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Research Article

Components of Soil Respiration and its Monthly Dynamics in Rubber Plantation Ecosystems

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Abstract: Aim: Our objective was to quantify four components and study effect factors of soil respiration in rubber plantation ecosystems. Providing the basic data support for the establishment of the trade of rubber plantation ecosystem carbon source/sink. Methods: We used Li-6400 (IRGA, Li-COR) to quantitate four components of soil respiration in rubber plantation ecosystems at different ages. Soil respiration can be separated as four components: heterotrophic respiration (Rh), Respiration of roots (Rr), respiration of litter layer (Rl) and respiration of mineral soil (Rm). Important findings: The soil respiration rate (Rs) showed significant seasonal variation. The maximum soil respiration rate of the whole year appeared in August and the minimum in November or December. The components of soil respiration rate order showed as: heterotrophic respiration>respiration of roots>respiration of litter layer> respiration of mineral soil. The soil respiration rate was highly significant correlation ($p<0.01$, $Q_{10} = 1.13\sim2.37$) with 0~10 cm soil temperature in dry season and significant correlation ($p<0.05$, $Q_{10} = 1.10\sim1.77$) with 0~10 cm soil temperature in wet season. And soil respiration rate was not significant correlation with soil water content of 5 cm ($p\geq0.05$). The soil respiration components of four kinds forest ages accounted for the percentage contribution to the flux of annual carbon emissions (Rs) as: Rh: 35.28~52.75%, Rr: 21.73~39.97%, Rl: 17.13~19.63%, Rm: 6.605~10.27%%, respectively. The soil respiration rate carbon flux of 5, 10, 19 and 33a respectively were 10.03, 10.34, 11.96 and 11.09 t/hm^2.a. And the annual carbon flux of soil respiration increased with stand ages increasing in rubber plantation ecosystems.

Keywords: Components, effect factors, rubber plantations, soil respiration, stand age

INTRODUCTION

Accumulation and distribution of soil carbon pool in forest ecosystems play an important role in the global carbon cycle of terrestrial ecosystems and climate change and the underground ecological processes critically affect and regulate the dynamic of the global soil carbon cycle. CO_2 released into the atmosphere from soil is a very important part of the global carbon cycle (Schlesinger *et al.*, 2000). Soil respiration (also as soil surface CO_2 flux) plays an important role in underground carbon cycle process and the size of the soil respiration CO_2 emissions is an important indicator to estimate soil carbon pool dynamics (Sedjo, 1993; Gomez *et al.*, 2012). Soil respiration is a complex biological and ecological process, which is constrained and influenced by many factors (Keutgen, 1998; Fang *et al.*, 2001; Fang *et al.*, 2007), such as vegetation type, ecosystem productivity, soil microbial activity, temperature, humidity, soil physical, chemical properties and a variety of environmental factors and its changes will affect the soil respiration rate. Methods of measuring soil respiration are increased and improved with the research work promoting. However, using the existing observation methods, we are not only difficult to separate biological processes and non-biological processes of soil respiration, but also difficult to accurately assess soil respiration the total amount and split into different groups of respiration (including root respiration of soil, litter respiration and oxidative decomposition of carbon-containing minerals, animals and micro-organisms in the soil respiration). And combined with the differences in measurement methods and technology, as well as parameter selection and spatial and temporal differences, accurate quantification of soil respiration will be caused some uncertainty and also some difficulties will be created to compare the emission flux data in large-scale spatial and temporal

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Table 1: Site conditions and stand characteristics of different ages rubber plantations ecosystems

Study sample		Site conditions			Stand characteristics					
Stand age (a)	Planted year	Soil depth (cm)①	0~60 cm SOC (g/kg)	Soil pH	Cultivation strains	Cultivation model	Stand density (tree/hm)②	Average perimeter (cm)③	LAI④	Vegetation composition⑤
5a	2006	53	7.87	5.2	Reyan 7-33-97	3 m×7 m	425	11.71	5.01	1～7, 11~2
10a	2001	69	7.25	4.58	Reyan 7-33-97	3 m×7 m	451	48.39	3.62	1～13, 15~16
19a	1992	81	8.31	4.53	Reyan 7-33-97	3 m×7 m	335	66.25	3.17	1～10, 14～19
33a	1978	75	10.35	4.72	PR107	1.5 m×10 m	350	82.78	2.25	1～19

① In this study, the soil types of the four samples are latosol, and the area of each is larger than 1.9hm^2; ② The number of actual survival trees in the forest stands may be reduced because of wind, cold, drought, pests, diseases, and other reasons; ③ Average perimeter is the average perimeter of the main stem at the height of 1.5 m from the ground; ④ Leaf area index was measured with LAI-2000. And all the above data determination time was in September, 2011; ⑤ The common vegetation understory in the samples are as follows; Herbal Plants: 1. *Strelitzia reginae* Linn, 2. *Alternanthera sessilis* Linn), 3. *Eupatorium odoratum* Linn, 4. *Chlorophytum laxum* R. Br, 5. *Elephantopus scaber* Linn, 6. *Praxelis clematidea* King Robinson, 7. Mimosa pudica, 8. *Adiantum flabellulatum* Linn, 9. *Crotalaria pallida* Ait., etc; Liana Plants: 10. *Bauhinia championii* Lour, 11. *Lygodium japonicum* (Thunb.); 12. *Pueraria montana* (Lour) Merr, 13. *Dioscorea hispida* Dennst; Shrub Plants: 14. *Phoenix hanceana* Naud, 15. *Ardisa porifera* Walker, 16. *Clerodendrum fortunatum* Lour, 17. *Urena procumbens* L, 18. *Mussaenda hainanensis* Merr, 19. *Acaciasinuata* (Lour.) Merr

scales of soil respiration (Liu, 1997; Yang *et al*., 2004; Wu *et al*., 2011a). Therefore, to explore a scientific and standardized technology to measure soil respiration is particularly important to explore the response characteristics and mechanisms of soil respiration to terrestrial ecosystem carbon cycle and global change.

