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Research article

# Relationship between Carbon Content and Growth of Teak in Natural Forest and Plantation, Lampang Province, Thailand

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**Abstract**

The relationship was studied between the carbon content (percentage dry weight of carbon in tree stems) and growth of teak in natural forest and plantation at Mae Ngao National Reserve Forest and at Huai Thak in a 63 year-old plantation in Lampang province, Thailand, respectively. Teak growth patterns were studied using dendrochronological techniques that were then classified into three growth-rate periods (small, medium, large). The carbon contents of teak in each growth-rate period within the natural forest and the plantation were compared using one-way analysis of variance, while differences between the natural forest and plantation within each growth-rate period were compared using an independent two-sample t test. The results indicated that the differences in the carbon contents between growth-rate periods of teak in natural forest were not significant ($p = 0.053$), with the carbon contents based on dry weight in the small, medium and large growth-rate periods in the natural forest being 49.16%, 49.49% and 49.75%, respectively. Similarly, the differences in the carbon contents among the growth-rate periods of teak in the plantation were not significant ($p = 0.583$), with the carbon contents based on dry weight in the small, medium and large growth-rate periods of teak in the plantation being 48.83%, 49.19% and 49.29%, respectively. The differences in the carbon contents of teak growing in natural forest and plantation were not significant ($p = 0.201$). The average carbon contents on a dry weight basis in natural forest and plantation were 49.47% and 49.10%, respectively.

## Introduction

An important aspect of forest management in natural forests and plantations is to consider tree growth and forest productivity (Davis, 1966; Matthews et al., 2016). At present, due to climate change and global warming concerns, forest management has given priority to increased carbon content (Bettinger et al., 2009). It has been indicated that forests have the potential to absorb a high proportion of carbon dioxide emissions to counter rising greenhouse gas levels (World Resources Institute, 2006).

The carbon content in forest biomass in natural forests and plantations depends on the difference in biomass and the carbon content accumulated in various parts of the tree (Faculty of Forestry, 2011), especially in the stem. Currently, most researchers calculate the carbon content in the stem without taking into account the different growth rates or annual ring widths that can affect the quantity of

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carbon in the wood. Owing to different annual ring widths, the cell wall thickness is different between the annual rings (Puangchit, 2007), resulting in differences in the density of wood. (Premyslovska et al., 2007; Franceschini et al., 2010) There exists a negative relationship between the annual ring width and wood density (Franceschini et al., 2010; Majid et al., 2012), which may result in different carbon contents in different sections of the wood.

To manage natural forests and plantations with regard to conservation or carbon content, information on tree growth and the amount of carbon in the wood each year where there are different growth patterns is important. Therefore, tree ring measurements need to be undertaken every year to study long-term growth information and this requires a substantial budget.

Tree growth studies of tropical species are difficult as there are usually no clear tree-ring boundaries, though this is not the case with teak, which has distinct annual growth rings (Palakit et al., 2012; Rathore and Jasrai, 2013). Over the years, teak has been used to study long-term environmental changes based on analysis of the annual rings, using dendrochronological techniques (Fritts, 1976; Madany and West, 1982; Sheppard et al., 1988; Schweingruber, 1996).

The purpose of this study was to investigate the relationship between the growth of teak and the carbon content during different teak growth-rate periods (small, medium, and large). Teak radial growth was analyzed using dendrochronological techniques in the Laboratory of Tropical Dendrochronology, Faculty of Forestry, Kasetsart University, Bangkok, Thailand using core samples taken to determine the carbon content. Subsequently, a comparison was undertaken of the carbon contents during each growth-rate period in natural forest and plantation in Lampang province, Thailand, (in the Mae Ngao National Reserve Forest and in a 63 year-old plantation in Huai Thak , respectively).

## Materials and Methods

### *Study area*

The study sites were located in the natural forest of Mae Ngao National Reserve Forest with a total area of 64,373 ha and in a plantation at Huai Thak established in 1952 with a total area of 39 ha. Both study sites were located in the Banghuad sub-district, Ngao district, Lampang province, northern Thailand (18°15’N, 99°30’E) as shown in Fig. 1.

### *Sample tree selection*

A sample of 21 trees was subjectively selected in the natural forest adjacent to the study plantation (to control environmental factors). Trees within the natural forest that were dominant with a straight trunk, having little defect and low scar occurrence and disease were considered for sampling (Ferguson, 1970; Fritts, 1976).

