THE EFFECT OF RAINFALL ON THE RADIAL GROWTH AND LONG-TERM GROWTH PATTERNS OF TEAK (*TECTONA GRANDIS* LINN.F.) IN NATURAL FORESTS OF MYANMAR

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ABSTRACT

Teak (*Tectona grandis* Linn.f.) naturally grows only in India, Myanmar, Laos and Thailand. In this study, tree-ring analyses of teak and the relationships between rainfall patterns and tree-ring width curves are discussed. Long-term rates of growth have also been estimated. The investigations were carried out in the natural teak forests of Myanmar in Taungoo, Mabein and Kanbalu. The growth rate of teak varies according to the site condition where it grows. In all study areas, regression analyses show that tree-ring width is strongly correlated with precipitation during the rainy season (May to October). The diameter growth dynamics of teak from Taungoo and Mabein are not significantly different. However, teak trees from Kanbalu grow significantly slower than the both trees from other sites. The volume growth of teak in Taungoo is the best among investigated natural teak stands.

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1. INTRODUCTION

Teak (*Tectona grandis* Linn.f.), a species of world-wide reputation as paragon among timber trees, belongs to the family Verbenaceae, and is distributed in tropical or subtropical region. It is indigenous to India, Myanmar, Laos and Thailand. Dense natural forests with big and beautiful admiralty quality teak have degraded and shrunk so rapidly that at present they are confined only to Myanmar and to some extent to India.

The total area of teak bearing forests in Myanmar has been estimated at about 16.5 million hectares (Gyi & Tint, 1998). As Myanmar relies heavily on teak to supply the national demand and for export, the extent and quality of teak forests are declining through clearing for agriculture, illegal logging, and population pressure, even though they have been being managed consistently for many years on the principle of sustained timber production. With teak remaining as the country's most valuable timber, Myanmar Forest Policy has stipulated to intensify natural forest management and never to substitute natural forests with plantations.

Teak is a long rotation species, but the intrinsic value of its wood justifies the long-term allocation of land and other resources. It is a medium to fast growing species, and as such field management practices must aim to concentrate on its maximum value growth (White, 1991).

The silvicultural system, which is based on the concept of sustainable forest management, requires knowledge of the long-term growth of trees and their response to climate. In view of this, reliable information on growth is essential for long-term management planning. One of the methods of estimating growth rate of trees is the measurement of ring-widths of the stem.

Systematic studies on the structure, growth and yield of natural teak forests of Myanmar started with the commencement of the working-plan operations in December 1883 (Tint & Schneider, 1980). Using these working-plan figures Troup (1911) analysed the growth and yield of teak forests and published the results of his analysis in 1911. Growth rate of teak trees was estimated by counting rings on the stumps and averaged by individual reserves or group of reserves to get the rotation age. Mean annual girth increment was computed by dividing the girth at breast height by corresponding stump age.

Anatomically, teak wood is ring-porous to semi-ring porous. The pattern of tree-ring widths of teak in Asia has already been tested for its dendroclimatic potential: Thailand (Pumijumnong, 1995), Indonesia (Murphy & Whetton, 1989; Jacoby & D' Arrigo, 1990; Palmer & Murphy, 1993) and India (Pant & Borgaonkar, 1983; Bhattacharyya et al., 1992; Wood, 1996).

The present study is focused on long-term growth patterns and climate-growth relationship of teak in different types of natural teak-bearing forests in Myanmar.

2. STUDY AREAS AND SITE CONDITIONS

In Myanmar natural teak forests occur within 25° 30’ and 10°N latitude. The high quality teak trees are found in the moist deciduous forests. These forests are mostly confined to the hilly and undulating terrains, the altitudinal range is between 100 and 900 meters above sea level. Teak grows well in warm, moist, tropical regions with an annual rainfall between 1250 mm and 2500 mm and a distinct dry season of 3-5 months.

The investigations were carried out in natural teak forests in three different localities, namely, Taungoo, Mabein and Kanbalu (Figure 2.1), which differ in precipitation and soil types.

Figure 2.1: Map of Myanmar showing study areas

Table (2.1) Site Description of the Study Areas

Study area	Taungoo	Mabein	Kanbalu
Forest type	MUMD	LMD	DD
Location	18°52´N 96°03´E	23°39´N 96°46´E	23°12´N 95°44´E
Altitude (m a.s.l)	325	170	240
Slope (%)	28-32	5-8	10-12
Mean annual Rainfall (mm)	1953	1789	860
Mean annual Temperature (°C)	26.9	24.3	26.9
Dry period* (months)	6	6	6
Soil type	*Cambisols*	*Rhodic Ferralsols*	*Xanthic Ferralsols*
Soil pH	5.3-6.3	5.0-5.8	6.0-6.9

MUMD= Moist upper mixed deciduous forest
LMD = Lower mixed deciduous forest
DD = Dry Deciduous forest
* Calculated by *De Martonne*'s aridity index.

