GROWTHS AND CARBON STOCKS IN RUBBER PLANTATIONS ON CHAKKARAT SOIL SERIES, NORTHEASTERN THAILAND

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Abstract

Growths and carbon stocks in a series of 1, 5, 10, 15, and 20-year-old para rubber plantations, together with a natural forest, on Chakkarat soil series in northeastern Thailand were investigated. In total, 15 40×40 m sampling plots were used for studying rubber growths, 3 plots per each age class plantation and 1 plot for the natural forest. In each plot, stem girth at 1.3 m above ground, crown width, and tree height were measured. One rubber tree having the mean growth in each age class plantation was cut and separated to stem, branch, leaf, and root biomass for estimating carbon amounts. Three soil pits were made in each plot, and soil samples were collected along with the soil profile. Soil physical and chemical properties were analyzed in the laboratory. Rubber tree densities varied between 469-500 trees/ha (75-80 trees/rai). Stem girth and height growths increased with the plantation age. The growth was very rapid for rubber trees having ages between 1 and 15 years old and became slow for the older trees. The biomass amounts of the 1, 5, 10, 15, and 20-year-old plantations were in the order of 20.17, 52.47, 92.59, 123.50, and 147.83 Mg/ha, respectively. The ecosystem carbon stocks in these plantations increased with tree ages at 25.53, 46.70, 71.06, 86.18, and 97.11 Mg/ha, respectively. Two compartments were involved; (1) biomass carbon: 11.42, 29.87, 52.54, 70.13, and 83.74 Mg/ha; and (2) soil carbon: 14.26, 16.83, 18.52, 16.05, and 13.37 Mg/ha. The total carbon storage in the natural forest was 134.62 Mg/ha; 124.20 Mg/ha in the biomass and 10.42 Mg/ha in the soil. The young plantations had high carbon percentages in the soil and low in the biomass whereas carbon allocation in the older plantations was higher in the biomass and lower in the soil system.

Keywords: Carbon stocks, rubber growth, rubber plantation, biomass, Chakkarat soil series

Introduction

Thailand is the country having the highest rubber production and exports in the world. The production is about 3.56 million tons/year, and 82.86% of the production is for export. In 2010, the total rubber plantation area of the country was 2.93 million ha (18.32 million

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rai) (Rubber Research Institute of Thailand, 2012). This included plantations in original sites in the south (1.81 million ha) and east (0.288 million ha). An area of 0.60 million ha was in new sites in the northeast (0.456 million ha), north (0.096 million ha), and the central area (0.048 million ha). In the northeastern region, an area of 6.653 million ha is suitable for planting rubber which needs at least 1350 mm of annual rainfall or at least 120 rainy days a year to provide sufficient moisture. At present, there are 3.090 million ha of plantations with rubber production above 1.563 ton/ha/year, and the remaining area of 3.563 million ha has the potential for rubber plantation (Rubber Research Institute of Thailand, 2012).

Global warming is recognized as being critical. Most countries have had plans to deal with the problem under the Kyoto Protocol, a part of the United Nations Framework Convention on Climate Change (UNFCCC) since 2005. Thailand has plans for reducing green house gases by using a clean development mechanism. A rubber plantation is considered as a way to increase a forest plantation with a cutting rotation of 20 years. Carbon storage in the rubber biomass will increase with the plantation's age, and the wood will be cut for making furniture and other wood products at the end of the plantation's life.

For the northeast, research on variations in rubber growths at different sites is important. The growths and production may be varied by the influence of many environmental factors such as the amount of rainfall, soil moisture, soil characteristics, parent rocks, etc. The soil nature including the depth, water drainage, physico-chemical, and biological properties has an influence on tree growths and production (Bowen and Nambiar, 1989; Fisher and Binkley, 2000).

Nong Khai province has the largest area of rubber plantations (102052 ha) in the northeastern region, and there is a large area of 238394 ha which has potential for planting rubber. The rubber plantations in this province have been promoted since 1978. Nowadays, most plantations are aged between 1-20 years old. The soil types are mainly the Phonpisai and Chakkarat soil series. The Chakkarat soil series are defined as the reference profiles for soil series having soil depth intervals of 0-25, 20-50, and 50-100 cm in the northeast region of Thailand (Office of Soil Survey and Land Use Planning, 2006). The soil surface characteristics are coarse-loamy soil which has a top soil pH at 5.5-6.0, a low soil pH at 4.5-5.0, low fertility, and is well drained. However, this research focused only on rubber growths, biomass production, and carbon storages in plantations on Chakkarat soil series. The data are useful for improving management practices as well as providing extensive information for increasing production and improving the environment.

