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Original Article

Growth of teak regenerated by coppice and stump planting in Mae Moh Plantation, Lampang province, Thailand

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A B S T R A C T

The current annual increment (CAI_{dbh}) and the mean annual increment (MAI_{dbh}) both for the diameter at breast height (1.3 m) were investigated to compare the differences between coppice and stump-planted teak in Mae Moh Plantation. Forty-eight sample cores were collected from a 9 yr-old teak plantation using an increment borer; annual increments were analyzed using dendrochronological techniques. The results indicated that there was no significant ($p > 0.05$) difference in the average diameter at breast height (DBH) between the coppice and stump-planted teak, whereas the total height of stump planting was significantly greater than that of coppice teak. The CAI_{dbh} of coppice teak was in the range 0.316–2.371 cm and continuously decreased throughout the 9 yr period. The CAI_{dbh} of stump planting was in the range 0.162–1.982 cm and continuously increased from the beginning of growth for 5 yr followed by a decline thereafter for 4 yr. The CAI_{dbh} of coppice showed rapid growth in the years 1–4 and was greater than for the stump-planted teak even in years 5–8 after planting; however, the growth of the stump-planted teak in the ninth year was higher than for the coppice. The MAI_{dbh} values of coppice and stump-planted teak were not significantly ($p > 0.05$) different. The results showed that CAI_{dbh} at age 5 yr can be used as a silvicultural guide to increase the yield of teak coppice.

Introduction

Teak (*Tectona grandis* Linn. f.) is one of the most widely planted hardwood timber species in the world (Ball et al., 1999). It is indigenous in Southeast Asia with a discontinuous or patchy distribution of 2.25 million ha at latitudes in the range 9°–25°30′N and longitudes in the range 73–104°30′E (Thaiutsa et al., 2001). In the deciduous forests of Thailand, teaks grow well on deep fertile soil with fine sandy loams and loams in an altitudinal range of 200–750 m above mean sea level (Thaiutsa, 1999). Bhumibhamon (1986) reported that teak was the best economic tree species and consequently was selected as one of the priority plantation species. However, the management of teak plantations is complex due to variations in environmental, social and economic conditions; therefore, government, private and state enterprises have trialed many different practices in teak plantation silviculture, including regeneration, intermediate cuttings and protection (Suwannapinant, 2001).

Planting and regeneration are important practices in teak plantation management; in Thailand, the Forest Industry Organization (FIO), which is the agency responsible for state teak plantations, improved the regeneration system of teak and reduced its rotation period, utilizing two techniques for teak planting and regeneration. The first technique was stump planting, where a stump is a seedling with all leaves and root hairs removed, leaving only the main stem and roots. Stump planting offers several benefits such as being able to be transported considerable distances while maintaining stump viability and being easy and quick to plant; consequently, this technique is used in several countries (Chaudhari, 1963; Thaiutsa, 1999; Midgley et al., 2007). The second technique was coppicing; it utilizes natural regeneration from the cut stump of a harvested tree and can contribute to rapid restoration of forest cover after clear cutting (Sukwong et al., 1976). The primary advantages of coppicing for short rotations are that it is easy, offers a low cost of establishment and accelerates early growth (Bailey and Harjanto, 2005; Chowdhury et al., 2008) and thus, is widely practiced in many countries (Smith, 1962). However the common technique in permanent sample plots for mean annual increment (MAI) analysis involves comparing the teak growth difference between coppice and stump planting by measuring tree diameter at breast height (1.3 m) either over bark or under bark, and there can be errors introduced due to bark moisture differences and bark loss between remeasurements and the delay in obtaining

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timely data for teak plantation management (Prasomsin and Duangsathaporn, 2005). In addition the average growth data provide an average, static value that might overestimate or underestimate tree growth periods over the rotation and the assumed rotation age may be incorrect. If plantations are harvested before or after that assumed rotation age, mean yields will be different.

Current annual increment (CAI) is the difference between the attribute value of interest at the beginning and at the end of a year's growth. It is a useful measure of site quality and forest stand dynamics, which are important factors in sustainable plantation management that vary with age (Prasomsin and Duangsathaporn, 2005), which means the MAI will also vary with age. This study used tree-ring analysis to investigate the CAI as dendrochronology allows rapid analysis of long-term growth data and comparison of the annual increment difference between coppice and stump-planted teak has not been reported in Thailand (Sukwong et al., 1976; Thaiutsa et al., 2001; Akkhaseeworn, 2007).

