



Carbon Stock of Teak Plantation in Subtropical Region of Lower Northern Thailand

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Abstract

An increase in atmospheric carbon dioxide is a serious environmental concern. The objective of this study was to assess carbon sequestration by teak plantations with varying ages from 21 to 36 years old. 36-year-old teak plantation had highest total above and below ground carbon and soil organic carbon which were 45.6 tCha⁻¹ and 180 tCha⁻¹, respectively. Teak plantation can help alleviate the problem of increased atmospheric carbon dioxide concentration.

Keywords: Carbon stock, Teak plantation, Aboveground carbon, Belowground carbon, Soil organic carbon

Introduction

Tropical deforestation is a major cause of increased atmospheric carbon dioxide concentration and the global average of the gross emission rate of tropical deforestation was 2.9 pentagrams of carbon from year 1990 to 2007 (Pan et al., 2011). There have been intense efforts to increase sinks for the gas at international level, including afforestation in deforested areas (Gibbs & Harold, 2007). One particular method to decrease CO₂ concentration is to promoting plantations. The perennial plants can decrease atmospheric carbon dioxide concentration through the photosynthetic process and carbon accumulates in trees plants as plant biomass (Redondo-Brenes & Montagnini, 2006). In addition, fallen leaves and branches on the top soils are degraded by soil microorganisms and the carbon is stored as soil organic carbon (Zhang & Zhang, 2003) also known as carbon stock.

Afforestation may help to reduce atmospheric CO₂ concentration. In Thailand and other countries, teak plantation has been promoted in deforested and degraded areas. Teak (*Tectona grandis* L.f.) is a principal tree species for timber since the middle of

the nineteenth century. Although native to south and southeast Asia, mainly India, Myanmar, Laos and Thailand, teak is cultivated in other parts of the world, including in Java, Indonesia. Teak performs well in plantations under favorable conditions and most commonly found in moist and dry deciduous forests below 1,000 m elevation. However, teak grows best in localities with annual rainfalls of 1,250 to 3,750 millimeters (mm) with minimum temperatures of 13°C to 17°C and maximum temperatures of 39°C to 43°C (Pandey & Brown, 2000). Although natural teak is found in productive soils derived from sediment such as limestone (Tanaka, Hamazaki, & Vacharangkura, 1998) teak plantations are now relatively common across Asia, Africa and Latin America. In 2010, the total area of cultivated teak was estimated to be 4.346 million hectares (ha), of which 83% are in Asia; 11 % in Africa; and 2 % in Americas and Oceania (Kollert & Cherubini, 2012; Teak Holz International, 2014). The majority of teak plantation in Asia is mostly state-owned. Thailand produces both natural and cultivated teak. The policy to promote teak plantations was initiated in 1956 (Amuntakul, 2010).



Teak plantations in Thailand were managed by the government sector in 2001 and the private sector in 2002 covering areas of 194,789.29 ha and 101,014.56 ha, respectively (Royal forest department, 2002).

Teak plantation can store substantial amount of carbon. Most studies on teak emphasized on estimating biomass, carbon stocks, and change in carbon stocks in relation to plantation ages: (Khanduri, Lalnundanga, & Vanlalremkimi, 2008; Bermejo, Can ellasa, & San Miguelbet, 2004; Kraenzal, Castillo, Moore, & Potvin, 2003; Krishnapillay, 2000; Karmacharya & Singh, 1992). Despite this, all studies were conducted on teak plantation with the age of less than 30 years. In order to emphasize the role of teak as carbon sink, above ground and underground carbon stocks were determined in teak plantation with varying ages from 21 to 36 years.

Methodology

1. The study area

The study area is located in lower northern Thailand (Figure 1), covering approximately 1,302.9 hectares. The topographical aspects vary from 110 meters above the sea level in flat areas in the southeastern part to 700 meters in mountainous areas on the western edge. Nevertheless, most trees were in a flat plain of 131–215 meters above the sea level. The local climates were tropical and subtropical with three distinctive seasons; summer (February to May); rainy (June to October); winter (November to January). According to the meteorological data collected for a period of 13 years between 1999–2013 by the Rainfall Station at Huay Rabum Plantation (25 km from the study site), the annual minimum and maximum temperatures are 18.5°C and 37°C, respectively with the average of

27°C and the average humidity is 85 %. The average annual rainfall is 1648.8 mm with the highest rainfall of 312.65 mm in September, and the lowest rainfall of 6.14 mm in January. The different ecotypes surrounding the study area range from hilly mixed deciduous forest and dry evergreen in the western part to lowland mono-agricultural crops such as tapioca, corn, and sugarcane.

