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Soil respiration under three different land use types in a tropical mountain region of China

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Abstract: Soil respiration (SR) is one of the largest contributors of terrestrial CO_2 to the atmosphere. Environmental as well as physicochemical parameters influence SR and thus, different land use practices impact the emissions of soil CO_2. In this study, we measured SR, bi-monthly, over a one-year period in a terrace tea plantation, a forest tea plantation and a secondary forest, in a subtropical mountain area in Xishuangbanna, China. Along with the measurement of SR rates, soil characteristics for each of the land use systems were investigated. Soil respiration rates in the different land use systems did not differ significantly during the dry season, ranging from 2.7±0.2 μmol m^{-2} s^{-1} to 2.8±0.2 μmol m^{-2} s^{-1}. During the wet season, however, SR rates were significantly larger in the terrace tea plantation (5.4±0.5 μmol m^{-2} s^{-1}) and secondary forest (4.9±0.4 μmol m^{-2} s^{-1}) than in the forest tea plantation (3.7±0.2 μmol m^{-2} s^{-1}). This resulted in significantly larger annual soil CO_2 emissions from the terrace tea and secondary forest, than from the forest tea plantation. It is likely that these differences in the SR rates are due to the 0.5 times lower soil organic carbon concentrations in the top mineral soil in the forest tea plantation, compared to the terrace tea plantation and secondary forest. Furthermore, we suggest that the lower sensitivity to temperature variation in the forest tea soil is a result of the lower soil organic carbon concentrations. The higher SR rates in the terrace tea plantation were partly due to weeding events, which caused CO_2 emission peaks that contributed almost 10% to the annual CO_2 flux. Our findings suggest that moving away from heavily managed tea plantations towards low-input forest tea can reduce the soil CO_2 emissions from these systems. However, our study is a case-study and further investigations and upscaling are necessary to show if these findings hold true at a landscape level.

Keywords: Soil respiration; Subtropical mountain region; Soil temperature; Soil moisture; Weeding; Tea plantation

Introduction

Soil respiration (SR), including autotrophic (root) and heterotrophic (microbes, soil fauna)

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respiration, is the largest global CO_2 flux from the terrestrial biosphere to the atmosphere (Schlesinger and Andrews 2000; Le Quéré et al. 2014). Thus, emissions of soil derived CO_2, an important greenhouse gas, are of major concern. Small changes in soil respiration rates may have a significant impact on the atmospheric CO_2 budget. Therefore, understanding soil respiration is essential to our understanding of the C balance related to a variety of land use systems, such as plantations, forests, and agricultural land.

Within the agricultural context, tea plantations cover an enormous area, approximately 3.2 million hectares worldwide, of which 50% are found within China (FAO 2011). Furthermore, the agricultural land used for tea production is expanding rapidly, in the last five decades roughly 1.3 million hectares have been established (Li et al. 2011), an expansion of more than 400%. This expansion of tea plantations is one of the major causes of degradation of tropical forests in Asia. Secondary forests, resulting from the recovery of degraded forest land, are extensive in the tropics and account for more than 40% of tropical forest area, furthermore, this area is continuously increasing throughout the tropical regions due to rapid land use change (Brown and Lugo 1990; Hughes et al. 1999). Based on this expansion of both tea plantations and secondary forests, which comprise a large portion of the anthropogenic landscape, knowledge regarding the C balance of these systems is critical.

SR is a product of physical and chemical soil parameters that are largely influenced by land use and management practices (Paustian et al. 2000). Unlike the highly managed terrace tea plantations, forest tea plantations contain ancient tea trees that have grown for up to hundreds of years within existing forest stands. Although forest tea is gaining in popularity, as well as value, the majority of tea plantations in China are intensive monoculture systems (Hung 2013). Agroforestry practices have received considerable attention recently as a strategy for increasing the carbon sink in soils (Bae et al. 2013; Lee and Jose 2003). However, few comparisons of soil carbon flux between agroforestry, monoculture and forest ecosystems have been conducted. And to our knowledge, there is no study that compares SR from terrace tea and forest tea.

Temporal and spatial variation in SR rates, for a variety of land use systems, is primarily influenced by soil water content (SWC) and soil temperature (ST; Davidson 1998; Xu and Qi 2001; Adachi et al. 2006). However, neither SWC nor ST can fully account for the spatial variation of SR (e.g., Yim et al. 2003; Sotta et al. 2004; Tedeschi et al. 2006), as SR exhibits a strong heterogeneity at scales ranging from plants to landscapes (Stoyan et al. 2000; Euskirchen et al. 2003). In addition to ST and SWC, several studies have shown that soil nutrient concentrations are important parameters for driving the spatial variation of SR (Xu and Qi 2001; Soe and Buchmann 2005). Therefore, more studies on CO_2 fluxes from different ecosystems are critical for furthering our understanding of the response of soils to different land use types, and to get reliable estimates of the CO_2 balance of ecosystems on a regional and, ultimately, global scale.

