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WATER DEFICIT EFFECT ON GROWTH OF YOUNG FAST GROWING TEAK (*Tectona Grandis* L.F.)

(Pengaruh Defisit Air Terhadap Pertumbuhan Jati Emas Muda)

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ABSTRAK

Penelitian dilakukan untuk menganalisis pengaruh defisit air terhadap pertumbuhan Jati Emas. Penelitian Lapang dilaksankan diJakarta selama bulan April 2002 sampai 2004, dengan tiga perlakuan irigasi yaitu kontrol (tanpa irigasi), irigasi 7 mm/hari, dan 14 mm/hari. Untuk menggambarkan variasi musiman air. Parameter pertumbuhan yang diukur adalah produksi biomas, kerapatan kayu, tinggi batang, dimater dan volume batang, jumlah dauan , dan indeks luas daun. Sedangkan parameter iklim yang diamati adalah curah hujan, radiasi matahari, kelembaban relatif, dan kadar air tanah. Curah hujan tahunan di lokasi penelitian berkisar 2598 sampai 2163 mm, dengan rata-rata total radiasi harian 12.8 MJ m^{-2} . Hasil penelitian menunjukkan bahwa ketersediaan air berpengaruh nyata terhadap pertumbuhan jati. Defisit air mengurangi produksi biomas 30-70%, menghambat pertumbuhan diameter dan tinggi batang, mengurangi volume batang, menurunkan jumlah daun dan indeks luas laun. Efisiensi penggunaan radiasi juga menjadi labih rendah pada saat terjadi defisit air. Sebaliknya, kelebihan kadar air tanah cenderung mengurangi kerapatan kayu.

Kata kunci: Jati, defisit air, parameter pertumbuhan

INTRODUCTION

Teak (*Tectona grandis* L.f.) has been grown in Indonesia since the beginning of 14th century. Teak forests in Indonesia are found mainly on the island of Java, which cover an area of about 1 million ha (Indonesia Forest State Enterprise, 1992). Outside Java, the natural area of teak is Muna Island, Southeast Sulawesi (Simon, 1997). In some recent years, teak has been planted in some other islands of Indonesia from Sumatra to Papua mainly by private sectors and farmers. Some of these plantations are in areas that would have been considered marginal for teak growing two decades ago.

This phenomenon was encouraged by relatively new perception of teak planting as a commercially profitable venture, as well as by policy and legal changes. The rotation cycle of new high-intensity teak plantations is generally between 20 and 25 years which is three to four times shorter than for older low-intensity plantations (Nair & Souvannavong, 2000). Nowadays, the government does not control its harvesting and utilization for teak grown on private land.

However, information on growth response of this kind of teak to climate is very limited. The fast growth of this kind of teak needs a specific environment that could be different for the slow growing one. Its resistance to water deficit may not be as high as the slow growing one as its needs

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much water to cover its fast growth particularly in the early period of growth. This experiment was intended to analyze the effects of water deficit to the growth of young fast growing teak.

METHOD

Four months old ‘Golden teak’ seedlings derived from tissue culture were planted on 19 April 2002, two weeks after soil tillage, in the Experimental Field of Mercu Buana University (MBU), Jakarta. Before planting, the seedling poly-bags were put into a solution of 2 g l^{-1} Dithane M-45 as a first prevention of pest.

Planting pits of 40 x 40 x 40 cm were dug out and spaced at 2.5 x 2 m. Two days after soil tillage, 5.4 t ha^{-1} of lime was applied to increase soil pH from 5.4 to 6. Chicken manure (1.5 ton ha^{-1}) was applied one week after soil tillage. One week after planting, mineral tablet fertilizer with the dose of 40 g per plant consisting of N 20%, P 10%, K 15%, Mg 4%, Ca 8%, and S 3% was applied.

The experiment was employing completely randomized block design with three treatments and three replications. The treatments were three levels of irrigation, *i.e.*: without irrigation (treatment A), irrigation with 7 mm day^{-1} (treatment B) and irrigation with 14 mm day^{-1} (treatment C). The treatments B and C were applied when rainfall was less than 7 mm day^{-1} and 14 mm day^{-1}, respectively. The irrigation treatments were applied for ten months since one week after planting.

The total number of plants was 81. Three plants per plot were labeled for measuring plant growth variables using a non-destructive. Growth variables such as stem diameter and height, leaf number and area were observed every week. The non-destructive measurements were continued until two years after planting.