2. The sampling sites

The teak plantation was established between 1977 and 1992. Most soils are sandy derived from metamorphic complexes of facies, banded quartzite, calc-silicate rocks, biotite schist and granite gneiss, and developed during Precambrian (Proterozoic) period. Based on the USDA classification system (Soil Survey Staff, 2014), the soils are classified as coarse-loamy, kaolinitic, isohyperthermic Typic Haplustulfs (Ban Rai soil series). The planting space of 4 m x 4 m are for the teak of 21, 23, 25, 26, 28, 35 and 36 years and of 2 m x 8 m for the teak of 30, 31, 33, and 34 years.

3. Study design and methods

Three study plot size of 50 m x 50 m size for all teak ages were randomly selected in each teak plantation. The study plots were mainly covered with teak trees whereas there were very few other tree species such as *Pterocarpus macrocarpus* Kurz, *Xylia xylocarpa* Roxb. Taub, *Spondias pinnata* (L.f.) Kurz, *Cassia fistula* L. In each study plot, all trees with girth size greater than 4.5 cm at the breast height of 1.30 m (DBH) were measured. The tree height was measured using Haga Hypsometer. Five 2 m x 2 m sub-plots (four sub-plot at the four corners and one at the middle) were assigned in each 50 m x 50 m plot. Saplings and shrubs with DBH less than 4.5 cm and with height greater than 1.3 m in all five 2 m x 2 m sub-plots were cleared off at ground level. A sub-plot of 1 m x 1 m was constructed at the middle of each 2 m x 2 m sub-plot to remove



all plants shorter than 1.3 m, along with seedlings, undergrowth, climbers, other vegetation and standing dead trees. Litters of all plants on the surface were also collected, weighed and recorded. The samples were oven-dried at 80°C for 48 hours or until the weight remained unchanged and dry weight determined. Teak biomass was calculated using the allometric equation of Petmark and Sahunalu (1980). The equation is as follows:

$$\text{Log}W_s = 0.9797 \log(D^2H - 1.6902; R^2 = 0.9930)$$

$$\text{Log}W_B = 0.0605 \log(D^2H - 2.06326; R^2 = 0.5967)$$

$$\text{Log}W_L = 0.7088 \log(D^2H - 1.7383; R^2 = 0.8523)$$

Where; D = Diameter at breast height (cm), H = Height of tree (m), W_s = Stem biomass (kg), W_B = Branch biomass (kg), W_L = Leaf biomass (kg).

Root biomass was calculated by using root equations (Viriyabuncha, Rattanaproncharoen, & Tiyanon, 2003).

$$W_R = 0.0054 D^2 H^{0.9894} R^2 = 0.9890$$

Where; W_R = Root biomass (Kg), D = Diameter at breast height (cm), H = Height of tree (m)

To estimate the soil organic carbon (SOC), soil samples were collected up to the depth of 0–0.15, 0.15–0.3, 0.3–0.5, 0.5–0.6, 0.6–0.9 and 0.9–1.0 m, at five random locations in each 50 m x 50 m plot. Soil samples were then air-dried and crushed to pass through a sieve of 2 mm mesh. Roots, other plants and debris were also removed. The content of SOC was estimated by organic matter measurement using the Walkley and Black method (1934), and bulk density of the soil was determined using undisturbed soil samples. The aboveground carbon stock per given area (tCha^{-1}) was determined and all the biomass contents of all plants were determined. The aboveground and root biomass were then multiplied by 0.47 (IPCC, 2006) to indicate the quantity of carbon stock (tCha^{-1}).