The climate is characterized by a dry period from November to April with a mean monthly rainfall of less than 50 mm.

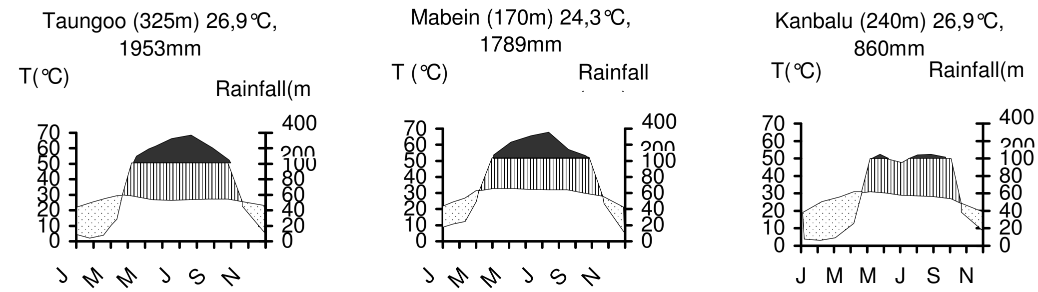


Figure 2.2 Climate diagram of the study areas (According to Walter & Lieth, 1964)

The soil in Taungoo is classified as *Cambisols* (FAO) and relatively fertile compared with the soils in Mabein (*Rhodic Ferralsols*) and Kanbalu (*Xanthic Ferralsols*). The soils are mostly sandy clay loam in Taungoo, and Mabein and loamy sand in Kanbalu.

The forest of Taungoo study area is moist upper mixed deciduous (*MUMD*). The most abundant tree species are Teak (*Tectona grandis*), Thitpagan (*Millettia brandisiana*), Myaukchaw (*Homalium tomentosum*), Thadi (*Protium serratum*), Pyinkado (*Xylia dolabriformis*), which have an average height of about 24 m. Total number of trees (≥10 cm dbh) is 173 per ha belonging to 30 species. Bamboo species, such as Kyathaung Wa (*Bambusa polymorpha*) and Tin Wa (*Cephalostachyum pergracile*) are also frequent in the study area.

The forest type of Mabein study area is lower mixed deciduous (*LMD*) in which the species of Teak (*Tectona grandis*), Thadi (*Protium serratum*), Petka (*Clerodendrum petasites*), Padauk (*Pterocarpus macrocarpus*) are abundant. The average height of the trees is about 18 m and the total number of trees (≥10 cm dbh) per ha is 267 of 62 species. In this area bamboo is almost absent.

The forest vegetation of Kanbalu study area is of dry deciduous type (*DD*) with Teak *Tectona grandis,* Thitpok (*Dalbergia kurzii*), Ingyin (*Shorea siamensis*), *and* Baing (*Tetrameles nudiflora*) as dominant species. This forest has an abundance of poor quality teak, which attains an average height of about 13 m and a growing stock of 156 trees (≥10 cm dbh) per ha comprising 38 different species.

3. MATERIALS AND METHODS

The experimental materials were collected in compartment 120, Kabaung Reserved Forest in Taungoo Township, in Meintha Public Forest coupe XI, in Mabein Township and in compartment 91, Sabe-natha Reserved Forest in Kanbalu Township.

Ten sample plots each 40m × 40m in size were laid out systematically on a grid of 80m × 120m, with a random start. 19, 20 and 21 teak trees with good cylindrical and straight boles having no visible damage were selected respectively in the above areas and on each tree two wood samples were taken at breast height (1.3m) using a regular increment corer. All samples were analysed in the tree-ring laboratory of the Institute of Forest Botany in Goettingen, Germany. Each core sample was dried and glued in a grooved wooden stick and the surface of the cores was sanded and polished to improve the distinctiveness of growth zones under the microscope. Ring-widths were measured to the nearest 0.01 mm under a binocular microscope attached to a linear measuring table interfaced with a computer.

