CO_2 efflux from different forest soils and impact factors in Dinghu Mountain, China

ZHOU Cunyu[1], ZHOU Guoyi[1], ZHANG Deqiang[1], WANG Yinghong[2] & LIU Shizhong[1]

1. Dinghushan Forest Ecosystem Research Station, Chinese Academy of Sciences, Guangzhou 510650, China;
2. Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China
Correspondence should be addressed to Zhou Guoyi (email: gyzhou@scib.ac.cn)

Received July 14, 2004; revised January 31, 2005

Abstract CO_2 fluxes from soils and related environmental factors were measured in three forest ecosystems of Dinghu Mountain using static chamber-gas chromatograph technique for one year. The seasonal pattern of CO_2 flux, contribution of litter on total CO_2 flux and the correlations of CO_2 flux with soil temperature and soil water content were examined for each type of forest. The results were given as followings: (1) The seasonal patterns of CO_2 flux from soil of the three types of forest were similar, with a higher CO_2 flux in rainy season than in dry season. The comparative relations of mean annual CO_2 fluxes between the three sites were expressed as: monsoon forest > mixed forest > pine forest. (2) CO_2 fluxes from litter decomposition in monsoon forest, mixed forest and pine forest accounted for 24.43%, 41.75% and 29.23% of the corresponding total CO_2 fluxes from forest floor, respectively. (3) Significant relationships were found between CO_2 fluxes and soil temperatures at 5 cm depth for the three types of forest, which could be best described by exponential equations. The calculated Q_{10} values based on soil temperature at 5 cm depth ranged from 1.86 to 3.24. More significant relationships were found between CO_2 fluxes and soil water content when the annual variation coefficients of soil moisture were higher.

Keywords: CO_2 flux, litter decomposition, Q_{10}, soil moisture.

DOI: 10.1360/05zd0020

CO_2 emission from forest floor, as a major carbon output of forest C pool, is a crucial component of carbon cycle of forest ecosystem, thus long-term and continuous measurement of CO_2 efflux from soil and the determination of the relationship between CO_2 flux and environmental factors are of great importance in understanding the C balance of the whole forest ecosystem. The area of subtropical evergreen broad-leaved forest accounts for 45.56% of the total forest area in China and the soil C pool of which accounts for 39.24% of the total soil C pool in Chinese forest. As small change in CO_2 flux from forest floor in response to global climate change may exacerbate the increase of atmospheric CO_2 level, it is of great significance to study CO_2 flux from soil in this area in identifying the role of forest in the future as C source or sink. Since the 1970s more and more research projects on CO_2 fluxes from soil surface in terrestrial ecosystem have been carried out worldwide, but mostly in temperate grassland and forest ecosystems[1]. In China, the corresponding work started relatively late and most of which focused on northern and middle China[2—4], while CO_2 flux from lower subtropical forest soil has been reported little, which prevented us from understanding the contribution of CO_2 emission from soil in this region to global C budget. In this study, CO_2 effluxes from soils of three main types of forest in the Dinghu Mountain and related environmental factors were measured once a week for one year in order to expound the seasonal patterns of soil CO_2 effluxes and find out key factors affecting CO_2 fluxes, which will provide evidence for the study of C cycle in this area.

1 Site description

The measurement sites were located in Dinghushan biosphere reserve (112°30′39″−112°33′41″E, 23°09′21″—23°11′30″N), which is the first natural reserve of China. It has an area of 1145 hm^2 with subtropical monsoon climate, mean annual precipitation 1956 mm, 76% of which occurred from April to September; annual mean air temperature is 20.9℃ and annual mean relative humidity is 80.8%. The highest and lowest monthly temperature are 28.0 ℃ and 12.0℃, respectively. In the reserve, three types of forest at different stages of succession were selected to measure their CO_2 emission fluxes from soil and related environmental factors. The three types of forest communities are monsoon evergreen broad-leaved forest, coniferous and broad-leaved mixed forest and *Pinus massoniana* forest.

Monsoon evergreen broad-leaved forest. dominated by *Cryptocarya concinna* and *Castanopsis chinensis*, has a complex community structure, its aboveground profile could be divided into six layers including four arbor layers, one shrub layers and one grass layer. Besides, it has many kinds of interlayer plant (liana and epiphytes). The soil under this community is hydration lateritic soil which is of 30−90 cm thickness and developed from sandy shale, with a pH of 4.06—4.34[5]. The coniferous and broad-leaved mixed forest, which was originated from artificial or natural *Pinus massoniana* forest after invasion by broad-leaved trees, is the representative forest type at the mid-successional stage. Its aboveground vertical structure can be divided into four layers: two arbor layers, one shrub layers and one grass layers. The soil under this community is lateritic soil which is of 30−60 cm thickness and developed from sandy shale, with a pH of 3.86. *Pinus massoniana* forest, about 60 years old , mainly consists of *Pinus massoniana* and occasionally some lower subtropical sun plants. Its aboveground vertical structure can be divided into an arbor layer with open canopy and well-developed shrub and a grass layer[6]. The undergrowth in it was dominated by *Rhodomyrtus tomentosa, Dicranopteris linearis.* It has lateritic soil, which is no more than 30 cm of thickness and developed from sandy shale, with a pH of 3.99—4.07.

