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Carbon stock assessment under different ages of rubber tree plantation

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Abstract

Rubber tree is an important economic crop which has created economic value of Thailand. Soil acts as one of important component of the global carbon cycle as they store large amounts of organic carbon. In addition, soil organic carbon and soil organic matter are crucial component for soil quality and productivity assessment. However, they probably sensitive to plant age, ecosystem management and climate change. The objective of this study was to investigate the effect of different rubber tree plantation ages, including 1) 3 years rubber tree plantation (3Y), 2) 11 years rubber tree plantation (11Y), 3) 17 years rubber tree plantation (17Y) and 4) 27 years rubber tree plantation (27Y) on carbon stock. The result suggested that different age of rubber tree plantation has an effect on carbon stock. The highest soil carbon stock was found in 17Y, but showed no significant different when compared to 27Y. The greatest above ground biomass was observed in 27Y. Interestingly, younger age of rubber tree showed that soil carbon stock was sequestered in the form of microbial biomass carbon, due to lowest qCO_2 was determined.

Keywords: Para rubber, plant age, carbon stock

1. Introduction

The rubber tree (*Hevea brasiliensis*) is an important economic crop which has created economic value of Thailand. In the last 30 years, rubber tree plantations are expanding rapidly into northeast Thailand with included different climate and also environment compare to southern Thailand which is the traditional area [1]. The northeastern region of Thailand has agricultural area of 15.90 million ha, of which 6.65 million ha are suitable for rubber plantation and nowadays, northeastern region of Thailand tends to be an important rubber production area for Thailand in the future [2].

Currently, there is a growing concern in the role of land use change from intensive annual cropping to rubber tree plantation on soil and environmental sustainability due to soil acts as an important component of the global carbon cycle as they store large amounts of soil organic carbon which plays an important role in maintaining fertility and enhancing crop productivity. Moreover, rubber tree plantation could also have a positive impact on soil functioning. However, cutting down unproductive rubber plants without environmental considerations probably affects on carbon stock above and below ground.

The aim of this study is to investigate the potential of carbon sequestration in different ages of rubber tree plantations. The finding of this study should be beneficial to recognize the amount of carbon accumulation in soil and also above ground for the purpose of soil and environment conservation.

2. Materials and Methods

2.1. Study sites

The study site was located in Tha Phra subdistrict, Khon Kaen province. Four treatments used in this research, including 1) 3 years rubber tree plantation (3Y) (16°29´ N; 102°83´ E), 2) 11 years rubber tree plantation (11Y)

(16°46´ N; 102°75´ E), 3) 17 years rubber tree plantation (17Y) (9°22´ N; 102°88´ E) and 4) 27 years rubber tree plantation (27Y) (16°29´ N; 102°82´ E). The area of each plot is 1,600 square meters. Tapping for rubber begins when the trees are 7 years old. Rubber tree cultivar RRIM600 was selected to use in this study.

2.2. Soil analysis

Soil sample were randomly collected at 0-25 cm depth with 5 locations per plot. Collecting time points, including May 2014 (represent early raining season), August 2014 (represent late raining season), December 2014 (represent early dry season) and February 2015 (represent late dry season). Soil characteristic analyses were done by studying the physical, chemical properties and nutrient contents of the soil. Physical properties studied include bulk density of the soil through the core method and particle-size distribution and soil texture by hydrometer method. In addition, field capacity (FC), permanent wilting point (PWP) and available water content (AWC) also determined. Chemical properties studied include soil reaction by pH meter in ratio of 1:1 with water, electrical conductivity (EC) of soil in ratio of 1:1 with water and cation exchange capacity (CEC) by extracting with ammonium acetate 1 N and titration method. Total nitrogen (total N) was determined by micro Kjedahl method [3], available phosphorus concentration by Bray II and colorimetric method [4], exchangeable potassium level by extracting with ammonium acetate 1N, pH 7.0 and measured by flame photometer. Moreover, soil organic carbon was investigated by wet oxidation method [5].

2.3. Microbial biomass carbon

Microbial biomass carbon was measured in fresh soil immediately after sampling by the chloroform fumigation extraction technique [6]. Briefly, 20 g of soil was extracted with 100 ml of 0.5 M K_2SO_4. Microbial biomass-C in the extracts was determined after oxidation with $K_2Cr_2O_7$. The calculation was made as the difference between fumigated and unfumigated values and employing K_{EC} factor of 0.33 [7] and K_{EN} factor of 3.1 [6].