Tree-ring width is traditionally used to establish relationships between tree growth and climate (Fritts, 1976). The TSAP program (Rinn, 1996) was used to plot the series for visual cross-dating. Cross-dating is the comparison of ring-width curves from different individuals for parallel run. Curves with high degree of similarity were combined to site chronologies. To enable comparison with rainfall data, all ring-width curves were transformed to index curves. Rainfall data were documented as the monthly sum of precipitation. Time series of monthly data were compared with tree-ring time series by regression analysis to study the influence of precipitation on ring width. Regression analysis considers for the time period from 1950 to 2000 for Taungoo and Mabein, and from 1960 to 2000 for Kanbalu, based on the climatic data available from the meteorological stations.

The following five different precipitation time series were calculated by regression analysis:

1) Sum of precipitation in the rainy season (May to October);
2) Sum of precipitation in the rainy season plus the transition months (April to November);
3) Sum of precipitation at the beginning of rainy season (April and May);
4) Sum of precipitation at the end of rainy season (October and November); and
5) Sum of precipitation in the transition months (April and May plus October and November).

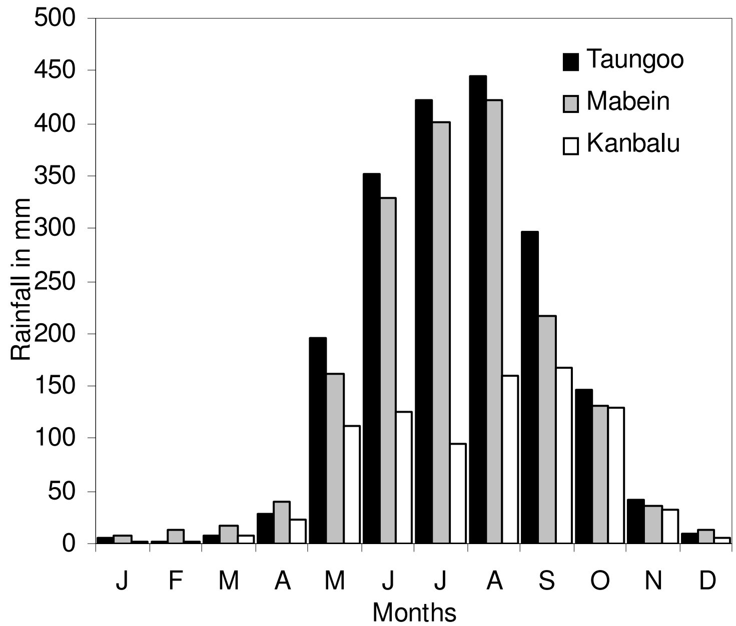


Figure 3.1 Comparison of monthly seasonality of rainfall in the study areas of Taungoo, Mabein and Kanbalu

Diameter growth curves were fitted by the polynomial function of the form:

$$d = b_0 + b_1 \cdot A + b_2 \cdot A^2$$

where d = dbh in cm
A = stand age in years
b_0, b_1, b_2 = coefficients of the function

To derive volume over bark, diameter increment over bark was calculated by multiplying the diameter increment estimated from the measurement of ring-widths with bark increment coefficient (k_i) according to Loetch et al. (1973, cited Tint & Schneider, 1980). The one-variable volume function developed by Tint and Schneider (1980) was used for calculation of tree volume of teak.

$$k_i = \frac{1}{1 - \left(\frac{b}{d}\right)}$$

where k_i = bark increment coefficient
b = bark thickness in cm
d = diameter at breast height in cm

$$v = 1.66 \cdot 10^{-5} \cdot d^{3.1616} \cdot 0.9866^{d}$$

where v = stem volume (over bark) in m^3
d = dbh in cm

To develop mean and current annual volume increment curves the following model, a variant of Bertalanffy (1941) and proved by Zeide (1993) as one of the best descriptor of volume growth, was used:

$$\ln(\Delta v) = b_0 + b_1 \cdot \ln(A) + b_2 \cdot A$$

where Δv = volume increment in m^3
A = stand age in years
b_0, b_1, b_2 = coefficients of the regression function

4. RESULTS AND DISCUSSION

4.1. Ring Width and Dendrochronological Information

The tree-ring width chronology calculated for each study sites separately show distinct differences in mean radial increment. Mean ring widths varied between 2.4 mm per year in Taungoo and 1.2 mm per year in the Kanbalu-forest, trees from Kanbalu showed lowest values.