2 Experimental methods

CO_2 efflux was measured using static chamber-gas chromatograph technique. Each sampling chamber was made of stainless steel consisting of two parts: chamber pedestal and top chamber. The specifications were: Length (L) × Width (W) × Height (H) × Thickness of steel plate (T) = 500 mm × 500 mm × 100 mm × 2.5 mm for pedestal and $L \times W \times H \times T$ = 500 mm × 500 mm × 500 mm × 1.5 mm for top chamber, respectively. Chamber pedestals were inserted into the soil in advance and adhesive tapes were stuck into the grooves on pedestals to prevent gas exchange between the chamber and atmosphere. Inside each chamber two small fans were used to improve the air circulation. Gas samples were collected using 100 mL nylon syringe for 30 min at 10 min intervals. Then the samples were analyzed using HP 4890 gas chromatogram (GC) equipped with flame ionization detector (FID) within 12 h. CO_2 was separated with 2 m column with inner diameter of 2 mm 60—80 mesh Porapak Q column, and 200℃ work temperature, also ultra-pure nitrogen carrier gas, with a flow rate of 30 mL/min.

There were two treatments in each experimental plot: (1) bare soil surface (litter was removed previously); and (2) litter+soil. At the time of gas sampling, soil moisture, ambient air temperature, soil temperature at surface and at the depth of 5 cm were recorded simultaneously using digital thermometer and TDR soil water detector.

The gas flux was computed from the concentration change over the measurement period. The positive value denotes the gas emission into the atmosphere from soil and the negative value represents the gas flow from air to soil or soil absorption of this gas from the atmosphere. It is expressed as following:

$$F=\frac{\Delta m}{\Delta t}\cdot D\frac{V}{A}=hD\frac{\Delta m}{\Delta t},$$

where F refers to gas flux ($mg \cdot m^{-2} \cdot h^{-1}$), $\frac{\Delta m}{\Delta t}$ denotes linear slope of concentration change with time over measurement period. D is the gas density of the chamber ($D = n/v = P/RT$, mol/m^3, P the air pressure, T the temperature inside of the chamber and R the air constant), h represents the height of the chamber.

3 Results and discussions

3.1 Comparison of CO_2 fluxes among the three forest types

The seasonal patterns of CO_2 flux from soil surface (with and without litter) in three forests are shown in fig. 1. For all three forests, CO_2 fluxes were relatively high during the rainy season and declined during the dry season. Variance analysis indicated that CO_2 flux from soil surface (whether with or without litter) differed significantly ($P < 0.01$) among all three forests. The contrast relations of mean annual CO_2 flux of three sites can be described as: monsoon forest > mixed forest > pine forest.

CO_2 emitted from forest soil surface mainly came from heterotrophic respiration of soil microbes and soil animals, autotrophic respiration of plant root. According to long-term observation data of Dinghushan natural reserve, soil microbial biomass, root biomass, soil organic carbon content and litter decomposition rate in all three forests showed the same pattern: monsoon forest > mixed forest > pine forest (see table 1), which was consistent with the contrast relations of CO_2 flux mentioned above. Besides, the microclimate in the monsoon forest, which was warm and damp, was in favor of metabolic activity of soil microbes and root system, thus the CO_2 flux in monsoon forest was biggest among all three forests.

Based on the annual mean value of CO_2 flux, we estimated the annual CO_2 emissions from soil surface (with litter) in the monsoon forest, mixed forest and pine forest in this study. They were 4169 ± 309, 3509 ± 255, 2210 ± 274 $g \cdot m^{-2} \cdot a^{-1}$, respectively. The annual CO_2 flux from soil of temperate *Betula platyphylla* forest, *Quercus liaotungensis* forest and *Pinus tabulaeformis* forest in China were 1132, 1431, 866 $g \cdot m^{-2} \cdot a^{-1}$, respectively[3]. The annual CO_2 flux from soil of evergreen broad-leaved forest, *Phyllostachys pubescens* plantation and *Camellia sinensis* garden in mid-subtropical zone of China were 2412, 3077, 2855 $g \cdot m^{-2} \cdot a^{-1}$, respectively[4]. Apparently, these values were lower than those of subtropical forest in this study. The annual CO_2 flux from tropical forest soil of Jianfengling, Hainan China was 3316 $g \cdot m^{-2} \cdot a^{-1}$[7], which was near to the results of this study. By converting all CO_2 flux values to common units from original source, we compared our results with those in other locations in the world as shown in table 2.

