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Carbon Storage in Above-Ground Biomass of Tropical Deciduous Forest in Ratchaburi Province, Thailand

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***Abstract*—**The study site was located in Ratchaburi Province, Thailand. Four experimental plots in dry dipterocarp forest (DDF) and four plots in mixed deciduous forest (MDF) were set up to estimate the above-ground biomass of tree, sapling and bamboo. The allometry equations were used to investigate above-ground biomass of these vegetation. Seedling and other understory were determined using direct harvesting method. Carbon storage in above-ground biomass was calculated based on IPCC 2006.

The results showed that the above-ground biomass of DDF at 20-40% slope, <20% slope and MDF at <20% slope were 91.96, 30.95 and 59.44 ton/ha, respectively. Bamboo covers about half of total aboveground biomass in MDF, which is a specific characteristic of this area. The carbon sequestration potential in above-ground biomass of plot slope range 20-40% DDF, <20% DDF and <20% MDF are 43.22, 14.55 and 27.94 ton C/ha, respectively.

***Keywords*—**Carbon storage, aboveground biomass, tropical deciduous forest, dry dipterocarp forest, mixed deciduous forest.

I. Introduction

TROPICAL deciduous forest land is one of the natural forest in Thailand. The forest is also one of the tropical forest type, which is an important resources of biodiversity, food and genome. Especially, the role of plant in this forest is the highest potential to capture carbon dioxide through the process of photosynthesis in range of 1-2 kg/m^2 [1]. In Thailand, the tropical deciduous forest type consists of mixed deciduous forest (MDF), dry dipterocarp forest (DDF) and savanna forest. MDF and DDF are the largest area can be found in north, west and north-east than other regions, which composed of 53.39% and 11.43%, respectively [2]. Moreover, MDF and DDF have high capacity as carbon sink [3], [4]. Both of forest types is usually located at altitude from 50 - 1,000 m asl., especially in area with drought more than 4 months and rainfall in range of 900-1200 mm per year. Plant families of these forest types consist of Dipterocapaceae, Leguminosae, Combretaceae, Verbenaceae and bamboo which are growing up on the barren slope and hillside. During dry season (from Dec. to Apr.), tree in both types of forest shed their leaves whereas seedlings do not. The forest fires have been occurred during dry season due to leaf shedding of the vegetation which is the main component in biomass fuels, and fire activities from the local communities. The composition of biomass fuels on ground cover composes of the leaf litter, twig, grass, herb, shrub, climber and seedling. Forest land is usually burned by human activities as the main causes by gathering of non-timber forest product, facilitate hunting and agricultural debris [5]. However, the fuel consumption is 95% as a result of anthropogenic surface burning [6]. The fire intensity is the key index to estimate the amount of fuel burned and pollutant released, which dependent to the fuel load, height and moisture content, humidity and temperature of environment. In DDF, the fuel load is in range of 5.44-5.93 ton/ha, releasing about 1.61 m of flame length and fire intensity 543-735 kW/m [7]. The high frequency of fire can drastically modify the structure and composition of aboveground biomass and influence to the carbon cycle in the ecosystem. In the annual area, the lowest growth of diameter and basal area was 0.237cm/year and 0.0007m^2/year, respectively. On the other hand, the growth diameter and basal area of the triennial burn and control plots are the higher than biennial and quadrennial burn plots, respectively. Moreover, survival of the burning was depended on the diameter base. The seedlings with diameter base less than 1 cm were completely dead [8]. Wildfire does not only directly affects biomass fuel i.e. undergrowth, litter and twig but also affects soil properties and processes, and nutrient dynamics [9]. However, the heat from fire directly affects insects on the ground or under the bark wood and also activates natural regeneration and development of undergrowth [8]. Furthermore, the fire management for maintain plant structure and ecosystem in the forest should be need, especially the high frequency fire occurrence area. However, the information of carbon sequestration in wildfire areas are still lacking of data and not covering all regions.

