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Comparing soil CO₂ emission in pine plantation and oak shrub: dynamics and correlations

Received: 11 April 2006 / Accepted: 10 August 2006 / Published online: 28 October 2006
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Abstract The magnitude of soil CO₂ emission varying significantly among different vegetation types for plants could alter the microclimatic environment of soil. In a *Pinus tabulaeformis* plantation and an adjacent *Quercus aliena* var. *acuteserrata* shrub, which are located in a dry-hot valley region of Minjiang River in the Southwest of China, the daily soil CO₂ emission dynamics was measured in August 2004 and in May, July, and October 2005. The results showed that the soil CO₂ emission in the oak shrub was significantly higher than the pine plantation in each measurement period. Additionally, soil organic matter, microbial biomass carbon, and the leaf litter decomposition rate in the two vegetations differed significantly from each other. The variation of soil organic matter and microbial biomass carbon partially contributed to the evident difference in soil CO₂ emission. Moreover, the correlations between soil CO₂ emission, soil temperature, and soil water content were evaluated in this study. The soil temperature positively controlled soil CO₂ emission in the pine plantation and the oak shrub, while the soil water content negatively influenced soil CO₂ emission in the two vegetation types. However, the soil temperature and soil water content played varied roles in the different vegetation types. By the means of stepwise regression, the soil temperature more significantly influenced the dynamics of soil CO₂ emission for the plantation than the soil water content; oppositely, the soil water content was the more significant controlling factor for the shrub. Based on the exponent model between the soil CO₂ emission and soil temperature, the Q_{10} values were estimated, which was 1.7 in the pine plantation and 3.0 in the oak shrub. The former was lower than the global average level of 2.0,

whereas the latter was higher than the global average level.

Keywords Soil CO₂ emission · Pine plantation · Oak shrub · Dynamics · Controlling factors

Introduction

The observed increase in the levels of atmospheric CO₂ and the signing of the UN Framework Convention on Climate Change have increased interest in the global carbon cycle, which has been severely disturbed and drastically changed by human activities, especially since the industrial revolution (Schimel et al. 1994, 1995; Rustad et al. 2000). As one of the key components in the global carbon cycle, soil CO₂ emission exceeds all other terrestrial-atmospheric carbon exchanges in most terrestrial ecosystems, and is only secondly to the gross primary productivity (Raich and Schlesinger 1992; Rustad et al. 2000; Davidson et al. 2002; Curiel Yuste et al. 2004). Based on the assumption that the observed sensitivity of soil CO₂ emission is related to the temperature, global warming will accelerate the decomposition of soil organic carbon, thereby, releasing more CO₂ to the atmosphere to further enhance the warming trend (Kirschbaum 1995; Cox et al. 2000; Schlesinger and Andrews 2000; Sarmiento 2000; Luo et al. 2001b). Therefore, identifying the environmental factors that control soil CO₂ emission and quantifying the effects on emission rates are the central issues in assessing the potential impacts of climate change (Raich and Tufekcioglu 2000; Luo et al. 2001b).

Soil CO₂ emission represents the combined respiration of roots and soil micro- and macro-organisms (Rustad et al. 2000). Vegetation types could significantly affect the magnitude of soil CO₂ emission by means of altering the quantity and quality of litters, especially the soil microenvironment (Schlesinger 1977; Singh and Gupta 1977; Raich and Schlesinger 1992; Raich and Tufekcioglu 2000; Li et al. 2005). Raich and Tufekcioglu

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(2000) have reviewed published studies and drew conclusions that grasslands had, on average, ~20% higher soil CO₂ emission than the comparable forest stands, and that coniferous forests had ~10% lower rates of soil CO₂ emission than the adjacent broad-leaved forests rates. In wet tropics, the annual mean soil CO₂ emission of a secondary forest was consistently higher than a pine plantation throughout the year, while in semiarid ecosystems in Arizona, the magnitude of soil CO₂ emission in pine forests was always higher than in shrubs. The importance of the spatial variation of both vegetation and surface soil features for the estimation of soil CO₂ emission was remarkable (Li et al. 2005; Conant et al. 2000; Maestre and Cortina 2003).