It is critical for understanding the soil respiration mechanism and its response to environmental change if the relative contribution amount of the different soil respiration components can be accurately qualified. Luo and Zhou (2006) reviewed that root respiration most ecosystem accounts for about 30 to 50% of total soil respiration and the contribution of root respiration changes seasonally. Hanson *et al*., (2000) estimated the average contribution of the root was 48% of the total soil respiration, but ranged from 10 to 90%. Complex interactions among the various components may bring about a positive or negative feedback to soil respiration decomposition process. So it is very difficult to precisely distinguish all the components of soil respiration (Subke, 2004; Ojanen *et al*., 2012). Bond-Lamberty *et al*., (2004) found that many factors and different measurements did not affect autotrophic respiration and heterotrophic respiration contribution, but it still need to evaluate the uncertainty coming from the methods (such as the interference of root elimination method or the assumptions of isotopes calculated method) and other factors (such as the type of ecosystem, the dominant species, developmental stage, season and weather conditions) to estimate the relative contribution of the different soil respiration components (Hanson, 2000; Zimmermann *et al*., 2010).

Rubber tree (*Hevea brasiliensis* Muell. Arg.) is native in tropical jungle of Amazon valley of Brazil. It will begin to tap and produce rubber after planted 5 to 7 years; the economic life is up to 30 years. Rubber tree is was introduced to China in 1904 and planted in large scales in August, 1951. Because of the international dry rubber price rising and the Ministry of Agriculture, P. R. China promoting with nature rubber fine breed subsidy, the rubber plantation acreage has been expanding each year in China (as to 2009, the rubber plantation acreage has reached 7 million hm 2 in Hainan Island). Rubber plantation is one of the largest plantation ecosystems in the tropical area of China and the ecological value is becoming increasingly apparent with the economic value. The research of rubber forest ecosystem carbon cycle is still in its infancy. Wu *et al*., (2010a) and Guan *et al*., (2012) studied the soil carbon content and storage of the different the rubber forest ages, Yi *et al*. (2012) conducted a preliminary study on the trunk respiration of a rubber plantation and Wu *et al*., (2010b, 2011b) carried out the study of the carbon flux of rubber forest ecosystem. But there are many issues so far not been studied thoroughly. This study aimed to study soil respiration in different growth stages and the response mechanisms of the different components to the environment and it will have important scientific significance to reveal rubber plantation soil carbon source emissions/sinks functional changes. There are a certain theoretical and practical significance to forest ecosystem biogeochemical cycle after estimating the rubber plantation soil carbon flux.

MATERIALS AND METHODS

Test area and sample description: The test area is located in Danzhou Scientific Observation Station of Tropical Crop (19°31′47″N, 109°28′30″E, 144 m asl) in test farm 3 of Chinese Academy of Tropical

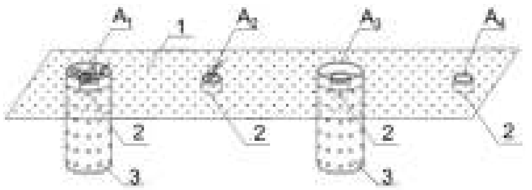

Fig. 1: Soil respiration separation measurement sample set
1. Soil; 2. Soil respiration ring; 3. Root exclude soil ring; A1: Plot of root exclude soil ring + the litter layer reserved; A2: Plot of non- root exclude soil ring + the litter layer reserved; A3: Plot of root exclude soil ring + the litter layer removed; A4: Plot of non- root exclude soil ring + the litter layer removed

Agricultural Sciences (west of Hainan and 15 km away from Danzhou). The test area is tropical zone maritime and monsoon climate with distinct dry and wet seasons. In detail, the annual temperature averages 20.5~28.5°C; the accumualted temperature of annual average temperature≥10°C is 8500~9100°C; rainy season is usually in May-October and dry season in November-April of the following year; average rainfall is 1607~000 mm, especially in July, August and September; annnual relative humidity averages 83%. In addition, the terrain is hills (differences of relative height <10 m); the soil is laterite weathered by granite parient materials; soil depth is about 100 cm and pH is 4.52~5.86. Herbaceous plant, perennial dungarunga, mulberrry, pepper and kudzu are distributed in the region.

The rubber plantation of the test area is the second generation rubber forest. The cultivation strains are PR107 which was planted in large area and Reyan 7-33-97 which is being planted in large area in Hainan Island. Four samples were selected in different forest stand ages: mature age trees (planted in 1978), later period of tapping trees (planted in 1996), early period of tapping trees (planted in 2001) and later period of young trees (planted in 2006). And the site conditions and stand characteristics are shown in Table 1.