Methodology/Experimental Design

The study areas consisted of 5 age classes (1, 5, 10, 15, and 20 years old) of rubber (variety RRM600) plantations in So Phisai district, Bueng Kan province (separated from Nong Khai province since 3 August 2010), Thailand. The geographical coordinates of the 1, 5, 10, 15, and 20-year-old sampling sites were 2012453N-0344095E, 2011909N-0344342E, 2012236N-0343963E, 2011891N-0344291E, and 2012478N-0343341E, respectively. And the sampling plots at the natural dry evergreen forest in Rattanawapi district, Nong Khai province, Thailand had the coordinate of 199294N-0299559E.

Growths and Biomass of Rubber

Five age classes rubber plantations 1, 5, 10, 15, and 20 years old were selected. For each age class stand, 3 40×40 m sampling plots were arranged in random, a total of 15 plots for all the plantations. The stem girth at 1.3 m above ground, height, and crown cover of all the rubber trees were measured in each plot. One rubber tree having the mean size in each plot was cut and separated for stem, branch, leaf, and root biomass. Fifteen trees of the different stand ages were used for making allometric equations. The biomass in a series of the plantations was calculated.

Biomass and Carbon Stocks in Adjacent Natural Forest

A sampling plot of 40×40 m in size was used for the vegetation survey and biomass study in an adjacent natural forest. It was a secondary dry evergreen forest.

In the plot, all trees with a height above 1.5 m were measured for stem girth and height. The above-ground forest biomass was calculated using the allometric equations of Ogino *et al*. (1967):-

$$W_S \text{ (stem)} = 189\,(D^2H)^{0.902}$$
$$W_B \text{ (branch)} = 0.125\,W_S^{1.024}$$
$$1/W_L \text{ (leaf)} = (1/W_S^{0.9}) + 0.172$$

The root biomass estimation followed an allometric equation of Ogawa *et al*. (1965):-

$$W_R \text{ (root)} = 0.0313\,(D^2H)^{0.805},$$

where W_S = biomass of stem (kg/tree)
W_B = biomass of branch (kg/tree)
W_L = biomass of leaf (kg/tree)
W_R = biomass of root (kg/tree)
D = stem diameter (cm)
H = height (m)

The carbon contents in the stem, branch, leaf, and root of the tree species were calculated by summarizing the total biomass accumulation in each part and then multiplying with a conversion factor at 0.5 for the carbon content estimation by equations (Atjay *et al*., 1979; Tsutsumi *et al*., 1983) as follows:

$$B_T = B_S + B_B + B_L + B_R$$
$$T_C = B_T \times 0.5,$$

where B_T = total biomass of tree (kg/ha)
B_S = total biomass of stem (kg/ha)
B_B = total biomass of branch (kg/ha)
B_L = total biomass of leaf (kg/ha)
B_R = total biomass of root (kg/ha)
T_C = total carbon content of tree (kg/ha)

Carbon Storages in Soils

Three soil pits were made in a selected plot of each age class stand, a total of 15 pits for all plantations. The soil samples were collected along with the soil profiles using a composite method for each soil layer of the 3 pits in each plot. Three pits were also made in the natural forest, and the samples were collected along with the profiles.

Analyses of the organic matter and carbon in the soil samples were evaluated based on the wet oxidation method of Walkley and Black (Nelson and Sommers, 1996). The amounts of carbon storage in the soils were calculated from the soil mass and carbon contents.