This study was undertaken with the objective to quantify and compare soil respiration rates, over a 12 month cycle, in two differently managed tea plantations: a terrace tea plantation and a forest tea plantation, and a secondary forest in Xishuangbanna, southwest China. Our goal was to better understand how these two different tea crop production systems, which are representative of the major tea farming methods of this region, contribute to annual soil CO_2 emissions. Secondary forests represent unmanaged, disturbed forest systems, thus functioning as an ideal control for this study. The findings of this study will contribute to guidelines for future experimental work, land use planning and mitigation of climate change. Due to the limited scale at which our study was conducted, we cannot extrapolate our results to a landscape scale. However, our findings can be used as the foundation of future work relating to this topic.

1 Materials and Methods

1.1 Site description

The study was conducted within an area surrounding the village Mengsong in Xishuangbanna (21°49'N, 100°50'E ~100°51'E; see Figure 1), Yunnan Province, China. Mengsong is

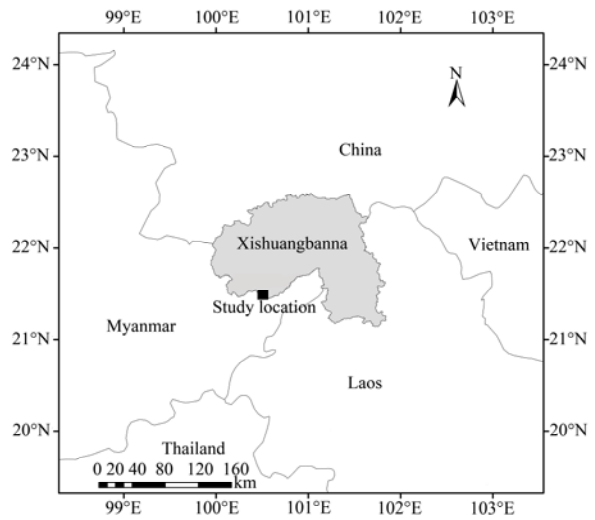

Figure 1 Location of the study area in Xishuangbanna, Yunnan, China.

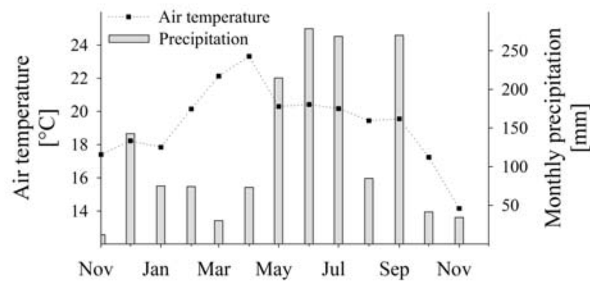

Figure 2 Monthly mean air temperature and precipitation of the study area in Xishuangbanna.

located in a mountainous region, with an elevation ranging between 800 and 2000 m a.s.l. During our study, from November 2010 to November 2011, mean annual temperature was 19.3°C and annual precipitation approximately 1570 mm, of which the majority (1160 mm) fell during the wet season (May - October). Climatic data were obtained from a local weather station (Figure 2).

Within the agricultural and forested areas surrounding the village, three different study sites, representing three different land use systems, were selected: a terrace tea plantation (21°49.20' N, 100°50.78' E), a forest tea plantation (21°49.61' N, 100°51.11' E) and a secondary forest (21°49.45' N, 100°49.97' E). The average elevation for the 3 sites was 1610 m a.s.l., with less than 30 m elevation differences for each site. Soils of all three sites are classified as Alisol with a sandy loam texture. The two tea plantations were planted with *Camellia sinensis* var. *assamica*. However, in the terrace tea plantation the tea plants were maintained at a height of about 1 m, whereas in the forest tea plantation the tea plants were grown to a maximum height of 2.5 m. The age of the terrace tea plantation was 31 years at the time of the experiment and the forest tea trees were between 100 and 150 years old. Weeding occurred in the terrace tea plantations three times during the wet season: in late June, early August and late September, weeded plants were left between the rows of tea plants. In the terrace tea plantation, *Lamiaceae* dominated the groundcover (> 90%). There was almost no groundcover in the forest tea plantation and thus no weeding events occurred. The secondary forest consisted of *Lithocarpus shima* and *Castanopsis sp.* trees, with an age between 30 and 35 years. For more details on the different sites refer to Table 1.

