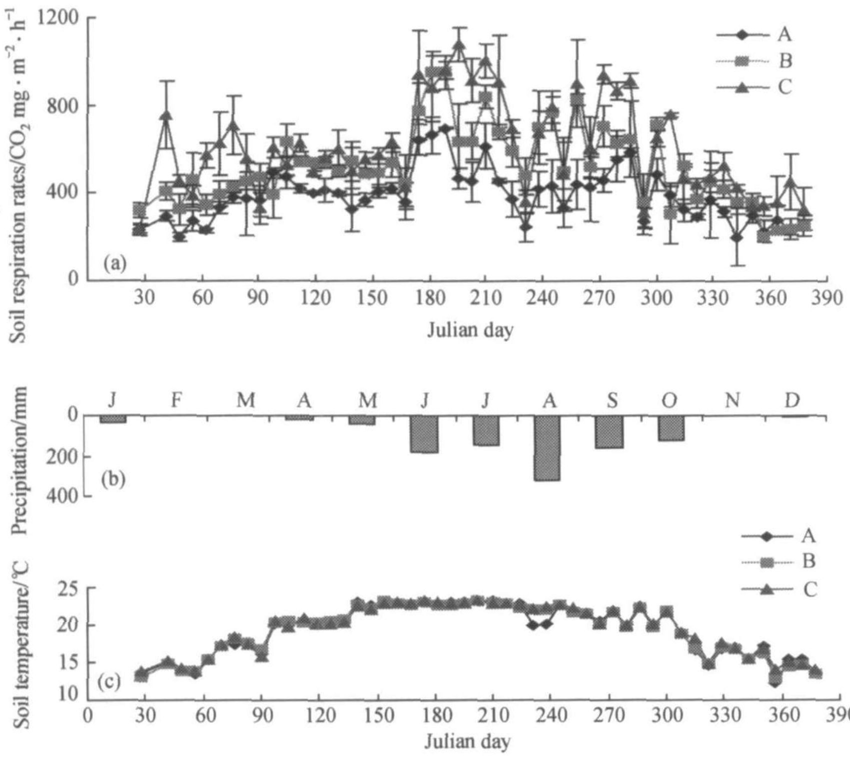

Fig. 1. Seasonal changes in soil respiration (a), precipitation (b) and soil temperature at the depth of 5 cm (c).

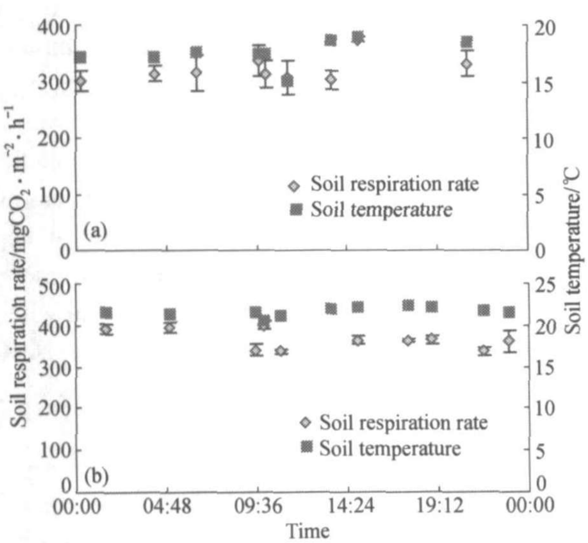

Fig. 2. Diurnal changes in soil respiration and soil temperature. (a) March 10—11, 2003; (b) May 12—13, 2003.

2.3 The relationship between soil respiration and soil moisture

The relationship between soil respiration and soil moisture is shown in fig. 3. Soil respiration correlated convex parabolaly with soil moisture at 1% level. Soil respiration rates were higher when soil moisture ranged from 35% to 45%.

2.4 The relationship between soil respiration and temperature

Soil respiration was affected by temperature with a parabola relationship between them as shown in fig. 4. Soil respiration correlated at 1% level with soil temperature on the surface and at the depth of 5 cm in mineral soil, air temperature in the chamber, and open air temperature, respectively. Because the soil temperature at the depth of 5 cm in mineral soil was more stable in a short period than the other temperatures described above, and it had a closer relationship with soil respiration, the soil temperature at the depth of 5 cm in mineral soil was chosen as the temperature index for the measurement of effect of temperature on soil respiration.