Design of experiments: Randomized block design was used to arrange experiments in the study. Four forest ages stands were: later period of young trees (5a), early period of tapping trees (10a), later period of tapping trees (19a) and mature age trees (33a). Four plots arranged in each forest ages stands: root exclude soil ring+the litter layer reserved, non- root exclude soil ring+the litter layer reserved, non- root exclude soil ring+the litter layer removed, root exclude soil ring+the litter layer removed. Three samples repeated in each treatment with 12 m×6 m plots (there were 12 plots in each stand and 48 plots in the four stands). The soil respiration was measured after the root exclude soil ring installation six months, its purpose is to restore the original condition to exclude the interference to the original plant roots and the soil structure (although there were little changes to the soil structure in this trial, but there were still some disturbances) (Wu *et al.*, 2011a). The four processing plots and component separation settings are shown in Fig. 1.

Soil respiration ring is a PVC soil ring (LI-6400 Portable Photosynthesis System equipped) placed randomly in each plot whose inner diameter is 10.2 cm, height 6 cm and 1 to 2 cm above the ground. To avoid external influence, each PVC ring is arranged 3 m away from the plot edge and marked the place to maintain it in same position at the entire measurement period.

Root exclude soil ring is a hard PVC pipe (inside diameter of 25 cm, height 50 cm and pipe thickness 5 mm) with 1 cm diameter holes (to prevent invasive of plant roots, but allow the free flow or move of moisture or part of micro-organisms in the soil and so the root exclude ring will not change the soil structure to affect the measurement accuracy) which embedded in soil 45 to 50 cm depth. Remove all live plants in the large PVC pipe and then place a soil respiration ring in the center of it.

The litter layer reserved refer to remove all the living plant in the PVC soil respiration ring but to retain the soil surface litter. Before measuring the soil respiration rate each time, herbal around the measuring point range of 1 m×1 m close to the surface should be cut off.

The litter layer removed refer to remove all the living plant in the PVC soil respiration ring and the soil surface litter, but only to retain the mineral soil layer. Same as above, herbal around the measuring point range of 1 m×1 m close to the surface should be cut off before measuring each time.

Research methods: Soil respiration was measured with Li-COR infrared gas analyzer (IRGA, LI-6400 Portable Photosynthesis System). Real-time soil respiration parameters and related environmental factors of each processing plot can be measured with the soil respiration chamber (09 leaf room). Soil respiration components of each forest age class rubber plantation are shown in Table 2.

In order to ensure the measurement reliable, the similar fine weather and the same measurement period should be selected. The monthly change measurement time of rubber plantation soil respiration is from 9:00 to 11:00 am in the middle of each month and at each sample 3 times repeated. Soil flux of the morning close to noon time period is close to the daily average value (Davidson, 1998; Xu *et al.*, 2001), therefore, the measured value of 9:00 am to 11:00 am is considered as the daily average value.

At the same time of measuring soil respiration rate, soil respiration parameters such as surface air temperature and humidity near measuring points, 0 to -10 cm soil temperature and -5 cm soil moisture were

Table 2: Soil respiration rate of each component

Components separation of soil respiration	Components quantification of soil respiration
Heterotrophic respiration rate (Rh)	Soil respiration rate of plot A1
Soil respiration rate (Rs)	Soil respiration rate of plot A2
Mineral soil respiration rate (Rm)	Soil respiration rate of plot A3
Litter respiration rate (Rl)	Soil respiration rate difference of A1 and A3 (A1-A3)
Roots respiration rate (Rr)	Soil respiration rate difference of A4 and A3 (A4-A3)

In this study, soil heterotrophic respiration consists of microbial respiration and animal respiration

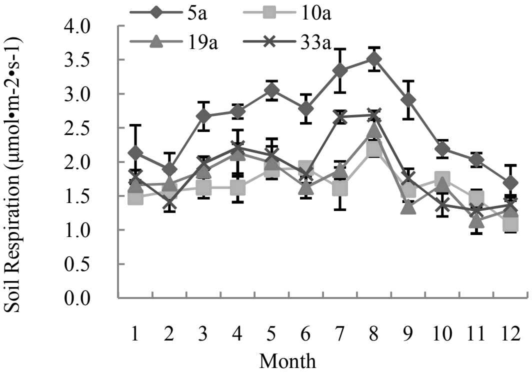

Fig. 2: Monthly changes of soil respiration rate in rubber plantations at different stand ages

measured, too. Observation time continued from January to December 2011.

Using the soil respiration data from January to December 2011, we can estimate soil respiration efflux in a total year. And the total amount of the soil respiration years release can be calculated through the following formula:

$$SR = \frac{\sum_{i=1}^{12} RRi \times M \times Ti \times 86400}{10^8}$$

where,

SR = The annual emission of soil respiration (t/hm^2)
RRi = The i-th month soil respiration rate (μmol/m$^{2\cdot}$s)
M = Carbon molar mass, M (C) = 12g/mol
Ti = The days of the i-th month, 86400 for the time in second (s) measurement

Data processing: Data processing and charts were generated by the software Microsoft Office 2010 and DPS 7.5. Multiple range (Duncan) and two-way ANOVA analysis were used to compare the differences among the different data sets (ages and components).

