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Temporal Variability in Soil CO_2 Emission in an Orchard Forest Ecosystem*[1]

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ABSTRACT

Temporal variability in soil CO_2 emission from an orchard was measured using a dynamic open-chamber system for measuring soil CO_2 efflux in Heshan Guangdong Province, in the lower subtropical area of China. Intensive measurements were conducted for a period of 12 months. Soil CO_2 emissions were also modeled by multiple regression analysis from daily air temperature, dry-bulb saturated vapor pressure, relative humidity, atmospheric pressure, soil moisture, and soil temperature. Data was analyzed based on soil moisture levels and air temperature with annual data being grouped into either hot-humid season or relatively cool season based on the precipitation patterns. This was essential in order to acquire simplified exponential models for parameter estimation. Minimum and maximum daily mean soil CO_2 efflux rates were observed in November and July, with respective rates of 1.98 ± 0.66 and 11.04 ± 0.96 μmol m^{-2} s^{-1} being recorded. Annual average soil CO_2 emission (FCO_2) was 5.92 μmol m^{-2} s^{-1}. Including all the weather variables into the model helped to explain 73.9% of temporal variability in soil CO_2 emission during the measurement period. Soil CO_2 efflux increased with increasing soil temperature and soil moisture. Preliminary results showed that Q_{10}, which is defined as the difference in respiration rates over a 10 °C interval, was partly explained by fine root biomass. Soil temperature and soil moisture were the dominant factors controlling soil CO_2 efflux and were regarded as the driving variables for CO_2 production in the soil. Including these two variables in regression models could provide a useful tool for predicting the variation of CO_2 emission in the commercial forest soils of South China .

Key Words: CO_2 emission, lower subtropical area, orchard forest ecosystem, soil moisture, soil temperature

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INTRODUCTION

Soil CO_2 emission is one of the major pathways by which CO_2 fixed by terrestrial plants is released back into the atmosphere. Recent studies emphasize the significant contribution of soil CO_2 emissions to the atmospheric CO_2 pool (Raich and Potter, 1995; Schlesinger and Andrews, 2000; Wang *et al.*, 2002; Chris *et al.*, 2005). Therefore, understanding the temporal variability in CO_2 exchange in forestry, agriculture and natural systems is a significant step towards understanding the global CO_2 exchange cycle. Environmental variables such as soil temperature, soil water content, air temperature, photosynthetically active radiation (PAR) and air humidity significantly affect ecosystem CO_2 exchange (Lloyd and Taylor, 1994; Davidson *et al.*, 1998; Liu *et al.*, 2006). Soil moisture deficit, for example, decreases root respiration by up to 17% (Burton *et al.*, 1998). Goulden *et al.* (1996) reported a higher decrease in heterotrophic respiration as compared to autotrophic respiration during an extended drought in a temperate forest. Another factor that significantly affects soil CO_2 emission is soil temperature. Sea-

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sonal variations in soil respiration have often been associated with either changes in soil temperature (Anderson, 1973; Fang *et al.*, 1998; Daniel, 2004) or changes in both soil temperature and soil water content (Davidson *et al.*, 1998; Epron *et al.*, 1999; Qi and Xu, 2001).

Empirical relationships between soil CO_2 effluxes and environmental variables, including soil temperature, soil water content and the coarse mineral soil fraction, show that efflux increases exponentially with temperature when soil moisture or other factors are not limiting (Bunnell *et al.*, 1977; Nakane, 1994; Hanson *et al.*, 1993; Raich and Schlesinger, 1992; Reichstein *et al.*, 2003). Different types of models using temperature time equivalence (Feng and Li, 1997; Fang and Moncrieff, 2001) consider atmospheric climate variables as the main factors governing temporal variability of soil CO_2 exchange in the long and short-term intervals. Thus, CO_2 exchange in soil-vegetation-atmosphere systems are both directly and indirectly associated with meteorological events, suggesting that meteorological data alone could explain a significant portion of the temporal variability in CO_2 emission from bare soils (La Scala *et al.*, 2003). Massmann and Farrier (1992); Ouyang and Zheng (2000) and Jassal *et al.* (2004) suggest that solar radiation and atmospheric pressure are the main variables controlling soil CO_2 production rates and transport and hence CO_2 emission into the atmosphere.

