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# Soil organic carbon in pure rubber and tea-rubber plantations in South-western China

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**Abstract:** Rubber tree (*Hevea brasiliensis*) plantation is a major land use practiced in Xishuangbanna of south-western China. Effects of rubber plantation (RP) and tea-rubber intercropping (TRI) systems on soil organic carbon pools were evaluated by recording changes in soil organic carbon in an age sequence of 12-, 20-, 26-, and 40-year old plantations. Labile organic carbon (LOC) increased in surface soils (0-10 cm) with aging of rubber plantation and tea-rubber intercropping stands. Total organic carbon (TOC) in the soils did not change between stand ages of 12 and 20 years, however it decreased at the 26-year old stand. The TOC increased remarkably in tea-rubber intercropping tea-row soils but remained low in the rubber plantations and tea-rubber intercropping rubber-row soils at the 40-year stand. The TOC did not show much difference between in tea-rubber intercropping rubber-row and rubber plantations at the 40-year stand, but these values were much lower than that in tea-rubber intercropping tea-row soils. The LOC and its turnover rate, and the ratio of LOC:TOC in tea-rubber intercropping rubber-row soils were lower than those in tea-rubber intercropping tea-row soils and rubber plantations. This study suggests that tea-rubber intercropping tends to sequestrate higher atmospheric carbon in soils than rubber monoculture through increased organic carbon pools in the tea-row soils and reduced organic carbon turnover rates in the rubber-row soils.

**Resumen:** La plantación de árboles de caucho (*Hevea brasiliensis*) constituye uno de los principales usos del suelo en Xishuangbanna, en el suroeste de China. Se evaluaron los efectos de los sistemas de plantación de caucho (PC) y de plantaciones mixtas de té-caucho (PTC) sobre el almacén de carbono orgánico del suelo a través del registro de los cambios en el carbono orgánico del suelo en una cronosecuencia de plantaciones con edades de 12, 20, 26 y 40 años. El carbono orgánico lábil (COL) aumentó en los suelos superficiales (0-10 cm) conforme aumentó la edad de las plantaciones puras de caucho y las mixtas de té-caucho. El carbono orgánico total (COT) en los suelos no cambió entre los rodales de 12 y 20 años de edad, pero disminuyó en el rodal de 26 años. El COT aumentó notablemente en los suelos de las hileras de té de las plantaciones mixtas té-caucho, pero permaneció bajo en las plantaciones de caucho y en el suelo de las hileras de caucho de las plantaciones mixtas en el rodal de 40 años. El COT no difirió grandemente entre las hileras de caucho en las plantaciones mixtas de té-caucho y en las plantaciones de caucho en el rodal de 40 años, pero estos valores fueron mucho más bajos que los registrados en los suelos en las hileras de té en la plantación mixta. El COL y su tasa de

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recambio, y el cociente COL:COT en los suelos de las hileras de caucho en las plantaciones mixtas fueron más bajos que en los suelos de las hileras de té en dichas plantaciones y en las plantaciones de caucho. El presente estudio sugiere que la mezcla de té-caucho tiende a secuestrar en el suelo una mayor cantidad de carbono atmosférico que el monocultivo de caucho, incrementando el carbono orgánico en los suelos de las hileras de té y reduciendo las tasas de recambio de carbono orgánico en los suelos de las hileras de caucho.