RESULTS AND ANALYSIS

Monthly changes of the total soil respiration in rubber plantations at different stand ages: As shown in Fig. 2, soil respiration rate (Rs) in the 5, 10, 19 and 33a 4 stand ages rubber plantation ecosystem changed very obviously. Monthly variation of soil respiration rate in a total year of the four stand ages rubber ecosystem generally showed a single peak, the peak was in July to August and showed a downward trend after August. The rate reached the maximum of the year in August, respectively, 2.69, 2.19, 2.47 and 3.51 μmol/m^2.s. The rate of 5a and 10a declined to the minimum in December, respectively, 1.69 and 1.06 μmol/m^2.s; 19a and 33a in November, respectively, 1.14 and 1.29 μmol/m^2.s. During the measuring year 2011, the soil respiration rate of 33a rubber plantation was significantly higher than the 10a, 19a and 5a. The difference was not significant among the Rs of 10a, 19a and 5a mutual; and Rs of 19a and 5a rubber forest were higher than of 10a in January to September, 5a slightly higher than 19a.

Separation and quantification of soil respiration components in rubber plantation at different stand ages: Through the experimental design, soil respiration components of rubber plantation can be separated and quantified and monthly dynamic of them were shown dynamics shown in Fig. 3. There were significant monthly changes of the various soil respiration components in rubber plantation at different stand ages.

In Fig. 3-I, soil respiration components average changes of 5a were shown that: Rh (1.47 μmol/m^2.s) >Rr (1.12 μmol/m^2.s) >Rl (0.91 μmol/m^2.s) >Rm (0.69 μmol/m^2.s). And in the months of January, March, April, May, July and October, Rh was significantly higher than Rr; in the month of March to December, Rr was generally higher than Rl and Rm and a significant difference with Rm ($p<0.05$), but no significant difference with Rr ($p>0.05$). In the 12 months of the year, there was no obvious fluctuation of Rm and it was the lowest in the four components. As shown in Fig. 3II, the average of soil respiration components at 10 years displayed that: Rh (0.98 μmol/m^2.s) >Rr (0.77 μmol/m^2.s) >Rl (0.71 μmol/m^2.s) >Rm (0.27 μmol/m^2.s) and Rm showed stable. In Fig. 3-III, soil respiration components average changes of 19a were shown that: Rh (1.20 μmol/m^2.s) >Rr (0.94 μmol/m^2.s) >Rl (0.88 μmol/m^2.s) >Rm (0.31 μmol/m^2.s). As shown in Fig. 3-IV, the average of soil respiration components at 33 years displayed that: Rh (0.96 μmol/m^2.s) >Rr (0.83 μmol/m^2.s) >Rl (0.51 μmol/m^2.s) >Rm (0.45 μmol/m^2.s).

Sensitivity analysis between soil respiration rate and soil temperature, moisture in rubber plantation at different stand ages: In order to explore the effect of hydrothermal factors on soil respiration rate, fitting analysis (Table 3) was carried out among 0~-10 cm soil temperature with -5 cm soil water content and soil respiration rate.