Table (4.1) Dendrochronological Data of Teak Trees from Three Investigated Stands

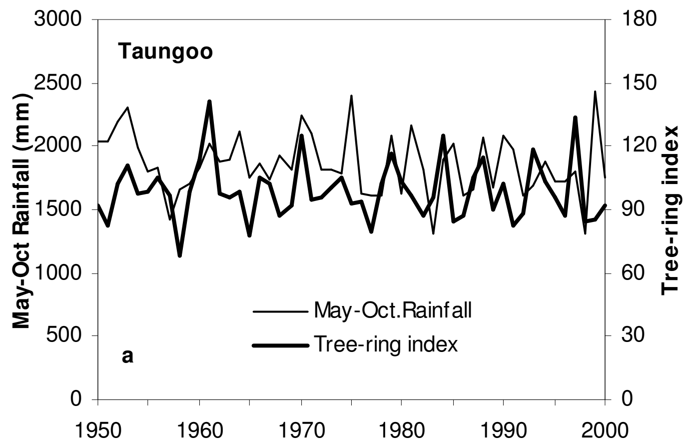
Study area	Tree (n)	Radii (n)	dbh (cm)	Mean age (years)	Range in ages (years)	Time pan	Radial increment mean/deviation (mm year^{-1})
Taungoo	19	38	35-77	82	43-142	1873-2000	2.4 ±1.3
Mabein	20	40	55-74	119	87-164	1837-2000	2.0 ±1.0
Kanbalu	21	42	32.5-52	86	32-152	1848-2000	1.2 ±1.0

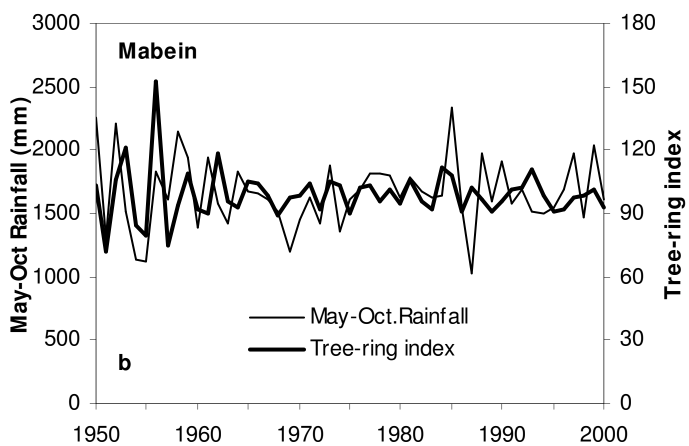
Tint and Schneider (1980) noted that the mean radial increment for total Myanmar of a yield tree of 68 cm dbh was about 2.2 mm with stump age of 155 years. The highest radial increment of 3.1 mm (stump age = 110 years) was observed in Kangyi, Satpok, Sitkwin and Thindawyo Reserved Forests, while the slowest radial increment of 1.9 mm (stump age = 190 years) was recorded in Ziyaing and

Mehaw Reserved Forests. It could be concluded that teak trees in the moist forest grow faster than in the dry regions.

4.2. Rainfall-growth Relationship

Different time series of precipitation from three investigated areas were correlated with the standardized tree-ring chronologies (Figure 4.1). In all study areas, the sum of precipitation in the rainy season (May to October) is positively correlated with teak growth. Significant correlations are found in Mabein and Kanbalu (see Table 4.2).





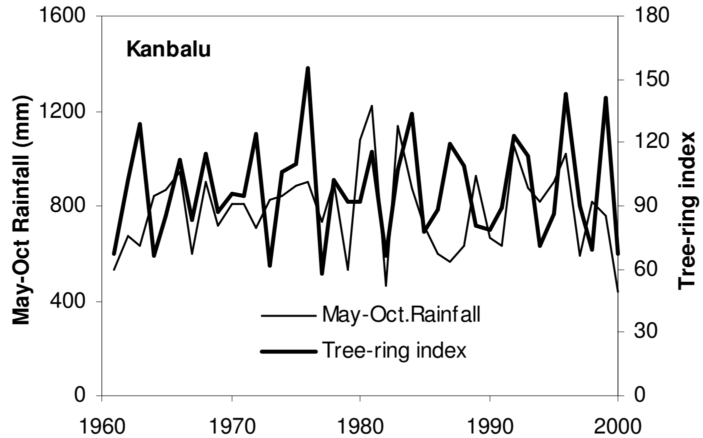


Figure 4.1: Ring-width indices and sum of precipitation (May to October)
a) Taungoo; $n = 51$, $r = 0.21$, p = 0.14, *Glk.* = 66%
b) Mabein; $n = 51$, $r = 0.29$, p = 0.02, *Glk.* = 67%
c) Kanbalu; $n = 40$, $r = 0.37$, p = 0.02, *Glk.* = 68%

Table (4.2) Correlation coefficients between tree-ring width indices and sums of precipitation