Biomass production and wood density were determined by cutting one representative plant per plot every two months. Sample plants then were separated into leaves, stems and roots and oven-dried until the weight was constant. Woody parts were coated with paraffin wax and their volume measured by displacement of water.

Soil physical and chemical properties were analyzed in the Soil Laboratory of SEAMEO-BIOTROP Bogor. Undisturbed soil samples were taken before planting for five layers from 0 – 100 cm, the depth of each layer was 20 cm. Disturbed soil samples for chemical analysis were taken from 0 - 30 cm soil depth. Soil water content for each treatment was measured using gravimetric method every two weeks.

The climate variables observed in the field were rainfall using observatorium and solar radiation using solarimeter above and below plant canopy. The other climate variables data were taken from Climatological Station of Pondok Betung, Tangerang, located at around 9 km from the research field of MBU Jakarta. The analysis of variance was done using General Linear Model and second order test using contrast ortogonal of Systat version 5.0.

RESULT AND DISCUSSION

Climate condition during experiment

The daily rainfall pattern during the research period is presented in Figure 1. The annual rainfall of the experiment site was 2598 mm in 2002 and 2163 mm in 2003 with a distinct wet and dry season. In the year 2002 the relative dry period began in the first decade of August and lasted until the first decade of November whereas in 2003 it began in the last decade of May and lasted until the first decade of September. The relative dry period was assessed using the criteria from the Office of Meteorology and Geophysics Indonesia, is if the rainfall for a decade is less than 50 mm then followed by the next decade. Other environmental conditions seemed to be appropriate for teak. The daily average air temperature was relatively constant at about 28.0 $\pm$ 1.1^{o}C, while the daily maximum and minimum air temperatures, which were at about 33.2 $\pm$ 1.6^{o}C and 24.1 $\pm$ 0.8^{o}C, respectively. The daily average relative humidity was at about 77 $\pm$ 7 % and the average daily cumulative solar radiation was at about 12.8 $\pm$ 3.6 MJ m^{-2}.

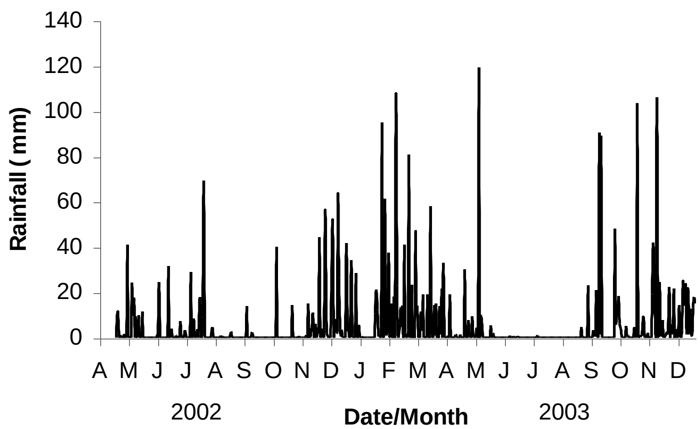
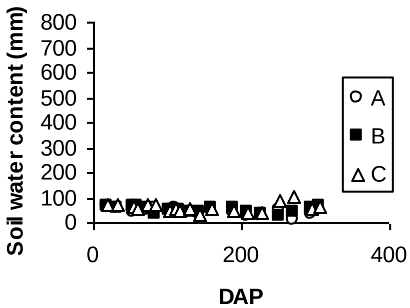


Figure 1. The daily rainfall pattern during observation period.

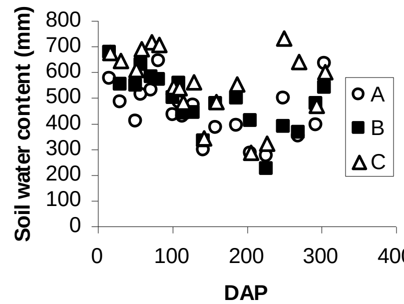
According to soil physical analysis, the soil water availability, that is the soil water content in the range of field capacity and permanent wilting point, was low at about of 3.60% (fraction by volume) in the lowest layer to 5.76% in the upper layer. The clay content reached up to 80% with the total pore space was at about 50%. The fast and slow drainage pores were lower in the upper layer compared to the lower layer because historically, the soil has been disturbed as the sub-soil was put above the topsoil. The soil permeability was also low at about 1.12 cm $hour^{-1}$.