Teak inventory sample tree data collected from temporary sample plots installed using the systematic sampling method (Cochran, 1963) at the Huai Thak plantation that was established in 1952 were pooled. The inventory sample tree data were used to construct a tree distribution of the diameter at breast height (DBH; at 1.3 m above the ground) outside bark. This DBH distribution was divided into three classes (low, medium, high). Next, the optimum number of subsample trees for coring ($n$) was calculated using Equation 1 based on Shiver and Borders (1996):

$$n = \frac{t^2(CV)^2}{AE^2} \quad (1)$$

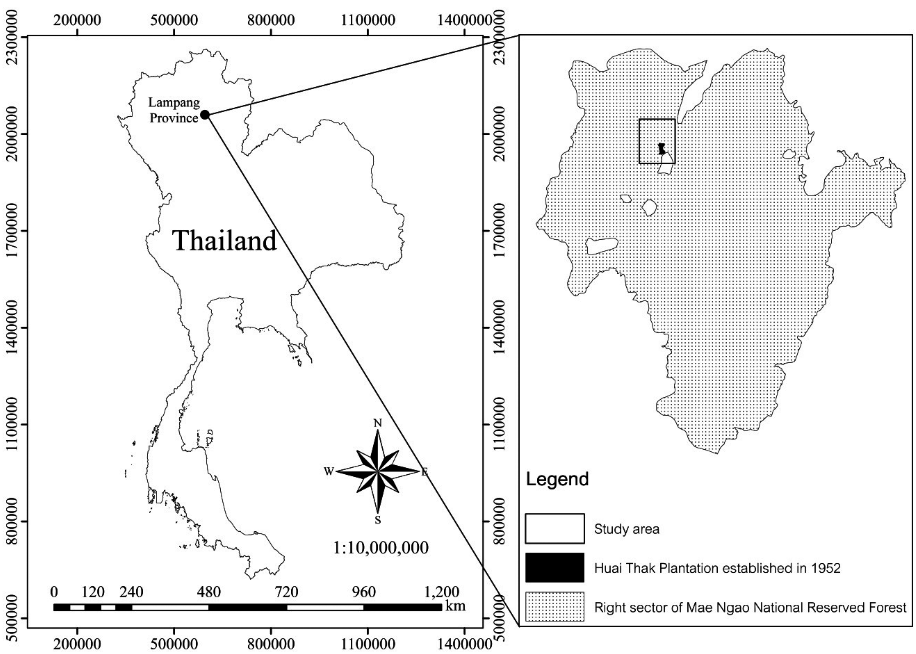


**Fig. 1** Locations of study areas in natural forest (right sector of Mae Ngao National Reserved Forest) and Huai Thak plantation in Lampang province, Thailand.

where *n* is the target number of sample trees; t is the confidence value at the 95% probability level; CV is the coefficient of variation for DBH (43%, from the inventory); and AE is the allowable standard error in DBH (10%). Then, the sample trees for coring were selected from each of the three classes of DBH distribution (low, medium, high), with 10 trees selected at random from each class. In total, 83 samples trees were selected for coring. This was higher than the calculated optimal sample size of 72 trees, based on Equation 1.

*Sample core collection*

Sample cores from the selected sample trees in the natural forest and plantation were collected according to two objectives: 1) analyze growth patterns and 2) to calculate the amount of carbon content in teak. Samples were drilled from the bark into the pith in the center of the tree using an increment borer at a height of 1.3 m from the ground. Four cores per sample tree in two perpendicular directions (two sample cores for each of the north-south and east-west directions) were taken with a total of 134 cores as shown in Table 1. Tree core samples were stored in plastic tubes and transported to the laboratory for further analysis.

*Tree core sample preparation and measurement for growth analysis*

The tree core samples were prepared in the Laboratory of Tropical Dendrochronology, Faculty of Forestry, Kasetsart University, Bangkok, Thailand following the standard methods of dendrochronology (Stokes and Smiley, 1996). Each tree core sample was removed from the plastic tube and mounted using glue on a slate and left at room temperature for 2–3 d until the glue had completely dried. The samples were scrubbed with sandpaper of several grades until the boundaries of annual rings were clear enough for microscopic investigation. Cross-dating and cross-matching techniques were used to define the growth ring during each year (Fritts, 1976; Ferguson, 1970). The accuracy of growth ring identification was verified using the program COFECHA (Holmes, 1983) that assesses the quality of cross-dating and measurement accuracy of a tree ring series, after each ring had been measured to a resolution of 0.001 mm.