By using the equations in fig. 4 and formula (2), Q_{10} values were calculated for treatments A, B and C. They were 2.03, 2.36 and 2.08, respectively, very close to those reported in other tropical forest soils[40].

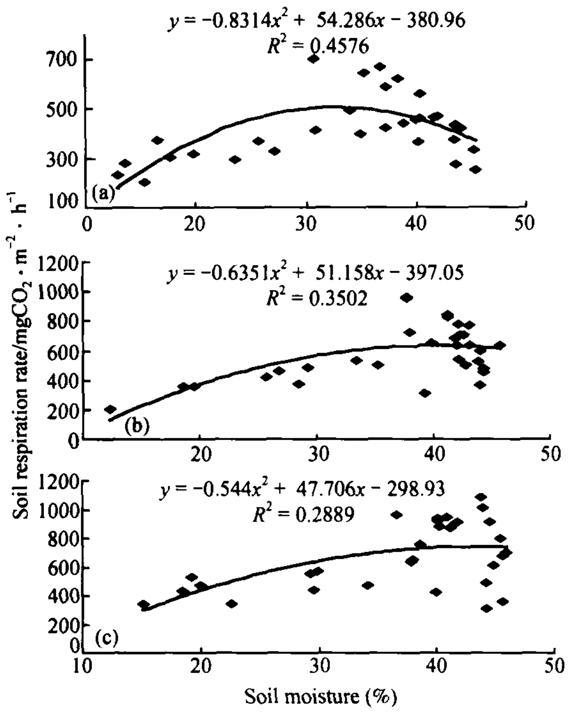

Fig. 3. The relationship between soil respiration rate and soil moisture. The results of treatments A, B and C are shown in (a), (b) and (c), respectively.

$$Q_{10} = \frac{R_{t+10}}{R_t}, \qquad (2)$$

where R_t and R_{t+10} were soil respiration rates when temperature at t and $t+10$, respectively.

2.5 Annual CO_2 efflux from soil respiration

There was little diurnal change in soil respiration due to small diurnal temperature difference in Xishuangbanna. When daily CO_2 efflux from soil respiration was calculated, soil respiration rate was multiplied by 24.

CO_2 efflux from soil respiration in a day:

Treatment A: $r_A = 24 \times 94.355e^{0.071t}$,

Treatment B: $r_B = 24 \times 93.301e^{0.0859t}$,

Treatment C: $r_C = 24 \times 138.82e^{0.0731t}$.

CO_2 efflux from soil respiration in a year:

Treatment A:

$$R_A = \sum_{i=1}^{z} r_{Ai}, \qquad (3)$$

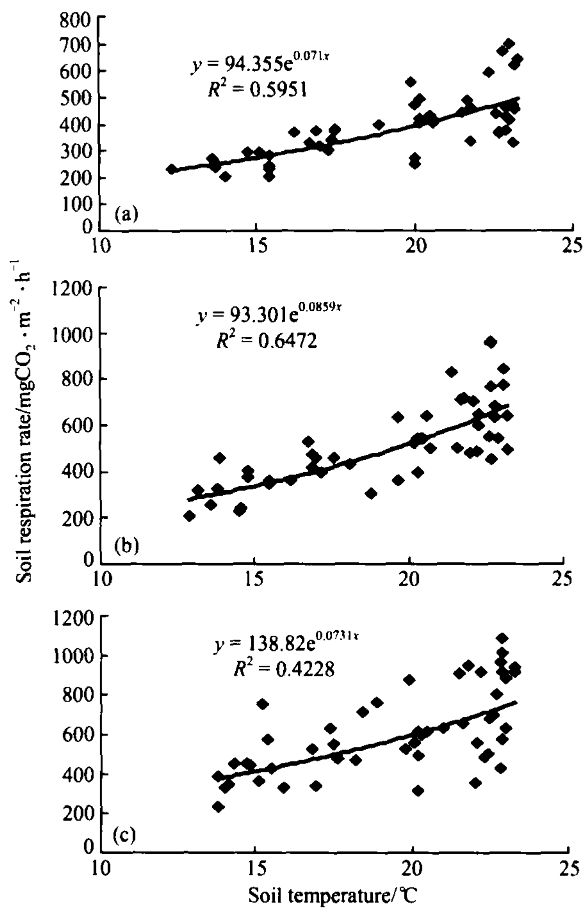

Fig. 4. The relationship between soil respiration and soil temperature at the depth of 5 cm. The results of treatments A, B and C are shown in (a), (b) and (c), respectively.

where z was the number of day in a year, ranging from 1 to 365. CO_2 efflux from soil respiration in a year for treatments B and C was calculated in the same way.