The soil water content in the evaporative layer, based on the measurement using the gravimetric method, is lower compared to the lower layer as can be seen in Figure 2. The soil bulk density was at about 1.3 g cm^{-3}. The value is in the range of developed mineral soil. The value was relatively uniform from upper to lower layers; therefore we assume that root penetration was not inhibited.

The soil was relatively fertile as the base saturation was at about 73% and the C/N ratio was at about 6.8. The soil salinity was low and the soil pH was about 5.4, which was normal for Indonesian soil but low for teak.



(a)



(b)

Figure 2. The fluctuation of soil water content of: (a) evaporative layer and (b) lower layer.

Plant Growth

Biomass Production, Stem Diameter and Height

The non-irrigated plants (treatment A) produced lower biomass as compared to the irrigated treatment: at about 70% of treatment B and 50% of treatment C on the average. In the dry period, the biomass of treatment A was at about 50% of treatment B and 30% of treatment C. The dynamics of biomass growth are presented in Figure 3, which shows that the growth was slowly in the first two months and relatively constant in the dry period (105 – 206 days after planting/DAP) for treatment A.

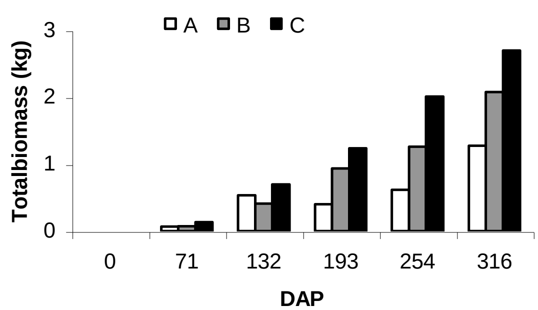


Fig. 3. The growth dynamics total biomass of each treatment.

The dynamics of biomass growth pattern were almost similar to the dynamics of stem diameter and height growth pattern. All the variables show that the irrigation supports a better growth. Higher stem height and diameter of the irrigated plants means higher stem volume compared to the non-irrigated plants as volume proportional to diameter and height.

At 294 DAP, *i.e.* the last time of the irrigation application, the stem height was significantly different between all treatments while stem diameter at 5 cm from soil surface was significantly different between the irrigated and the non-irrigated plants. Until 616 DAP (almost two years after planting), the stem height was not different significantly among treatments while stem diameter was significantly different between the non-irrigated and the irrigated plants. The stem height and diameter of seedlings were not significantly different among treatments as shown in Table 1.

Table 1. The stem height and diameter at 294 and 616 DAP in each treatment

Treatment	Stem height (m)			Stem diameter (cm)		
	0 DAP	294 DAP	616 DAP	0 DAP	294 DAP	616 DAP
A	0.08(0.13)[a]	2.54(0.13)[a]	4.00(0.19)[a]	0.35(0.20)[a]	4.64(0.22)[a]	5.95(0.27)[a]
B	0.08(0.13)[a]	2.76(0.13)[b]	4.26(0.19)[a]	0.37(0.20)[a]	6.16(0.22)[b]	6.76(0.27)[b]
C	0.09(0.13)[a]	3.23(0.13)[c]	4.75(0.19)[a]	0.31(0.20)[a]	6.90(0.22)[b]	7.54(0.27)[b]

Remarks: numbers in the brackets are standard error; lower case letters in the same column show the level of difference between treatments; number that is followed by the same letter is not significantly different.

<u>Leaf Area Index</u>

The irrigated plants had higher LAI and leaf number as compared to the non-irrigated plants. Leaf number and LAI for seedlings were not significantly different among treatments. However, at 294 DAP, total leaf number was significantly different between the non-irrigated plants and irrigated plants as is presented in Table 2. Standing leaf area index was also higher in the irrigated plants as compared to the non-irrigated plants, even during dry period the difference was significant.

Table 2. Total leaf number and LAI of seedlings and 294 DAP for each treatment.