*Tree core sample preparation and measurement for carbon content analysis*

Tree core samples for carbon content analysis were removed from the plastic tube and the bark and pith in the core sample were cut off using a surgical blade. The diameter of sample cores was measured using a set of Vernier calipers and the fresh weight of the sample core was also noted. The sample was then oven dried at 80°C for 24–48 hr to constant weight to determine the final dry weight of the sample core.

*Carbon content analysis of teak*

Classification of growth-rate periods was based on annual ring width data with carbon content analysis. The total annual ring width data (minimum, maximum, average of annual ring width data) were calculated and classified into the three growth-rate periods as small growth-rate period (annual ring width 0–3 mm/yr), medium growth-rate period (annual ring width 3–6 mm/yr) and large growth-rate period (annual ring width 6–12 mm/yr).

After the growth rate classification, the core sample was cut for carbon content analysis in each annual ring. According to growth-rate periods obtained previously, the annual ring width pattern in each annual ring was compared with sample cores for growth measurement. The sample cores in each growth-rate period were then placed in bags and labeled with a code.

All core samples in each growth-rate period were oven-dried at 80°C, powdered and then used for estimation of carbon. The carbon content in the samples was measured using a CHN analyzer (2400 series II CHNS/O Elemental Analyzer; PerkinElmer; Waltham, MA, USA). Each resultant carbon proportion was obtained as a percentage.

*Statistical Analysis*

The One-way Analysis of Variance was used to analyze the data of the carbon contents of teak in each growth-rate period within the natural forest and plantation (significance was tested at $p < 0.05$). The carbon contents during each growth-rate period of teak found in the natural forest and the plantation were compared using an independent two-sample t test (significance was tested at $p < 0.05$).

**Table 1** Teak samples obtained from Mae Ngao National Reserved Forest and Huai Thak plantation in Lampang province**,** Thailand

| Forest type | Number of sample trees | Number of sample cores | | |
|---|---|---|---|---|
| | | For growth analysis | For carbon content analysis | Total |
| Natural Forest | 18 | 36 | 36 | 72 |
| Plantation | 19 | 38 | 24* | 62 |
| Total | 37 | 74 | 60 | 134 |

* Since teak growing in the plantation had diameter at breast height variance less than in the natural forest, three dimeter classes were used, with four trees chosen randomly in each class, resulting in 12 trees and 24 cores in total.

## Results

### *Teak growth*

The number of rings taken at DBH in each sample core varied between 23 and 63 rings in the natural forest. The DBH range was 26.1–53.8 cm, with an average of 40.1 cm. The radial growth of teak in the natural forest had a mean annual increment of diameter at breast height ($MAI_{DBH}$) in the range 1.082–2.767 mm/yr, with an average of 2.004 mm/yr. The current annual increment of diameter at breast height ($CAI_{DBH}$) was in the range 0.707–7.072 mm/yr, with an average of 2.757 mm/yr. As shown in Fig. 2, the trend in the radial growth of teak during the first period was slow with 1–30 rings and a narrow annual ring width (average 3.235 mm). After that, the growth increased (average 5.936 mm).

The teak sampled in the Huai Thak plantation was aged about 63 yr. There were 61 rings identified in the core taken at DBH. The DBH was in range 32.3–56.8 cm, with an average of 44.2 cm. The radial growth in the plantation was mostly constant, as indicated in Fig. 3. The growth rate was stable, especially during terminal growth. The $MAI_{DBH}$ was in the range 2.992–5.249 mm, with an average of 4.281 mm and the $CAI_{DBH}$ was in the range 0.956–7.485 mm/yr, with an average of 3.281 mm/yr. The trend in radial growth during the initial period was in the range 1–16 rings with an average annual ring width of 5.083 mm/yr, and after that, the annual ring width decreased and was constant for 37 rings (average 2.586 mm).

### *Relationship between growth of teak and carbon content during each growth-rate period of teak*

During each growth-rate period of teak in the natural forest, the carbon content and growth were not significantly difference. As indicated in Table 2, the average carbon content of the dry weight during the periods of small growth rate (annual ring width 0–3 mm/yr) was 49.16%, for medium growth rate (annual ring width 3–6 mm/yr) was 49.49% and for large growth rate (annual ring width 6–12 mm/yr) was 49.75%.