Information is scant on soil CO_2 emission and its regulatory mechanisms in Chinese forests, particularly for orchards, which cover large areas of South China. In Guangdong Province of South China, orchards are widely established as a major economic activity and the area in use as plantations is significantly and steadily on the increase. For example, between 1979 and 2003 the area under commercial orchard systems increased more than tenfold. Out of the 9.33×10^6 ha forested land, 9.73×10^5 ha is covered by orchard plantations. It is not clear yet how the transformation of natural forest systems into orchards influences soil functioning and the overall ecosystem. Because soil CO_2 emissions are very sensitive to agricultural activities (Huang *et al.*, 2002; Peng, 2003), it is imperative that CO_2 emissions on these lands are evaluated and documented. The objectives of this study were to i) monitor temporal variation of CO_2 efflux in commercial forests of South China and ii) model the temporal variability of soil CO_2 efflux in terms of physical environmental factors and develop simplified models for describing soil CO_2 fluxes in the commercial forests.

MATERIALS AND METHODS

Site description

The study was conducted at the Heshan Interdisciplinary Research Station (112° 54′ E, 22° 41′ N), Chinese Academy of Sciences, in Guangdong Province, China. The experimental site lies in an area with low hills (peak elevation of 98 m) and small catchments (each having an area of about 5–8 ha). The climate is subtropical monsoon with a mean annual precipitation of 1 800–2 000 mm falling mainly from April to September. The period from October to January is particularly dry. The mean annual temperature is 21.7 °C, with mean maximum and minimum annual temperature of 28.7 and 13.1 °C occurring in July and January, respectively. The soil is an Oxisol developed from sandstone, with a pH of about 4.0. Some soil properties are listed in Table I.

TABLE I

Some properties of the orchard soil under consideration

Depth	pH (H_2O)	Soil bulk density[a)]	Organic carbon[a)]	Total nitrogen[a)]	C/N[a)]
cm		g cm^{-3}	g kg^{-1}	g kg^{-1}	
0–10	3.8	0.97	14.25	1.49	10
10–20	4.1	1.01	10.64	1.29	8
20–30	4.3	1.02	9.99	1.06	9

[a)]From Li *et al.* (2002)

Experimental

Six adjacent catchments covered only in grasses with a total estimated area of 21.59 ha were chosen for investigations in 1984, based on their similarities in soil, vegetation, slope and elevation. A different forest type was randomly allocated to each catchment and trees were planted on a 2.5 m × 3 m grid (Li *et al.*, 2000, Yu and Peng, 1995). Five catchments comprising single species stands of *Acacia mangium*, *Acacia auriculaiformis*, *Eucalyptus citriodora*, *Pinus elliotii*, *Schima superba* and one catchment of an agro-ecosystem along natural watersheds were established in 1984. The agro-ecosystem catchment was approximately 3.55 ha of "forest-orchard-grass belt-fish pond". This is a typical orchard forest model of South China. When this study commenced at the agro-ecosystem (orchard) plot in 2001, the fruit tree species on the plot were *Litchi chinensis* Sonn., *Dimocarpus longan* Lour and *Mangifera indica* L. with an average age of 5 years. The canopy closure was 40%–50%. The understory is mainly comprised of *Pennisetum purpureum* Schumach., *Paspalum conjugatum* Bergius, *Ischaemum aristatum* Linn., *Setaria faberii* Herrm., *Ageratum conyzoides* L., *Mimosa pudica* L. and *Aeschynomene indica* L.

Microclimate

Air temperature (T_{air}), dry-bulb saturated vapor pressure, relative humidity, atmospheric pressure and soil temperature were continuously recorded using a micro-meteorological station established on the experimental site (Vaisala M520, Helsinki, Finland). Data were recorded every 30 seconds, averaged and logged every 30 minutes. Soil moisture status was determined using MPKit volumetric soil moisture sensor (ICT International Pty Ltd., Armidale, NSW, Australia) installed at a 5 cm depth.

Soil CO_2 emission measurements

CO_2 emissions were measured on each plot during a 12-month study period starting in February 2001. On each measurement day, hourly measurements were typically conducted from 6:00 a.m. till 8:00 p.m. Measurements were conducted every fourth week over the course of the year. To capture the temporal variability in soil CO_2 emission on short and long-term scales, a sampling system was constructed, which was capable of continuously recording the instantaneous efflux rate from multiple sampling positions using the Licor-6200 gas exchange system (LI-COR Inc., Lincoln, USA). The CO_2 flux chamber is an open dynamic cylindrical system with an electric fan inside to make turbulence. The chamber is made of stainless steel and has a diameter of 0.25 m and a height of 0.35 m, with an open bottom end.