The amount of biomass fuel load can be applied to estimate the emission factor of gaseous and aerosols released from fire. The chemical and physical properties of pollutant released are dependent on the fire characteristic and biomass fuel properties, i.e. fuel composition, fuel moisture content, and fuel load. Not only greenhouse gases as carbon dioxide, which is the main impacts on the climate change and global warming, but also the particulate matter playing an important role to absorb and scatter light radiation [10], [11]. However, the forest land is a high potential area to sink carbon dioxide

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from the atmosphere by fixing it through the photosynthesis process but the forest cannot absorb the particulate matter. Therefore, this study aims to quantify carbon storage in aboveground biomass of tropical deciduous forest, which is also important for fire prevention, fire control, and effective fire management. Furthermore, the information of the study will be applied to characterize carbon in term of CO, CO_2 and carbonaceous aerosols released from burning of biomass fuel in tropical deciduous forest, Thailand.

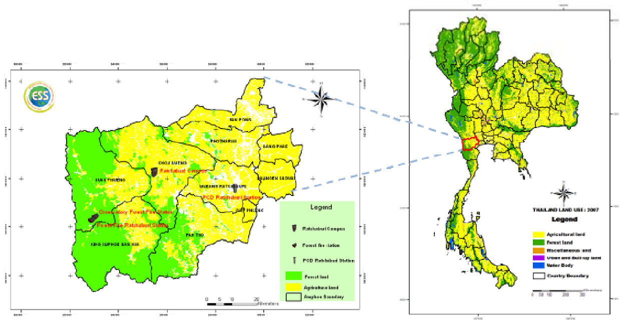
II. Materials and Methods

A. Study Area Description

Ratchaburi province is located in the western Thailand, lied between 13°32′ N - 13°54′N latitude and 99°49′ E - 99°82′E longitude. This province covers 5,196,462 km^2 areas. The high mountainous areas located in the western part of the province (Suan Pueng district, Khing Amphoe Ban Kha and Park Tho district) which close to the border of Thailand and Myanmar. The altitude for this area ranges from 200 - 1,400 m asl.

(Fig. 1). These areas have been considered as "the rain shadow zone" since most of the rain is blocked by Tanowsri Mountain. The average total rainfall and mean temperature during the year 2005 to 2008, were 959 - 1,285 mm and 28°**C**, respectively (Ratchaburi meteorological station reported). The highest temperature in dry season especially in April, lies between 30.3 - 31.3°C. On the other hand, December was the coolest month with temperature range from 24.5 - 26.9°C. January was the driest month range of 0.0 - 6.5 mm rainfall, contrary of October was the wettest month range of 117.6-441.5 mm rainfall. Of the total land area in the province (5,196,462 km^2), the tropical deciduous forest consists of 1,218 km^2 DDF and 167 km^2 MDF, while the area of tropical rain forest and pure stand bamboo forest are about 149 and 2 km^2, respectively.

The study site was located in the Mae Nam Phachi Wildlife Sanctuary. The wildlife sanctuary located in Baan Beung, Suan Pheung District, Ratchaburi province, of which the total area of this wildlife sanctuary is 489 km^2 (Fig. 1).



Source: An Inventory of air pollutant and Greenhouse Gas Emission and Concentrations in Ratchaburi province, Thailand, ESS (Earth System Science), KMUTT (King Mongkut's University of Technology Thonburi).

Fig. 1 Field experiment study area at Ratchaburi province, Thailand

B. Plot Set Up

The study site is located in tropical deciduous forest (DDF and MDF). In DDF, 2 study plots were setup at the steep area (the slope lies between 20-40%), while another 2 plots were setup at the terrain area (slope <20%). According to the MDF, four plots were set up in the terrain area (slope <20%). Each plot has a size of 40 m × 40 m. The aboveground estimation of tree (dbh >4.5 cm) and bamboo were collected in one square 20 m × 20 m plot located at the left corner of the main 40 m × 40 m plot, while sapling (dbh < 4.5, but > 1.3 m height) were estimated from 4 square 10 m × 10 m subplots. The seedling (total height <1.3 m), other understory (grass, herb, shrub, climber,) and litter (both leaf and small twig) were collected from 4 square 1 m × 1 m subplots (Fig. 2).