Table 2 shows that the CO_2 fluxes from forest soils in the Dinghu Mountain fell into the range of those in tropical and subtropical zones, such as India, Hawaii, etc., but were higher than those in temperate and frigid zones. CO_2 flux from temperate pine forest soil in Ontario was higher than that from subtropical pine forest soil in the Dinghu Mountain. One of the reasons might be that CO_2 flux was measured during growing season in Ontario, when the soil temperature

Table 1 Comparison of factors affecting CO_2 flux from soil surface among three types of forest

	Soil microbial biomass /$mgC_{mic} \cdot 100\ g^{-1}$ dry soil	Root biomass /$t \cdot hm^{-2}$	Density of soil organic C /$g \cdot m^{-2}$	Annual decomposition rate of litter (%)	Relative air humidity (%)
B.[a)]	82.20	96	16410	49.65	86.8
M.	58.62	88	11129	40.39	81.8
P.	52.99	81	10518	36.40	80.5

a) B. refers to monsoon evergreen broad-leaved forest; M. refers to coniferous and broad-leaved mixed forest; P. refers to *Pinus massoniana* forest.

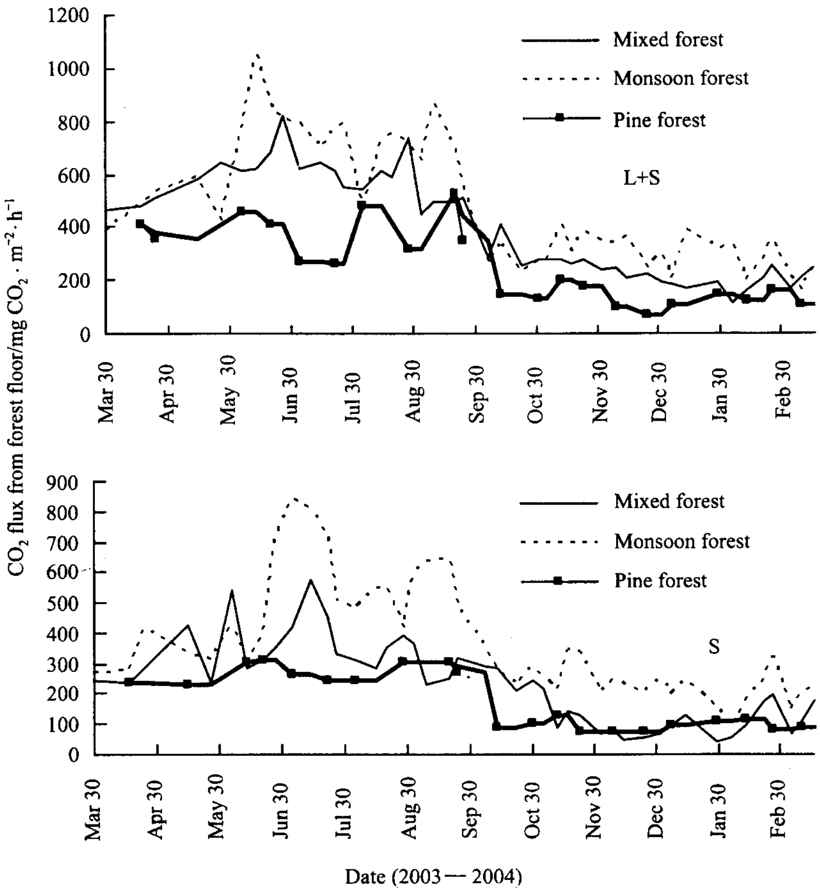

Fig. 1. Seasonal variations of CO_2 fluxes in three forests. L+S: with litter on soil surface, S: litter removed previously.

Table 2 Comparison of CO_2 flux from forest floor at different locations in the world

Location	Vegetation	Period	CO_2 flux/g · m^{-2} · d^{-1}	Reference
Dinghushan	Monsoon forest	Annual	11.42	This paper
Dinghushan	Mixed forest	Annual	9.61	This paper
Dinghushan	Pine forest	Annual	6.01	This paper
Ontario	Pine forest	Growing season	7.96	[8]
India	Pine forest	Annual	5.21	[9]
Brazil	Evergreen forest	Annual	13.65	[10]
Malaysia	Rubber plantation	Several days	5.03	[11]
Hawaii	Evergreen forest	Annual	7.23	[12]
New York	Red pine	Annual	1.50	[13]
Alaska	White spruce	139 d	3.12	[14]

and soil moisture were in favor of soil microbial activity.