Three plots within the orchard were chosen for CO_2 emission measurements in three different aspects (E, W and N) along the slope and each plot was replicated three times. Collars (with open ends) were installed 2 days before the sampling dates at each of the plots. Collars were inserted 5 cm deep into the soil, with 50 cm spacing at each of the measurement plots. All collars were positioned 2–3 meters away from the trees. Within each collar, all aboveground parts of the vegetation were removed two or three days before measurements were made. Records for soil CO_2 emissions in each plot were taken for approximately 120 s at 8–30 s intervals depending on the increment of the CO_2 concentration. Normally, 3 μmol mol^{-1} was necessary so that the CO_2 differential signal was stable and ensured that the concentration changes in the chamber during this cycling time were captured by analyzer, and also that soil temperature variations in the chamber during measurements were minimized.

Root biomass sampling

Soil samples were collected a day after CO_2 measurements at 0–20 cm depth from each of the plots using a soil corer with 5 cm diameter. Fine roots were extracted by washing the sampled soil masses, using sieves to free the roots from soil. Live roots with a diameter less than 2 mm were then oven-dried at 70 °C before weighing.

Statistical analysis and calculation

The CO_2 emission results and all the microclimate data were subjected to descriptive statistics and stepwise regression analysis (SPSS Inc., 1999; La Scala *et al.*, 2003). The soil flux was fitted into the model as the dependent variable and the environmental factors were fitted as the independent variables. Initially, all the meteorological factors were first combined to explain the variations in soil CO_2 emission. Then, based on the results from stepwise regression model, the deviations of these relatively complex relationships were assessed. Simple models with soil temperature and soil moisture were performed. Four exponential equations were used:

$$F_{(\mathrm{soil})} = k\mathrm{e}^{aT} \quad (1)$$

$$F_{(\mathrm{soil})} = k\mathrm{e}^{aT}\mathrm{e}^{b\theta} \quad (2)$$

where $F_{(\mathrm{soil})}$ is the soil respiration (mmol CO_2 m^{-2} s^{-1}), T is the soil temperature (°C), θ is the soil moisture (m^3 m^{-3}), and k, a, b are constants fitted to the regression equation.

$$F_{(\mathrm{soil})} = R_{\mathrm{ref}}\mathrm{e}^{E_0\left(\frac{1}{T_{\mathrm{ref}}-T_0}-\frac{1}{T_{\mathrm{air}}-T_0}\right)} \quad (3)$$

$$F_{(\mathrm{soil})} = R_{\mathrm{ref}}\mathrm{e}^{E_0\left(\frac{1}{T_{\mathrm{ref}}-T_0}-\frac{1}{T_{\mathrm{air}}-T_0}\right)}\frac{\mathrm{SWC}}{\mathrm{SWC}+k} \quad (4)$$

where Eq. 3 is the classic function as described by Lloyd and Taylor (1994) and Eq. 4 is a modified version of Eq. 3. T_{ref} (°C) is the reference temperature, $T_0 = -46.02$ °C, T_{air} is the air temperature, k is a constant, and SWC is the soil water content. R_{ref} (μmol m^{-2} s^{-1}) is the soil respiration under standard conditions and E_0 is the activation-energy-type parameter.

The index of soil respiration response to temperature was also described by the Q_{10} value, defined as the difference in respiration rates over a 10 °C interval. Q_{10} value was calculated using the exponential relationship between soil respiration and soil temperature (Buchmann, 2000; Xu and Qi, 2001b):

$$Q_{10} = \mathrm{e}^{10a} \quad (5)$$

where a is the constant fitted into Eq. 1.

Finally, based on the fine root biomass measurements, we tested the relationship between this biotic factor and Q_{10} values. All regression fits were performed by user-developed programs using PV-WAVE software, version 7.51 (Visual Numerics, Inc. USA).