**Resumo:** A plantação de borracheiras (*Hevea brasiliensis*) é um dos principais usos do solo em Xishuangbanna, sudoeste da China. Avaliou-se os efeitos dos sistemas de plantação das árvores de borracha (RP) e de plantações mistas chazeiros-borracheiras (TRI) no teor de carbono orgânico do solo através do registo das mudanças daquele teor no solo numa sequência de idades de plantação com 12, 20, 26 e 40 anos. O carbono orgânico lábil (LOC) aumentou na superfície do solo (0-10cm) com o aumento da idade das plantações puras de borracheiras e das plantações mistas chazeiros-borracheiras. O carbono orgânico total (TOC) nos solos não sofreu alterações nas parcelas com idades compreendidas entre os 12 e os 20 anos, diminuiu, contudo, nas parcelas de 26 anos de idade. O TOC aumentou consideravelmente nas filas de chazeiros nas plantações mistas chazeiros-borracheiras, mas permaneceu baixo nas plantações de borracha e nas filas de plantação das borracheiras nas plantações mistas nas parcelas com 40 anos, mas estes valores foram muito mais baixos do que os encontrados nas fileiras dos chazeiros. O LOC e a taxa de circulação, bem como a taxa LOC:TOC nos solos das fiadas de borracheiras nas plantações mistas foram menores do que as encontradas por seu turno, nas fiadas dos chazeiros. Este estudo sugere que a mistura de chazeiros-borracheiras tende a sequestrar um valor de carbono orgânico mais elevado do que a plantação pura de borracheiras, incrementando o carbono orgânico no solo nas fileiras dos chazeiros e reduzindo as taxas de libertação de carbono no das fileiras das borracheiras.

**Key words:** Carbon turnover rate, labile organic carbon, rubber and tea plantations, soil carbon, stand age, total organic carbon.

## Introduction

Soils in the tropics are recognized to play an important role in sustaining global food production and regulating carbon cycling (Sanchez 2002; Wood *et al.* 2000). Tropical areas are characterized by high risk of soil and environmental degradation because of rapid decomposition of soil organic matter under favorable environmental conditions. Thus, possible nutrient depletion and loss of soil organic matter are of great concerns for ecologists and resource managers.

Rubber trees form an important economic plant with high cash values in China. Varieties of rubber trees have widely been planted in tropical Hainan, Yunnan, and Guangdong provinces in China. Rubber tree plantation is a major land management practice in Xishuangbanna of Yunnan province in southwestern China. There is $1.3\times10^5$ ha of rubber plantations in Xishuangbanna, which accounts for approximately 14% of the forest lands in the region and 6% of the total land area (XBF 2001). For promoting ecosystem sustainability and increasing the economic returns in the region, another cash crop in the form of tea plants were introduced into pure rubber plantations in modified tea-rubber intercropping systems during 1960's (Feng *et al.* 1982; Hao 1991; Shan & Zhong 1988). The tea-rubber intercropping was found to be ecologically sound system compared to rubber plantation monoculture because the tea-rubber intercropping reduced the outbreak of pests and increased soil fertility (Feng *et al.* 1982; Ma 1994; Wang & Li 2003).

Forest tree plantations on arable lands has been shown to be an effective way to enhance carbon sequestration (Johnsen *et al.* 2001; Zilberman & Sunding 2001). Since 1970's, the local and national governments of China started implementing "Ecological Restoration Projects in Xishuangbanna" that resulted into reduced rates of native forest clearing while increasing forest tree plantations. Consequently, forest cover increased from 34% in 1975 to 59% in 1995, although a large proportion of the increased areas were secondary forests and commercial plantations (Tang *et al.* 1998). However, more recently, the appropriateness of commercial plantations in terms of their carbon sequestration potentials are questioned. Soil carbon sequestration is a complex process, affected by many factors such as vegetation type, climate, soil microbes, management, and land-use practices. Results from many studies showed that rubber plantation decreased soil organic carbon (Araujo *et al.* 2005; Duah-Yentumi *et al.* 1998; Jiao & Yang 1999; Li & Yan 2001; Schroth *et al.* 2002; Yang *et al.* 2004; Zhang & Zhang 2003). In contrast, studies by Wang & Li (2003) and Yang *et al.* (2005) have demonstrated that rubber plantation could potentially enhance soil carbon sequestration.