3.2 Contribution of litter to total CO_2 flux from forest floor

In order to study the influence of litter on the CO_2 flux from forest floor, two treatments were applied to the experimental plots: (1) bare soil surface (litters were previously removed); and (2) litter and mineral soil (intact forest floor). T-test illustrated that the difference between CO_2 fluxes of the two treatments were significant ($P<0.01$) in all three forests. The

CO_2 flux from litter decomposition accounted for 24.43%, 41.75% and 29.23% of the total CO_2 flux from intact floor of monsoon forest, mixed forest and pine forest, respectively. This indicated that CO_2 from litter decomposition was an important part of total CO_2 emission from forest floor in lower subtropical forest ecosystem. The ratio of CO_2 from litter to total CO_2 emission for monsoon forest was lowest among the three forests, which might be attributed to the following two facts: (1) soil respiration rate in monsoon forest was biggest among three forests, the mean annual CO_2 flux from soil surface (without litter) in monsoon forest, mixed forest and pine forest were 359.72 ± 28.05, 233.33 ± 20.62 and 178.56 ± 20.78 $mg \cdot m^{-2} \cdot h^{-1}$, respectively; and (2) the input of litter in monsoon forest has been decreasing in recent years while the input of litter in pine forest are still increasing these years[15], which resulted in the lowest standing litter biomass in monsoon forest. According to the survey in 2002, the standing litter biomass in monsoon forest, mixed forest and pine forest were 328 ± 71, 497 ± 103 and 436 ± 146 $g \cdot m^{-2}$, respectively.

CO_2 fluxes from litter decomposition both in rainy season and in dry season in the three forests are shown in fig. 2. CO_2 fluxes in rainy season were apparently higher than those in dry season for all three forests probably due to higher temperature and humidity in rainy season. Although the ratio of CO_2 flux from litter to total CO_2 flux from forest floor was the lowest in monsoon forest, the CO_2 flux from litter in this forest was higher than that in pine forest whether in rainy season or in dry season (fig. 2). The litter in pine forest mainly consisted of needle leaves, which were hard to decompose, so the CO_2 flux from litter decomposition in pine forest was lowest among the three forests. The mean annual CO_2 flux from litter decomposition of monsoon forest, mixed forest and pine forest were 116.28 ± 23.62, 167.27 ± 16.40 and 73.76 ± 15.48 $mg \cdot m^{-2} \cdot h^{-1}$, respectively, which was consistent with the standing litter biomass of the three forests mentioned above.

3.3 Effect of temperature on CO_2 flux

Forest floor CO_2 flux was generally well described by an exponential function of soil temperature at 5 cm depth[16—18]. In this study, significant relationships were also found between CO_2 flux from forest floor and soil temperature at 5 cm depth for all three forests as shown in fig. 3 ($R^2 = 0.49$—0.81, $P < 0.01$).

The Q_{10} coefficient, which is the relative increase in soil respiration rate for a 10℃ change in temperature, serves as an index for the sensitivity of soil respiration rate to temperature. Based on soil temperatures at 5 cm depth, the calculated Q_{10} values of monsoon forest, mixed forest and pine forest for treatment 1 (L+S) in this study were 1.86, 2.31and 2.72, respectively; and the Q_{10} values of the three forests for treatment 2(S) were 2.24, 3.24 and 2.47, respectively. The results demonstrated that the soil respiration of monsoon evergreen broad-leaved forest had the lowest

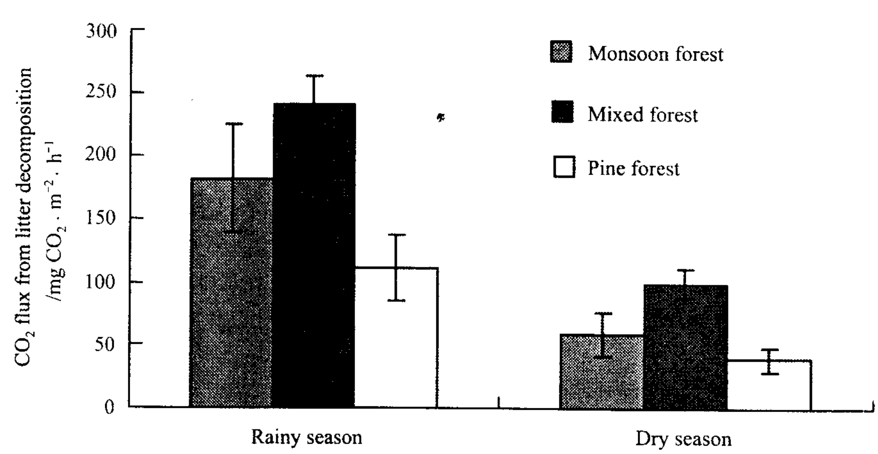

Fig. 2. CO_2 fluxes from litter decomposition for three forests both in rainy season and in dry season.