1.2 Soil respiration measurement

A closed dynamic system was used to measure SR at each site. Three PVC collars, 20 cm in diameter and 20 cm in height, were installed

Table 1 Site description of the three different land use (LS) sites: Terrace tea plantation (TT), forest tea plantation (FT), and secondary forest (SF)

Land use	Main plant species			Site age (years)	Management practice	BD	LLD
	Tree layer	Tea	Ground cover				
TT	—	*Camellia sinensis var. assamica*; 8200 bushes ha^{-1}	*Lamiaceae* > 90%	31	Harvest 3 times/year, in Mar, Jul and Sep, Weeding in Jun, Aug and Sep	1.00	0.34
FT	*Lithocarpus schima, Castanopsis sp., Legumenaceae*	*Camellia sinensis var. assamica*	—	> 100	Harvest 3 times/year, in Mar, Jul and Sep	0.98	0.37
SF	*Fagaceae*, *Litsea sp.*	—	tree seedlings: 5% - 40%	35	—	1.03	1.9

Notes: BD, Bulk density (g cm^{-3}); LLD, Litter layer depth (cm).

randomly within the three land use systems; but at least 1 m away from trees. The collars were driven 5 cm into the soil to minimize the disturbance of near-surface roots. SR measurements were performed from early November 2010 (two weeks after collars were inserted) until early November 2011. Measurements were made twice a month for the duration of the experiment. For each measurement, the collars were manually closed with a plastic lid and connected to a portable infrared gas analyzer (LI-8100, LI-COR, Lincoln, Nebraska, USA). Air was circulated in this closed system by a pump at a constant flow rate of 0.5 L min^{-1} and the CO_2 concentration inside the chamber was logged every 10 s for a period of 5 min. CO_2 fluxes were calculated from linear regressions of increasing CO_2 concentrations. The data was averaged from the three collars on every site to account for any spatial variation.

In addition to the SR measurements, soil temperature and soil water content (SWC) were measured at a depth of 10 cm, using sensors attached to the LI-8100 soil CO_2 flux system. Air temperature and precipitation were measured by an automatic weather station between the study sites.

1.3 Soil sampling and analysis

Soil samples were collected from each of the land use systems, these samples were taken from depths of 0-15 cm, 15-30 cm, and 30-60 cm, in June 2011. Sampling locations were 1 m north of the PVC collars. The soil samples were analyzed for pH, total C, total N, cation exchange capacity (CEC), available P, available K and bulk density. Analyses were conducted at the Yunnan Academy of Agricultural Science. At the same time, the litter layer depth at 0.5 m south of the collars was measured.

1.4 Statistics

The Mann-Whitney U-Test was used to compare the SR rates on single days and the cumulative SR in the different land use sites. SR rates between two measuring dates were linearly interpolated. Non-linear regression analysis was used to identify significant correlations between SR and soil temperature and SWC. The significance of correlations between two parameters from the same site was tested using Pearson's correlation test. All tests of significance were conducted at the 0.05 probability level, using SPSS Version 15.0. For the SR rate values n = 3, and all values given in the text, tables and graphs are representing means ± standard error.

2 Results

2.1 Soil analysis

Soil bulk density didn't differ significantly between the different study sites, with values ranging from 0.98 to 1.03 g cm^{-3} (Table 1). Litter layer depth was significantly higher in the secondary forest (1.9 cm) compared to that of the terrace and forest tea plantations (0.37 cm and 0.34 cm, respectively). Soil pH ranged from 4.1 to 4.9 in the 0 to 15 cm soil depth, with terrace tea and forest tea soil having significantly higher pH values than the secondary forest soils (Table 2). Soil organic C was lowest in the soils from the forest tea plantation, at a depth of 15 to 30 cm (26.5 ± 1.2 g kg^{-1}), compared to terrace tea (49.2 ± 6.0 g kg^{-1}) and secondary forest soil (50.6 ± 10.2 g kg^{-1}). There were no differences in the total N, available P and available K concentrations between the different land use systems (Table 2), neither were there any significant differences in the soil C:N ratios between land use types.

2.2 Seasonal and annual SR

During the dry season, mean SR rates (SR_{av}) were comparably low and did not differ significantly among land use types, with rates ranging between 2.7 and 2.8 μmol m^{-2} s^{-1} (Table 3). During the dry-wet season transition period, from March to May, SWC and ST significantly increased, followed by a significant increase in SR (Figure 3A-D). This increase in SR was observed in all sites, but most remarkably in the terrace tea plantation and the secondary forest, with increases of 150% and 65%, respectively, compared to a 30% increase in the forest tea plantation (Figure 3C and D). During the same period, ST and SWC, at 10 cm depth, didn't differ for both kinds of tea plantations, but showed significantly lower values in the

Table 2 Soil characteristics (mean ± standard error, n=3) of terrace tea, forest tea and secondary forest: pH, soil organic carbon (SOC), total nitrogen (TN), available phosphorus (AP), available potassium (AK), and cation exchange capacity (CEC). Superscript letters within a column indicate no significant difference between the management sites and/or soil depths according to the Mann-Whitney U-Test at $p \le 0.05$.