RESULTS AND DISCUSSION

Environmental factors

Fig. 1 shows rainfall, temperatures and global radiation patterns in the Heshan Interdisciplinary Research Station for the period 2001 and 2002. The descriptive statistics of soil CO_2 emission (FCO_2) and abiotic environmental factor variables observed during the studied measurement days of 12 months are presented in Table II. Results show high variability of dry-bulb saturated vapor pressure and relative humidity values while atmospheric pressure showed the lowest variability during the measurement. On account of all the variability in environmental factors, which may play an important role in the CO_2 emission, multiple regression was introduced taking into account the environmental variables and their first-order interaction. The results of a reverse stepwise regression procedure applied to the 12 studied months are presented in Table III.

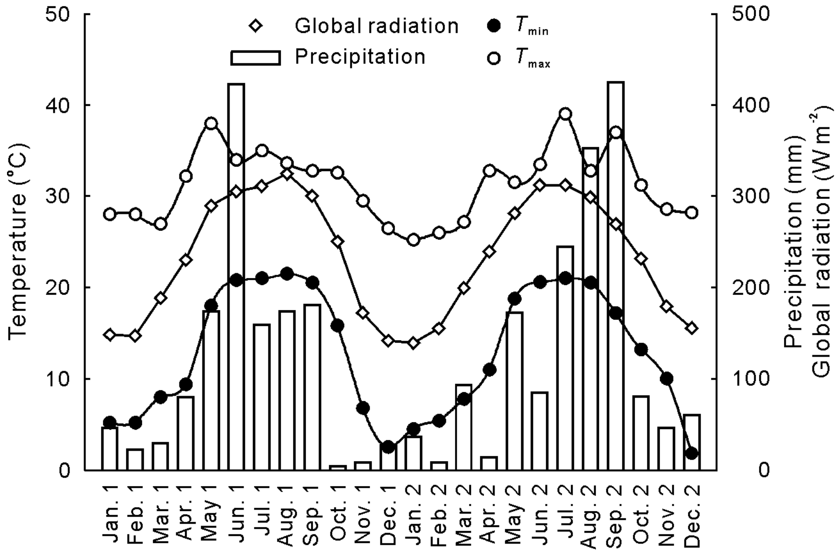

Fig. 1 Seasonal patterns of precipitation, air temperature (T) and global radiation recorded at the study site during 2001 and 2002.

TABLE II

Descriptive statistics of average soil CO_2 emission (FCO_2) and the corresponding environmental variables

Environmental variable	Mean	Minimum	Maximum	SD[a)]	CV[b)]
					%
Daily average FCO_2 (μmol m^{-2} s^{-1})	5.92	1.98	11.04	2.66	44.8
Air temperature (°C)	22.80	9.65	32.03	4.15	18.2
Dry-bulb saturated vapor pressure (10^2 Pa)	33.37	11.99	47.62	7.31	21.9
Relative humidity (%)	72.11	49.06	99.74	13.63	18.9
Atmospheric pressure ($\times$ 10^2 Pa)	1 030.44	998.40	1 102.80	42.13	4.1
Soil temperature (°C)	26.83	10.81	38.11	4.99	18.6
Soil moisture (m^3 m^{-3})	0.27	0.08	0.35	0.07	25.9

[a)]Standard deviation; [b)]Coefficient of variation.

TABLE III

Stepwise regression results from SPSS statistics of soil CO_2 emission[a)]

Variable	Parameter estimate	P-value
Intercept	−29 305.844	0.000
Relative humidity	11.929	0.001
Atmospheric pressure	32.972	0.000
Soil temperature	361.471	0.000
Soil moisture	45.328	0.002
Soil temperature × air temperature	33.904	0.000
Soil temperature × soil moisture	60.205	0.001
Soil temperature × dry-bulb saturated vapor pressure	−22.786	0.000
Soil temperature × relative humidity	−1.232	0.000
Soil temperature × atmospheric pressure	−0.615	0.000
Relative humidity × dry-bulb saturated vapor pressure	−6.234	0.000
Relative humidity × atmospheric pressure	−0.087	0.005
Relative humidity × air temperature	7.939	0.000
Atmospheric pressure × air temperature	−0.553	0.000
Air temperature × dry-bulb saturated vapor pressure	10.814	0.000

[a)]$R^2 = 0.739$.

Daily and seasonal variations in CO_2 flux

Results from continuous soil CO_2 efflux measurements between February 23, 2001 and January 4, 2002 and predicted soil CO_2 emissions are presented in Fig. 2. Two examples of the daily course of soil CO_2 efflux measured on day of year (DOY) 204 and 332 are also inscribed into the figure.