Treatment	Seedlings		294 DAP	
	Leaf Number	LAI	Leaf Number	LAI
A	5(0.80)[a]	0.013(0.002)[a]	55.1(2.17)[a]	6.15(0.47)[a]
B	5(0.80)[a]	0.017(0.002)[a]	68.9(2.17)[b]	6.76(0.47)[b]
C	5(0.80)[a]	0.016(0.002)[a]	72.9(2.17)[b]	8.42(0.47)[b]

Remarks: numbers in the brackets are standard error; lower case letters in the same column show the level of difference between treatments; number that is followed by the same letter is not significantly different.

<u>Light Use Efficiency</u>

Higher water input lead to a higher light use efficiency (€) with the highest value in the treatment C, *i.e.* 0.0003 kg/MJ as can be seen in Fig. 4. Light use efficiency is the slope of the relationship between produced dry mass (dW) and intercepted radiation. In this study, we supposed that all of the intercepted radiation (Q_{int}) was used to produce dry mass. Average Q_{int} was about 20% of total radiation.

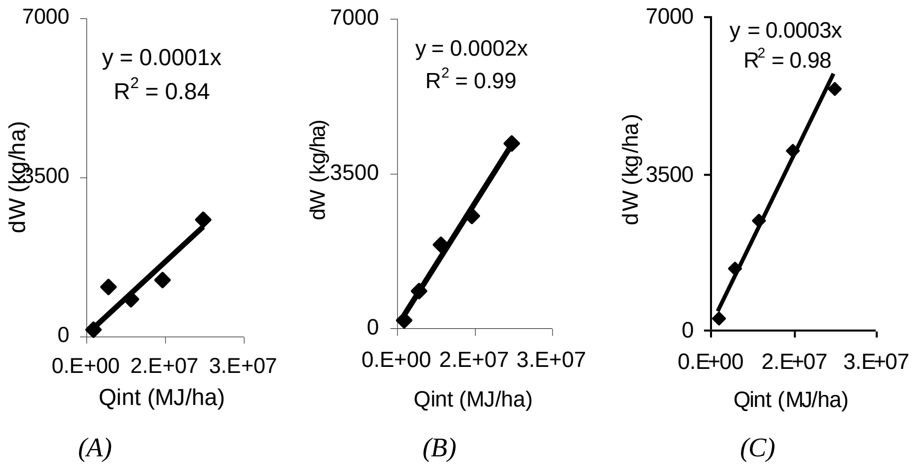


Figure 4. Light use efficiency of treatment: (A) control, (B) 7 mm day^{-1} and (C) 14 mm day^{-1}.

<u>Wood Density</u>

The average wood density for treatment A, B and C were around 0.71 gcm^{-3} (±0.10), 0.67 gcm^{-3} (±0.06) and 0.60 g cm^{-3} (±0.09), respectively. The data was calculated for the measurements since 132 DAP to 316 DAP in each treatment. The wood density for all treatments is presented in Table 3.

Table 3. The wood density of each treatment from 0 to 316 DAP

Treatment	Wood density (g cm^{-3})			
	132 DAP	193 DAP	254 DAP	316 DAP
A	0.85	0.75	0.61	0.70
B	0.71	0.77	0.61	0.62
C	0.53	0.76	0.53	0.57

<u>Other Effects of Water Deficit</u>

The other effects of water deficit were found in treatment A. Five months after the end of irrigation, 30% of plants in treatment A were bent, 3.7% in treatment B and 0% in treatment C. At the same date of observation, four plants in treatment A were attacked by stem borers while plants of other treatments were not. Treatment A had two missing plants due to wilting.

Discussion

<u>Biomass Production</u>

The overall rainfall conditions seemed to be favorable for teak. Teak grows much better in areas with a rainfall of 1250 to 3750 mm per year (Simon, 1997), provided that there is a significant difference between dry and wet seasons leading to about 3 to 6 dry months a year (Indonesia Forest

State Enterprise, 1992). However, the non-irrigated plants (treatment A) produced low biomass as compared to the irrigated treatments. In dry period, the biomass of treatment A was lower compared to wet period. This shows that the non-irrigated plants suffered from water deficiency stress. In 2002, the rainfall in dry period was only 75.9 mm and in 2003 only 38.7 mm. Dryness was aggregated by low soil water holding capacity and permeability.

The results of this study showed that although some references such as Simon (1997) or Indonesia Forest State Enterprise (1992) report that teak prefer the area with a distinct wet and dry seasons, but the season should not be too dry when there is a low soil moisture reserve. The study could not show exactly the range of teak water need but it indicated if the water input is at about the potential rate of evapotranspiration, teak will be in the optimum growth with a good wood density such as the plants in treatment B.