Land use	Depth (cm)	pH	SOC (g kg^{-1})	TN (g kg^{-1})	AP (mg kg^{-1})	AK (mg kg^{-1})	CEC (cmol kg^{-1})
Terrace tea	0-15	4.9±0.1^b	61.9±4.4^a	3.8±0.3^a	42.6±1.8^a	43.7±6.0^a	22.1±0.5^a
Forest tea		4.7±0.1^b	66.4±2.5^a	3.8±0.2^a	46.9±12.1^a	40.3±8.8^a	21.4±0.4^a
Sec. forest		4.1±0.0^a	66.4±14.4^a	3.3±0.6^a	32.5±3.6^a	32.8±0.8^a	21.8±3.1^a
Terrace tea	15-30	4.9±0.1^a	49.2±6.0^b	3.0±0.4^a	30.7±2.3^a	12.0±7.7^a	21.9±1.9^b
Forest tea		4.8±0.0^a	26.5±1.2^a	2.7±0.1^a	27.9±2.1^a	12.0±5.0^a	18.4±0.9^a
Sec. forest		4.7±0.1^a	50.6±10.2^b	2.8±0.5^a	20.9±1.8^a	5.3±3.3^a	20.1±2.4^{ab}
Terrace tea	30-60	5.1±0.1^a	24.6±1.4^a	1.7±0.1^a	14.5±0.2^a	15.4±2.9^b	15.4±0.9^a
Forest tea		5.1±0.0^a	21.9±0.7^a	1.6±0.1^a	12.6±0.9^a	10.7±2.7^{ab}	12.8±0.5^a
Sec. forest		5.0±0.1^a	31.2±8.3^a	1.7±0.4^a	11.8±2.3^a	6.7±0.7^a	14.9±1.8^a

Table 3 Mean soil respiration (SR_{av}, μmol m^{-2} s^{-1}), mean soil temperature (mean ST, °C) and mean soil water content (mean SWC, m^3 m^{-3}), at 10 cm soil depth, for dry season (November-April) and wet season (May-October), with standard errors (n=3). Superscript letters within a row indicate no significant difference between the management sites and/or seasons according to the Mann-Whitney U-Test at $p \le 0.05$.

	Terrace tea		Forest tea		Secondary forest	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
SR_{av}	2.7±0.3^a	5.4±0.5^c	2.7±0.2^a	3.7±0.2^b	2.8±0.2^a	4.9±0.4^c
Mean ST	17.2±0.4^a	20.5±0.5^b	17.4±0.3^a	20.8±0.3^b	16.5±0.2^a	18.9±0.2^a
Mean SWC	0.12±0.03^{ab}	0.38±0.01^d	0.15±0.03^b	0.39±0.01^d	0.09±0.02^a	0.32±0.01^c

secondary forest site (Figure 3B, C).

There were differences in the SR_{av} among the different land use types during the wet season with lowest rates in the forest tea plantation (3.7 μmol m^{-2} s^{-1}) and significantly higher rates in the secondary forest and terrace tea plantation (4.9 μmol m^{-2} s^{-1} and 5.4 μmol m^{-2} s^{-1}, respectively, Table 3). The increased soil CO_2 emissions from the terrace tea soil were partly due to three SR peaks that were measured in late June, early August and late September (Figure 3C). These peaks occurred three to four days after weeding. Annual SR in the forest tea plantation (101.1±6.6 mol m^{-2}) was found to be 21% and 25% less compared to the terrace tea and secondary forest, respectively (Figure 3D).

2.3 Relationship between SR, ST and SWC

Annual variation in SR on all three sites was significantly correlated to ST during the wet season (Figure 4A, C and E). This correlation was strongest in the secondary forest and weakest in the forest tea plantation. However, during the dry season, SR and ST were not correlated in any of the land use types. During the dry period, both the terrace tea and forest tea plantations showed a significant correlation between SR and SWC. However, SR from the secondary forest was not correlated to soil moisture during this period (Figure 4B, D and F). Annual and seasonal temperature sensitivity of soil respiration (Q_{10}) estimates can be found in Table 4.