The same analysis to investigate a relationship between the growth of teak and the carbon content in the plantation also indicated that carbon content during each growth-rate period of teak was not significantly difference. The average carbon contents of the dry weight during small (annual ring width 0–3 mm/yr), medium (annual ring width 3–6 mm/yr) and large growth-rate (annual ring width 6–12 mm/yr) periods were 48.83%, 49.19% and 49.29%, respectively (Table 2).

### *Comparison of carbon content of teak in natural forests and plantation.*

A comparison of the carbon content during each growth-rate period of teak in the natural forest and plantation indicated there was no significant difference for any of the three periods (Table 2).

From Table 2, the average carbon content percentages of the dry weight during the small growth-rate period in the natural forest and the plantation were 49.16% and 48.83%, respectively, during the medium

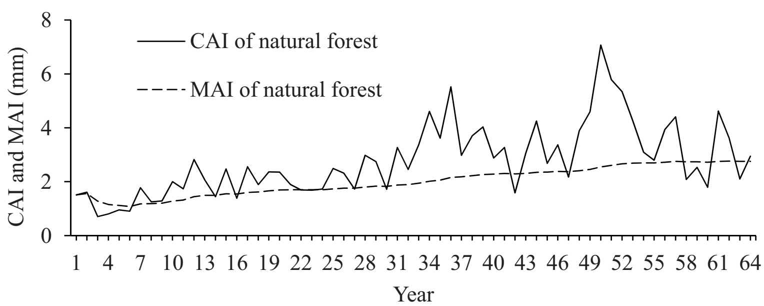


**Fig. 2** Current annual increment (CAI) and mean annual increment (MAI) of teak in the study area (right sector of Mae Ngao National Reserved Forest)

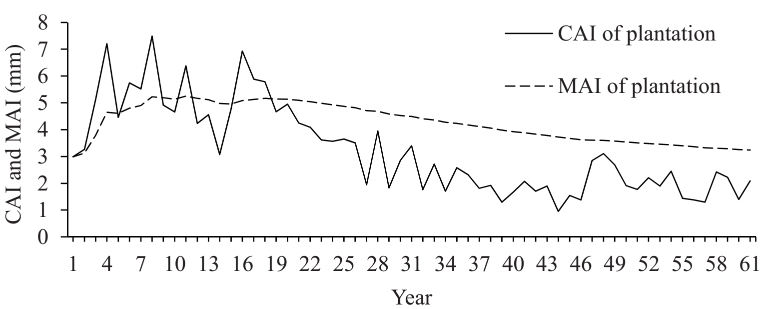


**Fig. 3** Current annual increment (CAI) and mean annual increment (MAI) of teak in the study area in Huai Thak plantation

**Table 2** Comparison of carbon content during each growth-rate period of teak in the natural forest and the plantation

| Growth-rate period | Forest type | Average carbon proportion (%) | Standard deviation (%) | t value | *p* value |
|---|---|---|---|---|---|
| Small | Natural forest | 49.16 | 0.774 | 0.728 | 0.473 |
| | Plantation | 48.83 | 1.689 | | |
| Medium | Natural forest | 49.49 | 0.682 | 1.084 | 0.288 |
| | Plantation | 49.19 | 0.854 | | |
| Large | Natural forest | 49.75 | 0.669 | 2.031 | 0.052 |
| | Plantation | 49.29 | 0.498 | | |

**Table 3** Comparison of overall carbon content of teak in the natural forest and the plantation

| Forest type | Number of sample trees | Average carbon proportion (%) | Standard deviation (%) | t value | *p* value |
|---|---|---|---|---|---|
| Natural forest | 18 | 49.47 | 0.909 | -1.308 | 0.201 |
| Plantation | 12 | 49.10 | 0.621 | | |

growth-rate period were 49.49% and 49.19%, respectively, and during large growth-rate period were 49.75% and 49.29%, respectively. Similar values for the overall carbon content were obtained for teak in natural forest and plantation (Table 3). The average wood carbon content percentages of dry weight in the natural forest and plantation were 49.47% and 49.10%, respectively (Table 3). In addition, the carbon contents in the natural forest and plantation were not significantly different.

## Discussion

The number of rings found in the Mae Ngao National Reserved Forest was in the range 23–63 rings, with a mean DBH of 40.1 cm and an average ring width of 2.757 mm, which were comparable to teak tree studies done in other locations. For example, a 60 year-old teak growing in the natural forests of India had a DBH of 48 cm (Gyi and Tint, 2017) which was similar to the current study. Average ring widths reported in a 99 year-old teak in Myanmar were around 3.36 mm (Pumijumnong, 1999) which were different from the current study. However, the ring width of wood is based on aggregate factors such as the age-related growth trend due to normal physiological aging processes, the climate during that year, the occurrence of disturbance factors within the forest stand (for example, a blow down of trees), the occurrence of disturbance factors from outside the forest stand (for example, an insect outbreak that defoliates the trees causing growth reduction) and other random (error) processes not accounted for by these processes (Fritts, 1976).