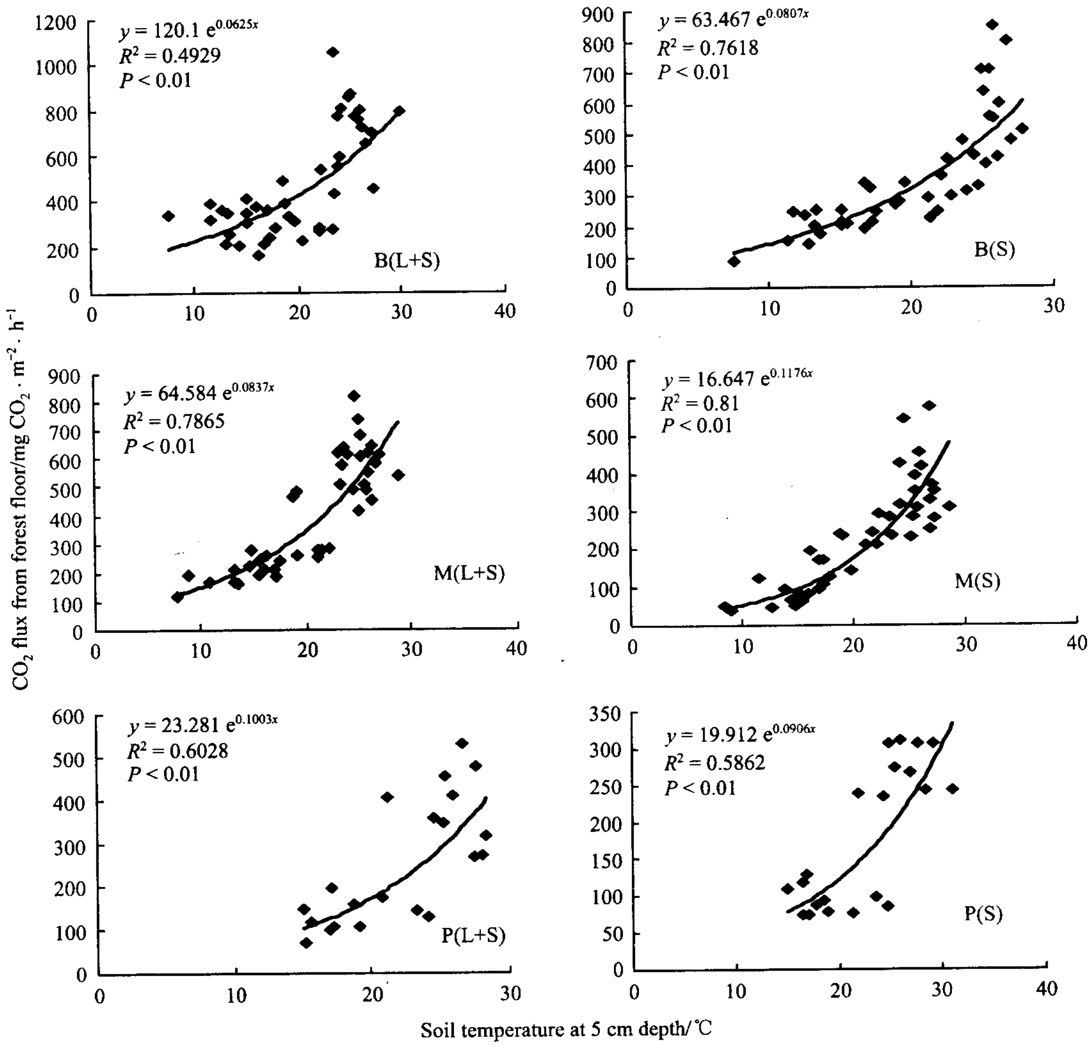

Fig. 3. Relationships between CO_2 evolution rate and soil temperature at 5cm depth for all three forests. B, Monsoon evergreen broad-leaved forest; M, coniferous broad-leaved mixed forest; P, pine forest; L+S, treatment where litter was maintained; S, treatment where litter was removed previously.

sensitivity to temperature change among the three forests, which suggested that the sensitivity of soil respiration to temperature change declined as forest was developing toward climax stage of succession. As far as a certain type of forest was concerned, difference of Q_{10} values existed between two treatments(with or without litter). Q_{10} values of the treatment with litter were lower than those of the treatment without litter for monsoon forest and mixed forest, while the Q_{10} value of the treatment with litter was higher than that of the treatment without litter for pine forest, the reasons were not clear.