3 Discussion

We observed that annual soil respiration (SR) in the forest tea plantation (101.1±6.6 mol m^{-2}) was more than 20% less compared to the terrace tea plantation (127.3 ± 13.0 mol m^{-2}) and secondary forest (121.9 ± 8.8 mol m^{-2}), resulting in approximately 3000 kg ha^{-1} less C being emitted as CO_2 from these soils annually. The annual soil CO_2 emission rates measured in this study are within the range of those measured in tropical forests and crop plantations, although they are at the upper end of these emission rates (Sha et al. 2005; Fang and Sha 2006; Lu et al. 2009).

During the dry season, cumulative CO_2 emissions from the soils of the different sites did not differ and accounted for 32%, 36% and 42% of the annual emissions from the terrace tea plantation, secondary forest and forest tea plantation, respectively. The difference in annual SR was only due to the fluxes during the wet season. We suggest that the highest SR rates in terrace tea

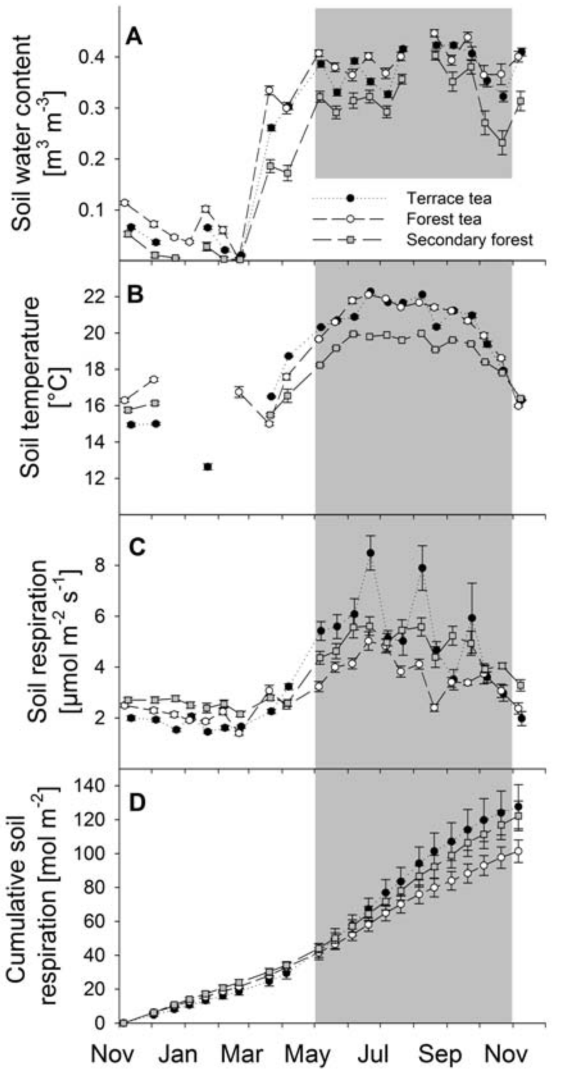

Figure 3 Time course of A) soil water content and B) soil temperature, both at 10 cm depth, C) soil respiration, and D) cumulative soil respiration under different land-uses: terrace tea plantation (terrace tea), forest tea plantation (forest tea), and secondary forest. Error bars indicate the standard error of the mean (n=3). The grey box marks the wet season.

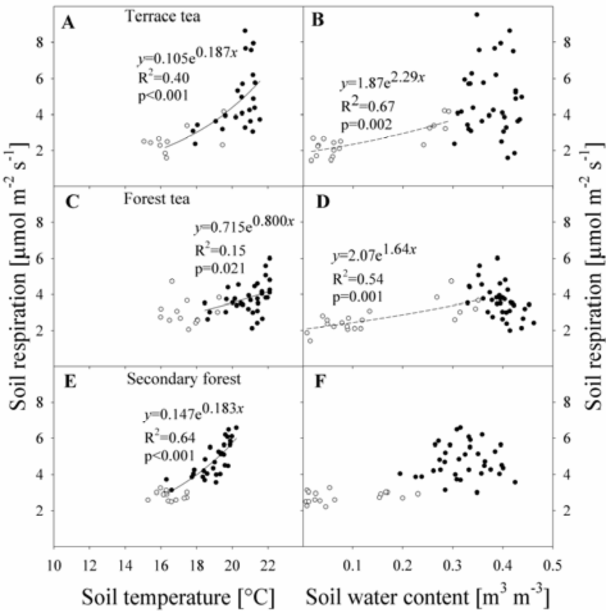

Figure 4 Relationship between soil respiration and soil temperature (left) and soil water content (right) in 10 cm depth in terrace tea plantation (A and B), forest tea plantation (C and D) and secondary forest (E and F). Solid circles and lines are during wet season and open circles and lines are during dry season. Only statistically significant regressions are shown.