Tree cores in the Huai Thak plantation indicated the age was 63 years, with an average DBH of 44.2 cm and average ring width of 3.281 mm, comparable to teak tree plantations reported in other locations. For example, teak growth studies in East Timor reported diameters around 38–43 cm (Thomas and Martin, 2012) for trees aged 50–60 yr and were comparable to a teak tree study with high growth in very favorable conditions in India, with reported diameters around 48 cm for trees aged 40 yr (Priya and Bhat, 1999). Teak growth in the current study was initially rapid, slowing down after 15 yr or 20–25 yr, which corresponded to the juvenile stage (Priya and Bhat, 1998; Bhat et al, 2001; Kumar et al., 2002). A similar trend was noted in Trinidad with the growth of teak slowing down after 25 yr (Schmincke, 2000). The growth rate has been reported to be rapid from 25–30 yr and subsequently slower up to 60 yr (Bhat et al., 2001), which was similar to the teak growth pattern reported by Sangram et al. (2016). The average ring width in each period of teak in the current study as well as that reported by Bhat et al. (2001) was 6.6 mm in the juvenile wood and 2.5 mm in the mature wood. Williamson and Wiemann (2010) found that the specific gravity of wood was closely linked with the mechanical properties of wood and with carbon storage. The juvenile wood had a wide ring width (average 6.6 mm) and the mature wood had a narrow ring width (average 2.5 mm).

The study of teak trees in natural forests and plantations, was reported by Michael (1994) and is summarized below. He indicated that trees occurring in natural forests have different growth patterns compared to those in plantations, with an early stage of extremely slow diameter growth while the sapling is dominated by other dominant trees. This is followed by an intermediate stage, when the tree grows more rapidly but the growth is still severely affected by larger neighbors. Trees in the final stages of growth have a large, free, well-developed crown and trees of a similar size are few and distant. On the other hand, the growth rate in tree diameter in plantations, during the early immature stage is not affected by competition to a large extent, before canopy closure because of the even spacing of the planted trees. During the responsive middle stage, as a result of canopy closure, the annual ring width decreases, but responds quickly to treatment such as thinning and fertilizing and is followed by the final (mature) stage, when the annual ring width is narrow and is not so markedly responsive to treatment.

The average carbon contents of the dry weight in the teak stems in the Mae Ngao National Reserved Forest and the Huai Thak plantation were 49.47% and 49.10%, respectively. Similar results in teak stems have been reported with an average carbon percentage of 49–50% of the dry weight in hardwood species (Lamlom and Savidge, 2003; Wachcharangkur et al., 2005). Other researchers reported the carbon content of teak stems in Thailand have a mean value of 46.60% of the dry weight (Treepattanasuwan et al., n.d.) and 48.10% of dry weight (Faculty of Forestry, 2011), which were lower than recorded in the current research.

The carbon content estimated in the current research was greater than the median internationally used value of 47% of the dry weight (Intergovernmental Panel on Climate Change, 2006), This difference may be because the Intergovernmental Panel on Climate Change (IPCC) value of carbon in the wood was taken from the average of above-ground biomass from various parts of the tree and the global IPCC study included trees from tropical, subtropical, temperate and boreal locations.

The carbon content in the biomass of the stem wood of teak in the current study was different from that in other studies which indicated that the percentage of carbon content on a dry weight basis in spruce, fir, beech, oak, birch and conifers was 50.1%, 51.1%, 48.6%, 49.5% and 48.5%, respectively (Weiss et al., 2000). However, the trees occurring in different forest types in Thailand have been reported to have carbon contents in the range 48–55% of biomass (Diloksumpun, 2007). The current result was consistent with Sreejesh et al. (2013), who reported that the amount of carbon content is different for different parts of trees and Thomas and Martin (2012) reported that the carbon content is different for different species.

Another important result of the current study was that the carbon content during each tree growth phase in natural forest and plantation indicated that their different annual ring widths did not have an influence on the carbon content in the wood.

The major conclusion for the current study was that for the study sites investigated, the teak carbon content was not related to the growth rate and there were no significant differences in the carbon content between the natural forest and plantation teak sites.

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