The objectives of this study were: 1) to investigate teak CAI growth of the diameter at breast height (1.3 m) under bark (CAI_{dbh}) of the coppice system and of the stump-planting system using a dendrochronological technique (tree-ring analysis); and 2) to compare the difference in teak growth in terms of CAI_{dbh} and the mean annual increment growth of the diameter at breast height (1.3 m) under bark (MAI_{dbh}) between coppice teak and stump planting, in order to select suitable planting and regeneration techniques.

Materials and methods

Study site

The study site was located at the Mae Moh Plantation belonging to FIO in Mae Moh district, Lampang province, northern Thailand, at a latitude of 18°25′N and longitude of 99°44′E (Fig. 1). The elevation of the study site was in the range 300–350 m above mean sea level. Means of annual rainfall and temperature in the period 1986–2011 were 1212 mm and 25 °C, respectively. The site was located in the foothills on a flat area and the soil type was sandy clay and slightly acidic with high organic matter. The stand (70.19 ha) was planted at an initial 4 × 4 m spacing. Old records showed that the study site had been clear cut in 2002 and natural regeneration had been allowed to grow from coppice, so this site had two ages of plants—teak from coppice and teak from stump planting with no thinning (Forest Industry Organization, 2012).

Sample collection

The study used the forest inventory line plot system (Sathit, 1982) comprising 35 plots. In each plot, information collected comprised: the regeneration system, each tree total height, each tree diameter at breast height over bark (DBH_{ob}) using a diameter tape and their distribution by diameter classes, with accurate checking of borderline trees, The radius of each sample plot was 12.62 m and the target number of plots was calculated using Eq. (1):

$$n = t^2 cv^2 \Big/ AE^2 \tag{1}$$

where n is the target number of the plots, t is the confidence value at the 95% probability level, cv is the coefficient of variation for DBH_{ob} and AE is the allowable error in the DBH_{ob} which was equal to 0.01 for the current study.

The number of sample plots from a forest inventory should be higher than the target calculation (Prasomsin and Duangsathaporn, 2005). Teak diameter classes were then classified and trees in each class were core sampled (Stokes and Smiley, 1968), using 10 trees per class for the CAI and MAI studies with CAI calculated using Eq. (2):

$$CAI_{dbh} = DBH_{t+1} - DBH_t \tag{2}$$

where CAI_{dbh} is the difference between the growth value measured at the beginning (DBH_t) and end (DBH_{t+1}) of a one-year period (where DBH is the diameter at breast height over bark).

The periodic MAI was calculated by dividing the mean annual increment by the stand age (Eq. (3)):

$$MAI_t = \frac{DBH\ _t}{t} \tag{3}$$

where MAI_t is the mean annual increment at stand age t years and DBH_t is the diameter at breast height under bark at age t years, with both tree measurements being either over bark or under bark. For the teak trees selected for tree-ring analysis, which were dominant, healthy and far away from watercourses, wood increment cores were collected from the bark to the pith at 1.30 m above the ground using an increment borer. In each tree, two wood increment cores were collected perpendicular to each other. The direction of core collection avoided tension wood (Cook and Kairiukstis, 1990), and wood cores were kept in plastic tubes to prevent them from breaking.

Preparation and measurement of annual ring width

The wood cores were prepared in the Laboratory of Tropical Dendrochronology, Kasetsart University, Faculty of Forestry (LTD–KUFF). Wood cores were ventilated at room temperature and fixed in wooden supports following the standard methods of dendrochronology (Stokes and Smiley, 1968). The fixed core samples were polished with several grades of sandpaper until the transverse surfaces and boundaries of annual rings were clear enough for macroscopic investigation. The growth year of each annual ring was determined using a cross matching technique and ring widths were measured on a tree-ring measuring stage with an accuracy of 0.001 mm. The results of annual ring width analysis were displayed and converted to a table format showing the growth year and ring width in columns using the KU-TRA program (version 1.0.; Laboratory of Tropical Dendrochronology, Faculty of Forestry, Kasetsart University, Bangkok, Thailand) The widths of annual rings were then cross-dated to verify the year of annual ring formation using the COFECHA program (Fritts, 1976).

Data analysis

Data analysis was conducted using the following four steps:

1. The distribution of diameter classes derived from the descriptive statistics was used to describe the characteristics of the selected coppice and stump-planted teak stand.
2. Mean plantation total height and DBH_{ob} of coppice and stump-planted teak were compared using the independent two-sample t-test statistics.
3. Annual ring widths of coppice and stump-planted teak were converted to CAI_{dbh} values using a forest mensuration technique (Prasomsin and Duangsathaporn, 2005).
4. Growth patterns between CAI_{dbh} and MAI_{dbh} of coppice and stump-planted teak were compared using the independent two-sample t-test statistics.