The biomass production of the irrigated plants was higher compared to the non-irrigated plants because of higher light use efficiency, leaf area index, and water availability.

Stem Diameter and Height

As the xylem constitutes almost all of the wood (Nobel, 1991), the stem diameter depends on the formation of the xylem, which is affected by water availability. Tomazello & da Silva Cardoso (1999) found that the differentiation and formation of the xylem cells of teak took place when temperature, rainfall and photoperiod started to increase. Pumijumnong (1999) also found that the radial growth of teak is mainly driven by precipitation. Nobel (1991) stated that trees from wet tropics may have no annual growth rings. This study showed that higher water input led to larger stem diameter. After almost two years of growth, the stem diameter of the irrigated plants was different significantly than of the non-irrigated plants.

The stem diameter slightly decreased during the dry period especially for treatment A. The plants store some water in stem, which can temporarily supply the water for transpiration (Lambers, Chapin III, & Pons, 1998). Teak has a shallow root system therefore a large diameter makes the plant stronger to the wind.

Stem height is sometimes used to estimate site index because stem height is not sensitive to tree density as found for *Cordia alliodora* (Hummel, 2000). This research showed that stem height is sensitive to water availability because it is a function of leaf emergence. Eliyani (2004) showed that leaf emergence was inhibited in dry period for the non-irrigated plants. Therefore, the irrigated plants were higher than the non-irrigated plants because they had a higher leaf number. When the irrigation ended, the stem height of treatment B and C was not significantly different to the stem height of treatment A. At that time, all treatments received the same amount of water input.

Leaf Area

This study showed that higher water input led to higher foliage area. The non-water stressed plants have higher number of leaves compare to the water stressed one. In dry season, the plants of treatment A were almost bare and left just the six upper leaves while the irrigated plants of treatment B and C had high leaf area.

The drought stress such as for the plants in treatment A occur very often in dry season in many areas in the tropics, made teak known as a deciduous tree. The plants shed their leaves periodically every year. In Bangladesh, the plants start shedding their leaves in December or January and the crowns became completely leafless for 3 to 4 weeks in March (Banik, 1992). In Myanmar, teak sheds leaves from November to January and remains leafless from January to March (Kyaw, 2003). However, Simon (1997) found that leaves of teaks did not fall in dry season in the areas with high soil water content.

Wood Density

The results of this study showed that more water input, lower wood density. However, wood density of treatment A was almost similar to the one of treatment B, which was at about 0.7 g cm^{-3} but higher than of treatment C which was at about 0.6 g cm^{-3}. Water storage in drought-deciduous trees is reversely related to wood density (Lambers *et al.*, 1998).

The wood density of the trees in all treatments were similar in 193 DAP which was at about 0.75 g cm^{-3}, 0.77 g cm^{-3}, and 0.76 g cm^{-3} for treatment A, B, and C respectively. The harvesting time, *i.e.* October 2002, was after the dry period. The seasonal pattern of wood density in all treatments was also higher in dry period but lower in wet period. In dry period, the plants produced much more dry matter because of higher solar radiation.

The values of wood density found in this research are comparable to the air-dried wood density of 13-year-old fast growing teak from Nilambur India which was at about 0.65 g cm^{-3} as presented by Bhat (2000).

Other Effects of Water Deficit

Water deficit can reduce the economic value of teak because of the irregular stem shape, which is, likely to be permanent. Two years after planting, after facing another wet season, the stem was still bent. Simon (1997) also found the irregular shape of the bole and many branches in the stem in the regions with rainfall of less than 1250 mm $year^{-1}$.

There was also an indication that water deficiency stress led the plants to be more susceptible to stem borer. The water stressed plant had a relatively small diameter compared to the non-water stressed plants that led the pest to be easier to bore the stem. Besides, the water-stressed plants in a weak condition therefore it has no sufficient resistance to the pest.