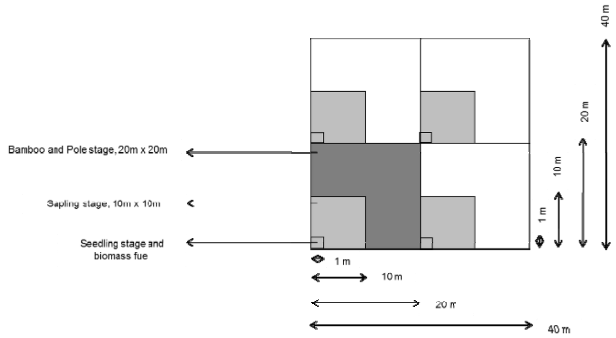


Fig. 2 Plot set up for aboveground biomass estimation in DDF and MDF at the study site, Ratchaburi province, Thailand

C. Aboveground Biomass and C-stock Estimation

Dbh and total height were recorded for all tree, sapling and bamboo. Aboveground tree biomass was estimated using the allometric equation of [12] as in (1). The estimation of aboveground sapling biomass and aboveground bamboo biomass (*T. siamensis*) were obtained from the allometric equation of [13] and [14] as in (2) and (3) respectively.

$$
\begin{aligned}
W_s &= 0.0396\ D^2 H^{0.9326} \\
W_b &= 0.003487\ D^2 H^{1.0270} \\
W_l &= \left(\frac{28.0}{W_{tc}} + 0.025\right)^{-1}
\end{aligned} \tag{1}
$$

$$
\begin{aligned}
W_s &= 0.0893059\ D^2 H^{0.66513} \\
W_b &= 0.0153063\ D^2 H^{0.58255} \\
W_l &= 0.0000140\ D^2 H^{0.44363}
\end{aligned} \tag{2}
$$

where:
D is the diameter at breast height [cm],
H is the height of tree stand [m],
W_s is the mass of stem [kg],
W_b is the mass of branch [kg],
W_l is the mass of leaf [kg],
W_{tc} is the total mass of stem and branch [kg],

$$W_c = 0.0691512\ D^2 H^{0.7930}$$
$$W_t = 0.0883689\ D^2 H^{0.7703} \qquad (3)$$
$$W_{b+l} = W_t - W_c$$

where:
D is the diameter at breast height [cm],
H is the height of culm [m],
W_c is the mass of culm [kg],
W_t is the total mass of culm, branch and leaf [kg],
W_{b+l} is the total mass of branch and leaf [kg],

The understory fuel biomass including seedling, grass, shrub, climber, herb and litter (leaf and twig) was determined directly using harvesting method, and fresh weight were measured. Samples were collected to determine fuel moisture content and calculate dry weight. Samples were oven-dried at 80 °C for at least 48 hrs, and weighted The total dry weight of biomass fuel as live and dead parts were converted from fresh weight and dry weight ratios from the sampling area based on (4).

$$Total\ \ DW\ \ (kg\ \ m^2) = \frac{Total\ \ FW\ \ (kg) \times Subsample\ \ \ DW\ \ (g)}{Subsample\ \ \ FW\ \ (g) \times Sample\ \ \ area\ (m^2)} \qquad (4)$$

C-stock in aboveground biomass was calculated based on IPCC 2006 by multiplying the 0.47 conversion factor to the biomass [15].

