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Carbon storage in rubber plantations of various stand ages in Cambodia

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Abstract: Rubber plantations have expanded rapidly on the Indochinese peninsula, and clarifying the major carbon (C) pools in those plantations is necessary to more accurately evaluate their influence on the regional terrestrial C cycle. Here, we compared the C storage function of rubber plantations and natural forests by relating the stand biomass of rubber plantations to stand age. Study plots were established in 1-, 2-, 6-, 7-, 8-, and 9-year-old rubber plantations situated on basaltic soils in Cambodia. Stand biomass (tree, understory, and deadwood biomass) and soil and litter C stocks were investigated. Tree biomass and stand biomass increased and deadwood biomass decreased with stand age. When the carbon content in tree biomass was 0.5 g C g^{-1}, tree biomass C was 30.3 and 40.2 Mg C ha^{-1} in 9-year-old stands, much lower than that in secondary forests in the region. No clear trend in soil C stock was observed with stand age. The mean soil C stock at 0–30 cm depth ranged from 34.3 to 48.4 Mg C ha^{-1}.

Key words: Cambodia, ecosystem carbon storage, rubber plantation

I Introduction

Recently, a rapid increase has occurred in the rate of conversion of natural forests to rubber plantations on the Indochinese peninsula (*4*). Although this peninsula is a key region in the Reducing Emissions from Deforestation and Forest Degradation (REDD) project in Southeast Asia, information about the impact of land-use change in this area on the terrestrial carbon (C) cycle is currently lacking.

Estimation of the major C pools (tree and understory biomass, deadwood, litter, and soil) in rubber plantations, using the same methodology applied to natural forests under the REDD scheme (*1*), may be the first step in evaluating the effect of deforestation in Indochina on the terrestrial C cycle.

Accordingly, we investigated the major C pools in young rubber plantations of various ages in central Cambodia.

II Material and methods

1. Study area

The study site is located in northern Kampong Thom province, Cambodia (12° 92–93′ N, 105° 37–39′ E). The mean annual temperature in the province is 27°C, and the annual rainfall from 1994 to 2004 ranged from 1,085 to 1,857 mm (*3*). The region has a pronounced dry season from November to February. The basaltic bedrock is described as Triassic intermediate to mafic volcanic rock, and the soils are Ferralsols. The natural forest type of the study area is secondary dry evergreen forest, and the dominant tree species are *Irvingia malayana* and *Peltophorum dasyrhachis* (*5*).

2. Rubber plantations

Since 2001, secondary forests in the study area have been converted to rubber plantations, and at present, rubber plantations occupy about 4,700 ha in total. Prior to the establishment of rubber plantations, burning and cultivation were practiced by local people. Rubber trees are planted 3 m apart in rows spaced 6.5 m apart. Soil between the rows is plowed by heavy equipment to 20 cm depth to control weeds.

We established one study plot each in 1-, 2-, 6-, and 7-year-old rubber plantations (R1, R2, R6, and R7, respectively) and two plots each in 8- and 9-year-old plantations (R8a, R8b, R9a, and R9b, respectively). The size of each plot was 30 m × 40 m.

3. Estimation of stand biomass

Tree (above- and belowground) biomass of each rubber tree was estimated from the basal area (*ba*, m^2) and wood density (*D*, kg m^{-3}) using the allometric equation proposed in Kiyono et al. (*2*) as follows,

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Tree biomass (kg) = $4.08 \times ba^{1.25} \times D^{1.33}$.

Understory biomass was estimated with an allometric equation using community height (*2*). The amount of deadwood (mainly dead tree stumps of former secondary forest) was calculated on the basis of stump girth and height and cavity proportion. Belowground deadwood was not determined in this study.

4. Sampling and analyses of soil and litter

Soil and litter sampling was conducted in R1, R2, R6, and R9a. One sampling point was selected in each of these four study plots. Litter thickness (T, L, and F) was recorded and the litter was collected from a 50×50-cm-quadrat at each sampling point. Three replicate soil samples were collected from 0–5, 5–15, and 15–30 cm depths using 100-ml steel cylinders.