Most researches in the past compared total soil organic carbon pools only between mature plantations and native forest or immature plantations (Araujo *et al.* 2005; Duah-Yentumi *et al.* 1998; Jiao & Yang 1999; Li & Yan 2001; Schroth *et al.* 2002; Wang & Li 2003; Yang *et al.* 2004, 2005; Zhang & Zhang 2003). Such comparisons were useful, but did not address the quality changes in soil organic carbon levels during the entire rubber plantation cycle. Furthermore, there was little information on potential carbon sequestration capacity associated with intercropping agroforestry systems.

This study was designed to examine: (i) changes in soil organic carbon pools (labile organic carbon and total organic carbon) in an age sequence of rubber plantations and tea-rubber intercropping systems, and (ii) differences in soil carbon pools between rubber plantations and tea-rubber intercropping system. Labile organic carbon and its potential turnover rates were used as indicators to evaluate changes in the soil quality.

## Material and methods

The study sites were located in the Xishuangbana Tropical Botanical Gardens in Yunnan Province of China. This region receives an average annual precipitation of 1560 mm of which 80% are received between May and October (wet season). Average annual temperature is 21.4°C. The study area is located at 21°56′N, 101°15′E with an elevation of 550 m asl (Tang *et al.* 1998). This region has experienced large scale deforestation during the last several decades and conversions of forest to agriculture land and rubber plantation are commonly practiced.

Soil samples were randomly collected in replicates of three for each of the 12-, 20-, 26- and 40-year old rubber plantations (RP) and tea-rubber intercropping (TRI) during the wet season. Each soil sample from a site was a composite of three soil cores separating into surface soil (0-10 cm) and lower soil (10-20 cm) depths. In the TRI, soils were sampled both in tea-tree rows (TRI-T) and rubber-tree rows (TRI-R). All the sampled plantations were located in the same ravine rain forest area within a distance of one kilometer. Soil samples were analyzed for labile organic carbon (LOC) using a sequential fumigation-incubation method with fresh soils that passed a 2-mm pore size sieve. The total organic carbon (TOC) was estimated using air dried soil samples that was grounded and sieved through 60 mesh.

The TOC was estimated by $H_2SO_4$-$K_2Cr_2O_7$ oxidation method (Li 1983). Since there was no detectable inorganic carbon in the acidic soils treatment of soils with acids prior to the analyses was not necessary. Sequential fumigation-incubation procedure was used for estimating soil LOC pools and turnover time (Zou *et al.* 2005). For estimating soil LOC, the fumigated sub-samples were subjected to the fumigation-incubation procedure for a total of 5 cycles. Carbon dioxide evolved from the first and the subsequent incubations of the fumigated soils was used for estimating labile organic carbon.

Statistical analyses were performed by using SPSS 12.0 programme. Two-way ANOVA were performed by taking age (12, 20, 26 and 40-year old) and crop management systems (RP, TRI-T, and TRI-R) as independent variables. Dependent variables included LOC, TOC and turnover rate of LOC.

## Results

### *Soil organic carbon*

LOC and TOC varied among stand age groups (Table 1). LOC content tended to increase as plantations aged in surface soils (0-10 cm) and tended to decrease between stand age 12 and 26 which increased afterwards in the lower soil (10-20 cm) depth. The TOC levels in both surface and lower soils were lowest at stand age of 26-year old. The TRI-T soils showed the highest levels of TOC at 40-year stand compared to the RP and TRI-R soils The TRI-R soils showed the lowest turnover rate of LOC, much lower than the RP and TRI-T stand soils.

TOC in surface soils ranged from 12.91 g $kg^{-1}$ in the 26-year stand of TRI-T to 23.98 g $kg^{-1}$ in 40-year old TRI-T (Fig. 1). In RP and TRI-R samples, TOC in soil of 26- and 40-year old plantations were similar to be were lower than that in the other two younger plantations. In the case of TRI-T, TOC in the 40-year old plantation increased greatly and was higher than that in the 12- and 26-year old plantation by 49% and 86%, respectively. In addition, TOC in TRI-T in the 40-year old plantations was significantly higher than those in the same age of RP and TRI-R soils by 72% and 66%, respectively.