Sum of precipitation	Taungoo (MUMD)	Mabein (LMD)	Kanbalu (DD)
Rainy season (May to October)	0.21	0.29*	0.37*
Rainy season plus the transition months (April to November)	0.16	0.28*	0.33*
Beginning of rainy season (April and May)	0.15	0.37*	0.05
End of rainy season (October and November)	-0.05	0.11	0.08
Transition months (April and May plus October and November)	0.09	0.38*	0.08

The asterisks indicate significant correlations at the 95% confidence level

For study area Taungoo the correlation analysis between growth and monthly precipitation does not give a significant coefficient. In Mabein significant correlations were also found with sum of precipitation from April to November, the beginning of raining season (April and May) and transition months (April + May and October + November). As shown in table 4.2, tree growth in Kanbalu was strongly correlated with May to October as well as April to November rainfall. The amount of water may be the most limiting factor for tree growth in the study area Kanbalu where the annual rainfall is only 860 mm and the tree produces narrow rings compared to those from the other sites. Fritts (1976) explained that ring-widths can be cross-dated only if one or more environmental factor becomes critically limiting, persists sufficiently long, and acts over a wide enough geographic area to cause ring-widths or other features to vary the same way in many trees. It implies that the narrower rings provide more precise information on limiting climatic conditions than do the wider rings.

The coefficients of parallel variation (*Gleichläufigkeit-Koeffizient*) used by German dendrochronologists were also calculated. *Gleichläufigkeit* is the percentage of slope equivalence (= internal trend) of sample along the overlap interval. The slope of two series is digitised for every year-to-year interval into 1 for increasing, -1 for decreasing and 0 for zero slope and results of digitised slope values of sample are compared. The number of equivalent values is divided by the overlap points and multiplied by 100 to get a percentage value. Generally, matches are expected to have a *Glk*-value of more than 55 or 60 percent (Rinn, 1996). In this case, *Glk*-values are 66, 67, and 68 in Taungoo, Mabein, and Kanbalu respectively.

The results of climate-growth relationship in this study differ from the findings of Berlage (1931) and Jacoby and D'Arrigo (1990) who stated that tree growth of teak in Java was found to be significantly correlated with precipitation during the dry season (east monsoon). Berlage (1966) noted that the intensity and timing of the previous dry season and the beginning of the following dry season are important to growth of teak in Java. During some extremely wet or extended monsoon events, precipitation can influence growth well into the next growing season. These and other variations in phasing may account for weaker climate-growth association in some years (Berlage, 1966). Pumijumnong et al. (1995) found that the growth of teak in northern Thailand was correlated with first half of the wet season (April through July). But in another study by Pumijumnong (1999) tree growth was found to be mainly dependent on rainfall during the late rainy season in the same region of northern Thailand. Pant and Borgaonkar (1983) however confirmed the response of teak to rainfall in the rainy season for India. Worbes (1999) observed that planted teak trees in Caparo, Venezuela, also showed significant correlation with the amount of precipitation in the rainy season. Thus, it is reasonable to conclude that the length of the rainy season (west monsoon) in the northern hemisphere influences strongly on the growth of teak.

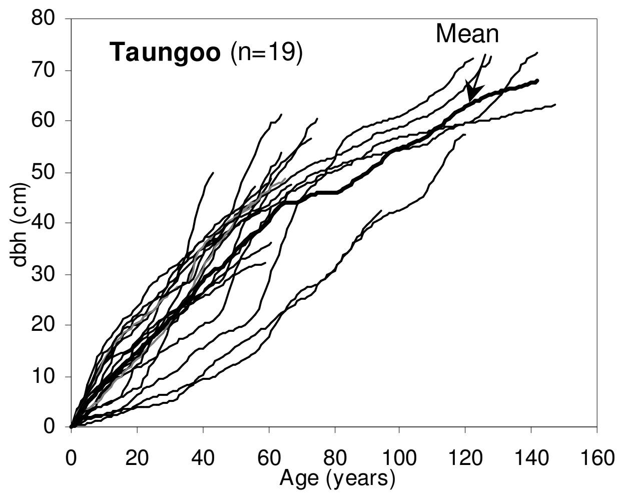
A study on the relationship between teak tree growth and monthly temperatures in northern Thailand by Pumijumnong et al. (1995) suggested that above average temperature probably had an adverse effect on radial growth of teak. High temperature may increase the evapotranspiration and thus put the trees under drought stress. However, the correlation analysis between growth and monthly mean temperature did not give significant coefficients. It is recognized that the monthly temperature in this study does not vary significantly from one year to the next and thus it would not have greatly influenced the variability in ring-width. Temperature is said to be less important to growth, although the inverse relationships are probably due to water stress, and the direct relationships due to respiration.