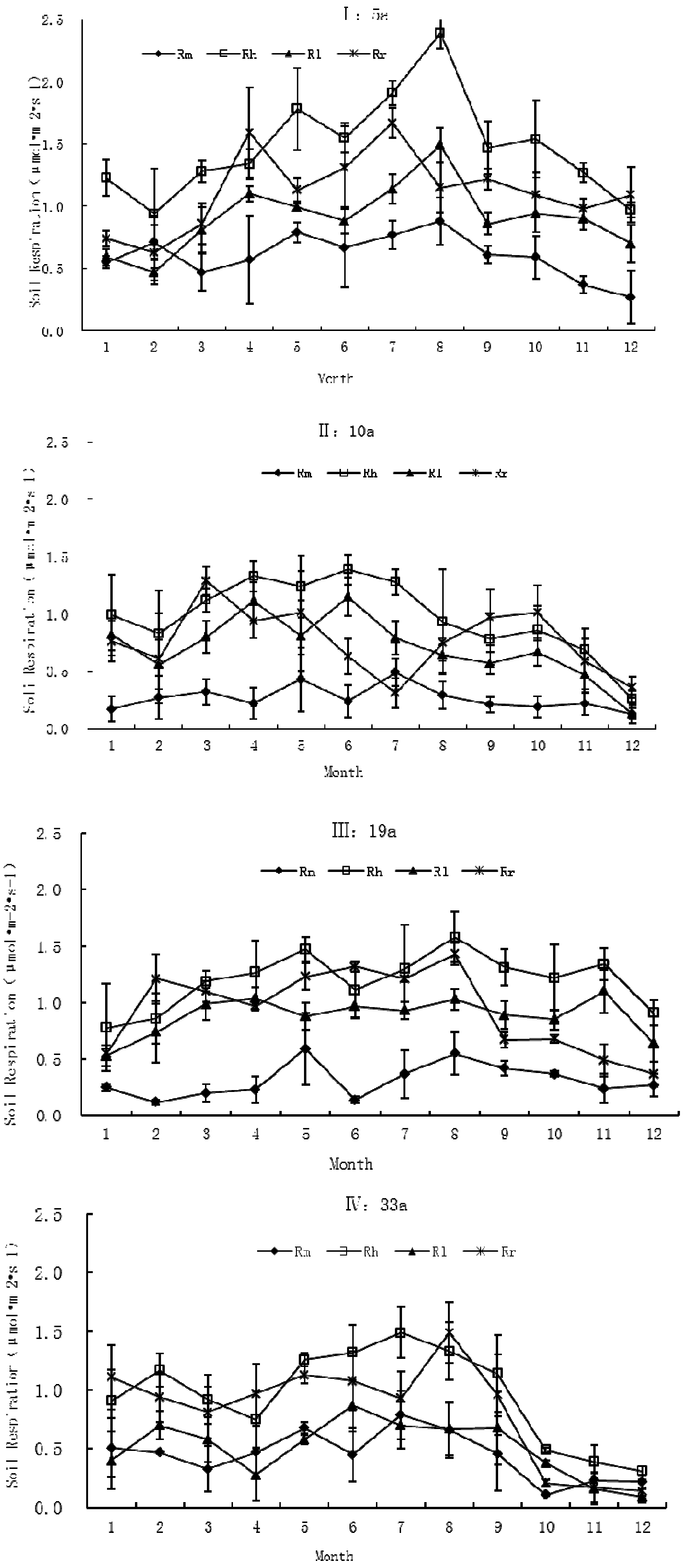

Fig. 3: Monthly changes of soil respiration components in rubber plantations at different stand ages; Rh, Rr, Rl and Rm as shown in Table 2. The following description is the same

Table 3: Correlation fitting analysis among soil respiration rate with soil temperature and humidity

		0~-10 cm soil temperature			-5 cm soil water content	
Stand	Research period	Fitting equation	R^2	Q_{10} Value	Fitting equation	R^2
5a	drought season	$Rs = 1.138e^{0.6511T}$	0.6175**	1.92	$Rs = 13.2451e^{0.0841X}$	0.2571***
	Rainy season	$Rs = 0.9213e^{0.1987T}$	0.5534*	1.22	$Rs = 13.7536e^{0.00837X}$	0.2763***
10a	drought season	$Rs = 1.351e^{0.2872T}$	0.7558**	1.33	$Rs = 14.8572e^{0.0784X}$	0.2157***
	Rainy season	$Rs = 1.2175e^{0.5689T}$	0.7491*	1.77	$Rs = 14.5741e^{0.07425X}$	0.2364***
19a	drought season	$Rs = 1.2015e^{0.8647T}$	0.8955**	2.37	$Rs = 15.2451e^{0.04627X}$	0.3109*
	Rainy season	$Rs = 1.395e^{0.1257T}$	0.8791**	1.14	$Rs = 15.8935e^{0.0233X}$	0.3365***
33a	drought season	$Rs = 1.257e^{0.8174T}$	0.7541**	2.26	$Rs = 15.6771e^{0.06824X}$	0.1794*
	Rainy season	$Rs = 1.079e^{0.0974T}$	0.7425*	1.10	$Rs = 15.8537e^{0.06274X}$	0.1825***

1. T for 0~-10 cm soil temperature (℃); X for -5 cm soil volumetric water content (%); 2. *: Significant difference ($p< 0.05$); **: Extremely significant difference ($p< 0.01$); ***: No significant difference ($p\geq 0.05$)

Table 4: Annual carbon emissions content of soil respiration and its components in rubber plantation of different stand ages ($t/hm^2.a$)

Component of soil respiration	Annual emissions of carbon flux ($t/hm^2.a$)			
	5a	10a	19a	33a
Mineral soil respiration rate (Rm)	1.030 (10.27)	0.8500(8.220)	0.7900(6.605)	0.9100(8.2056)
Heterotrophic respiration rate (Rh)	3.850 (35.70)	3.930 (38.00)	4.220 (35.28)	5.850 (52.75)
Roots respiration rate (Rr)	3.210 (32.00)	3.530(34.14)	4.780 (39.97)	2.410 (21.73)
Litter respiration rate (Rl)	1.94 0(19.34)	2.030 (19.63)	2.170 (18.14)	1.920 (17.13)
Soil respiration rate (Rs)	10.03	10.34	11.96	11.09

Figures in brackets refer to the percentage contribution of each component accounting for the total annual carbon emission flux of soil respiration in rubber plantation of different stand ages

selecting distinct drought and wet seasons' data. The results showed that, in the drought season there was extremely significant correlation ($p<0.01$) between soil respiration rate and 0~-10 cm soil temperature in different ages rubber plantation and in the humid rainy season, significant correlation ($p<0.05$) between them. And generally, there was no significant correlation ($p\geq 0.05$) between soil respiration rate and -5 cm soil moisture.

The contribute of each component to the total annual carbon emission of soil respiration in rubber plantation ecosystem at different stand ages: The annual amount estimate of each component carbon emissions were shown in Table 4 after measuring in situ and separating and qualifying all the components. The carbon emissions of soil respiration components in rubber plantation ecosystem were in the order: soil heterotrophic respiration>root respiration>litter respiration>mineral soil respiration.