TOC was significantly higher in surface soil than that in lower soil depth. In 10-20 cm soil

**Table 1.** Analysis of variance for labile organic carbon and total organic carbon in soils of two management systems (a) rubber monoculture and (b) tea-rubber intercropping systems in an age sequence (12-, 20-, 26-, and 40-year old) of plantations.

| Soil carbon (g $kg^{-1}$) | Variance ratio and Significance | | | | | |
|---|---|---|---|---|---|---|
| | Age vs management | | Age | | Management | |
| | *F* | *p*< | *F* | *p*< | *F* | *p*< |
| 0-10 cm soil layer | | | | | | |
| Total Organic Carbon | 3.6 | 0.05 | 3.4 | 0.05 | 1.3 | NS |
| Labile Organic Carbon | 2.2 | NS | 6.8 | 0.05 | 2.9 | NS |
| 10-20 cm soil layer | | | | | | |
| Total Organic Carbon | 0.5 | NS | 3.9 | 0.05 | 2.3 | NS |
| Labile Organic Carbon | 1.6 | NS | 3.4 | 0.05 | 0.3 | NS |

NS = Not significant

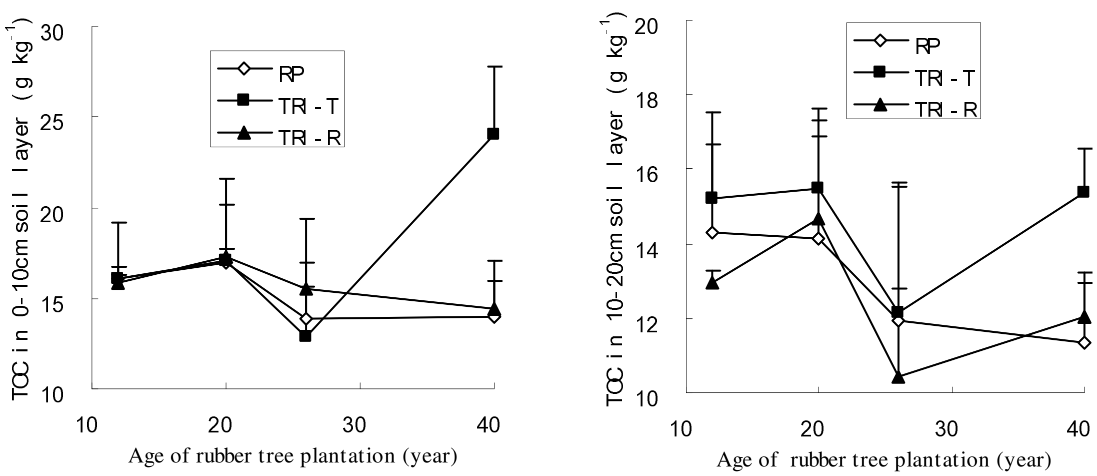


**Fig. 1.** Total organic carbon (TOC) in soils of rubber plantations (RP) and tea-rubber intercropping for tea row (TRI-T), and tea-rubber intercropping for rubber row (TRI-R) in an age sequence (12-, 20-, 26-, and 40-year old) of plantations.