Figure 3 shows that the relationship between CO_2 flux and soil temperature was of higher fitness at lower temperature than at higher temperature for the forest type with a higher correlation coefficient ($R^2 >$ 0.75) between CO_2 flux and temperature. In other words, the influence of temperature on CO_2 flux was more conspicuous at lower temperature than at higher temperature. The result mentioned above was consistent with those reported in other studies, which demonstrated that the Q_{10} value decreased with the increase of temperature, described as so-called acclimation of soil respiration to warming[18,19]. For the pine forest with a lower correlation coefficient, such an acclimation was not found because its soil moisture was so low (the mean soil moisture of pine forest in dry season was only 6.61% with a minimum of 2.22%) in dry season that the metabolic activity of soil microbes and plant roots was restricted[20], thus the response of soil respiration to temperature was interrupted.

Comparing the Q_{10} values in this area with those reported in other climatic zones, we found that Q_{10} values of the main types of forest in the Dinghu Mountain were apparently lower than those of the hardwood mixed forest (Q_{10} = 3.4—5.6) and beech forest (Q_{10} = 4.2) distributed in temperate zone [17,21], but near to those of forests (Q_{10} = 1.75—2.55) in middle subtropics of China[4]. This indicated that the sensitivity of CO_2 flux to temperature decreased from temperate zone to subtropical zone.

3.4 Effect of soil moisture on CO_2 flux

Besides temperature, soil water content is another major factor controlling CO_2 flux from forest floor. Fig. 4 shows that there existed a significant linear relationship between CO_2 flux and soil moisture in all three forests (R^2 = 0.29—0.68).