III. Results and Discussion

A. Vegetation Structure and Composition

The dominant species in DDF are *Shorea obtusa, S. siamensis, Lannea coromandelica* and *Dipterocarpus obtusifolius,* while dominant species in MDF are *S. siamensis, Millettia brandisiara, Grewia eriocarpa* and *Pterocarpus macrocarpus*. They are growing up in rainy season (Aug. to Nov.) and shed leave in dry season (from Dec. to Apr.) as illustrated in Fig. 3 and 4.

(A) (B)

Fig. 3 DDF plot at the study site, Ratchaburi province, Thailand; (A) rainy season and (B) dry season

(C) (D)

Fig. 4 MDF plot at the study site, Ratchaburi province, Thailand; (C) rainy season and (D) dry season.

The tree density in steep slope and terrain DDF are 2,350 ± 354 and 1,225 ± 71 indiv./ha, respectively, and sapling density in steep slope and terrain are 813 ± 477 and 825 ± 106 indiv./ha, respectively (Table I). The number of individual in DBH size distribution of tree in DDF and MDF decreased with an increase in DBH.(L-shape). The dbh distributions showed that a high proportion of trees present belonged to the small diameter class (4.5-20 cm) both for DDF and MDF (Fig. 5). A high number of individual tree per area, a small size of DBH and Ht is determined that this is a secondary forest.

Although the diameter size classes of tree in range 20 - 40 cm are the highest capacity to sink carbon dioxide via photosynthesis process [4] but these small trees in the study area can grow in the further as well.

The mean tree DBH of DDF located in steep slope and terrain are 9.50 and 8.45 cm, respectively. According to the sapling, DBH mean value in the steep slope and terrain are 2.82 and 2.86 cm, respectively (Table I). However, the DBH and Ht mean values of tree in MDF is higher than that of the DDF, while both dbh and Ht for sapling in DDF and MDF are similar. Since bamboo (*T. siamensis*) present in the MDF, the average diameter of the culm is 2.62 cm. In this study, we use the DBH and Ht of each vegetation category (Table I) to estimate the aboveground biomass using the allometric equation (1) to (3).

B. Above Ground Biomass of Tree Stand

The aboveground biomass of the stand composed of tree and sapling, which were estimated from 3 parts, i.e. stem, branch, and leaf. The aboveground biomass of tree in DDF at the steep slope, terrain and in MDF are 81.91, 23.82 and 18.93 t/ha, respectively. While aboveground biomass for sapling of each plot was equal among the forest (i.e. 1.74, 1.94 and 1.64 t/ha for the DDF at steep slope, terrain, and MDF, respectively). The highest of aboveground biomass of tree in DDF at steep slope is related to the stand density. Based on the DBH mean values and density of tree stand in tropical deciduous forest, we estimate that the above-ground biomass in this area will slightly increase in the further.

TABLE I
THE VEGETATION STRUCTURE (DENSITY DIAMETER AT BREAST HEIGHT, DBH AND HEIGHT, HT) IN DDF AND MDF PLOTS

Forest type	Vegetation Category	Plot slope (%)	Density (indiv./ha)	DBH (cm)		Ht (m)	
				mean	range	mean	range
DDF	Tree	20-40	2,350 ±354	9.50	4.77-43.29	9.33	2.50-20.50
	Tree	<20	1,225 ±71	8.45	4.77-43.29	6.35	2.60-13.00
	Sapling	20-40	813 ± 477	2.82	0.64-4.46	3.28	1.50-8.20
	Sapling	<20	825 ± 106	2.86	1.02-4.39	2.50	1.50-4.80
MDF	Tree	<20	481 ±189	10.92	4.62-67.48	10.03	3.00-24.30
	Sapling	<20	383 ± 225	3.02	0.57-4.20	4.23	1.30-7.80
	Bamboo	<20	13,931 ± 3,319[a]	2.62	1.29-5.87	7.73	2.00-21.70
	Bamboo	<20	1,438 ± 651[b]	36.90	10.67-106.88	7.73	2.00-21.70

[a,b] The individual number of bamboo in unit trunk/ha, and clump/ha, respectively.