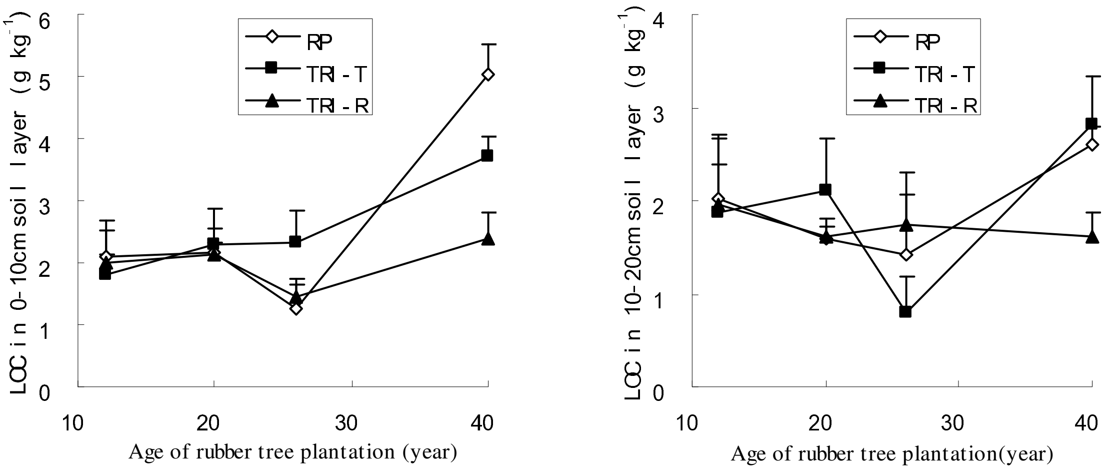


**Fig. 2.** Labile organic carbon (LOC) in soils of rubber plantations (RP) and tea-rubber intercropping for tea row (TRI-T), and tea-rubber intercropping for rubber row (TRI-R) in an age sequence (12-, 20-, 26-, and 40-year old) of plantations.

depth, TOC increased from 15 to 27% in the 40-year old TRI-T as compared to that of the 26-year old TRI-T sample. The values were also higher than that of the same stand age of RP and TRI-R soils by 36% and 28%, respectively.

LOC in surface soils of TRI-T increased with increasing plantation ages (Fig. 2). However, LOC decreased in 10-20 cm soil depth of the 26-year old plantation which rose to higher values in the 40-year old plantations. LOC in both soil layers of 26 years old RP showed the lowest levels of 1.25 and 1.43g $kg^{-1}$, respectively. The values increased sharply and reached the highest levels (5.02 and 2.6 g $kg^{-1}$) in the 40-year old plantation. In the younger plantations below 40 years, LOC in RP and TRI-R were similar, however, at 40-year stand LOC in RP was greater than that in TRI-R.

### *Potential turnover of soil labile organic carbon*

The differences in potential turnover rate (k) of soil LOC between plantations of various ages were not significant because of large SE values (Table 2). Potential turnover rate (k) of LOC in surface (0-10 cm) soils ranged from 0.13 in the 26-year old TRI-T soils to 1.06 in the 40-year old RP soils. For lower depth (10-20 cm) soils, they ranged from 0.16 in the 26-year old RP soils to 0.65 in the 40-year old TRI-T soils. Corresponding with potential turnover rate the turnover times ranged from 76 to 10 days in surface (0-10 cm) soils and 63 to15 days in lower depth (10-20 cm) soils. LOC in the 40-year old TRI-T and RP turned over faster than in younger plantations. The turnover rate of TRI-R soils was the lowest compared to the RP and TRI-T soils at 40-year old plantation.

### *Ratio of LOC to TOC*

Ratios of LOC to TOC changed in a similar pattern as that of LOC along the stand age sequence. LOC to TOC ratio in surface (0-10 cm) soils of TRI-T increased slightly as plantation aged, while that in lower depth (10-20 cm) soils it decreased sharply in the 26-year-old plantation. It again increased at 40-year old plantation stand. The ratio of LOC to TOC in both soil depths of RP reached the highest level at 40-year stand, 36% and 23%, respectively. The ratio of LOC to TOC in TRI-R remained unchanged from age 12 through the age of 40-year stand.