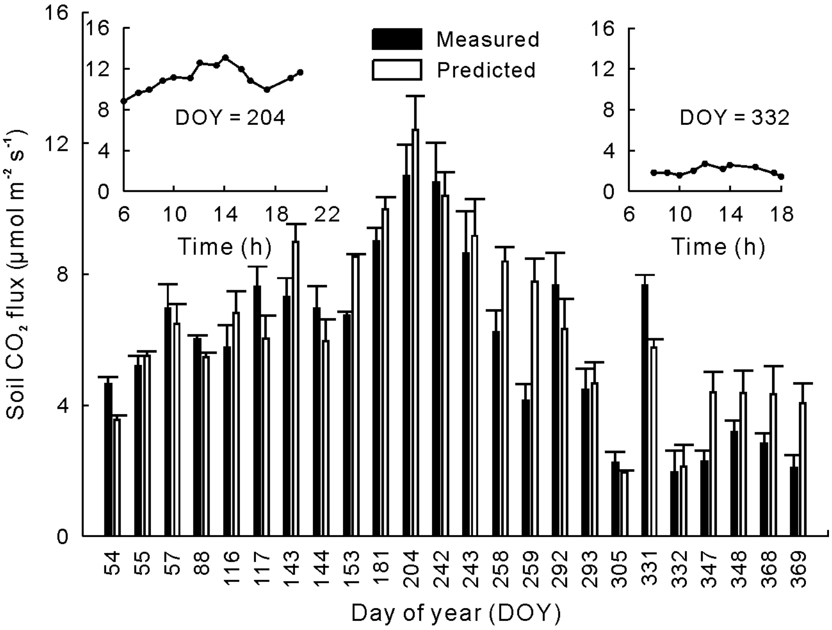

Fig. 2 Variation in soil CO_2 efflux over the whole measuring year.

Varying flux rates were observed throughout the year. Mean daily soil CO_2 efflux rates ranged between 1.98 ± 0.66 μmol m^{-2} s^{-1} in November and 11.04 ± 0.96 μmol m^{-2} s^{-1} in July. The annual average FCO_2 registered during the 12 months of study was 5.92 μmol m^{-2} s^{-1}. Minimum CO_2 efflux rates during the year were observed in November (DOY = 332). During this period, relative humidity was 75.81%, dry-bulb saturated vapor pressure was 2.389×10^3 Pa, atmospheric pressure was 1.008×10^5 Pa and soil temperature was 27.93 °C. Maximum CO_2 efflux rates were observed in July (DOY = 204). The parallel relative humidity reading during this period was 90.60%, dry-bulb saturated vapor pressure was 3.441×10^3 Pa, atmospheric pressure was 1.005×10^5 Pa and soil temperature was 28.48 °C. Although the mean annual precipitation recorded for this site from the past 20 years ranges between 1 800–2 000 mm (Heshan Meteorological Station), falling mainly between April and September, we recorded precipitation amounts of 1 326.2 mm during the study year. Soil moisture content of the 0–10 cm layer in all the plots ranged between 0.25–0.35 m^3 m^{-3}, while seasonal variations in soil temperature were minimal. The intensity and frequency of precipitation, favorable soil moisture status and temperatures during July must have favored decomposition of soil organic matter. Qi and Xu (2001) reported high rates of organic matter decomposition under similar conditions.

There were minimal variations in diurnal soil CO_2 efflux (see inscribed figures), while seasonal variations were relatively large (Fig. 2). For example between July and August, CO_2 emission coefficient of variation (CV) was 8.10%. This is relatively larger than in Dinghushan in South China where bare land surfaces within mixed forests show CV of 7.6% during the hot-humid season (Tang *et al.*, 2006). Our results also show significantly higher CO_2 flux during the summer than in winter. Maximum CO_2 emissions were observed during the months of July and August while minimum emission occurred in November when little precipitation and very low soil moisture occurred. For each month, no significant linear correlation was found between FCO_2 and any of the individual environmental parameters, indicating that none of the environmental factors on its own was responsible for the changes that occurred in FCO_2 during the time of experimentation. When all the considered physical variables were fitted into the multiple stepwise regression model for predicting CO_2 emission (see Table III for parameter estimates), then 73.9% of temporal variability of soil CO_2 emission during the measurement period could be explained by the model.