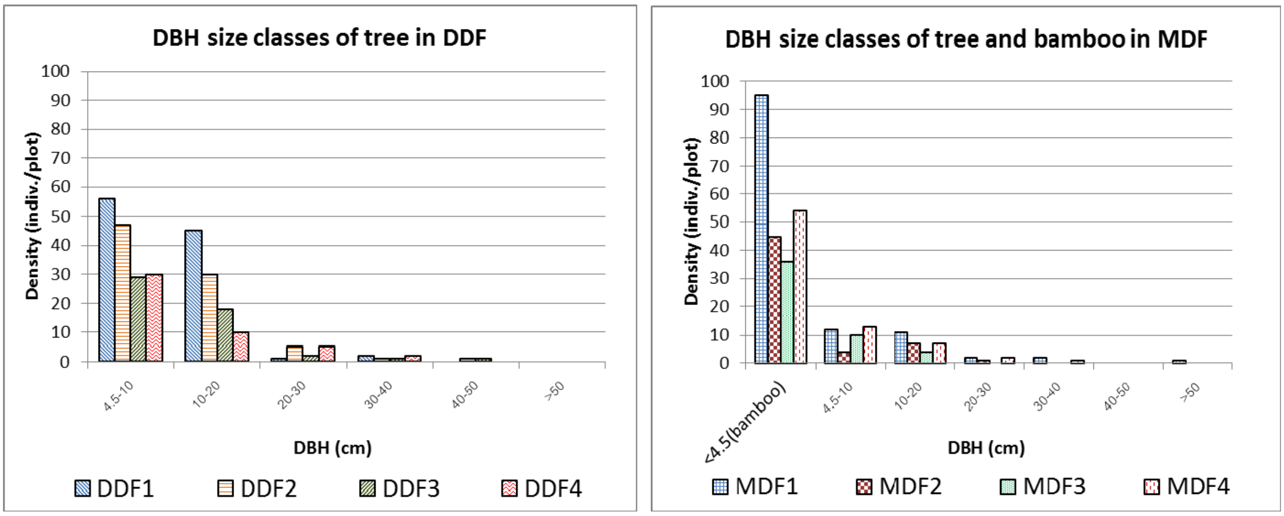


Fig. 5 Tree diameter distribution in the DDF and MDF plots.

TABLE II
ABOVEGROUND BIOMASS (AGB) OF EACH MASS SECTION OF VEGETATION CATEGORY IN DDF AND MDF

Category	Biomass section	AGB (ton/ha) DDF Slope 20-40%	AGB (ton/ha) DDF Slope <20%	AGB (ton/ha) MDF Slope <20%
tree	Stem	68.40	19.90	16.83
	Branch	7.43	2.08	1.84
	Leaf	6.08	1.84	0.26
Sapling	Stem	1.51	1.10	0.66
	Branch	0.23	0.18	0.98
	Leaf	0.0002	0.66	0.0001
bamboo	Culm	-	-	26.98
	Branch and leaf	-	-	4.22
Biomass fuel	understory	-	0.26	1.13
	Litter	7.83	3.29	4.96
	Twig	0.48	1.64	1.58
Total AGB, t/ha		91.96	30.95	59.44

C. Above Ground Biomass of Bamboo *(T. siamensis)*

MDF usually consists of tree species that mixed with many bamboo species. In the study plot of MDF, we found *T. siamensis*, which is the main bamboo species. The density of *T. siamensis* is 13,931 culm/ha, of which their dbh ranged from 1.29-5.87 cm (TABLE I). The number of clump in MDF ranged from 36-95 clumps per plot. Each clump composed of 5-50 culms. The aboveground biomass of the culm and branch (with leaf) of *T. siamensis* are 26.98 and 4.22 ton/ha (Table II).