DISCUSSION

Monthly changes and impact factors of the soil respiration in rubber plantation: In this study, it was found that soil respiration rate in different stand ages rubber plantation showed obvious monthly variation in different growing seasons. And it was consistent with a lot of research have significant seasonal dynamics (Yang, 2004; Billings *et al.*, 1998; Rustad *et al.*, 2000; Carbone *et al.*, 2011; Kukumägi *et al.*, 2011) in soil respiration. Here, the Q10 value was 1.14 to 2.37, the average value 1.64 lower than the world average of 2.4 (Raich *et al.*, 1992). Temperature affected by understory vegetation growth and land use cover changes and the soil thermal conductivity caused by the soil physical and chemical properties in different stand ages rubber plantation, will lead to a difference response of soil respiration rate to the temperature in day and night change. High leaf area index, canopy density and more understory vegetation cover, etc. reduced the sensitivity of soil temperature to air temperature. And in addition, the differences of soil organic carbon content, litter decomposition rate and biological the diversity in rubber forest may affect the pattern of soil respiration diurnal variation.

Some studies have shown that there were direct and dynamic contacts between substrate supply from the ground parts or canopy photosynthesis and underground soil respiration (Högberg, 2001; Reichstein *et al.*, 2003; Wan *et al.*, 2003; Verburg *et al.*, 2004). Semicircle girdling to the rubber stems cut off the supply of photosynthesis carbon to the roots from the ground parts during 10-15 times tapping each month of 7a rubber plantation after June. And in addition, affected by tropical oceanic monsoon climate and terrain, the drought and rainy seasons in the west of Hainan Island was obvious, soil moisture content too high or too low was frequent in the study area and so increasing rainfall variability reduced the Q10 value (Harp *et al.*, 2005), which may be one of the reasons of the soil respiration rates and Q10 value in rubber forest is lower than the world average value or other forest ecosystems.

In the study area, there is more precipitation from June to September and hydrothermal conditions are better suitable for the activities of soil microorganisms and roots in July and August, soil respiration rate reached the peaks in the rubber forest at different stand ages. The soil respiration rate of rubber forest changes seasonally accompanied by changes in soil temperature and humidity, but the continuous rainy in summer will limit soil respiration and offset the role of temperature increasing on soil respiration. There was no obvious correlation between soil moisture and soil respiration, no-root respiration and root respiration in the four rubber forest. This may be due to the relatively abundant rainfall in the region, water was not the key factor limiting soil respiration and the effect of moisture on soil respiration often was covered by the effect of temperature. From November, as the temperature decreasing, the microbial metabolic activities declined sharply, the microbial respiration changes similarly with the seasons in rubber forest, which was lower in January, February, November and December. And with the temperature elevating, microbial respiration increased, the maximum occurred in August. To the 5a rubber plantation, because of uneven ground, more soil gravel, better soil permeability and weak water-holding capacity, even if the rainfall is heavy, the water is easy to drain and no excessive soil moisture will affect root respiration. From June to August, water and heat conditions are better for root and microbial activities and respiratory metabolism will show an increasing trend in the emission flux of soil respiration. In July and August, rubber trees grow very lushly, underground roots and microbial activity enhance with a more appropriate water and heat and the CO_2 emission of the rubber plantation soil surface reached the highest value.

During the measurement time, lower soil temperature and humidity limited rubber root and microbial activity and so soil respiration was weak in January, November and December. From March to May, with the increasing in temperatures and rubber forest LAI (leaf area index), carbon metabolism rate in rubber plantation ecosystem increased rapidly, too. And from June to September, rubber soil surface CO_2 flux reached the strongest, which was the major significance to the soil carbon budget of the whole year. With the little change of LAI in the tapping period, water and temperature became the key factors determining the soil carbon budget. Mutual compensation effects of temperature and precipitation, the summer litter decomposition and soil water content maintained the suitable roots and microorganisms, therefore, in the hot and rainy summer, the soil carbon emission flux of rubber forest was at a high level of the whole year. Han *et al.* (2008) reported that the effect of water to soil respiration often overshadowed by temperature during the abundant rainfall seasons in their research of four forest soil respiration and environmental factors in Changbai Mountain. In the more humid September-October, precipitation events may produce significant inhibition to soil respiration and from November to the next March, soil respiration was likely to be restrained by the long-term drought stress. In the alternating wet and dry from April to June, the sudden moments of heavy precipitation events after long-term drought may strongly stimulate soil respiration carbon emission, which caused soil carbon loss intensely in rubber plantation ecosystem.

The separation and quantification of soil respiration components in rubber plantation: In soil respiration processing, three biological processes (plant root autotrophic respiration, soil microbial and soil animals heterotrophic respiration) and a non-biological processes (chemical oxidation of carbon-containing minerals) (Singh *et al.*, 1977; Uchida, 2010) must be distinguished first and then the environmental response mechanism of the different components of soil respiration will be ascertained and their roles in the terrestrial ecosystems carbon cycle will be quantified. So, soil respiration components must be measured by different methods, either directly or indirectly and then to separate them. This study improved the method of soil respiration measurement and the four major components of soil respiration: soil heterotrophic respiration, root respiration, litter respiration and mineral soil respiration were separated by this approach. And at the same time, the measurement accuracy was improved too, because of measurement in situ without destroying the original soil and biological structure. It was simple and feasible using the morning data of soil respiration as the monthly average data (Wu *et al.*, 2011a). The soil respiration components in rubber plantation forest showed: soil heterotrophic respiration (Rh)> root respiration (Rr)> litter respiration (Rl)> mineral soil respiration (Rm). And the results were consistent with Bowden (1993) and Rey *et al.* (2002). The percentage contribution of soil respiration components accounted for the total annual carbon emissions flux in rubber plantation at different stand ages as: Rh: 35.28~52.75%, Rr: 21.73~39.97%, Rl: 17.13~19.63%, Rm: 6.605~10.27%. In this study of rubber plantation, the contribution of heterotrophic respiration was significantly higher than the other three components. The contribution of root respiration to total soil respiration in four stand ages rubber plantation amounted from 21.73 to 39.97%, which was slightly lower than Luo and Zhou's report (2006) 48.6% of an average proportion root respiration to forest vegetation. The possible reasons were the vegetation types studied, measurement methods, spatial and temporal differences and climate conditions and so on.