Tree-ring data could be used to reconstruct the yearly variations in climate that occurred prior to the instrumental climatic records. These reconstructions can extend the climate record backwards in time and increase its length sufficiently to improve the existing knowledge on climatic variability. Such improvements could help man to better anticipate possible future climatic changes as well as to better understand those of the past. The similar climatic response of teak in different regions in the tropics suggests that this species may be of significant dendroclimatological importance.

4.3. Stand Growth Characteristics

4.3.1. Diameter growth

To study growth characteristics of the investigated teak stands, mean and current annual volume increments were computed. The cumulative annual diameter increment was calculated from the mean tree-ring widths of all the sample trees. The cumulative annual diameter growth curves of all measured individuals and mean tree in three different study areas are shown in figure 4.4.



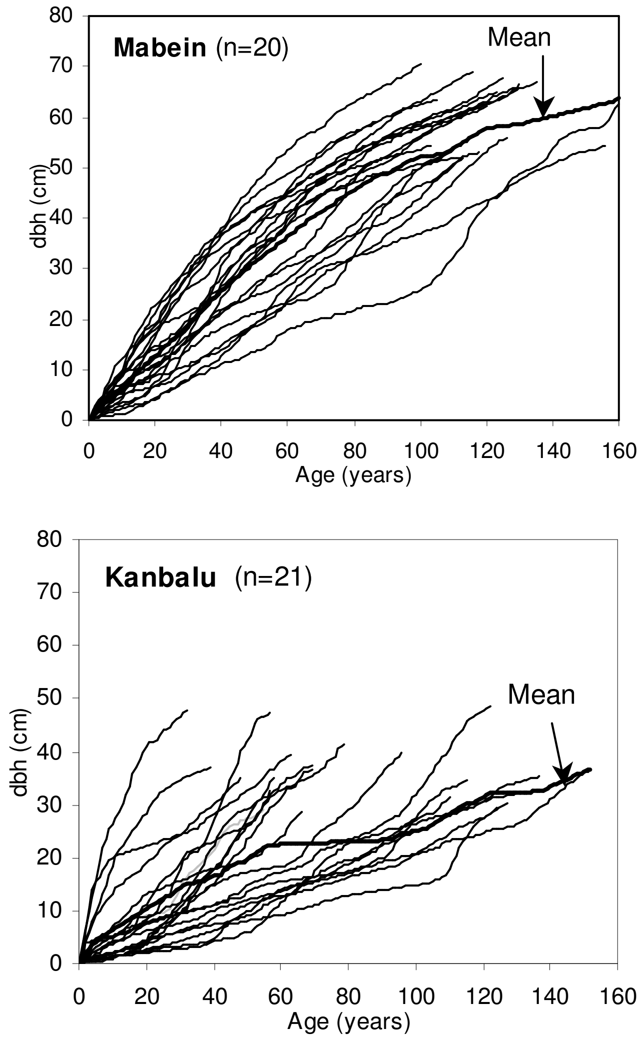


Figure 4.4: Individual and mean cumulative diameter increment of teak trees from the investigated stands of Taungoo, Mabein and Kanbalu

To study the patterns of the diameter growth of teak stands, mean values of the individuals from respective areas were computed and treated as the mean tree. The fitted diameter-age curves of the mean trees are shown in Figure 4.5.