Results and Discussion

Rubber Growths

Table 1 shows the rubber growths in the 5 age classes of the plantations. The densities varied between 469-500 trees/ha. The growths increased with the stand's age. Stem girths at

Table 1. Mean growths and biomass of rubber trees in different age plantations on Chakkarat soil series

Plantation age (years)	Density (trees/ha)	GBH* (cm)	Tree height (m)	Crown width (m)	Biomass (kg/tree)
1	475	15.61 ± 2.33	5.56 ± 1.55	2.46 ± 0.19	42.5
5	475	34.88 ± 5.84	9.61 ± 1.12	5.58 ± 0.58	110.5
10	475	51.67 ± 9.52	11.98 ± 0.85	6.19 ± 1.27	195.8
15	500	56.83 ± 10.55	22.50 ± 3.13	5.92 ± 1.53	247.0
20	469	73.18 ± 22.86	23.95 ± 2.63	6.96 ± 1.22	316.2

* *GBH, Girth/Diameter at breast height (cm).*

1, 5, 10, 15, and 20 years old were 15.61, 34.88, 51.67, 56.83, and 73.18 cm, respectively. Tree heights were 5.56, 9.61, 11.98, 22.50, and 23.95 m, respectively, and the crown widths were 2.46, 5.58, 6.19, 5.92, and 6.96 m, respectively, (Figure 1). According to the standard growth rate based on girth at breast height (GBH), defined by the Rubber Research Institute of Thailand (2012), it was shown that the GBH of rubber trees aged 5 years planted in Chakkarat soil series was 34.88 cm, which was slightly lower than the standard growth rate at low level (36 cm) (Rubber Research Institute of Thailand, 2012).

The rubber tree starts to be tapped when the tree is considered mature which is when the trunk girth reaches 50 cm. This maturity is usually achieved around 5-6 years after planting in traditional conditions and around 8-10 years in sub-optimal conditions. Compared with the plantations in the south, the growth rate was slower due to lower soil fertility in this region (Chardrashekar *et al*., 1998).

Biomass of Rubber Plantations and Natural Forest

In Table 2, the means of the total rubber tree biomass at 1, 5, 10, 15, and 20 years old were calculated at 20.17, 52.47, 92.59, 123.50, and 147.83 Mg/ha (42.5, 110.5, 195.8, 247.0, and 316.2 kg/tree), respectively.

The biomass increased with the stand's age. The percentages of biomass distribution in the various organs were similar for both the young and older plantations. The percentages in the stem, branch, leaf, and root were in the order of 27.91, 26.81, 19.52, and 25.76% of the total biomass, respectively, (Table 2). The relatively high percentage in the leaf component is an indication of the rapid rubber growth on Chakkarat soil. It is a poor soil but has a deep fine sand profile with relatively high moisture which may be good for root penetration. Moreover, the average annual rainfall of this province is usually high at about 1843.6 mm and about 134 rainy days per year (Meteoro-ogical Department of Thailand, 2009).