Table 4 Estimated annual and seasonal (dry season: November-April; wet season: May-October) soil respiration (Q_{10} ± SE) (n=3) in the three different study sites. Superscript letters within a column indicate no significant difference between the management sites at p≤0.05.

Land use	Soil respiration(Q_{10})		
	annual	dry season	wet season
Terrace tea	$5.7±0.4^{b}$	$3.6±0.9^{b}$	$8.3±2.2^{b}$
Forest tea	$2.1±0.1^{a}$	$1.5±0.5^{ab}$	$2.5±0.2^{a}$
Sec. forest	$5.8±1.3^{b}$	$0.9±0.1^{a}$	$5.1±1.3^{ab}$

and lowest in forest tea are due to: 1) Lower SOC content within the forest tea soil, and 2) weeding as a management practice only executed in terrace tea plantation that led to CO_2 peaks with significant impact on the annual soil CO_2 emission.

The diminished rates of SR in the forest tea plantation are best explained by the lower SOC levels observed in these soils (*ca.* 47% lower), as there were no differences found in any of the other soil parameters, such as ST, SWC, and soil chemical parameters. A few studies have demonstrated that annual soil CO_2 effluxes in different ecosystems positively correlate with SOC concentrations and root biomass (Wang et al. 2006; Zheng et al. 2009; Bae et al. 2013). The labile pool of SOC provides an important substrate for microbial respiration, therefore, under similar climatic conditions, soils with higher SOC contents generally show greater soil microbial activities (Atkin et al. 2000), and thus increased SR rates. In our study, SOC in the forest tea plantation was only reduced in 15 to 30 cm depth and not throughout the profile. The primary sources of SOC are litter and roots. A possible cause for the lower SOC at this depth may be a result of the reduced vegetation cover within the forest tea plantations, thus lowering the contribution of root derived material to the SOC pool.

Our results regarding seasonal variation in SR are consistent with previous research pertaining to SR (Cleveland et al. 2010; Zhang and Tan 2010). During the transition from the dry to the wet season, soil moisture and temperature rapidly increased, followed by greatly enhanced soil respiration rates. Other studies, in a variety of ecosystems, including tropical forests, showed the same pattern of SR, with CO_2 emissions peaking at the onset of rain events (Davidson et al. 2000; Davidson et al. 2002; Epron et al. 2004; Bréchet et al. 2009). The work of Yavitt et al. (2004) confirms that soil moisture can limit SR in tropical rainforests. For the current study, SR in the two different tea plantations was correlated with soil moisture during the dry season, and not with soil temperature, demonstrating that soil water content was the limiting factor for soil respiration in the tea plantations. This finding is in agreement with previous studies (Davidson et al. 2000; Yuste et al. 2003).

Within the secondary forest, SR was not influenced by soil water status, as evidenced by the low SWC for these plots and the lack of any significant correlations between these factors. The terrace tea and forest tea plantations had significantly higher SWC than the secondary forest, displaying between 24% and 35% greater SWC during the dry season, when differences were most pronounced. However, for all of the land use systems in this study, during the wet season, with no limitation of water, ST appeared to be the main driving factor for SR, as shown by a strong correlation between soil CO_2 emissions and ST.

Despite the terrace tea plantation and secondary forest exhibiting high temperature sensitivity during the wet season, this was not the case for the forest tea plantation, which has shown to contain lower SOC. Zheng et al. (2009) found that the SR rates of various ecosystems, in different climate zones (alpine, temperate and tropical), with higher SOC content, increased to a significantly larger extent with a temperature increase compared to those with lower SOC contents.

In our study three peaks in SR were observed in the terrace tea plantation, all of which occurred three to four days after weeding events, during the wet season. Weeding has been shown to increase the oxidation of organic C, releasing high amounts of CO_2 into the atmosphere (Ellert and Janzen 1999; Prior et al. 2000; La Scala et al. 2006). One of the major factors related to soil C losses after weeding is the disruption of soil aggregates and the exposition of protected organic matter to decomposition (Six et al. 1999; De Gryze et al. 2006; Grandy and Robertson 2007; La Scala 2008). The CO_2 peaks resulting from the weeding events contributed almost 10% (*ca.* 1300 kg C ha^{-1}) to the annual C emissions, and thus stress the importance of management practices on soil CO_2 emission.