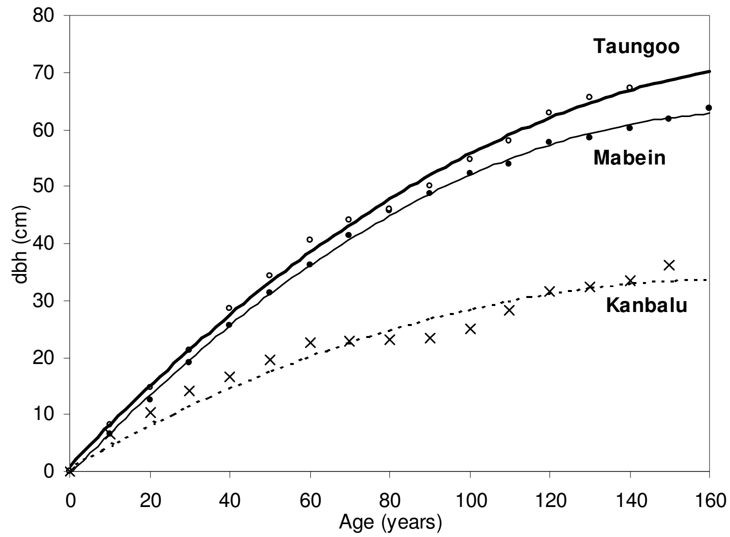


Figure 4.5: Fitted diameter curves of the investigated teak stands

The diameter growth rate of teak in Kanbalu differs distinctly from those of teak in Taungoo and Mabein, whereas the latter show similar diameter growths dynamics. Both stands had an average diameter at breast height of above 50 cm at the age of 100 years, when trees from Kanbalu reached only an average diameter of 25 cm at the same age. Later on, teak trees from Taungoo seem to grow at increasingly higher rates while the diameter growth of teak from Mabein leveled off gradually.

Table (4.3) Coefficients of the Function and Coefficients of Determination for the Diameter Growth Functions of Teak Stands

Study area	b_0	b_1	b_2	r^2
Taungoo	0.9513	0.7395	-0.0019	0.9967
Mabein	-0.5869	0.7416	-0.0022	0.9997
Kanbalu	0.5375	0.3992	-0.0012	0.9551

4.3.2. Volume growth

The fitted *MAI* and *CAI* curves and dbh growth curves of the investigated stands of Taungoo, Mabein and Kanbalu are shown in figure 4.6.

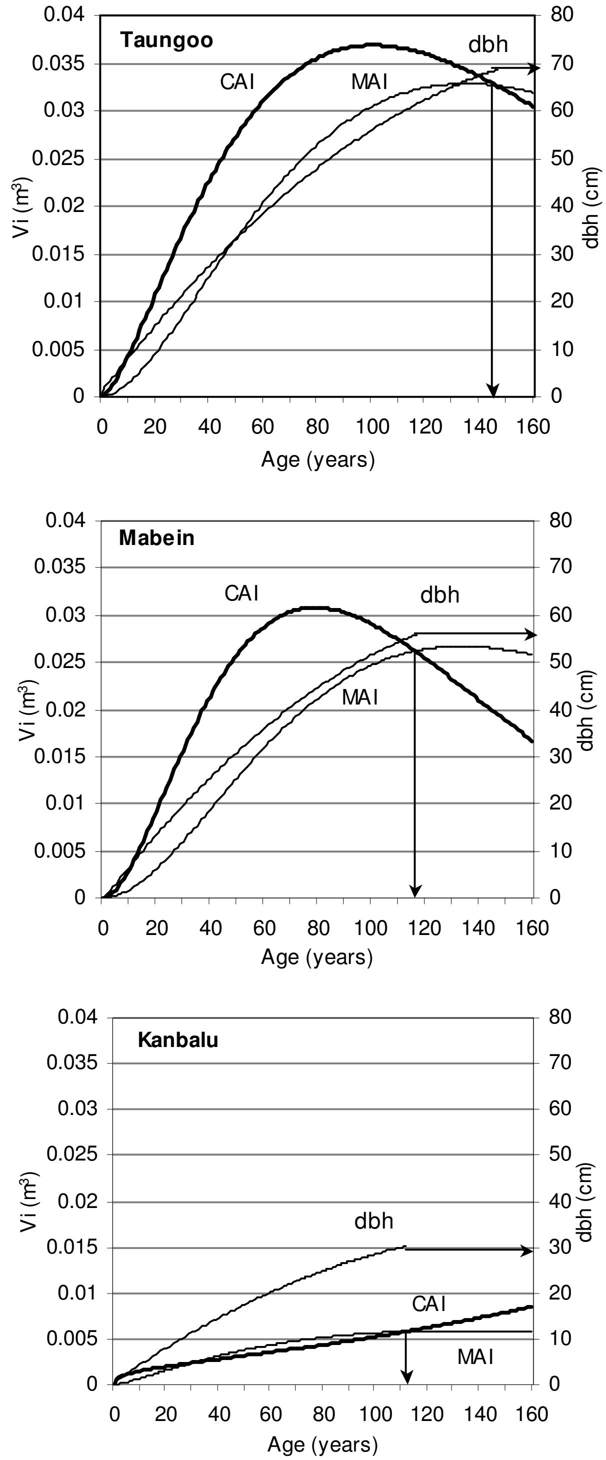


Figure 4.6: Volume increment and dbh curves of teak trees in the study areas

The fitted volume increment equations are:

$\boldsymbol{CAI}_{Taungoo}$ = exp [-8.7752 + 1.5165 · *ln* (*Age*)-0.0151 · *Age*] (r^2 = 0.61, S_x = 0.743)