The first variables removed by reverse procedure were air temperature and dry-bulb saturated pressure, indicating that these two variables could least explain the variability. The parameter estimates for relative humidity (11.929), soil temperature (361.471), soil moisture (25.328) and atmospheric pressure (32.972) were positive. And the parameter value estimated for soil temperature was the highest. Interactions involving all the variables were included in the model, especially those associated with soil temperature *e.g.* solar radiation which has strong correlation with soil temperature in the energy exchange system (Bi *et al.*, 2004). The results suggested that soil temperature plays a major role in determining soil CO_2 fluxes in these forest ecosystems. Soil temperature regulation of soil CO_2 production and emission into the atmosphere is likely through its regulation of decomposition of soil organic matter (Mikou and Kirschbaum, 1995; Subke *et al.*, 2003). Equally, natural pressure variations have been suggested as a possible mechanism for gas movement in soils (Buckingham, 1904; Takle *et al.*, 2003). Increased CO_2 efflux rates with increased levels of standard deviation of static pressure have been reported (Baldocchi and Meyers, 1991), with possible roles of horizontal surface pressure and high-frequency pressure variations in soil gas exchange (Takle *et al.*, 2003). Inclusion of atmospheric pressure as one of the variables related to FCO_2 was also suggested by Massmann and Farrier (1992), which showed that daily trends in the atmospheric pressure may influence the efflux of CO_2 from soil.

Simplified models comparison

Previous studies on changes in bare soil CO_2 emission have shown that changes in air and soil temperature, solar radiation, air humidity evaporation atmospheric pressure and soil moisture accounts for 76.0%–97.8% of the temporal variability, and these studies were based on data produced from continuous measurements over a few weeks (Buyanovsky *et al.*, 1986; La Scala *et al.*, 2003). In our study, no single factor on its own could explain the variations that were observed. The coefficient of variability of air temperature was 18.2% during the 12-month measurement period when soil temperature was used as the main driving force for soil CO_2 emission. Parameter fits were therefore performed for soil temperature and soil moisture with Eqs. 2–4 as the regression functions. There was a strong interaction between soil temperature and soil moisture (soil temperature $\times$ soil moisture parameter estimate value is 60.205). Thus, based on our field observations, it was clear that different periods of the year should be treated separately in order to make it easy to understand the results.

Air temperature and global radiation exhibited clear seasonal courses (Fig. 1). This seasonality of soil temperature was consistent with the seasonal patterns of global radiation and precipitation (Fig. 1). The hot-humid season (April–September) and relatively cool season (October–March) were separated, and typical measuring days during the periods integrated into estimate fits.

There were strong relationships among soil temperature, soil moisture and soil CO_2 efflux (Table IV and Fig. 3). The parameter fitting results from Eq. 1 also supported other results, showing that temperature alone, as a single factor could not explain the variations in CO_2 emission, especially during the water stress period in winter. Including soil moisture function in the soil CO_2 efflux model remarkably increased the explanatory value of the models (Table IV). Thus, simplified models with temperature and soil moisture input functions could explain most of the variations in CO_2 emission observed. Soil temperature and moisture regulation of CO_2 emission have also been reported for natural forest ecosystems of South China (Tang *et al.*, 2006; Yan *et al.*, 2006). Limitations in soil CO_2 efflux resulting from soil moisture stress during drought have been described extensively (Bowden *et al.*, 1998; Xu and Qi, 2001a). Natural forest soils act as reservoirs of organic carbon (Zhou *et al.*, 2006). In the short-term, conversions of natural forests into orchards causes an initial increase in CO_2 flux. However, long-term monitoring studies (Zhou *et al.*, 2006) indicate that the rate of CO_2 emission declines over time. Therefore, the introduction of orchard systems in southern China poses a limited environmental threat with minimal disturbance to the soil layers. We observed that soil flooding during a hot-humid season limited CO_2 efflux. This has been reported before (Ostendorf, 1996). As a result of this effect, volumetric soil moisture between 0.35 and 0.50 were therefore excluded from the fit. Implications of