2.4. Soil respiration

Alkaline trap method was used to measure field CO_2 emission, a small glass jar (5.5 cm height, 6 cm diameter) containing 20 ml of 1 M NaOH was placed in a closed metal chamber (16 cm diameter and 29 cm height) and left for 24 h. The evolved CO_2 trapped was subsequently determined by back titration with 0.5 M HCl after precipitating the carbonate with excess 0.5 M $BaCl_2$. Soil respiration, i.e., CO_2 emission, was computed according to the equation described by Anderson [8]. The metabolic quotient (qCO_2), the ratio of soil respiration to microbial biomass carbon was also determined [9].

2.5. Carbon stock in soil

Carbon stock in soil was calculated using the formula introduced by Milne [10] as follows equation:
SOC stock = SOC content x BD x depth x area
Where the SOC stock is carbon content accumulated in soil (t/ha), SOC content is carbon content in soil (g C/g soil), BD is soil bulk density (g/cm), depth is soil depth (m) and area is land area (m^2).

2.6. Carbon stock in tree biomass

Biomass tree was calculated using the formula introduced by Kraenzel [11] as follows equation:

$$M_T = M_S + M_B + M_L + M_S \quad (1)$$

$$C_T = 0.5\ M_T \quad (2)$$

Where M_T is total tree biomass (t/ha), M_S is stem biomass (t/ha), M_B is braches biomass (t/ha), M_L is leaf biomass (t/ha), M_S is rubber seed biomass (t/ha) and C_T is carbon stock in tree biomass (t/ha).

2.7. Statistical analysis

This experiment has been designed as the completely randomized design (CRD). F-test along with method of least significant difference (LSD) was used to analyze the differences of the average on each experiment.

3. Results and discussion

3.1. Physical and chemical properties of soil

The data of physical properties of soil, including soil texture, moisture and bulk density were collected before starting the experiment (May 2014) as showed in Table 1. The results of particle distribution analysis and field soil water contents (FC, PWP and AWC) indicated that soil samples of all treatment were sandy soil with 93.78, 5.18 and 1.04% of sand, silt and clay, respectively for 3Y, 95.86, 3.38 and 0.76% of sand, silt and clay, respectively for 11Y, 93.78, 5.53 and 0.69% of sand, silt and clay, respectively for 17Y and 95.86, 3.31 and 0.83% of sand, silt and clay, respectively for 27Y. The Bulk densities of soil were within the range of 1.76-1.87 g/cm^3. The greatest bulk density as 1.87 g/cm^3 was found in young age of rubber tree (3Y). The data of chemical properties of soil are shown in Table 2. Soil pH varied in a moderately acid range, from 4.48 to 5.68, with most acidity in the soils under 11 years of rubber tree plantation. EC of soil varied in a range of 12.71-67.60 µS/cm with no salinity problems in crop plants. The highest CEC was found in rubber tree after tapping (17Y) at all time points. The data of soil nutrient contents are shown in Table 3. The highest total nitrogen as 0.057% was observed in rubber tree after tapping (27Y) at August 2014 due to 27Y contained high leaf litter fall and then nitrogen are returned to the soil. The lowest total nitrogen as 0.010% was observed in young rubber tree plantation (3Y) in May 2014. Interestingly, there was no significantly different among treatment observed in February 2015. The highest available phosphorus content was found in 11 years rubber tree plantation as 23.06 mg/kg in early raining season (May 2014). Interestingly, no significantly different among treatment was observed in August 2014 and December 2014 then, in February 2015, the highest available phosphorus content was found in 3 years rubber plantation. However, no significantly different of available phosphorus content was found among 3Y, 11Y and 27Y. In addition, 17 years rubber tree plantation tended to have lower available phosphorus content when compared to other treatment. On the other hand, 17 years rubber tree plantation tended to have higher exchangeable potassium content when compared to other treatment. The lowest exchangeable potassium content was observed in 11 years rubber tree plantation in February 2015 as 14.30 mg/kg due to potassium absorption by plants from soil and accumulated in seeds, and so on latex rubber that has been harvested by tree tapping. In addition, potassium was the nutrient with the highest retranslocation rates and was the most exported nutrient by the harvested rubber [12].