## Discussion

Zhang & Zhang (2003) found that soil microbial biomass carbon of rubber tree plantations decreased by 56% when latex were collected at age of eight in Hainan Province, China. Soil TOC also decreased but the difference was not significant. This low level in soil microbial biomass carbon remained unchanged until the age of ten; however, when soil microbial biomass

**Table 2.** Potential turnover time (10/*k*) and rate (*k*) of soil labile organic carbon and the ratio of LOC to TOC in two soil depths (a) 0-10 cm and (b) 10-20 cm estimated by the sequential fumigation-incubation method.

| Age | Management Systems | *k* | | 10/*k* | | LOC/TOC (%) | |
|---|---|---|---|---|---|---|---|
| | | a | b | a | b | a | b |
| 12 | RP | 0.32 | 0.48 | 31.1 | 20.6 | 12.93 | 14.19 |
| | TRI-T | 0.26 | 0.20 | 37.9 | 50.0 | 11.21 | 12.35 |
| | TRI-R | 0.57 | 0.49 | 17.5 | 20.5 | 12.60 | 15.14 |
| 20 | RP | 0.25 | 0.26 | 40.6 | 39.0 | 12.85 | 11.20 |
| | TRI-T | 0.24 | 0.25 | 42.0 | 39.6 | 13.44 | 13.61 |
| | TRI-R | 0.29 | 0.34 | 34.0 | 29.3 | 12.27 | 11.01 |
| 26 | RP | 0.38 | 0.16 | 26.4 | 62.5 | 8.87 | 11.72 |
| | TRI-T | 0.13 | 0.47 | 76.0 | 21.3 | 17.35 | 6.46 |
| | TRI-R | 0.33 | 0.18 | 30.7 | 57.0 | 9.37 | 16.66 |
| 40 | RP | 1.06 | 0.65 | 9.5 | 15.3 | 35.95 | 22.94 |
| | TRI-T | 0.71 | 0.65 | 14.2 | 15.3 | 15.46 | 18.38 |
| | TRI-R | 0.49 | 0.24 | 20.3 | 41.2 | 16.61 | 13.40 |

carbon increased the soil TOC continued showing the decreasing trend.

In this study, the soil organic carbon pools continued to decrease until the 26-year plantation stand then increased to reach the highest level at the 40-year old plantation stand. This change in soil organic pools corresponded negatively with latex yield which started at the age of seven in these stands, maximized at the 20-year plantation, and ceased typically at 35-year old stand. The removal of rubber latex might have caused the decline in soil organic carbon pools between ages 12 and 26, whereas the recovery of soil organic pools at age 40 might have resulted from the ceased or reduced harvesting of rubber latex.

In the research about soil carbon sequestration of rubber tree plantation established on former arable land, Yang *et al.* (2005) found rubber plantation enhanced carbon sequestration where higher carbon stock was recorded at the 21-year old rubber plantation. The results showed that soil TOC increased indicating carbon sequestration before rubber tapping. The carbon sequestration decreased significantly at early stages of latex tapping which stabilized during the continuous harvesting and finally increased when latex harvest ceased. It can be inferred that the latex yield greatly affects soil carbon levels and sequestration.

Wang & Li (2003) reported that TRI-T showed higher respiration rate than TRI-R, and TRI had greater soil microorganisms than RP in four-year old plantations. However, this study results showed that the soil LOC in TRI–R changed slowly as plantations aged unlike the RP and TRI-T soils at 40-year old stand. This low level of LOC in TRI-R soils might be due to the continuously higher latex harvest compared other management stands. Reduction in latex yield in RP system at later age might have resulted in the increase of below-ground organic carbon input, whereas TRI-T soils was expected to have additional carbon input from tea plants.

At ages 10, 20 and 26, there were no differences in TOC between TRI-R and TRI-T soils. However, at age 40, TOC in TRI-T soils increased significantly whereas soils in TRI-R did not show much change. These results indicate that soil TOC in TRI-T was more sensitive to rubber latex harvesting than in TRI-R and the accumulation of soil organic matter in rubber tree rows was slower than that in the tea rows during the period from 26- to 40-year plantations.

Furthermore, the ratio of LOC to TOC and the turnover rate of soil LOC in TRI-R were much lower than those in the RP at 40-year plantation. Our study results suggest that tea-rubber intercropping systems were superior to rubber monocultures in sequestrating atmospheric carbon dioxide both by increasing soil organic carbon levels and reducing the turnover rates of LOC.

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