Daily, monthly and yearly CO_2 efflux from soil respiration were calculated by using the equation above based on daily mean soil temperature at the depth of 5 cm in 2003 (as shown in fig. 5).

The calculated CO_2 efflux from soil respiration in 2003 for treatments A, B and C were 3.48, 4.67 and 5.34 $kgCO_2 \cdot m^{-2} \cdot a^{-1}$, respectively. If the CO_2 efflux for treatment C (soil+litter+seedling) was taken as 100%, then the CO_2 efflux from bare soil accounted for 65.2%, litter layer 22.3% (1.19 $kgCO_2 \cdot m^{-2} \cdot a^{-1}$), seedlings 12.5% (0.67 $kgCO_2 \cdot m^{-2} \cdot a^{-1}$). The CO_2 efflux from seedlings was very low due to their small

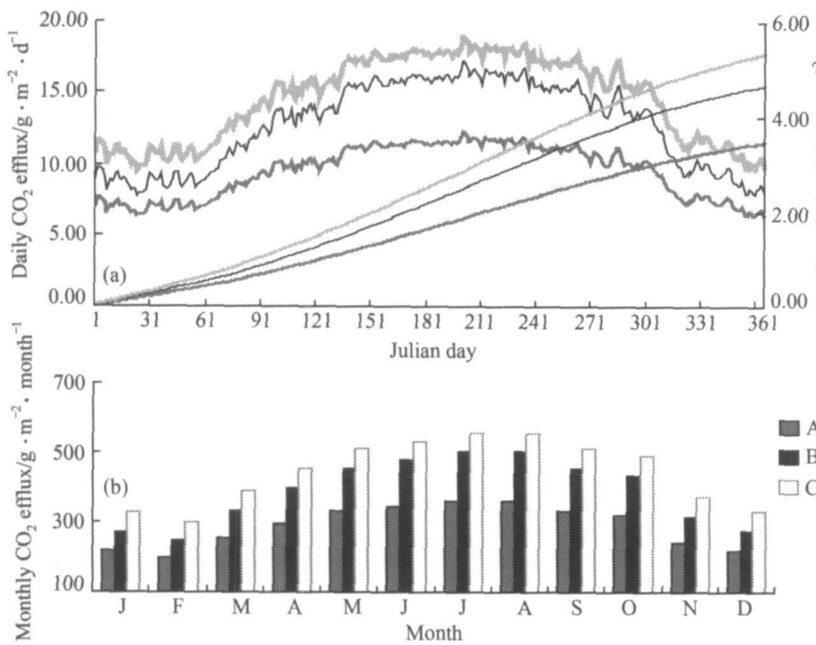

Fig. 5. The calculated values of daily CO_2 efflux and cumulative CO_2 efflux (a), and monthly CO_2 efflux (b).

biomass (as shown in fig. 6). The CO_2 efflux from soil respiration of seasonal rain forest in Xishuangbanna was larger than that (29.89 $tCO_2 \cdot hm^{-2} \cdot a^{-1}$) of montane rain forest in Hainan Province[33], but the efflux from litter was larger in the later forest (3.27 $tCO_2 \cdot hm^{-2} \cdot a^{-1}$). The CO_2 efflux from soil respiration of seasonal rain forest in Xishuangbanna was as low as one half of that (2.56 $kgC \cdot m^{-2} \cdot a^{-1}$) in tropical monsoon forest in Thailand[32]. However, the value reported by Davidson et al. in Amazon was similar to that in Thailand[41].

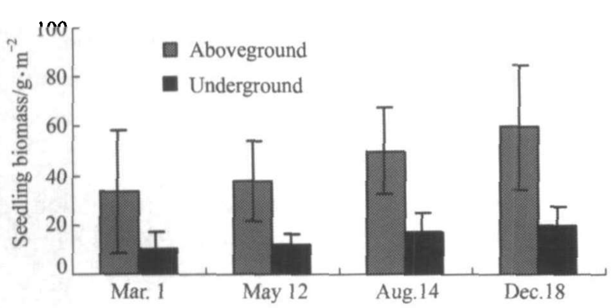

Fig. 6. The biomass of seedlings inside the collars in different seasons.