3.2. Microbial biomass and activity

The data of microbial properties of soil are shown in Table 4. Microbial biomass results showed varied among time point. In early raining season (May 2014), the highest microbial biomass carbon was found in the soil under rubber tree after tapping (27Y). However, in early dry season (December 2014), the highest microbial biomass carbon was found in 11 years rubber tree plantation. In late dry season (February 2015), the highest microbial biomass carbon was observed in 3Y as 2,911.2 mg/kg. Interestingly, the most efficiency of the microbial community to convert organic carbon into microbial biomass was also found in 3Y with lowest qCO_2. However, there was no significantly different of microbial biomass carbon among treatment was found at all time points. The highest levels of CO_2 release occurred in 17Y in early dry season (August 2014) due to rubber tree made the highest amount of biomass fallen above ground and contained high litter accumulation (data not shown). Moreover, at that time point soil moisture was suitable for microbe to use litter as energy source for their activity and to produce high CO_2–emission. The lowest levels of CO_2 release occurred in 3Y in late dry season (February 2015) with lowest litter accumulation. These findings suggested that higher rainfall may promote higher litter production, higher organic matter accumulation on the soil, and consequently, increase in microorganism activity [13].

3.3. Above- and below ground carbon stock

The data of above- and below ground carbon stock are shown in Table 5. The results of biomass tree carbon indicated that higher above ground carbon stock was found in rubber tree plantation after tapping (27Y) which related to higher plantation age at all time points suggesting a accumulation of litter fall over a long period which was consistent with previously reported data [14], [2] & [15]. The lower C stock in soil was found in rubber tree plantation before tapping (3Y) when compared to older ages of rubber tree plantation (17Y and 27Y). In December 2014 with early dry season, the lowest C stock was observed in 11Y. The highest C stock was observed in 17Y which not significant different when compared to 27Y at all time points. The increase of SOC with increasing year was observed and indicating a low soil fertility conditions. The accumulation of SOC was highest in 17Y as 0.72% and showed no significantly different of SOC when compared to 27Y in late raining season (August 2014). The lowest SOC was observed in 11Y as 0.13% in early dry season (December 2014). These findings suggested that the reduction in latex yield at later age (27Y) might have resulted in the increase of below-ground organic carbon input [14] & [16].

Table 1 Physical properties of soil (May 2014)

Treatment	Soil particle distribution (% w/w)			Soil texture	FC (%) *	PWP (%) *	AWC (%) *	Bulk density (g/cm^3)
	sand	silt	clay					
3	94	5	1	sand	13.25	3.23	10.02	1.87
11	96	3	1	sand	12.93	4.54	8.39	1.76
17	94	5	1	sand	15.20	2.93	12.27	1.77
27	96	3	1	sand	12.90	2.47	10.43	1.85

*FC= filed capacity; PWP=Permanent wilting point; AWC= available water content

Table 2 Chemical properties of soil (May 2014-February 2015)

Treatment	pH				EC (µS/cm)				CEC (cmol/kg)			
	May	August	December	February	May	August	December	February	May	August	December	February
3	4.86^{ab}	5.28^{a}	5.20	5.68^{a}	17.08^{b}	15.01^{b}	50.31^{b}	20.78^{b}	2.62^{b}	3.86^{ab}	3.06^{b}	2.80^{b}
11	4.48^{b}	$4.95A^{b}$	5.27	5.15^{b}	25.44^{b}	13.40^{b}	56.54^{ab}	12.71^{c}	3.18^{b}	2.90^{b}	2.70^{b}	5.82^{a}
17	4.77^{a}	4.75^{b}	5.58	5.18^{b}	34.61^{a}	39.49^{a}	65.79^{a}	22.42^{b}	6.08a	5.14^{a}	5.20^{a}	5.74^{a}
27	5.10^{a}	4.71^{b}	5.43	5.26^{b}	37.77^{a}	33.05^{a}	67.60^{a}	23.58^{a}	5.83a	5.90^{a}	5.64^{a}	6.54^{a}
C.V. (%)	6.31	5.76	4.72	5.06	38.01	36.17	16.89	57.89	27.17	34.4	26.25	29.45
F-test	*	*	ns	*	*	**	*	*	**	*	**	**

In each column, means followed by the same letter do not differ statistically from each other at p≤0.05 according to LSD test

Table 3 Soil nutrient content analyses (May 2014-February 2015)