Statistical significance was tested at the ($p < 0.05$) level.

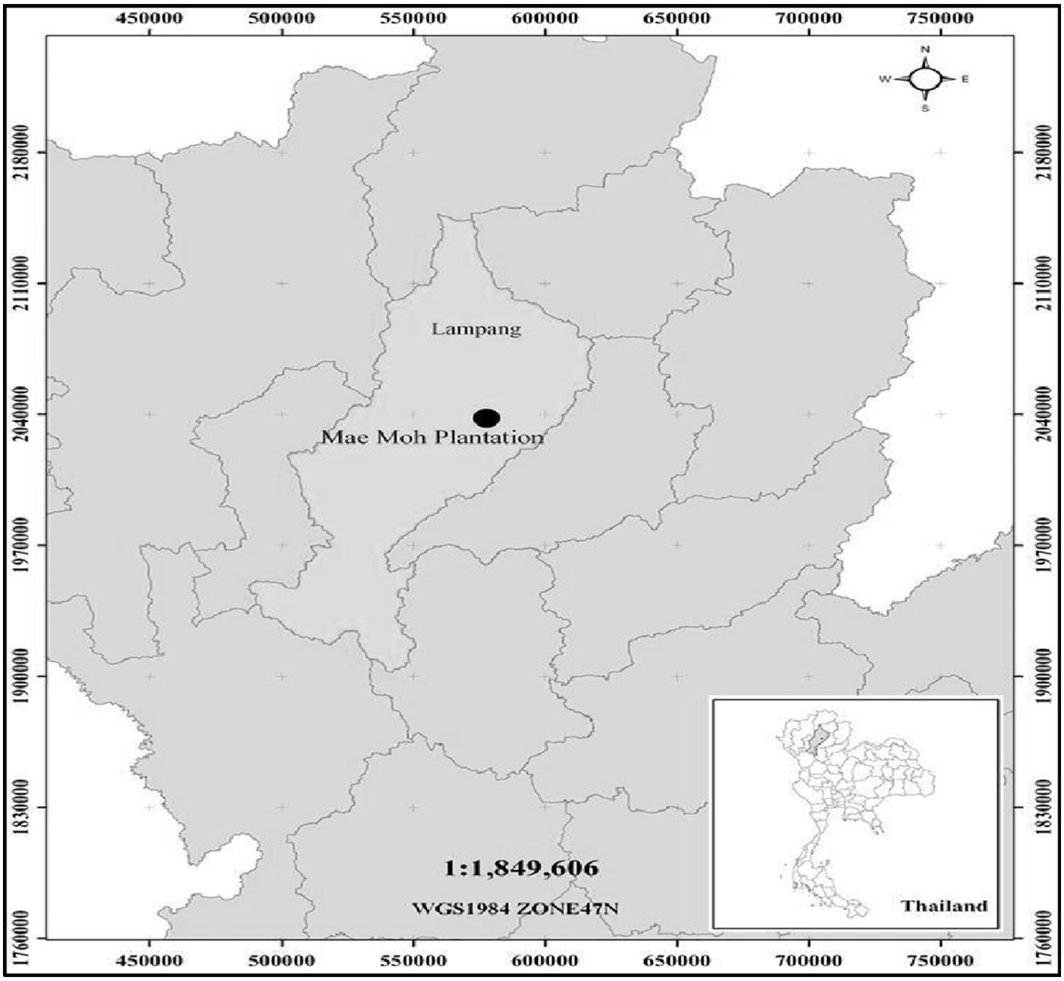

Fig. 1. Study site location in Mae Moh Plantation, Mae Moh district, Lampang province, northern Thailand.

Results and discussion

Distribution of diameter classes analysis

The number of sample plots depends on the variance of the diameters as shown in Eq. (1). For this study, 35 sample plots established in the stand inventory was adequate and in fact higher than the number of sample plots required (32 plots) using Eq. (1). The DBH_{ob} and the total height of coppice teak were within the ranges 10.2–26.4 cm and 7.0–14.5 m, respectively. The DBH and the total height of the stump-planted teak were within the ranges 10.8–24.5 cm and 8.0–14.0 m, respectively. Based on the independent two-sample *t*-test, the average values of DBH of coppice and stump-planted teak were not significantly different ($p > 0.05$), whereas the mean total height for stump planting was significantly different ($p < 0.05$) and higher than that of coppice teak (Table 1). The numbers of coppice and stump-planted teak were 280 and 278, respectively.