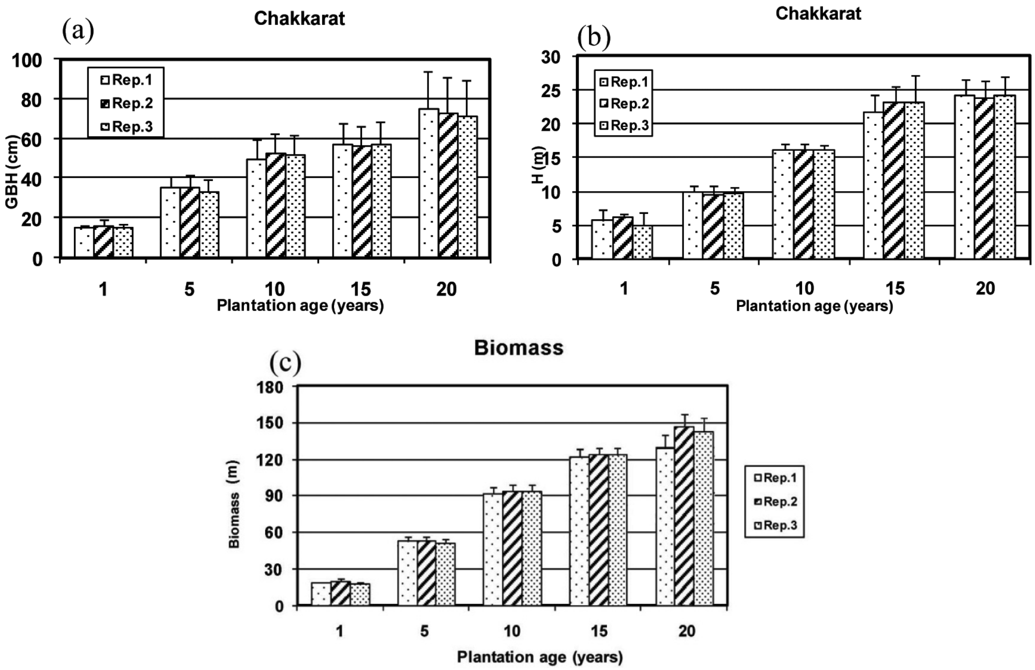

Figure 1. (a) Stem girth, (b) tree height, and (c) biomass of para rubber in 1, 5, 10, 15, and 20-year-old plantations on Chakkarat soil series

Carbon Stocks in Rubber Plantations and Natural Forest

Biomass Carbon Storage

Rubber Plantations

Through the photosynthesis process, atmospheric carbon dioxide is absorbed by rubber trees and converted to organic compounds such as carbohydrates. The organic carbon will be accumulated in various tissues in the stem, branch, leaf, and root components. The biomass production (dry matter) of rubber trees is dependent upon growth rates, and is used to identify the amount of carbon storage.

Analysis of the carbon content in various organs of the sample rubber trees was taken by multiplying with the 0.5 conversion factor for the aboveground biomass based on the method reported by Atjay (1979). The mean carbon contents in the stems and branches of different age rubber trees were nearly the same (Table 2). They varied between 57.02-57.61% (57.25%) for the stem, and 56.96-57.62% (57.24%) for the branch. The mean content was 54.89% for the leaf and 57.08% for the root. As a result, the amounts of biomass carbon in the 1, 5, 10, 15, and 20-year-old plantations increased with the stand's age;

Table 2. Biomass of rubber trees in different age plantations on Chakkarat soil series

Plantation age (year)	Tree density (Tree/ha)	Biomass (Mg/ha)					Total biomass (Mg/ha)
		Ws	Wb	Wl	Wr	Total	
1	475	5.68 (28.15)	5.15 (25.55)	4.15 (20.60)	5.19 (25.70)	3227.47 (100)	20.17
5	475	14.68 (27.97)	13.90 (26.50)	10.38 (19.78)	13.51 (25.75)	8395.47 (100)	52.47
10	475	25.80 (27.86)	25.07 (27.08)	17.85 (19.28)	23.87 (25.78)	14814.20 (100)	92.59
15	500	34.34 (27.81)	33.74 (27.32)	23.56 (19.08)	31.85 (25.79)	19759.67 (100)	123.49
20	468.75	41.03 (27.76)	400.78 (27.58)	27.88 (18.86)	38.14 (25.80)	23652.00 (100)	147.83
Average	478.75	27.91	26.81	19.52	25.76	100	

Note: Values in parenthesis are percentages.

Table 3. Biomass carbon storages of rubber trees in different age plantations on Chakkarat soil series

Plantation age (year)	Carbon amounts (kg/ha)					Total biomass carbon (Mg/ha)
	Stem	Branch	Leaf	Root	Total	
1	519.13	469.56	364.95	473.45	1827.08	11.42
5	1329.91	1177.29	1000.10	2379.43	5886.73	29.87
10	2360.80	2297.95	1567.75	2179.89	8406.52	52.54
15	3147.40	3094.27	2069.44	2908.65	11219.91	70.13
20	3743.52	3722.69	2448.56	3483.03	13397.78	83.74

they were 11.42, 29.87, 52.54, 70.13, and 83.74 Mg/ha, respectively (Table 3). Compared with the plantations in the eastern region, this 20-year-old stand had a lower amount of biomass carbon (Yoosuk, 2005). This is due to the slower growth rate caused by a long dry period, low soil fertility, and high tree density of up to 500 trees/ha or more.

Natural Forest

The secondary dry evergreen forest was composed of 66 species and had a tree density of 528 trees/ha. The dominant trees were mainly Schima wallichii and some oak species including Quercus elegans, Castanopsis sp., and Lithocarpus sp. The usual mesic dipterocarp tree species did not exist in the forest. The total forest biomass was estimated as 251.47 Mg/ha divided into stem, branch, leaf, and root of 162.0, 47.42, 5.18, and 36.87 Mg/ha, respectively (Table 2). The amounts of biomass carbon in these organs were calculated as 80.83, 23.08, 2.50, and 17.77 Mg/ha, respectively, (Table 2). The biomass carbon in this forest was 124.20 Mg/ha (Table 4).