CONCLUSION

Soil respiration components in rubber plantation at different stand ages: The order of soil respiration components in rubber plantation at different stand ages was: soil heterotrophic respiration> root respiration> litter respiration> mineral soil respiration. The total soil respiration rate (Rs) of the four rubber plantation in different growth seasons changes significantly monthly of the whole year. The Rs rate reaches the maximum in August and minimum in November and December.

Carbon emissions of soil respiration and its components in rubber plantation at different stand Ages: There is no significant mutual difference between the soil respirations in rubber plantation at different stand ages. The amount of carbon emissions in 5a, 10a, 19a and 33a rubber plantation are 10.03, 10.34, 11.96 and 11.09 t/hm^2.a, respectively. And carbon emissions of soil respiration components show as: emissions flux of Rh> of Rr> of Rl> of Rm.

Soil respiration carbon emissions of rubber plantation at different ages: There is a relative increasing trend accompanied by the increase of forest age in the whole year soil respiration emission flux of rubber plantation at different stand ages. And the annual carbon emission value of 5a, 11a, 19a and 33a rubber forest are 10.03, 10.34, 11.96 and 11.09 t/hm^2.a. Of course, the emission of old rubber ecosystem may be a little low due to the low LAI or other reasons.

There is important scientific significance to reveal the rubber plantation carbon soil/sinks function changes with accurately quantify soil carbon components and carbon emissions of the soil carbon pool. Soil respiration is a complex biological and ecological processes which affected by many factors and constraints. Comprehensive analysis and consider the impact of various factors on soil respiration and accurately assess the size of the effects, we will understand fully soil carbon budget response to the current rubber planting environment, learn more about environmental factors affecting the rubber plantation soil carbon balance and ultimately provide the basic data for the establishment of a rubber plantation ecosystem carbon sink trade and for government decision-making.

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REFERENCES

Billings, S.A., D.D. Richter and J. Yarie, 1998. Soils carbon dioxide fluxes and profile concentrations in two boreal forest. Can. J. Forest Res., 28: 1773-1783.

Bond-Lamberty, B., C. Wang and S.T. Gower, 2004. A global relationship between the heterotrophic and autotrophic components of soil respiration. Glob. Change Biol., 10: 1756-1766.

Bowden, R.D., 1993, Contributions of above-ground litter, below-ground litter and root respiration to total soil respiration in a temperate missed hardwood forest. Can. J. Forest Res., 23: 1402-1407.

Carbone, M.S., C.J. Still, A.R. Ambrose T.E. Dawson, A.P. Williams et al., 2011.Seasonal and episodic moisture controls on plant and microbial contributions to soil respiration. Oecologia. 167: 265-278.

Davidson, E.A., E. Belk and R.D. Boone, 1998. Soil water content and temperature as independent or confound factors controlling soil respiration in a in a temperature mixed hardwood forest. Glob. Change Biol., 4: 217-227.

Fang, J. Y., S. L. Piao and S. Q. Zhao, 2001. The carbon sink: The role of the middle and high latitudes terrestrial ecosystems in the northern hemisphere. Acta Phytoecologica Sinica, 25: 594-602. (In Chinese with English abstract)

Fang, J. Y. and W .Wang, 2007. Soli respiration as a key belowground process: Issues and perspectives. Acta Phytoecologica Sinica, 31: 345-347. (In Chinese with English abstract)

Gomez, C.N., R . Matamala, D.R. Cook and M.A. Gonzalez-Meler, 2012. Net ecosystem exchange modifies the relationship between the autotrophic and heterotrophic components of soil respiration with abiotic factors in prairie grasslands. Glob. Change Biol. 18(8):2532-2545.

Guan, L., Z. Wu, C. Yang, G. Xie and Z. Zhou, 2012. Soil Organic Carbon Pool and Its Influencing Factors in Rubber Planted Forest Ecosystem at Different Ages in West Hainan Province. Agr. Sci. Technol.13: 2163-2168.

Han, S., Y. Dong, Z. Cai *et al*., 2008. Carbon Cycle and Biogeochemical Process of Chinese Terrestrial Ecosystem. Sciences Press, Beijing: 185-192 (In Chinese).

Hanson, P. J., N. Edwards, C.T. Garten and J.A. Andrews, 2000. Separating root and soil microbial contributions to soil respiration: A review of methods and observations. Biogeochemistry, 48: 115-146.