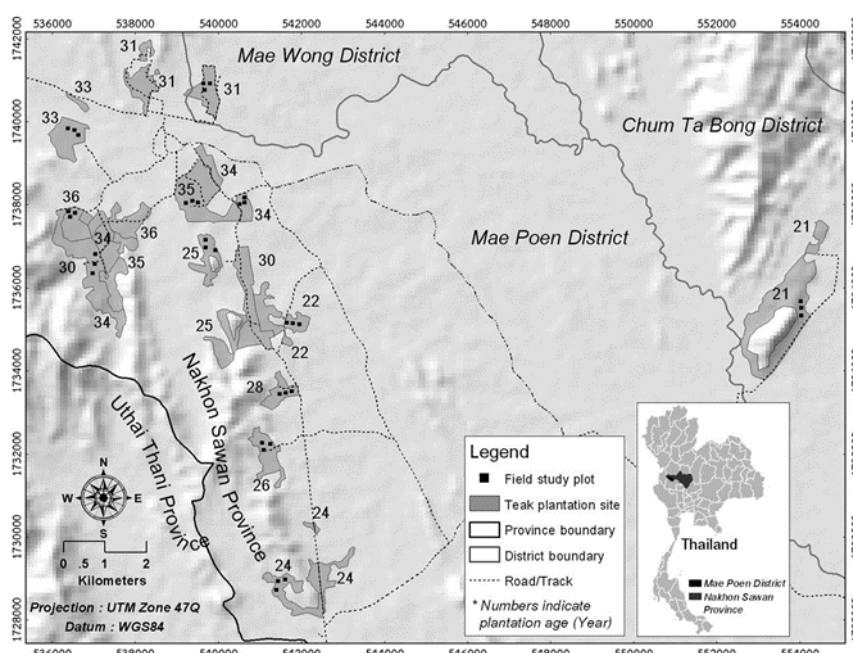


Figure 1 Location of teak plantation sites

Results and discussion

1. Characteristics in teak plantation

In general teak DBH tended to be greater with increasing ages. For spacing of 4 m x 4 m, plants at the age of 21, 23, 24, 25, 26, 28, 35, and 36 years had DBH of 20.9, 20.6, 22.0, 21.8, 23.0, 22.6, 17.4, 18.3, 26.7 and 28.42 cm, respectively. For the spacing of 2 m x 8 m, the plants with the age of 31, 33, 34 had DBH of, 28.1, 30.7, 29.0 cm, respectively. The relation between the mean DBH and age of teak was significantly correlated ($R^2=0.672$; $P<0.05$). With regards to teak height, the tallest teak was in the plot of teak aged 34 years followed by the teak at the age of 33 years old and the heights were 15.1 and 14.7 m, respectively. The shortest teak was 11.36 m at the age of 28 years old (Table 1). The undergrowth vegetation in all plots had similar species although some plots dominated by grass species. Most of the plant species found in the site were of the same types found in mixed deciduous forest. Examples of tree seedlings include *Tectona grandis* L.f., *Pterocarpus macrocarpus* Kurz, *Xylia xylocarpa*

Taub. var. *Kerrii* Nielson, *Careya sphaerica* Roxb, *Vitex limonifolia* Wall, *Bombax ceiba* Linn., *Licuala kunstleri* Becc., *Zollingeria dongnaiensis* Pierre, *Chukrasia velutina* Roem., *Acacia tomentosa* Willd., *Diospyros rhodcalyx* Kurz, *Cassia fistula* L., *Spondias pinnata* (L.f.) Kurz, *Millettia brandisiana* Kurz, *Lagerstroemia floribunda* Jack, *Cassia garrettiana* (Craib.) Irwin & Basneby and so forth. Ground covers and understory plants were *Zingiber zerumbet* (L.) Smith, *Leucaena leucocephala* (Lam.) de Wit, *Jasminum nervosum* Lour, *Amomum villosum* Lour, *Alpinia zerumbet*. There were also shrubs such as *Cajanus cajan* (L.) Millsp., *Combretum procusum* Craib., *Chromolaena odorata* (L.) King & Robinson., *Zingiber zerumbet* Smith. *Helicteres isora* Linn., *Gmelina elliptica* Sm., *Luvunga scandens* (Roxb.) Buch.-Ham (*Paramignys Scandens* Craib.), and grass species such as *Pogonatherum paniceum* (Lamk.) Hack., *Imperata cylindrica* (L.) P. Beauv., *Brachiaria mutica* (Forssk.) Stapf., *Eremochloa ciliatifolia* Hack., *Echinochloa crus-galli* (L.) Beauv., and so forth. The plots with the age of 24 and 28 year old were partly covered with higher density of grasses, especially *Imperata cylindrica* (L.) P. Beauv or cogon grass.