China is a key region in the global carbon cycle (Cao et al. 2003; Yu et al. 2006; Lal 2004). Soil CO₂ emission varied between 2.89 and 3.21 G t C a⁻¹, with a growth rate of 0.40% a⁻¹ in the period 1981–1998; from 1950s to 1990s, soil CO₂ emissions have been steadily increasing by more than 30%. While the forest ecosystem played an important role in the Chinese carbon cycle, between 1993 and 1998, the average carbon accumulation rate of Chinese forests was 0.03–0.08 P g C a⁻¹. Obviously, it was a net carbon sink during this period (Fang 2000; Gong et al. 2002). From the 1980s, many studies on soil CO₂ emission have been conducted in subtropical forests (Luo et al. 2001a; Yi et al. 2003; Yang et al. 2005), temperate forests (Sang et al. 2002; Du et al. 2004), boreal forests (Wang et al. 2003; Lin et al. 2004; Wu et al. 2006), which focused mainly on the dynamics and the driving mechanism of soil CO₂ emission in a special ecosystem (Liu and Fang 1997; Jia et al. 2005; Zhang et al. 2005). Only a limited understanding was concerned about soil CO₂ emission dynamics and controlling factors in different vegetations. Conducting a comparison study on the correlations between vegetation and soil CO₂ emission could provide profound information about the response of different vegetation types to global change.

In this paper, a *Pinus tabulaeformis* plantation and the adjacent *Quercus aliena* var. *acuteserrata* shrub in the dry-hot valley of upper Minjiang River, Sichuan Province, China, were chosen, which were the typical vegetation types in the local area. The objectives of this study are: (1) to measure the soil CO₂ emission in two different vegetation types in different periods; (2) to distinguish the influence of soil temperature and soil water content on soil CO₂ emission for pine plantation and oak shrub; (3) and to estimate the temperature sensitivity of soil CO₂ emission (Q_{10}) in two vegetation types.

Materials and methods

Study site

The study was conducted in a 25-year-old pine plantation and the adjacent shrub in the Dagou catchment

of Mao County, Sichuan Province, southwestern China. Both sites are located at 103°52'23"E and 31°42'N, with a southwestern aspect, a gentle slope, and an elevation of 1,987 m. The soil is classified as Humic Cambisols in terms of the FAO-UNESCO system (FAO-UNESCO 1998), and the parent material is phyllite. The mean annual temperature of the study area is 8.9°C and the mean annual precipitation is about 900 mm.

The pine plantation was dominated by *P. tabulaeformis* and was planted on previously degraded native shrub. The mean canopy height was 13 m and the mean diameter at breast height was 11.2 cm. Understory was with about 40% coverage, and was mainly consisted of *Rosa hugonis* and *Cystopteris fragilis*, of which, the height was about 0.4–1.1 m. The oak shrub was dominated by *Q. aliena* var. *acuteserrata*, which was about 1.5 m in height, and with more than 90% coverage. Others were shrub or herbage with a height of 0.6–1.2 m, for example, *Qstryopsis davidianti*, *Carex capilliformis*, *C. fragilis*, *Phlomis umbrosa* var. *Australis*, etc. The litter layer in pine plantation was about 1 cm in thickness, which was composed of withered needles and branches. However, the litter layer was about 1.5 cm in thickness in the oak shrub and was mainly composed of the fallen leaves.

Soil sampling and analysis

In late July 2004, soil samples of A and B layers (A layer is at a depth of 0–15 cm and B layer at 15–30 cm) were collected from the pine plantation and oak shrub sites. For each site, nine soil cores (100 cm³) of two layers were sampled from three random soil profiles and were mixed to obtain a composite sample for each layer.

The bulk density of the soil samples was determined from an undisturbed soil sample by the core method. The soil pH was determined in 1:2.5 soil–water slurry using a combination pH electrode. Part of the air-dried samples was finely ground to pass through a 0.1-mm sieve for chemical analysis. Soil organic matter was determined by the Walkley-Black dichromate oxidation procedure (Nelson and Sommers 1982). Microbial biomass carbon was measured using the chloroform fumigation–extraction method (Brookes et al. 1985; Vance et al. 1987).

Leaf litter decomposition rate analysis

The decomposed litterfall provided food source for soil organisms, which could influence the soil CO₂ emission. The leaf litter decomposition rate was determined using the litterbag method (Hartemink and O'Sullivan 2001; Li et al. 2005; Osono and Takeda 2005). Recently fallen leaves and needles were hand-picked from two sites, and were placed in litterbags constructed of nylon

cloth with 1-mm mesh openings. Each site was placed with 40 bags in April 2005, with each bag containing 43 g fresh leaf litter from the pine plantation, while 23 g from the oak shrub, respectively, for the quality of leaf litter from the two sites differed from each other significantly. These litterbags were collected and weighed after 0, 2, 3, 4, 6, 7, 8, and 11 months. Three litterbags were collected each time at each site, which were then oven-dried to a constant mass at 80°C in the laboratory, and then the dried litter was weighed for analyzing the decomposition rate.