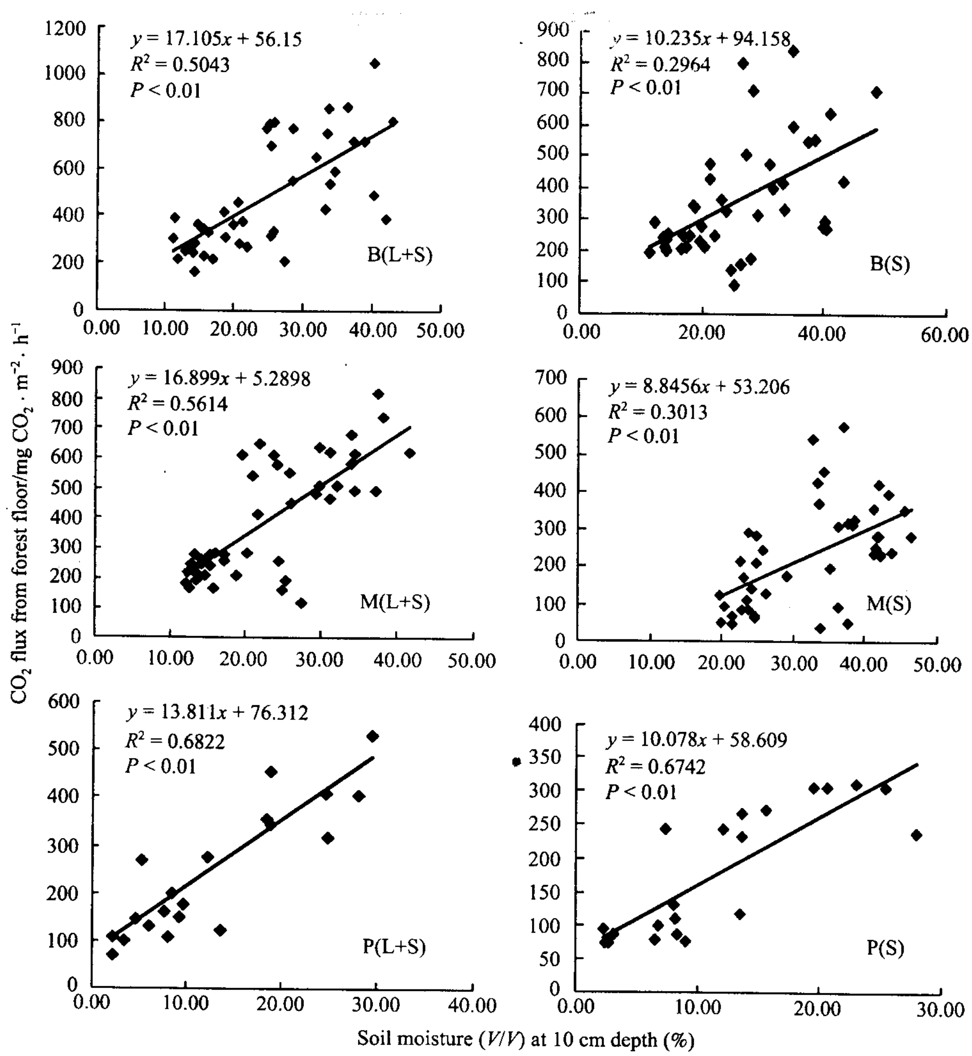

Fig. 4. Relationship between CO_2 flux and soil moisture at 10 cm depth for the three types of forest. The meanings of letters in this figure are the same as in fig. 3.

Table 3 Comparison of soil water regime under different forest types

Forest type (treatment)	Variation (%)	Annual average (%)	Average in rain season (%)	Average in dry season (%)	Variation coefficient
B(l+s)[a)]	11.07—43.09	24.55	32.90	17.07	0.39
B(s)	11.40—48.57	25.95	34.14	18.62	0.33
M(l+s)	12.02—41.68	23.39	30.31	16.71	0.37
M(s)	19.78—45.49	32.39	39.75	25.80	0.26
P(l+s)	2.22—29.48	12.74	19.29	6.80	0.67
P(s)	2.30—28.04	11.90	17.94	6.42	0.65

a) The meanings of letters in this column are the same as in fig. 3.

It is noticed that the relationship between CO_2 flux and soil moisture was most significant in pine forest among three forests, which might be due to the special soil water regime in pine forest. The sandy soil of pine forest, with poor water holding capacity, was severely short of water during the dry season (see table 3), so the water became the limiting factor for soil respiration. The soil water regimes were much better in monsoon forest and in mixed forest than in pine forest, with a lower annual variation coefficient of soil moisture, in this case, the water might not be the limiting factor for soil microbes and plant roots. The relationship between soil moisture and CO_2 flux from bare soil surface in monsoon forest and mixed forest was least significant, which could be attributed to their lower annual variation coefficients of soil moisture, especially for the site without litter in mixed forest. Compared with other sites in this study, soil moisture in this site kept relatively high for the whole year due to its special micro-environment(a bottomland in the slope that easy to keep rain water), with minimum soil moisture 19.78%, even a little bit higher than the mean soil moisture in rainy season of pine forest (see table 3). It had been reported by Kucera and Kirkham[20]that only when soil water regime was in case of extremity (very dry or beyond field capability), the CO_2 production could be greatly restrained, otherwise the influence of soil moisture on CO_2 flux could hardly be detected. The least significant relationship between soil moisture and CO_2 flux from bare soil surface in mixed forest was just a case to the point.

On all accounts, the relationship between soil moisture and CO_2 flux were largely dependent on soil water regime as affected by forest type, soil property, micro-environment, etc. Higher annual variation coefficient of soil moisture and very low soil water content in dry season resulted in a more significant relationship between soil moisture and CO_2 flux. Soil moisture was not a limiting factor for soil CO_2 flux if the annual range of soil moisture was narrow enough in the Dinghu Mountain.

4 Conclusions

(1) The seasonal patterns of CO_2 flux from forest floor in three main types of vegetation of Dinghu Mountain—monsoon evergreen broad-leaved forest, coniferous and broad-leaved mixed forest and *Pinus massoniana* forest—were similar, and CO_2 flux was higher in rainy season than in dry season due to a higher soil temperature and soil moisture in rainy season. The relations of CO_2 emission of the three forests appeared as: monsoon forest > mixed forest > pine forest.

(2) The contribution of litter decomposition on total CO_2 flux from forest floor was remarkable for all three forests. CO_2 fluxes from the litter decomposition in monsoon forest, mixed forest and pine forest accounted for 24.43%, 41.75%and 29.23%of the corresponding total CO_2 fluxes from forest floor, respectively. The highest ratio for mixed forest was attributed to its largest standing litter biomass among the three forest types. The seasonal patterns of CO_2 fluxes from litter decomposition were consistent with those of total CO_2 flux for all three forests.

(3) Significant exponential correlation was found between CO_2 flux and soil temperature at 5 cm depth

for all three forests and the calculated Q_{10} based on soil temperature at 5 cm depth ranged from 1.86 to 3.24. The Q_{10} for monsoon forest was the lowest among the three forests, indicating that the sensitivity of CO_2 flux on temperature decreased with the succession of forest towards climax.