Table 1 Description of teak plantation plots in each age stage

| Age (year) | Planting Space (m) | Area size (ha) | Teak density (tree/ha) | Mean Slope (%) | Mean Elevation (m) | Mean DBH (Diameter, cm) | | | Mean Height (H,m) | | |
|---------------|--------------------------|-------------------|------------------------------|----------------------|--------------------------|-------------------------------|-------|--------------------|----------------------|-------|-----------------------|
| | | | | | | Min | Max | Mean \pm S.D. | Min | Max | Mean \pm S.D. |
| 21 | 4x4 | 266.32 | 272 | 4.33 | 140.00 | 19.72 | 21.99 | 20.86 \pm 1.15bc | 11.73 | 12.04 | 11.91 \pm 0.16cde |
| 23 | 4x4 | 24.96 | 343 | 6.67 | 135.00 | 18.96 | 22.37 | 20.64 \pm 1.94bc | 12.11 | 13.58 | 13.01 \pm 0.79abcde |
| 24 | 4x4 | 118.62 | 363 | 3.67 | 146.00 | 21.13 | 22.45 | 21.79 \pm 0.72b | 13.45 | 13.47 | 13.45 \pm 0.01abcde |
| 25 | 4x4 | 40.16 | 468 | 4.33 | 183.00 | 22.30 | 23.61 | 22.96 \pm 0.68b | 12.72 | 14.41 | 13.63 \pm 0.85abcd |
| 26 | 4x4 | 56.96 | 200 | 9.33 | 136.00 | 17.29 | 27.96 | 22.63 \pm 5.33b | 12.40 | 16.89 | 14.39 \pm 2.28ab |
| 28 | 4x4 | 30.08 | 411 | 5.00 | 143.67 | 15.05 | 19.72 | 17.38 \pm 2.34c | 9.53 | 12.28 | 11.26 \pm 1.51e |
| 30 | 2x8 | 221.24 | 330 | 6.67 | 191.33 | 15.89 | 20.66 | 18.27 \pm 2.67bc | 10.16 | 12.91 | 11.73 \pm 1.42de |
| 31 | 2x8 | 88.32 | 187 | 6.33 | 169.00 | 25.87 | 30.41 | 28.14 \pm 2.41a | 13.50 | 14.76 | 14.30 \pm 0.64abcd |
| 33 | 2x8 | 91.20 | 148 | 5.67 | 193.00 | 29.24 | 32.15 | 30.70 \pm 1.46a | 13.01 | 15.83 | 14.69 \pm 1.47a |

**Table 1** (Cont.)

| Age (year) | Planting Space (m) | Area size (ha) | Teak density (tree/ha) | Mean Slope (%) | Mean Elevation (m) | Mean DBH (Diameter, cm) | | | Mean Height (H,m) | | |
|---------------|--------------------------|-------------------|------------------------------|----------------------|--------------------------|-------------------------------|-------|--------------------|----------------------|-------|---------------------|
| | | | | | | Min | Max | Mean \pm S.D. | Min | Max | Mean \pm S.D. |
| 34 | 2x8 | 160.04 | 99 | 11.00 | 166.00 | 25.23 | 32.74 | 28.99 \pm 3.85a | 14.52 | 16.00 | 15.11 \pm 0.78.a |
| 35 | 4x4 | 153.80 | 328 | 3.33 | 185.67 | 24.76 | 28.64 | 26.70 \pm 1.97ab | 13.21 | 15.13 | 14.11 \pm 0.96ab |
| 36 | 4x4 | 51.20 | 252 | 9.33 | 212.33 | 26.20 | 30.60 | 28.42 \pm 2.56a | 12.30 | 15.61 | 14.14 \pm 1.68abc |