$\boldsymbol{MAI}_{Taungoo}$ = exp [-10.7163 + 1.8691 · *ln* (*Age*) – 0.0138 · *Age*] (r^2 = 0.99, S_x = 0.084)

$\boldsymbol{CAI}_{Mabein}$ = exp [-9.9978 + 1.9329 · *ln* (*Age*)-0.0244 · *Age*] (r^2 = 0.67, S_x = 0.677)

$\boldsymbol{MAI}_{Mabein}$ = exp [-11.6786 + 2.0679 · *ln* (*Age*) – 0.0155 · *Age*] (r^2 = 0.99, S_x = 0.084)

$\boldsymbol{CAI}_{Kanbalu}$ = exp [-7.2981 + 0.3237 · *ln* (*Age*) + 0.0056 · *Age*] (r^2 = 0.17, S_x = 1.173)

$\boldsymbol{MAI}_{Kanbalu}$ = exp [-10.1171 + 1.2877 · *ln* (*Age*) – 0.0099 · *Age*] (r^2 = 0.95, S_x = 0.191)

The constructed volume-age curves reveal that the *CAI* culminates at the age of about 100 years for Taungoo and 80 years for Mabein with corresponding volume increments of 0.037 m^3 and 0.031 m^3. However, in the Kanbalu study area, the *CAI* curve follows an abnormal trend with an increase in older age being more pronounced. The *CAI* is only 0.009 m^3 at 160 years of age and trees from Kanbalu have relatively constant growth over their entire life span. It may be due to different growth patterns of individuals especially between young trees and old trees as seen in figure 4.4. The maximum *MAI* attains at the same age of 135 years for both Taungoo and Mabein although the volume increment reaches 0.033 m^3 for Taungoo and 0.027 m^3 for Mabein. The age of culmination of the *MAI* for Kanbalu is 126 years with the poor rate of volume increment of 0.006 m^3. Tint and Schneider (1980) found that the *MAI* attained its peak at age of 110 years with 0.03 m^3 in volume increment and *CAI* culminated at about 60 years with 0.04 m^3 for teak trees from Pyay Forest District. The difference in environmental factors such as rainfall and soil conditions affects on the ages of culmination of *MAI* and *CAI*. To determine the rotation age and exploitable diameter the volume increment and dbh growth curves of all study areas are combined.

The volume of teak trees in Taungoo is found to be 4.45 m^3 at the age of 135 years while the *MAI* is at culmination. The *MAI* catches up *CAI* at 147 years with about 70 cm in diameter. The mean tree of Mabein attains the maximum volume of 3.65 m^3 at 135 years and the *MAI* and *CAI* curves cross at the age of 118 years while the dbh reaches 58 cm. The growth of teak in Kanbalu is abnormal, as shown in figure 4.6, and incredibly poor compared to the other sites. Its maximum volume is only 0.72 m^3 at the age of 120 years (six times lower than the growth of Taungoo). The maximum volume at 178 years of teak tree from Pyay was 4.2 m^3 (Tint and Schneider 1980). The growth of teak in Taungoo is the best among the investigated natural teak stands. The rotation age for the natural teak stands of different investigated sites could be recommended based on volume increment perspective. In the context of the results of the current study, the rotations and the minimum exploitable diameter of teak trees may be fixed as follows;

Site	Recommended rotation (years)	Exploitable dbh (cm)	Expected volume (m^3)
Taungoo	147	70	4.85
Mabein	118	58	3.20

The annual growth rate of trees in the Kanbalu teak forest is sufficiently low that the area is not suitable for producing a sustainable source of teak therefore it is inappropriate to suppose a practical rotation and the minimum exploitable dbh limit.

5. CONCLUSION

According to the rainfall-growth analysis of teak stands, there is a strong dependence of wood growth on the amount and the distribution of precipitation. Radial growth in teak is positively related to precipitation in all study areas during rainy season which extends from May to October. Rainfall is required for the tree growth throughout the entire growing season. The variation of the length of the growing period is reflected in the width of the tree rings (Worbes, 1999). These results may be valid for the whole area of natural distribution of teak in the northern hemisphere (west monsoon).

The development of volume growth of teak in different types of forest could aid decision on the length of rotation or on the choice of exploitable size. On the other hand, while deciding the rotation or exploitable dbh limit, other objectives of management in environmental, technical, and economical aspects should also be considered. Notwithstanding the rather slim database, results of this study on growth characteristics of natural grown teak would be potentially useful for the management of remaining Myanmar natural teak forests.

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