(4) Regression analysis showed that the correlation between soil water content and CO_2 flux was largely dependent on soil water regime as affected by forest type and micro-environment. In general, the relationship between soil water content and CO_2 flux was more significant when the variation coefficient of soil water content was higher.

Acknowledgements This work was supported by the Knowledge Innovation Programs of the Chinese Academy of Sciences (Grant Nos. KZCX1-SW-01 and KSCX2-SW-120).

References

1. Raich, J. W., Schlesinger, W. H., The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate, Tellus, 1992, 44(B): 81—99.
2. Li, L. H., Wang, Q. B., Bai, Y. F., et al., Soil respiraton of a *Leymus chinensis* grassland stand in the Xilin river basin as affected by over-grazing and climate, Acta Phytoecologica Sinica (in Chinese), 2000, 24(6): 680—686.
3. Liu, S. H., Fang, J. Y., Makoto, K., Soil respiration of mountainous temperate forests in Beijing, China, Acta Phytoecologica Sinica (in Chinese), 1998, 22(2): 119—126.
4. Huang, C. C., Ge, Y., Chang, J. et al., Studies on the soil respiration of three woody plant communities in the east mid-subtropical zone, China, Acta Ecologica Sinica (in Chinese), 1999, 19(3): 324—328.
5. Wang, Z. H., He, D. Q., Song, S. D. et al., The vegetation of Dinghushan biosphere reserve, Tropical and Subtropical Forest Ecosystem (in Chinese), 1982, 1: 77—141.
6. Zhou, H. C., Li, M. J., Zhou, Y. R. et al., Vegetation map of Dinghushan biosphere reserve, Tropical and Subtropical Forest Ecosystem (in Chinese), 1986, 4: 43—49.
7. Wu, Z. M., Zeng, Q. B., Li, Y. D. et al., A preliminary research on the carbon storage and CO_2 release of the tropical forest soils in Jianfengling, Hainan Island, China, Acta Phytoecologica Sinica (in Chinese), 1997, 21(5): 416—423.
8. Ellis, R. C., The Seasonal pattern of nitrogen and carbon mineralization in forest and pasture soils in southern Ontario, Can. J. Soil Sci., 1974, 54: 15—28.
9. Rout, S. K., Gupta, S. R., Soil respiration in relation to abiotic factors, forest floor litter, root biomass and litter quality in forest ecosystem of Siwaliks in northern India, Acta Oecol./Oecol. Plant, 1989, 10: 229—244.
10. Goreau, T. J., Mello, W. Z., Tropical deforestation: Some effects on atmospheric chemistry, Ambio, 1988, 17: 275—281.
11. Ceulemans, R., Impens, I., CO_2 evolution from different types of soil cover in the tropics, Trop. Agric., 1987, 64: 68—69.
12. Townsend, A. R., Vitousek, P. M., Trumbore S E. Soil organic matter dynamics along gradients in temperature and land use on the island of Hawaii, Ecology, 1995, 76: 721—733.
13. Hudgens, E., Yavitt, J. B., Land-use effects on soil methane and carbon dioxide fluxes in forests near Ithaca, New York, Ecoscience, 1994, 4: 214—222.
14. Ruess, R. W., Van, C. K., Yarie, J. et al., Contributions of fine root production and turnover to carbon and nitrogen cycling in taiga forests of the Alaskan interior, Can. J. For.Res. 1996, 26: 1326—1336.
15. Zhang, D. Q., Ye, W. H., Yu, Q. F. et al., The litter-fall of representative forests of successional series in Dinghushan, Acta Ecologica Sinica (in Chinese), 2000, 20(6): 938—944.
16. Lloyd, J., Tailor, J. A., On the temperature dependence of soil respiration, Functional Ecology, 1994, 8: 315—323.
17. Davidson, E. A., Belk, E., Boone, R. D., Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest, Global Change Biology, 1998, 4: 217—227.
18. Luo, Y., Wan, S., Hui, D. et al., Acclimation of soil respiration to warming in a tall grass prairie, Nature, 2001, 413: 622—625.
19. Oechel, W. C., Vourlitis, G. L., Hastings, S. J. et al., Acclimation of ecosystem CO_2 exchange in the Alaskan Arctic in response to decadal climate warming, Nature, 2000, 406: 978—981.
20. Kucera, C. L., Kirkham, D. R., Soil respiration studies in tall grass prairie in Missourt, Ecology, 1971, 52: 912—915.
21. Ivan, A. J., Kim, P., Large seasonal changes in Q_{10} of soil respiration in a beech forest, Global Change Biology, 2003, 9: 911—918.