For physical analysis, clay (<0.002 mm), silt (0.002–006 mm), and sand (0.06–2 mm) content was determined using the pipette method and wet sieving. Charcoal in coarse organic matter (>2 mm) was detected by wet sieving and visual check. The bulk density of fine soil was measured on an oven-dry (105°C, 24 h) basis. The total carbon (Total C) and total nitrogen (Total N) contents of the soil and litter samples were assessed using the dry combustion method (varioMAX, Elementar Corp.). Soil C stock (mg C ha^{-1}) in each soil horizon was calculated by multiplying Total C by the bulk density and horizon thickness. Soil C density (mg C ha^{-1} cm^{-1}) in each soil layer was calculated by dividing the soil C stock by the thickness of the soil layer.

III Results and discussion

1. Field observations

Stands R1 and R2

The canopies of stands R1 and R2 were open. Grass species, both from the former secondary forest vegetation and newly invaded Poaceae, were observed on the forest floor (Photo 1). Tree stumps from the former forest were dry and hardly decayed. The mean litter thickness (T, L, and F) was 0.65 (R1) and 0.29 cm (R2). Charcoal (>2 mm) was observed on the soil surface. The clear plowing (Ap) horizons ranged from 7 to 22 cm in thickness.

Stand R6

The canopy of the stand was almost closed, and some trees were already bearing fruit. Poaceae and shade tolerant species (*Chromolaena odorata*, *Cyrtococcum* sp.) were distributed on the forest floor. The remaining tree stumps on the forest floor were relatively wet and in a state of advanced decomposition, accompanied by hard fungi and termites. The litter of rubber leaves had accumulated with a mean thickness of 0.70 cm. Plowing horizons were not clear and ranged from 5 to 15 cm in thickness.

Stands R7, R8, and R9

The canopy was closed, and a large portion of the rubber trees had fruit (Photo 2). Sap harvesting had already begun for some rubber breeds. Shade-tolerant grasses were distributed locally on the forest floor. Tree stumps were almost completely decomposed, and termite activity had decreased. A mixture of rubber twigs and leaves had accumulated to a mean thickness of 2.13 cm. Plowing horizons were not clear and ranged from 5 to 8 cm in thickness.

2. Stand biomass

Despite fluctuations, our measured results suggested that the rubber tree biomass increased and the deadwood biomass decreased with plantation age (Table 1). Understory biomass increased early on (R1, R2 to R6), and then decreased in R9a and R9b, possibly as a result of canopy closure. These trends indicated that the C storage function of rubber plantations can be qualified in terms of age-related parameters in the C cycle model.

When the C content of tree biomass was 0.5 g C g^{-1}, tree biomass C was 30.3 and 40.2 Mg C ha^{-1} in R9a and R9b, respectively (Table 1). These values were lower than the estimated tree biomass C in secondary forest plots of this region (133.5 Mg C ha^{-1}, Toriyama, data not published).

3. Soil and litter C stock

The soil C stock in the study area may be more related to soil texture than to stand age. The clay content of the upper soil layers (0–15 cm depth) was high in R1 and R2, and low in R6 (Table 2). Bulk density was slightly lower in R1 (Table 2), and Total C was low in R6 that showed low clay content. Accordingly, it might be difficult to relate soil C stock to stand age in this study. The mean soil C stock at 0–30 cm depth ranged from 34.3 to 48.4 Mg C ha^{-1} in the four sampled plots (Table 2), lower than levels in secondary forest soil (62.7 Mg C ha^{-1}, Toriyama, data not published).

Plowing at the time of rubber plantation establishment may have influenced the distribution of soil C stock within the soil profile. The mean soil C density at 5–15 cm depth was comparable to that at 0–5 cm in R1 and R2. In contrast, soil C density in R6 and R9a decreased at 0-15cm in depth.