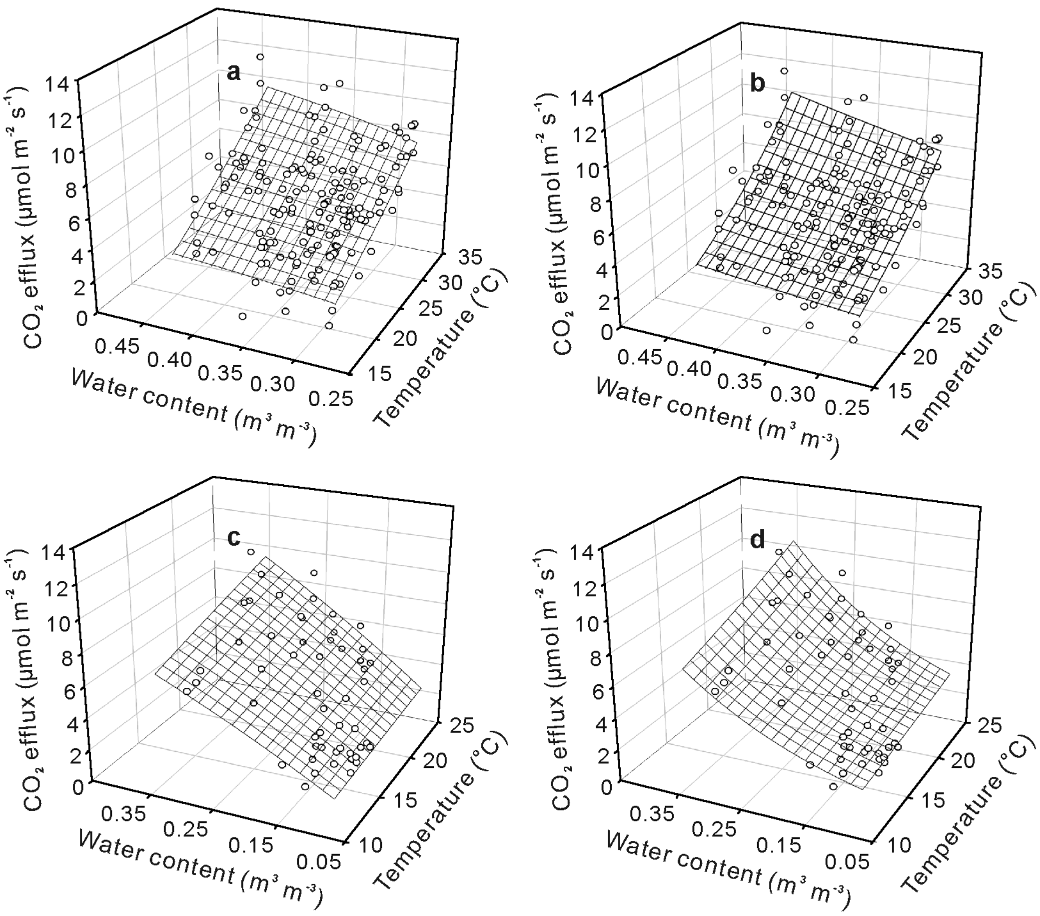

Fig. 3 Soil CO_2 efflux *vs.* soil temperature at 5 cm depth and soil water content during (top panel) the hot-humid season in summer fitted by Eq. 2 (a) and Eq. 4 (b), and during (lower panel) the cool winter season fitted by Eq. 2 (c) and Eq. 4 (d).

TABLE IV

Coefficients and statistics of the multiple exponential regressions applied in the analysis of model parameters to hot-humid season and relatively cool season

Season	Equation	k[a]	a[a]	b[a]	R_{ref}[b]	E_0[c]	R^2
					μmol m^{-2} s^{-1}		
Hot-humid season (non-water stress period)	Eq. 1	2.10	0.05	-	-	-	0.32
	Eq. 2	1.25***	0.05***	1.45***	-	-	0.72
	Eq. 3	-	-	-	4.38*	233.49**	0.48
	Eq. 4	0.28*	-	-	8.10***	241.44***	0.72
Relatively cool season (water stress period)	Eq. 1	1.35	0.06	-	-	-	0.35
	Eq. 2	1.27***	0.03***	4.17***	-	-	0.86
	Eq. 3	-	-	-	3.92	260.5	0.33
	Eq. 4	1.79***	-	-	47.83***	87.72***	0.86

*,**, and ***Significant at $P = 0.05$, $P = 0.01$ and $P = 0.001$ levels, respectively.