Table 1
General characteristics of coppice and stump-planted teak in Mae Moh Plantation, Lampang province, Thailand.

Regeneration	Number of trees	Number of plots	DBH_{ob} (cm)		Total height (m)	
			Mean ± SD	*t*-value	Mean ± SD	*t*-value
Coppice	280	35	15.91 ± 3.35	−0.87	11.30 ± 1.48	−2.41*
Stump planting	278	35	16.12 ± 3.47		11.55 ± 1.37	

DBH_{ob} = diameter at breast height over bark.
*significance tested at ($p < 0.05$).

Mean annual increment and current annual increment comparison of coppice and stump-planted teak

The MAI values determined using the DBH_{ob} measurement in the ninth year between coppice and stump-planted teak were not significantly different as shown in Table 2.

For CAI values, the teak coppice ring widths were in the range 3.035–10.023 mm, with the largest ring width occurring in the first year and the narrowest ring width occurring in the eighth year (Fig. 2A). The ring widths of the stump-planted teak were in the range 3.445–6.865 mm, with the highest value in the fifth year and the lowest value in the eighth year (Fig. 2A). The CAI_{dbh} for coppice teak was in the range 0.316–2.371 cm and continually decreased throughout the nine years. The CAI_{dbh} of stump-planted teak was in the range 0.186–1.982 cm and gradually increased in the years 1–5 followed by a decrease in the years 6 –9 (Fig. 2B).

The mean CAI of coppice teak was significantly higher than that of stump-planted teak from years 1–4. However, from years 5–8, there were no significant differences in the CAI_{dbh} between the coppice and stump-planted teak. In the ninth year, the CAI_{dbh} was significantly higher for stump-planted teak than for coppice teak.

This study showed that CAI_{dbh} of coppice teak was higher than that of stump-planted teak during early growth but the values were

Table 2
Mean values of current annual increment and mean annual increment both at diameter at breast height of coppice and stump-planted teak in Mae Moh Plantation, Lampang province, Thailand.

Age	Mean CAI_{dbh} ± SD (cm)			Mean MAI_{dbh} ± SD (cm/year)		
	Coppice	Stump Planting	*t*-value	Coppice	Stump Planting	*t*-value
1	2.005 ± 0.190	1.079 ± 0.380	7.150*			
2	1.953 ± 0.250	1.140 ± 0.280	9.480*			
3	1.880 ± 0.220	1.032 ± 0.320	9.590*			
4	1.838 ± 0.270	1.330 ± 0.160	5.840*			
5	1.506 ± 0.320	1.373 ± 0.160	1.480			
6	1.066 ± 0.280	0.878 ± 0.260	1.200			
7	1.024 ± 0.250	1.226 ± 0.280	−2.260			
8	0.607 ± 0.200	0.689 ± 0.230	−0.990			
9	0.607 ± 0.310	1.237 ± 0.210	9.450*	1.980 ± 0.410	1.87 ± 0.120	0.856
Overall mean	1.412	1.109				

CAI_{dhb} = current annual increment at diameter at breast height; MAI_{dhb} = mean annual increment at diameter at breast height.
*significance tested at ($p < 0.05$).