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References

Adachi M, Bekku YS, Rashidah W, et al. (2006) Differences in soil respiration between different tropical ecosystems. Applied Soil Ecology 34: 258-265. DOI: 10.1016/j.apsoil. 2006.01.006

Atkin OK, Edwards EJ, Loveys BR (2000) Response of root respiration to changes in temperature and its relevance to global warming. NewPhytologist 147: 141-154. DOI: 10.1046/ j.1469-8137.2000.00683.x

Bae K, Lee DK, Fahey TJ, et al. (2013) Seasonal variation of soil respiration rates in a secondary forest and agroforestry systems. Agroforestry Systems 87: 131-139. DOI: 10.1007/ s10457-012-9530-8

Bréchet L, Ponton S, Roy J, et al. (2009) Do tree species characteristics influence soil respiration in tropical forests? A test based on 16 tree species planted in monospecific plots. Plant and Soil 319: 235-246. DOI: 10.1007/s11104-008-9866-z

Brown S, Lugo AE (1990) Tropical secondary forests. Journal of Tropical Ecology 6: 1-32. DOI: 10.1017/S0266467400003989

Cleveland CC, Wieder WR, Reed SC, Townsend AR (2010) Experimental drought in a tropical rain forest increases soil carbon dioxide losses to the atmosphere. Ecology 91: 2313-2323. DOI: 10.1890/09-1582.1

Davidson EA, Belk E, Boone RD (1998) Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest. Global Change Biology 4: 217-227. DOI: 10.1046/