TABLE III
FUEL HEIGHT OF BIOMASS FUELS IN DDF AND MDF PLOTS

Plot	Slope (%)	Biomass fuel height (cm) Live: seedling	Live: grass, herb, climber, etc.	Dead: litter	Dead: twig
DDF	20-40%	10-12	7-21	5-10	3-4
	<20%	30-55	10-25	0-3	2-6
MDF	<20%	12-50	25-30	4-6	1-4

D. Understory and litter Biomass Fuels

The height of understory varied among sites, depends on the structure and composition of live and dead vegetation type. The biomass of understory vegetation usually changes with the season, which its peak in rainy season. The height of seedling at the terrain in DDF site is the highest among other. The height of litter at the steep slope DDF, terrain DDF and terrain MDF are 5-10, 0-3 and 4-6 cm, respectively (TABLE III). The good agreement was found when compared with the other research in western region of Thailand, Huay Kha Khaeng Wildlife Sanctuary, Uthai-thani province, which the average of litter height in DDF was 5.27 cm and litter was highest in dry season (7-10 cm) [7]. However, the litter height at the terrain DDF is the lowest and the fuel arrangement was discontinuously (TABLE III and Fig. 6) which can be attributed to the low density of vegetation plant. This low fuel eight and fuel discontinuity, therefore, may affect rate of fire spread, and hence fire intensity of this plot.

Fig. 6 Biomass fuels sampling in DDF plots (slope <20%)

TABLE IV
ABOVE-GROUND BIOMASS AND CARBON STOCK OF TROPICAL DECIDUOUS FOREST IN WESTERN REGION, THAILAND

Forest type	AGB (ton/ha)	C-stock (ton C/ha)	Ref.
DDF slope20-40%	91.96	43.22	this study
DDF slope <20%	30.95	14.55	this study
DDF	58.62 ± 19.42	29.31 ± 9.71	[16]
MDF slope <20%	59.44	27.94	this study
MDF	68.52 ± 48.36	34.26 ± 24.18	[16]
MDF	141.06	66.30	[3]
MDF	96.28 ± 33.44	45.28 ± 15.72	[3]
MDF	158.68	74.58	[17]

E. Carbon Stock of Above-Ground Biomass

Biomass carbon storage at the steep slope DDF, terrain DDF and terrain MDF are 43.22, 14.55 and 27.94 ton·C/ha, respectively. The comparison of carbon storage with the other research is based on the IPCC 2006 conversion the aboveground biomass by factor value (TABLE IV). We found that the variation values of carbon storage in tropical deciduous forest in western region are in range of 10 - 66 ton·C/ha. The aboveground biomass in the study was estimated by means of the allometry correlation between mean value of DBH, Ht, and biomass. Obviously, the result of our study is comparable with other studies. Moreover, the variation of carbon stock in aboveground dependent on many factors such as the stand structure and composition, topography, altitude, and disturbance, forest fire in particular. However, the organic carbon component in above-ground biomass of secondary forest is less than 51.90 ton C/ha [18].

IV. CONCLUSION

The number of individual in DBH size distribution of tree in DDF and MDF decreased with an increase in DBH, which mean dbh was in range of 8.50-11.0 cm. It was shown that the forest of this area is a secondary forest. The number of individual tree at the steep slope DDF is the highest. According to the aboveground biomass of the steep slope DDF, terrain DDF and terrain MDF were 91.96, 30.95 and 59.44 ton/ha, respectively. The aboveground biomass at the terrain MDF had included the aboveground biomass of *T. siamensis* bamboo, which is the dominant species in MDF of Ratchaburi province. However, the aboveground biomass and aboveground carbon storage at the steep slope DDF was the highest, followed by the terrain MDF and they were lowest at the terrain DDF. The great proportion of the biomass fuel load for both forest types composed is leaf litter, of which its contribution up to 60-94%. This great proportion of fuel biomass can be used to estimate the pollutant released from the burning. Furthermore, this tropical deciduous forest, either DDF or MDF in this study have a high potential for absorbing carbon dioxide (CO_2) from the ambient atmosphere and also CO_2 released from the wildfire.

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