Treatment	Total nitrogen (%)				Available phosphorus (mg/kg)				Exchangeable potassium (mg/kg)			
	May	August	December	February	May	August	December	February	May	August	December	February
3	0.010[b]	0.025[b]	0.019[ab]	0.035	19.40[a]	16.78	19.16	19.30[a]	10.77[d]	17.25[c]	28.24[b]	14.67[c]
11	0.021[b]	0.020[b]	0.013[b]	0.020	23.06[a]	19.57	11.09	18.73[a]	18.75[c]	18.82[c]	24.31[b]	14.30[c]
17	0.049[a]	0.052[a]	0.028[b]	0.037	14.71[b]	15.58	13.14	8.85[b]	44.13[a]	56.49[a]	57.65[a]	37.25[a]
27	0.040[a]	0.057[a]	0.034[a]	0.037	21.65[a]	20.77	17.02	19.03[a]	35.57[b]	33.73[b]	36.47[ab]	28.97[b]
C.V. (%)	38.07	50.39	53.48	43.57	30.08	29.42	89.80	44.56	16.91	30.98	49.17	23.55
F-test	**	*	*	ns	*	ns	ns	*	**	**	**	*

In each column, means followed by the same letter do not differ statistically from each other at $p \leq 0.05$ according to LSD test

Table 4 Soil microbial properties (May 2014-February 2015)

Treatment	Microbial biomass carbon (mg/kg)				CO_2-emission (mg CO_2/kg/day)				Metabolic quotient (qCO_2) (mg CO_2-C/kg microbial biomass C/day)			
	May	August	December	February	May	August	December	February	May	August	December	February
3	1029.7[b]	1307.8	997.1[c]	2911.2	4.89[d]	5.91[d]	8.61[a]	3.72[c]	0.0068	0.0092	0.031	0.0016
11	1168.3[b]	795.29	2721.4[a]	2224.5	7.62[b]	7.75[c]	8.66[a]	4.32[c]	0.0120	0.0242	0.0044	0.0022
17	2386.1[a]	1426.4	1768.9[b]	1639.7	6.98[c]	11.67[a]	5.26[c]	7.77[a]	0.0030	0.0198	0.0033	0.0272
27	2886.5[a]	1250.5	1710.6[b]	1428.2	10.25[a]	10.31[b]	6.09[b]	6.32[b]	0.0037	0.0118	0.0034	0.0055
C.V. (%)	35.46	76.2	68	61.88	13.67	10.64	25.25	28.48	15.44	18.71	22.03	22.44
F-test	**	ns	*	ns	**	**	*	*	ns	ns	ns	ns

In each column, means followed by the same letter do not differ statistically from each other at $p \leq 0.05$ according to LSD test

Table 5 Above- and below ground carbon stock (May 2014-February 2015)

Treatment	Biomass tree carbon (t/ha)				Carbon stock (t/ha)				Soil organic carbon (%)			
	May	August	December	February	May	August	December	February	May	August	December	February
3	2.68[d]	3.52[d]	4.44[d]	5.09[d]	7.34[b]	12.45[b]	3.68[b]	6.76[bc]	0.15[b]	0.26[b]	0.15[c]	0.22[bc]
11	11.91[c]	15.94[c]	17.44[c]	19.60[c]	7.00[b]	12.92[b]	3.08[b]	5.04[c]	0.19[b]	0.29[b]	0.13[c]	0.16[c]
17	21.62[b]	23.36[b]	24.38[b]	33.11[ab]	22.91[a]	29.99[a]	8.84[a]	11.25[a]	0.46[a]	0.72[a]	0.31[b]	0.45[a]
27	48.11[a]	50.52[a]	50.54[a]	65.18[a]	24.59[a]	29.65[a]	11.7[a]	9.89[a]	0.45[a]	0.64[a]	0.39[a]	0.31[ab]
C.V. (%)	15.65	16. 02	15. 23	14.45	31.30	17.08	30.07	33.13	43.23	27.83	21.4	36.34
F-test	**	**	**	**	**	**	**	**	**	**	**	**

In each column, means followed by the same letter do not differ statistically from each other at $p \leq 0.05$ according to LSD test

4. Conclusion

The higher age of rubber tree plantation (17Y and 27Y) showed higher above ground carbon stock related to the result of higher biomass tree accumulation was observed. In addition, the higher age of rubber plantation also showed higher below ground carbon stock due to higher SOC accumulation. Interestingly, more efficient in carbon use with lower qCO_2 was found in younger age of rubber tree plantation than the communities in the other treatment notably in February 2015 with dry season. This finding indicated the improvement in soil microbial biomass efficiency related to nutrient immobilization in younger age of rubber tree plantation.

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