Rubber plantation stand age may be related to the quality of soil C through the decomposition of charcoal. The ratio of charcoal to coarse organic matter was high in R1 (>0.3) and relatively low in R6 and R9a (<0.2). The plots in order from highest to lowest C/N value were R1 > R2 > R6 > R9a, suggesting that the mixing of charcoal may have influenced these C/N values.

Dry matter and C stock in litter (sum of T, L, and F) rapidly decreased from R1 to R2, and increased from R2 to R9 (Table 3). Although twigs (T) contributed greatly to litter C stock in both R1 and R9, our field observations suggested that twigs from the former secondary forest decomposed within a few years of rubber plantation management and that twigs from rubber trees became increasingly important to these levels.

IV Conclusions

We evaluated the major C pools in rubber plantations in central Cambodia and proposed a method of comparing C storage function between rubber plantations and natural forests that involves relating rubber plantation stand biomass to stand age. Future studies should incorporate field data sampled from widely ranged soil textures and older stand age than this study.

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Table 1. Stand biomass in rubber plantations

	R1	R2	R6	R7	R8a	R8b	R9a	R9b
Biomass (Mg ha^{-1})								
Tree	0.2	0.8	32.9	52.6	59.5	44.5	60.5	80.4
Understory	0.7	0.9	2.4	1.1	1.6	3.2	1.2	0.8
DW (Mg ha^{-1})	6.6	7.1	0.2	0.0	0.0	0.0	0.0	0.0
Sum (Mg ha^{-1})	7.5	8.8	35.5	53.7	61.1	47.7	61.7	81.2

DW = Deadwood

Table 2. Physicochemical properties of soils in rubber plantations

	Depth (cm)	R1	R2	R6	R9a
Clay (g g^{-1})	0-5	0.66	0.67	0.17	0.37
	5-15	0.62	0.68	0.26	0.53
	15-30	0.79	0.78	0.46	0.39
Silt (g g^{-1})	0-5	0.17	0.14	0.36	0.45
	5-15	0.15	0.12	0.42	0.37
	15-30	0.11	0.08	0.43	0.49
Sand (g g^{-1})	0-5	0.17	0.19	0.47	0.18
	5-15	0.23	0.19	0.32	0.10
	15-30	0.10	0.14	0.12	0.11
Bulk density (g cc^{-1})	0-5	0.81 ± 0.12	0.93 ± 0.11	1.04 ± 0.05	1.05 ± 0.02
	5-15	0.95 ± 0.19	1.03 ± 0.16	1.07 ± 0.08	1.14 ± 0.07
	15-30	0.88 ± 0.25	1.09 ± 0.14	0.99 ± 0.06	1.05 ± 0.07
COM (mg cc^{-1})	0-5	7.99 ± 8.39	3.23 ± 2.62	4.23 ± 0.56	2.84 ± 0.82
	5-15	7.58 ± 13.56	2.43 ± 1.43	0.86 ± 0.52	1.63 ± 0.86
	15-30	2.16 ± 2.37	0.62 ± 0.68	0.44 ± 0.29	0.81 ± 0.53
Charcoal in COM (g g^{-1})	0-5	0.54	0.48	0.15	0.03
	5-15	0.80	0.10	0.08	0.17
	15-30	0.38	0.03	0.08	0.04
Total C (g 100g^{-1})	0-5	2.11 ± 0.78	1.92 ± 0.20	1.39 ± 0.29	1.96 ± 0.26
	5-15	1.85 ± 0.88	1.78 ± 0.35	1.17 ± 0.28	1.45 ± 0.23
	15-30	1.51 ± 0.29	1.26 ± 0.29	0.99 ± 0.52	0.88 ± 0.11
Total N (g 100g^{-1})	0-5	0.14 ± 0.05	0.14 ± 0.02	0.11 ± 0.02	0.15 ± 0.02
	5-15	0.11 ± 0.05	0.12 ± 0.03	0.09 ± 0.02	0.11 ± 0.01
	15-30	0.11 ± 0.03	0.09 ± 0.02	0.08 ± 0.03	0.07 ± 0.00
C/N	0-5	15.7 ± 2.5	14.2 ± 1.6	13.0 ± 0.9	13.0 ± 0.4
	5-15	16.6 ± 4.1	14.5 ± 2.4	12.8 ± 0.6	12.7 ± 0.7
	15-30	14.4 ± 1.8	13.6 ± 0.5	12.4 ± 0.9	12.9 ± 2.1
Soil C density (Mg C ha^{-1} cm^{-1})	0-5	1.68 ± 0.56	1.79 ± 0.39	1.44 ± 0.25	2.06 ± 0.28
	5-15	1.70 ± 0.65	1.86 ± 0.57	1.25 ± 0.28	1.65 ± 0.32
	15-30	1.34 ± 0.47	1.40 ± 0.41	0.98 ± 0.52	0.93 ± 0.13
Soil C stock (Mg C ha^{-1})	0-5	8.4 ± 2.8	8.9 ± 2.0	7.2 ± 1.3	10.3 ± 1.4
	0-15	25.4 ± 8.7	27.5 ± 7.3	19.6 ± 3.6	26.8 ± 4.4
	0-30	45.6 ± 7.0	48.4 ± 13.4	34.3 ± 11.4	40.7 ± 5.9