Irrigation and Drainage

The research shows that irrigation is important especially in dry period for young fast growing teak. Irrigation is a common practice in teak silviculture in India but not in Indonesia. Khandwe & Sharma (2003) found that teak under drip irrigation system with an application rate of 2 litre water $tree^{-1}$ day^{-1} had a better performance over traditional irrigation method of 14 litre water $tree^{-1}$ day^{-1} at one time or natural forest. Teak plants with drip irrigation had the highest plant height (380 cm), biggest DBH (14.4 cm) with 97% survival after one year, in comparison with traditional irrigation method having a plant height of 165 cm with 5.0 DBH and 74% survival, while natural forest had plant height of 43 cm with 30 % survival.

As compared to standard Indian teak from Nilambur India, some studies revealed high values for bending and compression strength of irrigated plantation timber from two different states in India. However, when sewage water used for the irrigation, the value of the two quality variables was lower (Bhat, 2000). For wet areas, the research also indicated that appropriate drainage is needed especially in wet season to avoid low wood density.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results, it can be concluded that water can be a limiting factor in the early growth stage of teak. Water deficit can inhibit leaf emergence, reduce biomass production, stem diameter and height, stem volume, light use efficiency, leaf number, and leaf area index even reduce the quality of wood by the irregular stem form, more susceptible to stem borer and lead to a death plant. On the other hand, the excessive of water tends to reduce wood density.

It is important to assure the availability of water in the early growth stage of teak. Distribution of rainfall in a year should be considered in choosing the location for plantations and silvicultural practices. In the area of high rainfall throughout the year, drainage should be good enough to avoid low wood density. During the dry period in a region with a distinct wet and dry season, irrigation is important to be applied.

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REFERENCES

Banik, R.L. 1992. Teak in Bangladesh. In : Henry Wood (Ed.), Teak in Asia, Proc. The China/ESCAP/FAO Regional Seminar on Research and Development of Teak held at Guangzhou, China, 19-27 March, 1991. Asian Development Bank, United Nations Development Programme, CAB International, Food and Agriculture of the United Nations. Bangkok. pp. 1-10.

Bhat, K.M. 2000. Timber quality of teak from managed tropical plantations with special reference to Indian plantations. Bois et Forêts 263(1): 6-16.

Eliyani. 2004. Process Based Modelling of Growth and Carbon Sequestration of Young Teak (*Tectona grandis* L.f.). Dissertation. School of Post Graduate, Bogor Agricultural University. Bogor.

Hummel, S. 2000. Height, diameter and crown dimensions of *Cordia alliodora* associated with tree density. For. Ecol. Manage. 127: 31-40.

Indonesia Forest State Enterprise. 1992. Teak in Indonesia. In: Henry Wood (Ed.), Teak in Asia, Proc. The China/ESCAP/FAO Regional Seminar on Research and Development of Teak held at Guangzhou, China, 19-27 March, 1991. Asian Development Bank, United Nations Development Programme, CAB International, Food and Agriculture of the United Nations. Bangkok. pp. 35-38.

Khandwe, R & R.C. Sharma. 2003. Effect of drip irrigation on growth and production of teak (*Tectona grandis*) in Satpura plateau of Madhya Pradesh. Abstract. Res. On Crops 4(1): 114-116.

Kyaw, N.N. 2003. Site influence on growth and phenotype of teak (*Tectona grandis* Linn. f.) in Natural Forests of Myanmar. Dissertation. Georg-August-Universität Göttingen. Göttingen, Germany. 163 p.

Lambers, H., Chapin III, F.S., & Pons, T.L. 1998. Plant Physiological Ecology. Springer-Verlag Inc. New York. 540 p.

Nair, C.T.S. & Souvannavong, O. 2000. Emerging research issues in the management of teak. Unasylva 201(51): 45-54.

Nobel, P.S. 1991. Physicochemical and Environmental Plant Physiology. Acad. Press. Inc. New York, Boston. 635 p.

Pumijumnong, N. 1999. Climate-Growth relationships of teak (*Tectona grandis* L.) from Nothern Thailand. In: R. Wimmer & R.E. Vetter (Eds.), Tree-Ring Analysis. CAB International. pp: 155-168.

Simon, H. 1997. History of teak forest management in Indonesia. Proc. Int. Teak. Symp., pp. 52-60.

Tomazello, M. & N. da Silva Cardoso. 1999. Seasonal Variations of the Vascular Cambium of Teak (*Tectona grandis* L.) in Brazil. In: R. Wimmer & R.E. Vetter (Eds.), Tree-Ring Analysis. CAB International. Pp: 147-154.