2. Aboveground and belowground carbon stock

The proportion of aboveground and belowground carbon stock in teak plantation with varying ages was presented in Table 2. Plantation teak in the subtropical region of lower northern Thailand can store carbon at the highest amount of 45.62 tCha⁻¹ when the plants were 36 years old. This was higher than above ground carbon of 10-year-old teak (Derwisch, Schwendenmann, Olschewski, & Hölscher, 2009). The carbon contents in stems and branches were 26.28 tCha⁻¹ and 6.58 tCha⁻¹, respectively. The carbon stock in

leaves was the highest, 2.03 tCha⁻¹, at the plantation age of 22 years. The highest total carbon stock of undergrowth of 2.52 tCha⁻¹ was found at the age of 30 years. This was comparable to the undergrowth of 20-year old teak (Kraenzal et al., 2003). Carbon stock in litters at the age of 25 years was highest at 3.44 tCha⁻¹ which similar to the liter of teak plantation at 20 years old (Kraenzal et al., 2003) and Teak root carbon stock was highest of 7.60 tCha⁻¹ at the age of 36 years (Table 2).

Table 2 Aboveground and belowground carbon stock in teak plantation (tCha⁻¹)

| Age (Years) | C _s | C _B | C _L | C _R | TTC | UG _c | L _c | FFC | ABGC | TFFC |
|----------------|----------------|----------------|----------------|----------------|-------|-----------------|----------------|------|-------|-------|
| 21 | 13.79 | 3.26 | 1.09 | 3.96 | 22.10 | 1.00 | 2.38 | 3.38 | 21.52 | 27.48 |
| 22 | 18.12 | 5.80 | 2.03 | 5.00 | 30.95 | 2.32 | 2.11 | 4.43 | 30.38 | 35.38 |
| 24 | 20.52 | 4.86 | 1.60 | 5.90 | 32.88 | 1.37 | 3.29 | 4.66 | 31.64 | 37.54 |
| 25 | 20.81 | 4.93 | 1.62 | 5.99 | 33.35 | 1.39 | 3.44 | 4.83 | 32.19 | 38.18 |
| 26 | 12.36 | 2.98 | 0.92 | 3.56 | 19.82 | 1.06 | 1.64 | 2.70 | 18.96 | 22.52 |
| 28 | 13.78 | 3.20 | 1.24 | 3.77 | 21.99 | 1.09 | 2.37 | 3.46 | 21.68 | 25.45 |
| 30 | 18.04 | 4.32 | 1.44 | 5.19 | 28.99 | 2.52 | 1.64 | 4.16 | 27.96 | 33.15 |
| 31 | 17.64 | 4.34 | 1.21 | 5.09 | 28.28 | 2.24 | 2.30 | 4.54 | 27.73 | 32.82 |
| 33 | 19.74 | 5.04 | 1.21 | 5.72 | 31.71 | 1.46 | 1.72 | 3.18 | 29.17 | 34.89 |
| 34 | 11.96 | 3.01 | 0.76 | 3.46 | 19.19 | 1.52 | 1.95 | 3.47 | 19.20 | 22.66 |
| 35 | 19.94 | 6.28 | 2.10 | 5.74 | 34.06 | 1.54 | 1.88 | 3.42 | 31.74 | 37.48 |
| 36 | 26.28 | 6.58 | 1.72 | 7.60 | 42.18 | 1.80 | 1.64 | 3.44 | 38.02 | 45.62 |

Note: C_s: teak stem carbon; C_B: teak branch carbon; C_L: teak leaf carbon; C_R: teak root carbon; TTC: total tree organic carbon (C_s + C_B + C_L + C_R); UG_c: total carbon stock of under growth, seedling, and sampling; L_c: carbon in litter; FFC: forest floor carbon (UG_c + L_c); ABGC: aboveground carbon (C_s + C_B + C_L + FFC); TFFC: Total carbon stock of aboveground

3. Soil organic carbon

The percentage of soil organic carbon tends to decrease with depth of soil. At the depth of 1–15 cm, percentage of soil organic carbon were between 0.5 and 2.4. At the depth of 90–100 cm, the range of percentage of soil organic carbon was 0.5 and 1.5 (Figure 2). There was no significant correlation ($P < 0.05$) between the aboveground carbon quantity and teak age. However, when teak plantations were grouped according to the ages, Group 1 = 21–22 years, Group 2 = 24–25 years, Group 3 = 26–28 years, Group 4 = 30–31 years, Group 5 = 33–34 years, and Group 6 = 35–36 years, there was a positive correlation between the soil

organic carbon and age groups ($R^2 = 0.860^{**}$, $P < 0.01$) and also between the age groups and the total carbon stock (TCS) ($R^2 = 0.794^*$, $P < 0.05$) (Figure 3). Soil organic carbons at different age groups were between 110 and 180 tCha^{-1} (Figure 3). The proportion of carbon stock in different teak plantation ages are shown in Figure 4. Soil organic carbon dominates the proportion of total carbon stock for all ages of teak plantation (Figure 4). Teak plantation at the age of 36 years old had highest soil organic carbon of 180 tCha^{-1} .