3 Discussion

Soil respiration includes autotrophic respiration from plant roots, heterotrophic respiration from soil microbes and soil fauna, as well as chemical decomposition of inorganic carbonates. Soil respiration, as a complex biological process, was affected by many factors, of which temperature and moisture were two key ones[42–47]. Some studies reported that soil temperature but not soil moisture was the key factor affecting soil respiration in boreal forests[42,44,47]. In temperature forests soil respiration seasonally fluctuated with changing temperature and moisture[43,45,46]. The study on monsoon forest in Thailand by Hashimoto et al. showed that in tropics temperature was high around the year and relatively constant, therefore temperature was not the main factor affecting soil respiration, while the great seasonal variation in soil moisture was made the key factor affecting soil respiration[32]. The results showed that soil respiration of seasonal rain forest in Xishuangbanna changed seasonally and was affected greatly by temperature and moisture. This pattern was well in agreement with the climatic characteristics in Xishuangbanna.

Litter fall, photosynthesis production transferred to the underground and root exudates can affect soil respiration by changing microbe activity[48,51]. Plant growth is controlled by temperature and moisture. Litter fall, photosynthesis production transferred to the underground as well as soil respiration vary seasonally.

Q_{10} is an index normally used for figuring the relationship between soil respiration and temperature. In physiology Q_{10} is time(s) of increased respiration when temperature rises by 10℃. Q_{10} values of soils globally range from 2.0 to 2.4, with the mean of 2.0[37]. Q_{10} values in high latitude are larger than in low latitude. Q_{10} is of importance in estimating the trend of soil CO_2 efflux and understanding the global carbon cycle against the background of global warming.

The soil CO_2 efflux of seasonal rain forest in Xishuangbanna was higher than that of montane rain forest in Hainan Province, but much lower than those in Thailand and in Amazon. The value (2.56 $kgC \cdot m^{-2} \cdot a^{-1}$) reported in Thailand was the highest reported in terrestrial and wetland ecosystems[27]. Soil respiration might have been underestimated or overestimated due to different temperature and moisture conditions, forest biomass and productivity, soil organic matter content, as well as measure techniques.

Here is the report on the soil respiration characteristics in 2003 and its relationship with temperature and moisture, and the annual CO_2 efflux from soil respiration is also estimated. Q_{10} changed seasonally, affected by temperature, moisture as well as vegetation types and phenology[49]. Soil respiration varied inter-annually due to great inter-annual climate variation. Therefore, the long-term observation is essential for a better understanding of soil respiration in Xishuangbanna.

4 Conclusions

(1) The soil respiration of seasonal rain forest in Xishuangbanna varied significantly with the seasonal change in temperature and moisture, but with little diurnal variation in soil respiration.

(2) The soil respiration differed among the treatments at 1% level, with the rank of C (14642 $mgCO_2 \cdot m^{-2} \cdot h^{-1}$) > B (12807 $mgCO_2 \cdot m^{-2} \cdot h^{-1}$) > A (9532 $mgCO_2 \cdot m^{-2} \cdot h^{-1}$).

(3) Soil respiration parabolaly correlated with soil moisture, and exponentialy with soil temperature, at 1% level.

(4) Q_{10} values ranged from 2.03 to 2.36, close to those reported in other tropics.

(5) The CO_2 efflux in 2003 was 5.34 $kgCO_2 \cdot m^{-2} \cdot a^{-1}$ from soil plus litter plus seedling, of which 3.48 $kgCO_2 \cdot m^{-2} \cdot a^{-1}$ from soil (accounting for 62.5%), 1.19 $kgCO_2 \cdot m^{-2} \cdot a^{-1}$ from litter (22.3%) and 0.67 $kgCO_2 \cdot m^{-2} \cdot a^{-1}$ from seedling (12.5%).

Acknowledgements The Biogeochemical Laboratory of Xishuangbanna Tropical Botanical Garden helped in soil analysis. Xishuangbanna Station for Tropical Rain Forest Ecosystem Studies of CERN provided this study with the data of soil temperature and precipitation in 2003. This work was supported by the Knowledge Innovation Program of the Chinese Academy of Sciences (Grant No. KZCX1-SW-01), the Basic Science Development Program of China (Grant No. 2002CB412501), and the National Natural Science Foundation of China (Grant No. 40173039).

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