Several models were tested, but it was found that the single exponential model provided the best fit for the decomposition pattern of the leaves. The single exponential model was fitted to the data (Eq. 1) as follows:

$$Y = e^{-kt} \quad (1)$$

where Y is the proportion of oven-dried remaining mass (g) to the dried initial mass (g) at time t (days) and k is the decomposition factor ($\text{g g}^{-1} \text{d}^{-1}$) (Olson 1963; Zhang et al. 2000; Hartemink and O'Sullivan 2001).

Measurements of soil CO₂ emission

In this study, the soil CO₂ emission was measured using a LI-COR soil CO₂ emission chamber (model LI-6400-09; LI-COR Biosciences, Lincoln, Nebraska) and a LI-6400 infrared gas analyzer (LI-COR Biosciences, Lincoln, Nebraska). Four or five soil collars were positioned randomly in each plot and the 24-h continuous measurements were conducted in two days of August in 2004, and in May, July, and October in 2005. To minimize the CO₂ emission from litter, the litterfall layer was removed, then the PVC soil collars (10.5 cm in internal diameter and 8 cm in height) were inserted 5 cm into the soil the day before the measurement was made. The LI-6400 read four flux values each time, and the average of these values was used as the mean soil CO₂ emission rate of this interval.

Measurements of environmental factors

The air temperature, soil temperature, and soil water content (%) were measured at the same time as the measuring of the soil CO₂ emission rate. The air temperature was measured at the soil surface (5 cm above floor) by the portable Testo-615 (Germany, $\pm 0.5^\circ\text{C}$). The soil temperature was measured at 5 cm soil depth with a soil temperature probe (6000-09TC, LI-COR Inc., Nebraska, USA, $\pm 1.5^\circ\text{C}$, $0\text{--}50^\circ\text{C}$) simultaneously when the soil CO₂ emission measurements were made. A TDR probe (ML2X, England, $\pm 0.01\%$, $0\text{--}40^\circ\text{C}$; $\pm 0.02\%$, $40\text{--}70^\circ\text{C}$) was used for detecting the volumetric soil moisture content at each soil CO₂ emission measuring time.

The sensitivity of soil CO₂ emission to temperature

The temperature sensitivity of soil CO₂ emission, the Q_{10} value, which is an empirically fitted parameter that represents the relative increase (R/R_c) as the temperature increases by 10°C , was calculated according to the Arrhenius type equation (Eq. 2) (Buchmann 2000):

$$R = \alpha e^{\beta T} \quad (2)$$

$$Q_{10} = e^{10\beta} \quad (3)$$

where R is the soil CO₂ emission ($\mu\text{mol m}^{-2} \text{s}^{-1}$), T is the temperature ($^\circ\text{C}$), and α and β are constants of the modeled exponential equation between soil CO₂ emission and temperature.

Data analysis

The Statistical Package for the Social Sciences (SPSS) version 10.0 was used for the data analysis. Significant differences of the leaf litter decomposition rate, soil organic matter, and microbial biomass carbon between the pine plantation and the oak shrub was determined by the independent-samples t test. Variation of the soil CO₂ emission and other environmental factors in the plantation and shrub among each measurement period was tested by Tukey's test at a level of $\alpha = 0.05$. Stepwise regression was used to evaluate the contribution of soil temperature and soil water content to the soil CO₂ emission.

Results

Soil physicochemical characteristics

As elemental properties, the pH and the bulk density of the pine plantation soil were 5.58 ± 0.06 and $1.02 \pm 0.02 \text{ g cm}^{-3}$, while the soil pH and the bulk density in the oak shrub were 5.09 ± 0.11 and $1.10 \pm 0.01 \text{ g cm}^{-3}$, respectively.

The soil organic matter significantly differed between the pine plantation and oak shrub. Not only in A layer but also in B layer, the soil organic matter in the shrub soil was higher than that in the pine plantation. Additionally, there was a similar trend of microbial biomass carbon to the soil organic matter. Microbial biomass carbon was higher in the shrub than in the plantation in two layers (Table 1).