Harper, C.W., J.M. Blair, P.A.Fay A. K. Knapp and J. D. Carlisle ,2005 . Increased rainfall variability and reduced rainfall amount decrease soil CO2 flux in a grassland ecosystem. Glob. Change Biol. 11: 322-334.

Högberg, P., A. Nordgren, N. Buchman, A.F.S. Taylor A. Ekblad *et al*, 2001. Large-scale forest girdling shows that current photosynthesis drives soil respiration. Nature.411:789-792.

Keutgen, N. and M. Huysamer, 1998. Soil respiration in adjacent pear and citrus orchards. J. South. Afr. Soc. Hortic. Sci., 8:15-17.

Kukumägi, M., V. Uri and O. Kull, 2011. Seasonal dynamics of soil respiration in a chronosequence of the Norway spruce stands.Forest.Stud.54:5-17.

Liu, S and J. Fang, 1997.Effect factors of soil respiration and the temperatures effects on soil respiration in the global scale. Acta Ecol. Sinica. 17: 469-476. (In Chinese with English abstract)

Luo, Y. and X. Zhou, 2006. Soil respiration and the Environment. Academic Press of Elsevier America., PP: 179-181.

Ojanen, P., K. Minkkinen, A. Lohila Badoreka T. and Penttiläc T, 2012. Chamber measured soil respiration: A useful tool for estimating the carbon balance of peatland forest soils.Forest Ecol.Manag.277:132-140.

Raich, J.W. and W. H . Schlesinger, 1992. The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. Tellus B.44: 81-99.

Reichstein, M., A. Rey, A. Freibauer and J. Tenhunen, R. Valentini *et al*., 2003. Modeling temporal and large-scale spatial variability of soil respiration from soil water availability, temperature and vegetation productivity indices. Glob. Biogeochem. Cycles., 17(4): 1104, Doi: 10.1029/2003GB002035.

Rey, A., E. Pegoraro, V. Tedeschi, I.D. Parri, P.G. Jarvis *et al*., 2002. Annual variation in soil respiration and its components in a coppice oak forest in Central Italy.Glob. Change Biol ,8(9): 851-866.

Rustad, L. E., T. G. Huntington and R.D.Boone ,2000. Controls on soil respiration : Implications for climate change. Biogeochemistry, 48:1-6.

Schlesinger, W. H. and J. A. Andrews, 2000. Soil respiration and the global carbon cycle.Biogeochemistry, 48: 7-20.

Sedjo, R. A, 1993. The carbon cycle and global forest ecosystem. Water Air Soil Pollut.70:295-307.

Singh, J. S. and S. R. Gupta, 1977. Plant decomposition and soil respiration in terrestrial ecosystems. Bot. Rev.43:449-528.

Subke, J. A. and J. D.Tenhunen ,2004. Direct measurements of CO2 flux below a spruce forest canopy.Agr. Forest Meteorol.126:157-168.

Uchida, Y, 2010. The effects of substrate, temperature and soil fertility on respiration and N_2O production in pastoral soils. Ph.D. Thesis, Lincoln University, pp: 1-156.

Verburg, P. J., J. A. Arnone, D. Obrist and *et al*., 2004. Net ecosystem carbon exchange in two experimental grassland ecosystems.Glob. Change Biol.10:498-508.

Wan, S. and Y. Luo , 2003. Substrate regulation of soil respiration in a tallgrass prairie: Results of a clipping and shading experiment. Glob. Biogeochemical cycles, 17(2): 1054, Doi: 10.1029/2002GB001971.

Wu, Z., Z. Zhou, G. Xie *et al*., 2011a. A method for determination of soil respiration in rubber forest: China, CN101949919A, 1: 19. (In Chinese)

Wu, Z., G. Xie, B. Chen *et al*., 2011b. Fluxes Footprint and Source Area of Rubber Plantation. Agr. Sci. Technol.12:1937-1942.

Wu, Z., G. Xie, Z. Tao *et al*., 2010a. Characteristics of Soil Organic Carbon and Total Nitrogen in Rubber Plantations Soil at Different Age Stages in the Western Region of Hainan Island. Agr.Sci.Technol.11:147-153.

Wu, Z., G. Xie, C. Yang *et al*., 2010b. Characteristics of Microclimate and Flux of a Rubber Plantation Ecosystem in Dry Season of Hainan Island, South China. Chinese J.Trop.Crops.31:2081-2090.(In Chinese with English abstract)

Xu, M. and Y. Qi, 2001. Soil-surface CO2 efflux and its spatial and temporal variations in a young ponderosa pine plantation in northern California. Glob. Change Biol. 7:667-777.

Yang, Y., B. Dong , J. Xie *et al*., 2004. Soil respiration of forest ecosystems and its respondence to global change. Acta Ecologica Sinica, 24: 583-591 .(In Chinese with English abstract)

Yi, J., G. Xie, J. Wang *et al*., 2012. Stem Respiration of Rubber Tree of Different Strains and Different Girth. J. Anhui Agric.Sci.40:13433-13436. (In Chinese with English abstract)

Zimmermann, M., P. Meir, M. I. Bird *et al*., 2010. Temporal variation and climate dependence of soil respiration and its components along a 3000 m altitudinal tropical forest gradient. Glob. Biogeochemical Cycles. 24(4):DOI: 10. 1029/ 2010GB003787.