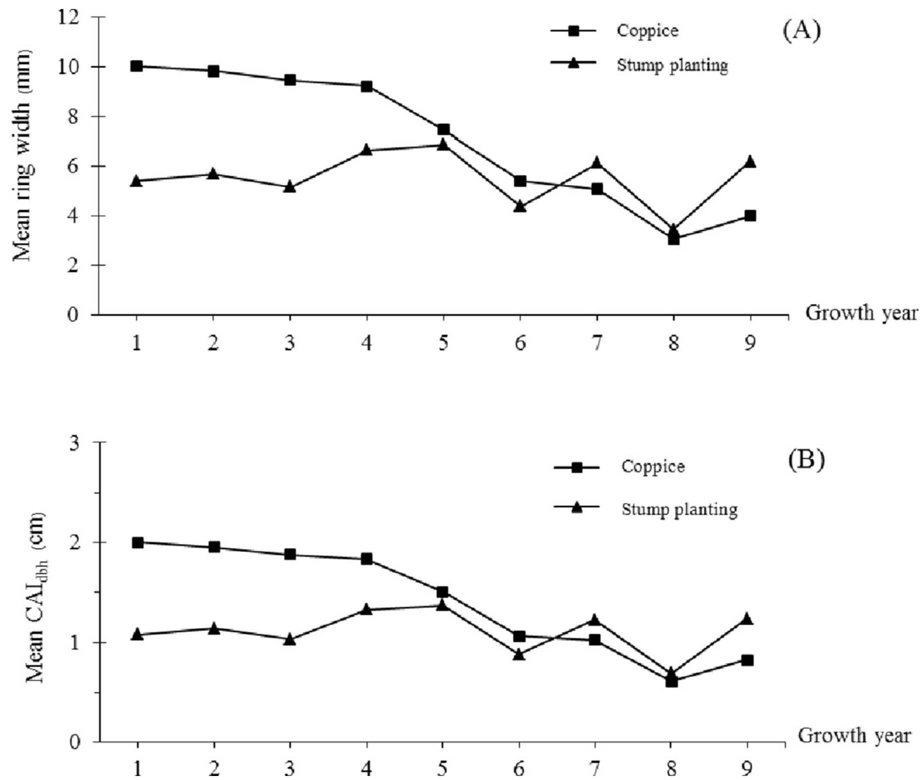

Fig. 2. Tree-ring width for coppice and stump-planted teak in Mae Moh Plantation, Lampang province, Thailand: (A) mean ring width; (B) mean current annual increment of diameter at breast height under bark (CAI_{dbh}).

similar as the teak grew. This suggested that coppice teak should be thinned when the CAI_{dbh} decreased in years 5–6. Stump-planted teak, where the CAI_{dbh} continued to increase, should be continuously monitored until CAI_{dbh} begins to decrease at which stage silvicultural intervention might be required. Yahya et al. (2011) reported 10 yr-old teak stands showed a positive growth response to a reduction in stand density and a change in the stand environment.

Findings from other studies on planting treatments were supported by the current results where the diameter of teak coppice was greater than that of stump-planted teak, perhaps because coppice teak was budded at the root collar and connected to the pith of the old stem. Bailey and Harjanto (2005) suggested that the diameter growth and height of coppice were higher than for stump-planted teak due to the stored food reserves in the mother stump, and this was similar to Sukwong et al. (1976) and Akkhaseeworn (2007). The CAI_{dbh} of coppice teak was higher than that of stump-planted teak from years 1–4 perhaps due to using accumulated nutrient supplies in the old stem. Later, the creation of new roots by the stump-planted teak increased the efficiency of nutrient consumption (Thammanon, 1980). Therefore, there was no significant difference between the CAI_{dbh} of teak coppice compared to stump-planted teak in years 5–8.

Teak planting based on a coppice system may save time and money associated with seed collection, transportation, nursery production of seedlings, and/or bureaucratic delays in establishing stump planting and nurseries. It may be necessary in areas where labor and money for stump planting are limited (Hamzah, 1975). Compared with stump planting, a potential disadvantage of using coppice is the increased amount of first log sweep, which is created when sprouts develop on the neck of stumps and grow away from a central position and this might affect the wood quality and ultimately, logging and milling efficiency (Wendel, 1975).

The study also identified several advantages of tree-ring analysis for forest management instead of relying on data collection from permanent sample plots. Tree-ring analysis yields direct values for specific age and lifetime growth rates and is therefore more accurate than extrapolations based on short-term growth data. Tree-ring data obtained from living trees reflect the growth rates of those trees that have survived to harvestable sizes (Roel, 2005). In the current study, the CAI growth data on coppice and stump-planted teak derived from tree-ring analysis were suitably accurate for forest management. Future research is needed to determine the number of cycles that teak can be successfully regenerated using coppice and also on teak growth under different climatic conditions and management in plantations using dendrochronological techniques to remove the error from bark moisture and in standing tree measurement.

The CAI analysis using tree-ring analysis provided both annual and total growth of the standing tree while the MAI provided only the total growth on the collected date. The average CAI_{dbh} of the coppice teak continually decreased throughout the nine years. The average CAI_{dbh} of the stump-planted teak tended to increase from year 1 to year 4 and then continually decreased in years 6–9. The CAI_{dbh} of coppice teak was significantly higher than that of stump-planted teak from years 1–4, but was not significantly different to stump-planted teak in years 5–8. There was no significant difference between the MAI_{dbh} for coppice and for stump-planted teak at year 9. The CAI analysis showed that after 5 years, silvicultural intervention might be required to increase the growth rate; however the MAI cannot provide the same level of detail as it is only applicable to the time of measurement.

Conflict of interest

None declared.

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