This natural forest had been disturbed, but had not been disturbed for about 20 years, the same as the age of the oldest rubber plantation (Yoosuk, 2005).The biomass carbon stock in the 20-year-old rubber plantation (83.74 Mg/ha) was a lower amount than in this natural forest.

Carbon Storage in Soils

Accumulations of organic matter and carbon in the soils under the 5 plantations were different as shown in Table 5. The carbon content in the soil organic matter is based on the average value, 58%, which is the value generally used to convert the soil organic matter concentration into carbon content (Perie and Ouimet, 2007). However, the amounts did not increase with the plantation's age. The carbon storages in the 1, 5, 10, 15, and 20-year-old stands were in the order of 14.26, 16.83, 18.52, 16.05, and 13.37 Mg/ha, respectively,whereas the natural forest had 10.42 Mg/ha. It was the lowest in the 20-year-old stand. The young plantations may have a higher organic matter in the Ap horizon caused by input from weeding. Loss of soil organic matter can occur in all plantations through soil erosion in surface runoff and a leaching process. However, farmers may apply manure to surface soils and create an increase in soil organic matter in some plantations. Overall, the amounts of soil organic matter and carbon in the Chakkarat soils were relatively low.

Table 4. Carbon stocks in ecosystems of rubber trees in different age plantations and a natural forest on Chakkarat soil series

Plantation age (year)	Biomass carbon		Soil carbon		Total %
	Mg/ha	%	Mg/ha	%	
1	11.42	44.13	14.26	55.87	25.53
5	29.87	63.96	16.83	36.04	46.70
10	52.54	73.94	18.52	26.06	71.06
15	70.13	81.38	16.05	18.62	86.18
20	83.74	86.23	13.37	13.77	97.11
Natural forest	124.20	92.25	10.42	7.74	134.62

Ecosystem Carbon Stocks

The carbon stocks in the ecosystems of rubber plantations involve mainly 2 compartments; biomass and soil carbon. Accumulation of organic layers on surface soils did not occur in these plantations. Although the carbon stocks in the soils were not increased with the stand's ages, in contrast, the biomass carbon storages were much higher in the older plantations according to the increasing growth rates. As a result, the ecosystem carbon stocks in the 1, 5, 10, 15, and 20-year-old plantations increased with the plantation's ages; 25.53, 46.70, 71.60, 86.18, and 97.11 Mg/ha, respectively (Table 4).

The young plantations had high percentages of carbon distribution in the soil system, and low percentages in the biomass. However, the percentages were conversely higher in the biomass and lower in the soils of the older plantations.

Conclusions

The original areas, before being changed into rubber plantations on the Chakkarat soil, had been covered by dry evergreen forest on shale, siltstone, and sandstone. It was a poor soil with deep fine sandy profiles. Compared with the plantations in the south, the growth rates were slower due to the lower soil fertility in this region.

The rubber biomass in the 1, 5, 10, 15, and 20-year-old plantations increased with the stands' ages. The amount of biomass carbon stocks in the 20-year-old rubber plantation (83.74 Mg/ha) was lower than in the adjacent natural forest of the same age (124.20 Mg/ha). The carbon stocks were lower than those in the east. However, improvement of management practices by farmers to a good level would increase the growth rates as well as the carbon stocks in the future to be near the levels in the east. When a plantationis about 20 years old, the rubber trees will be cut for making wood products which implies carbon harvesting and during growth it is capable of fixing CO_2 to help reduce the emission of atmospheric green house gases.

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Table 5. Carbon accumulated in 100 cm depth of Chakkarat soil series under rubber plantations and a natural forest (a secondary dry evergreen forest)

Plantation age (year)	Organic matter		Organic carbon	
	kg/rai	Mg/ha	kg/rai	Mg/ha
1	3934.90	24.59	2282.24	14.26
5	4642.14	29.01	2692.44	16.83
10	5109.20	31.93	2963.34	18.52
15	4428.51	27.68	2568.54	16.05
20	3689.47	23.06	2139.89	13.37
Natural Forest	2874.30	17.96	1667.10	10.42

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