Leaf litter decomposition rate

The leaf litter decomposition rate was not significantly different between the plantation and the shrub (Table 2), while the litterfall in the shrub decomposed a little faster than the leaf litter in the plantation. The decomposition rates were similar when the remaining mass was about

Table 1 Soil organic matter and microbial biomass carbon in the plantation and shrub

	Soil organic matter (%)		Microbial biomass carbon (mg C kg ⁻¹)	
	A	B	A	B
Plantation	3.95 (0.19) b	1.97 (0.13) b	651 (31) b	320 (26) a
Shrub	5.12 (0.09) a	2.98 (0.19) a	796 (35) a	364 (22) a

The different letters within each column indicate significant difference by the independent-samples *t* test at a level of $\alpha=0.05$, $n=3$. In this table, A and B indicate different soil layers, of which, layer A was at a depth of 0–15 cm and layer B was at 15–30 cm, respectively

Table 2 Mean annual decay constant, *k*, in the plantation and the shrub

Leaf source	<i>k</i>	<i>R</i> ²	<i>P</i>
Plantation	0.29 (0.08) a	0.51	< 0.01
Shrub	0.51 (0.12) a	0.88	< 0.01

The values in the parentheses were derived from seven-time sampling with three replicates. Common letters within each column indicate no significant difference by the independent-samples *t* test at a level of $\alpha=0.05$ level

70% of the initial mass during April 2005–October 2005 in the plantation and shrub, and then there was a faster decomposition rate in the shrub after that period (Fig. 1).

The diurnal dynamics of soil CO₂ emission and environmental factors

The diurnal dynamics of soil CO₂ emission and other environmental factors in the pine plantation and shrub are shown in Fig. 2. The air temperature was measured on the surface of the soil and there were significant variations among different measurement periods. Nevertheless, the air temperature in the plantation was a little lower than in the shrub (Table 3).

Across each study period, the diurnal dynamics of soil CO₂ emission displayed similar trends in the plantation and shrub. A peak soil CO₂ emission appeared during 12:00–15:00 pm when the temperature was highest in a day, and the depression appeared before sunrise, when the temperature was lowest (Fig. 2a, a'). However, soil CO₂ emissions in the shrub were always higher than that in the plantation during each measurement period.

The spatial and temporal variations in the soil CO₂ emission are significant and sensitive to the environmental conditions (Hanson et al. 1993; Tang and Baldocchi 2005). The diurnal variation of soil CO₂ emission was similar to the soil temperature, whereas it

Fig. 1 Leaf litter decomposition (represented by the percentage of leaf litter mass remaining in the litterbags) in the pine plantation (filled circles) and oak shrub (open circles) from April 2005 to March 2006

was dissimilar to the soil water content in two vegetations (Fig. 2a–c, a'–c'). As shown in Table 3, there was a more obviously dynamic correlation pattern between the soil CO₂ emission and the environmental factors. In August 2004 and July 2005, the soil CO₂ emission in the plantation and shrub were significantly higher than in May and October 2005. At the same time, the soil temperature in the two vegetations were much higher than in May and October 2005. In contrast, the soil water content in October 2005 was significantly higher than in the other measurement periods in the plantation and shrub (>40%), in spite of the higher soil water content (37.7%) in the shrub in May 2005.

The relationship between soil CO₂ emission, soil temperature, and soil water content

The soil temperature and soil water content were climatic factors that influenced the soil CO₂ emission rate. There were significantly positive relationships between soil CO₂ emission and soil temperature (Fig. 3a), which meant that the soil CO₂ emission would increase with the enhancement of temperature. On the other hand, the soil CO₂ emission decreased with the increased soil water content in the two vegetations (Fig. 3b). Despite the disagreement on the model of soil CO₂ emission and soil water content, this paper documented a significantly negatively linear correlation between the soil CO₂ emission and soil water content. However, the relative importance of individual processes or factors on controlling soil CO₂ emission varied in different vegetations. Soil temperature was the only variable to significantly dominate soil CO₂ emission in the plantation ($R^2=0.92$, $P<0.001$), and the soil water content met the model entry requirements for the shrub ($R^2=0.84$, $P<0.001$), but not for the plantation from a stepwise regression analysis (Table 4).