[a]Constant fitted to the regression equation; [b]Soil respiration under standard conditions; and [c]Activation-energy-type parameter.

such observations on the overall ecosystem CO_2 budget of South China is unknown and requires further detailed investigations.

Relationship between root biomass, Q_{10} values and soil CO_2 flux

Equations 1 and 5 were used to perform monthly data parameter estimation, because it was not possible to apply it on the entire data set from the measuring period. The temperature response of soil respiration (Q_{10}) was strongly correlated with fine root biomass at all the plots. Monthly Q_{10} values varied from 0.3 to 3.2 during 2001 and 2002 (Fig. 4a). During the hot-humid season Q_{10} was 3.46, while in the relatively cool season Q_{10} was 2.46. Data analysis showed a positive correlation between Q_{10} to soil respiration and fine root biomass. The differences in the fine root biomass explained 88.4% of the variation in the Q_{10} values. Temperature sensitivity of soil respiration was probably linked to biological activity of the roots and also those of soil microorganisms (Bunnell, 1977; Buchmann, 2000). Contribution of fine root metabolism was assessed by relating the amount of fine root biomass to soil CO_2 flux (Fig. 4b). Our results indicated that differences in fine root biomass could explain 52.0% of the variability of soil CO_2 flux. Similar results have been shown for mixed temperate North American forests (Boone *et al.*, 1998), where it was demonstrated that root respiration was more sensitive to changes in temperature ($Q_{10} = 4.6$) than was microbial respiration ($Q_{10} = 2.5$). Higher Q_{10} value for the roots (3.86) than for the microbes (2.34) was also reported for a French beech forest (Janssens *et al.*, 2003). Thus, spatial heterogeneity of temperature sensitivity of the soil respiration rates as observed in our case can be partly explained by differences in root density.

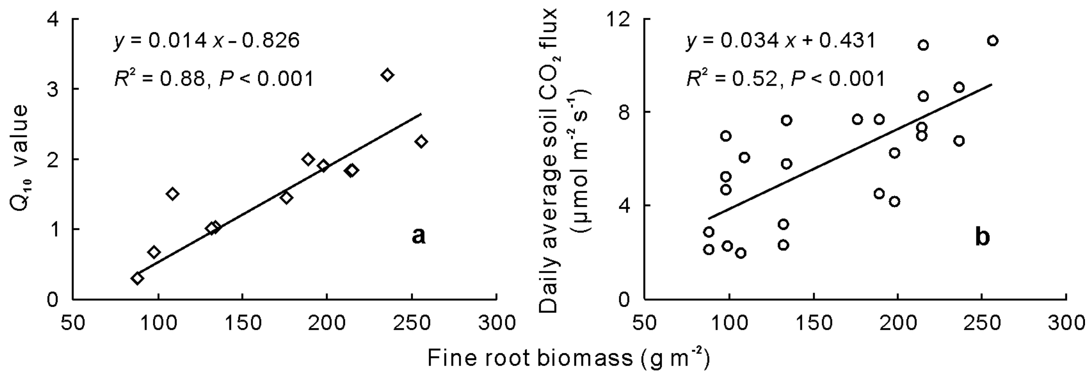

Fig. 4 Temperature sensitivity, Q_{10}, (a) and soil CO_2 efflux (b) are correlated with fine root biomass. Root biomass was obtained from monthly sample collecting.

CONCLUSIONS

Temporal variability in soil CO_2 emission in the orchards of South China was regulated by the interplay of meteorological variables, although soil temperature and moisture content seem to be the principle factors. Stepwise regression provided detailed information that can be used to parameterize other models, and on this basis, we obtained exponential models which suitably analyzed the temporal variability in soil CO_2 emission. The model showed the need for localized meteorological data collection for better understanding of the dynamics of CO_2 exchange in the orchard-soil-atmosphere ecosystems. Although the study focused mainly on soil CO_2 emission, it provided a basis for applying model inversions to continually assess the developing commercial agricultural ecosystems in South China. This is crucial because a large portion of natural forests are now being converted into "model" Chinese agro-ecosystems with limited knowledge on its possible environmental ramifications. The long-term objective is to incorporate the model inversions into land management systems in order to check CO_2 emissions in orchards and deviations from the natural forest set-up. Thorough analysis of abiotic and biotic factors contributing to CO_2 emission from the soil in both systems is recommended so that we can better understand CO_2 emissions in this changing scenario of southern China land use.

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