j.1365-2486.1998.00128.x
Davidson EA, Savage K, Bolstad P, et al. (2002) Belowground carbon allocation in forests estimated from litterfall and IRGA-based soil respiration measurements. Agricultural and Forest Meteorology 113: 39-51. DOI: 10.1016/S0168-1923(02) 00101-6
Davidson EA, Verchot LV, Chattanio JH, et al. (2000) Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia. Biogeochemistry 48: 53-69. DOI: 10.1023/A:1006204113917
De Gryze SS, Six J, Merckx S (2006) Quantifying water-stable soil aggregate turnover and its implication for soil organic matter dynamics in a model study. European Journal of Soil Science 57: 693-707. DOI: 10.1111/j.1365-2389.2005.00760.x
Ellert BH, Janzen HH (1999) Short-term influence of tillage on CO_2 fluxes from a semi-arid soil on the Canadian prairies. Soil and Tillage Research 50: 21-32. DOI: 10.1016/S0167-1987(98) 00188-3
Epron D, Nouvellon Y, Roupsard O, et al. (2004) Spatial and temporal variations of soil respiration in a Eucalyptus plantation in Congo. Forest Ecology and Management 202: 149-16. DOI: 10.1016/j.foreco.2004.07.019
Euskirchen ES, Chen J, Gustafson EJ, Ma S (2003) Soil respiration at dominant patch types within a managed Northern Wisconsin landscape. Ecosystems 6: 595-607.
Fang Q, Sha, LQ (2006) Soil respiration in a tropical seasonal rain forest and rubber plantation in Xishuangbanna, Yunnan, SW China. Chinese Journal of Plant Ecology 30: 97-103. DOI: 1005-264X(2006)30:1<97:XSBNRD>2.0.TX;2-2
FAO (2011) FAOSTAT data. Available on: http://www.fao.org. (Accessed on 4-7-2013)
Grandy AS, Robertson GP (2007) Land-use intensity effects on soil organic carbon accumulation rates and mechanisms. Ecosystems 10: 58-73. DOI: 10.1007/s10021-006-9010-y
Hanson PJ, Wullschleger SD, Bohlman SA, Todd DE (1993) Seasonal and topographic patterns of forest floor CO_2 efflux from upland Oak forest. Tree Physiology 13: 1-15. DOI: 10.1093/treephys/13.1.1
Hughes RF, Kauffman JB, Jaramillo VJ (1999) Biomass, carbon, and nutrient dynamics of secondary forests in a humid tropical region of Mexico. Ecology 80: 1892-1907. DOI: 10.1890/0012-9658(1999)080[1892:BCANDO]2.0.CO;2
Hung PY (2013) Tea forest in the making: Tea production and the ambiguity of modernity on China's southwest frontier. Geoforum 47: 178-188. DOI: 10.1016/j.geoforum.2013.01.007
La Scala N, Bolonhezi D, Pereira GT (2006) Short-term soil CO_2 emission after conventional and reduced tillage of a no-till sugar cane area in southern Brazil. Soil and Tillage Research 91: 244-248. DOI: 10.1016/j.still.2005.11.012
La Scala N (2008) Short-term temporal changes of soil carbon losses after tillage described by a first-order decay model. Soil and Tillage Research 99: 108-118. DOI: 10.1111/j.1365-2389. 2008.01102.x
Lee K, Jose S (2003) Soil respiration and microbial biomass in a pecan–cotton alley cropping system in Southern USA. Agroforestry Systems 58: 45-54. DOI: 10.1023/A:1025404 019211
Le Quéré C, Moriarty R, Andrew RM, et al. (2014) Global carbon budget 2014. Earth System Science Data Discussions 7: 521-610. DOI: 10.5194/essdd-7-521-2014.
Li S, Wu X, Xue H, et al. (2011) Quantifying carbon storage for tea plantations in China. Agriculture, Ecosystems & Environment 141: 390-398. DOI: 10.1016/j.agee.2011.04.003
Lu HZ, Sha LQ, Wang J, et al. (2009) Seasonal variation of soil respiration and its components in tropical rain forest and rubber plantation in Xishuangbanna, Yunnan. Chinese Journal of Applied Ecology 20: 2315-2322.
Paustian K, Six J, Elliott ET, Hunt HW (2000) Management options for reducing CO_2 emissions from agricultural soils. Biogeochemistry 48: 147-163. DOI: 10.1023/A:100627
Prior SA, Reicosky DC, Reeves DW, et al. (2000) Residue and tillage effects on planting implement-induced short-term CO_2 and water loss from a loamy sand soil in Alabama. Soil and Tillage Research 54: 197-199. DOI: 10.1016/S0167-1987(99) 00092-6
Raich JW, Schlesinger WH (1992) The global carbon dioxyde flux in soil respiration and its relationship to vegetation and climate. Tellus 44B: 81-99. DOI: 10.1034/j.1600-0889.1992. t01-1-00001.x
Schlesinger WH, Andrews JA (2000) Soil respiration and the global carbon cycle. Biogeochemistry 48: 7–20. DOI: 10.1023/
A:1006247623877
Sha LQ, Zheng Z, Tang JW, et al. (2005) Soil respiration in tropical seasonal rain forest in Xishuangbanna, SW China. Science in China Series D: Earth Sciences 48: 189-197. DOI: 10.1360/05zd0019
Six J, Elliott ET, Paustian K (1999) Aggregate and soil organic matter dynamics under conventional and no-tillage systems. Soil Science Society of America Journal 63: 1350-1358. DOI: 10.2136/sssaj1999.6351350x
Soe ARB, Buchmann N (2005) Spatial and temporal variations in soil respiration in relation to stand structure and soil parameters in an unmanaged beech forest. Tree Physiology 25: 1427-1436. DOI: 10.1093/treephys/25.11.1427
Sotta ED, Meir P, Malhi Y, et al. (2004) Soil CO_2 efflux in a tropical forest in the central Amazon. Global Change Biology 10: 601-617. DOI: 10.1111/j.1529-8817.2003.00761.x
Stoyan H, De-Polli H, Bohm S, et al. (2000) Spatial heterogeneity of soil respiration and related properties at the plant scale. Plant Soil 222: 203-214. DOI: 10.1023/A:100 4757405147
Tedeschi V, Rey A, Manca G, et al. (2006) Soil respiration in a Mediterranean oak forest at different developmental stages after coppicing. Global Change Biology 12: 110-121. DOI: 10.1111/j.1365-2486.2005.01081.x
Wang CK, Yang JY, Zhang QZ (2006) Soil respiration in six temperate forests in China. Global Change Biology 12: 2103-2114. DOI: 10.1111/j.1365-2486.2006.01234.x
Xu M, Qi Y (2001) Soil-surface CO_2 efflux and its spatial and temporal variations in a young ponderosa pine plantation in northern California. Global Change Biology 7: 667-677. DOI: 10.1046/j.1354-1013.2001.00435.x
Yavitt JB, Wright SJ, Wieder RK (2004) Seasonal drought and dry-season irrigation influence leaf-litter nutrients and soil enzymes in a moist, lowland forest in Panama. Austral Ecology 29: 177-188. DOI: 10.1111/j.1442-9993.2004.01334.x
Yim MH, Joo SJ, Shutou K, Nakane K (2003) Spatial variability of soil respiration in a larch plantation: estimation of the number of sampling points required. Forest Ecology and Management 175: 585-588. DOI: 10.1016/S0378-1127(02) 00222-0
Yuste JC, Janssens IA, Carrara A, et al. (2003) Inteactive effects of temperature and precipitation on soil respiration in a temperature maritime pine forest. Tree Physiology 23: 1263-1270. DOI: 10.1093/treephys/23.18.1263
Zhang Y, Tan Z (2010) Respiration controls the unexpected seasonal pattern of carbon flux in an Asian tropical rain forest. Atmospheric Environment 44: 3886-3893. DOI: 10.1016/ j.atmosenv.2010.07.027
Zheng ZM, Yu GR, Fu YL, et al. (2009) Temperature sensitivity of soil respiration is affected by prevailing climatic conditions and soil organic carbon content: A trans-China based case study. Soil Biology and Biochemistry 41: 1531-1540. DOI: 10.1016/j.soilbio.2009.04.013