Fig. 2a–d Diurnal dynamics of soil CO₂ emission, soil temperature, water content, and air temperature in the pine plantation (a–d) and the oak shrub (a'–d') in August 2004 (filled squares), May 2005 (filled circles), July 2005 (open triangles), and October 2005 (crosses)

Table 3 Mean soil CO₂ emission, soil temperature, and soil water content during different measurement periods in the two vegetations

Plot	Month	Soil CO ₂ emission ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Soil temperature (°C)	Soil water content (%)	Air temperature (°C)
Plantation	August 2004	1.85 (0.09) a	17.81 (0.76) a	11.87 (0.80) c	20.98 (1.71) a
	April 2005	1.27 (0.17) b	10.92 (0.65) c	32.90 (1.81) b	12.39 (2.33) b
	July 2005	1.76 (0.14) a	18.28 (1.15) a	31.50 (1.30) b	20.02 (2.98) a
	October 2005	1.28 (0.13) b	12.01 (0.78) b	41.76 (1.54) a	11.45 (2.42) b
Shrub	August 2005	4.82 (0.21) a	19.82 (0.92) a	11.41 (1.47) c	24.47 (2.69) a
	April 2005	1.52 (0.58) b	14.09 (2.64) b	37.73 (1.12) a	17.49 (7.91) b
	July 2005	2.72 (0.33) a	20.57 (1.82) a	29.04 (7.04) b	22.17 (4.56) a
	October 2005	1.41 (0.30) b	11.83 (1.61) b	43.96 (6.12) a	11.68 (3.84) c

The common letters within a column indicate no significant difference among different measurement periods for each vegetation type according to Tukey's test at a level of $\alpha = 0.05$. The numbers in the parentheses are the standard deviations

Fig. 3a, b Relationship between soil CO₂ emission and soil temperature (a), soil CO₂ emission and soil water content (b) in the pine plantation (filled circles) and in the oak shrub (open circles). In addition, the simulated trend in the plantation (solid line) and in the shrub (dashed line) are shown. In Fig. 3a, the exponential model between the soil CO₂ emission and temperature in the two sites are shown, and in Fig. 3b, the linear models are shown

Moreover, the temperature sensitivity index Q_{10} values in the plantation and shrub were obtained according to Eq. 3, which were 1.7 ($R^2 = 0.83$, $P < 0.001$, $n = 64$) and 3.0 ($R^2 = 0.76$, $P < 0.001$, $n = 64$), respectively. The results revealed that the soil CO₂ emission in the shrub was more sensitive to the soil temperature change than in the plantation.

Discussion

Vegetation types and soil CO₂ emission

Vegetation influences significantly the accumulation and turnover of soil organic matter directly by determining

Table 4 Stepwise regression analysis

Plot	Equation	R^2	P	n
Plantation	Soil CO ₂ emission = 0.078 Soil temperature + 0.372	0.92	<0.001	64
Shrub	Soil CO ₂ emission = -0.095 Soil water content + 5.472	0.81	<0.001	64

the palatability of plant material and indirectly by conditioning the pathways of biomass incorporation into the soil. Generally, the detritus from a broad leaves plant is a larger quantity than that from pine forest, and is more easily decomposed. In the highly controlled conditions, soil organic matter turnover rates and litter decomposition into the mineral soil were all faster under oak (Quideau et al. 2001). Moreover, microorganism species that populate the rhizosphere depended on the species and age of plant, the type of soil, and the organic matter content (Roldan et al. 1994; Garcia et al. 2000; Li et al. 2005). In the present paper, though there was no study conducted on the input rate of litterfall in the two vegetations, a thicker litterfall layer and a faster leaf litter decomposition rate in the shrub both contributed to a higher soil organic matter in the oak shrub for the different litter quantities and the quality could dominate the decomposition processes in two the vegetations, and lead to different soil substrate for microorganisms.

Previous studies have demonstrated that the soil CO₂ emission was closely related to the soil organic matter and microbial biomass carbon (Liu and Fang 1997; Bohlen and Edwards 1995; Shen et al. 1997; Carpenter-Boggs et al. 2003). But also, treatments containing greater amounts of carbon content and higher microbial biomass carbon produced greater soil CO₂ emission (Dugas et al. 1999; Franzluebbers et al. 2002; Lohila et al. 2003). Frank et al. (2005) reported the soil organic carbon and microbial biomass carbon for grassland, which were 1.3 and 4 times over the cropped sites, respectively, which led to higher soil CO₂ emission throughout a year, especially in the summer. In this research, soil CO₂ emission in the shrub was always higher than that in the adjacent plantation, partially due to higher soil organic matter and microbial biomass carbon.