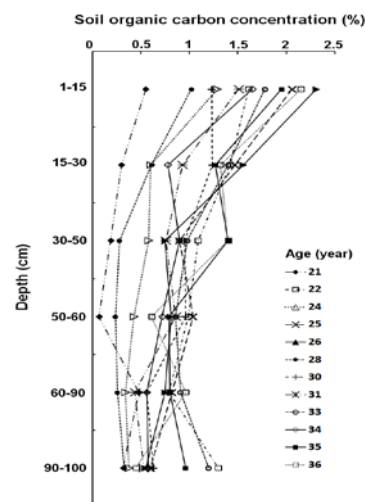


Figure 2 Vertical distribution of soil carbon stock in teak plantation categorized by plantation age

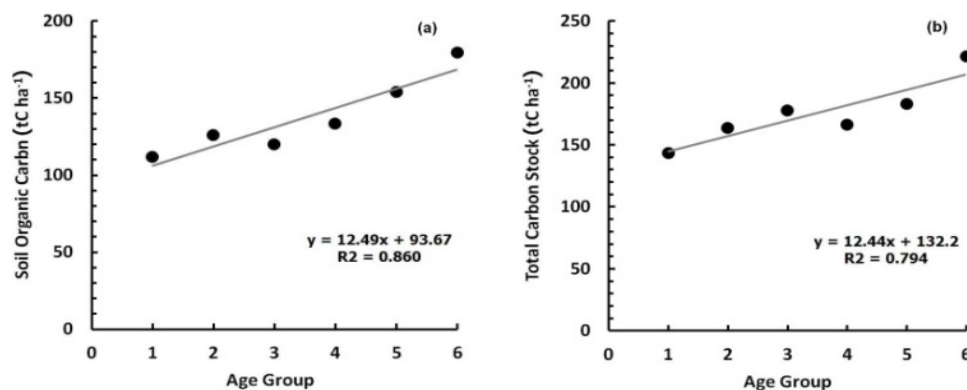


Figure 3 Soil Organic Carbon (a) and total carbon stock (b) in teak plantation categorized by age group

Note: Age group of teak plantation were categorized into 6 groups; Group 1 = 21–22 years, Group 2 = 24–25 years, Group 3 = 26–28 years, Group 4 = 30–31 years, Group 5 = 33–34 years, Group 6 = 35–36 years.

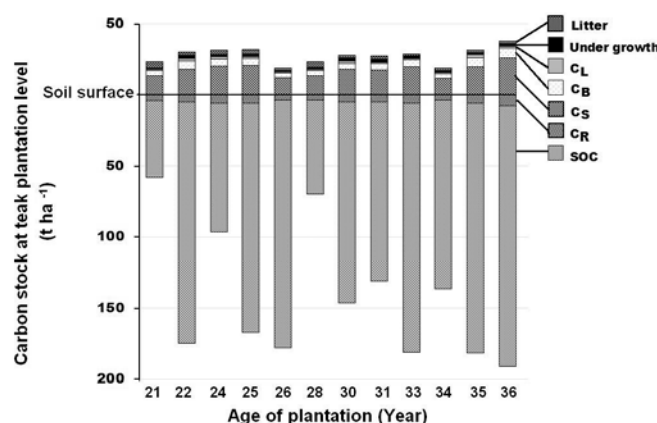


Figure 4 The proportion of carbon stock in different plantation ages

4. Total carbon stock

Total carbon stocks highly correlate with ages of teak plantation (Figure 3). Teak plantations with the ages between 21–23 had the lowest total carbon stock of 140 tCha^{-1} . The highest total carbon stock of 220 tCha^{-1} was found in teak plantation with the ages between 35 and 36 years old.

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