COM = Coarse organic matter (>2 mm)

Table 3. Physicochemical properties of litter in rubber plantations

	Type	R1	R2	R6	R9a
Dry matter (Mg ha^{-1})	T	2.11 ± 1.40	0.22 ± 0.34	0.11 ± 0.10	2.63 ± 1.21
	L	0.77 ± 0.87	0.17 ± 0.23	0.49 ± 0.15	0.64 ± 0.24
	F	0.00 ± 0.00	0.00 ± 0.00	0.47 ± 0.62	0.24 ± 0.08
	Sum	2.88 ± 1.37	0.39 ± 0.56	1.07 ± 0.67	3.52 ± 1.42
Total C (g 100g^{-1})	T	39.3 ± 16.7	45.0 ± 5.5	43.4 ± 3.5	44.5 ± 2.6
	L	40.2 ± 1.2	37.5 ± 3.3	47.3 ± 2.8	49.9 ± 0.6
	F	NA	NA	26.2 ± 13.8	42.2 ± 2.3
Total N (g 100g^{-1})	T	0.55 ± 0.20	0.73 ± 0.38	0.69 ± 0.05	0.77 ± 0.13
	L	1.77 ± 0.25	1.33 ± 0.42	1.30 ± 0.03	1.39 ± 0.32
	F	NA	NA	0.94 ± 0.30	1.61 ± 0.23
C/N	T	69.3 ± 15.1	78.2 ± 53.0	63.4 ± 9.1	59.2 ± 11.9
	L	23.1 ± 3.6	31.4 ± 14.0	36.4 ± 2.7	37.2 ± 7.9
	F	NA	NA	26.5 ± 6.2	26.5 ± 3.6
C stock (Mg C ha^{-1})	T	0.92 ± 0.87	0.14 ± 0.19	0.05 ± 0.04	1.16 ± 0.51
	L	0.30 ± 0.34	0.07 ± 0.09	0.23 ± 0.07	0.32 ± 0.12
	F	0.00 ± 0.00	0.00 ± 0.00	0.10 ± 0.09	0.10 ± 0.03
	Sum	1.22 ± 0.81	0.17 ± 0.26	0.36 ± 0.14	1.58 ± 0.62

NA = Not available

Photo 1. A 1-year-old rubber plantation (R1)
Large tree stumps still remain. Degraded secondary forest can be seen in the distance.

Photo 2. A 9-year-old rubber plantation (R9a)
Litter has accumulated on the forest floor.