Soil CO₂ emission is controlled simultaneously by many factors, such as climate, the availability of nutrient and energy sources, and substrate and microbial population changes, while the foremost abiotic factors are soil temperature and soil moisture. Temperature is a good predictor of soil CO₂ emission when the soil moisture is adequate and is not a limited factor (Raich and Schlesinger 1992; Sjögersten and Wookey 2002; Zheng et al. 2005). However, when the soil moisture is insufficient or excessive, it would become a limited factor, such as for arid or wet regions, the temperature and soil moisture influenced the soil CO₂ emission jointly (Wildung et al. 1975; Edwards and Harris 1977; Peterjohn et al. 1994; Dong et al. 1998; Conant et al. 2004). Laboratory studies have demonstrated clearly the importance of soil water content as a factor influencing soil CO₂ emission. This research clearly documented that the soil temper-

ature and soil water content were good predictors of soil CO₂ emission, in spite of the vegetation types (Fig. 3), and it is argued that variations among different measurement periods in the soil CO₂ emission were better explained by the temperature and parallel changes in the soil water content. However, in field studies, the temperature effect is often more pronounced than the water effect, and the effects which the soil temperature and soil water content on soil CO₂ emission alters often differed among vegetation types (Davidson et al. 2000; Gates 1980; Raich and Tufekcioglu 2000; Frank et al. 2005). The soil temperature for the plantation more strongly affected the soil CO₂ emission, while the soil water content for the shrub more strongly affected the CO₂ emission from a stepwise regression. A possible reason for this might be the differences on the plant canopy and the community substrate between the two vegetation types, but future work is still needed to explain this mechanism.

The response of soil CO₂ emission to global changes

The whole world has raised concerns about the response of the terrestrial carbon pool to the elevated atmospheric CO₂ concentration and the potential global warming. On larger spatial and temporal scales, the forest free-air CO₂ enrichment (FACE) experiment has documented that the soil CO₂ emission generally increased due to the stimulated NPP and the root growth under the elevated CO₂ conditions, though this was still not statistically significant (Andrews et al. 1999; Allen et al. 2000; Hamilton et al. 2002). On the other hand, the temperature sensitivity of the soil CO₂ emission, Q_{10} value was always used to evaluate the response of soil CO₂ emission to the increased atmospheric temperature; different Q_{10} values resulted in very different predictions of soil carbon dynamics and carbon storage (Hashimoto 2005). In spite of the increasing amplitude of soil CO₂ emission differing from various vegetations and different places with the global change (Liu and Fu 2001; Fang 2000), the Q_{10} value of the pine plantation was 1.7, which was lower than the global average level of 2.0, but the Q_{10} value of the shrub was 3.0, much higher than the global average level. With global warming, increasing soil temperature would lead to more carbon release. In this area, the oak shrub might be a carbon source, while the plantation might be a sink (Kirschbaum 1995; Palmer-Winkler et al. 1996; Kätterer et al. 1998; Schlesinger and Andrews 2000).

According to the provided data from a positioning weather station in the study area, the average annual air temperature during 1995–2004 could be obtained.

Integrating the exponential model between soil CO₂ emission and air temperature in the two vegetations (for the plantation, the exponential model was $R = 0.80e^{0.0387T}$, $R^2 = 0.90$, $P < 0.001$; for the shrub, the model was $R = 0.70e^{0.0586T}$, $R^2 = 0.63$, $P < 0.001$), the estimated annual soil CO₂ emissions were 4.35 and 4.58 t C hm⁻² a⁻¹ in the plantation and shrub, respectively. While the air temperature close to the soil surface in the shrub was higher than in the plantation, the annual soil CO₂ emission in the shrub, 4.58 t C hm⁻² a⁻¹, was underestimated a little. With the development of the plantation and the shrub, the roles which the two vegetation types played would be altered, but the plantation would be of more significance in the local carbon cycle on a regional scale.

Acknowledgments This work was funded by the State Key Basic Research and Development Program Plan (2002CB412503) and the National Natural Science Foundation of China (40321101). We are thankful for the help from the Field Research Station of the Mountain Ecosystem in Mao County, Chengdu Institute of Biology, CAS.

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