Effect of Growth Rate on Wood Quality of Teak (Tectona grandis L.f.) Plantations at Malsiripura, Kurunegala, Sri Lanka

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Abstract

This study was designed to find out how the quality of teak wood changes with growth rates. Based on the diameter at breast height and total tree height, three crown classes namely, suppressed, co-dominant and dominant were selected from a 45-year-old state Tectona grandis L.f. (teak) plantation at Malsiripura, Kurunegala, Sri Lanka. Three trees from each crown class were studied. Sample disks were extracted at breast height from each tree, to measure ring width whose values indicate growth rate and specific gravity of each ring. Percentage heartwood was also measured. Mean ring width and mean specific gravity values for each crown class were analyzed. Results indicated that there is no relationship between growth rate and specific gravity. Hence, fast growth rates in shorter rotations is unlikely to reduce specific gravity in teak. Wood property patterns were found similar between the crown classes, indicating that these trends are inherent to teak. It was also found that the percentage heartwood is positively affected by growth rate.

Keywords : Crown classes, Percentage heartwood, Ring width, Specific gravity, *Tectona grandis*

Introduction

Properties of wood vary within a tree due to both intrinsic (effect of ageing of cambium or apical meristem) and extrinsic (environmentally dependent) characteristics such as size and distribution of the live crown (Amarasekera, 1990). It is important to distinguish intrinsic and extrinsic factors, as extrinsic factors can be regulated by management practices so as to obtain the optimum quality wood for its products, where as intrinsic factors cannot be altered.

It is generally believed that faster growth rates result wood of inferior quality. As teak wood is used for construction purposes, specific gravity which has a strong relationship with strength properties is taken as the major indicator of quality of teak wood. The percentage of heartwood has been used by previous studies (Okuyama *et al.*, 2001) as a good indicator specially for the quality of teak wood. Ring width, which reflects the radial growth of a tree resulting from vascular cambial activity, has been used as the indicator of growth rate (Zobel and van Buijtenen, 1989).

Studies suggest that fast growth rates in ring porous hardwoods are generally associated with higher wood density (Zobel and van Buijtenen, 1989). As teak wood is ring porous, it is important to understand the effect of growth rate on specific gravity in order to manipulate growth conditions to yield better quality wood. As teak heartwood contains extractives responsible for its durability (*Kjaer et al.,* 1999), study of the effect of growth rate on the percentage of heartwood is also important.

Since no systematic research studies have been conducted for plantation grown teak wood in the country, the present study was aimed to collect data on growth and quality of teak timber in teak plantations of Sri Lanka. Consequently, objectives of the study were to (i) distinguish the properties of teka wood affected by intrinsic and extrinsic factors, (ii) investgate basic patterns of wood property variations and (iii) study the relationship between growth rate and wood quality with the effect of short rotation on the quality of teak.

Materials and Methods

Selection of the sites

Teak trees were obtained from an even-aged, single species plantation of teak on rotation from the plantations established by the Forest Department at Malsiripura, Kurunegala in the dry zone. This plantation was established in 1962 and at the time of felling in 2007, trees were at site class 1 and 45 year old according to Forestry Department Database at Malsiripura. Rainfall in the area ranged from 1250-1500 mm and the soil was red-yellow podzolic.

Selection of sample trees

Initially 100 trees were randomly selected and their diameters at breast height (DBH) and heights were measured. Based on these data trees were classified into three-crown classes, dominant, codominant and suppressed (Table 1)

Table 1: Classification of trees into crown classes

Crown class	Diameter range (cm)	Height range (m)	No. of trees
Suppressed	15.2-30.0	7.6-13.5	59
Co-dominant	30.1-45.0	13.6-19.5	35
Dominant	45.1-60.0	19.6-25.5	6

There trees with straight and non-leaning boles from each crown class were randomly selected and were felled. Suppressed, co-dominant and dominant trees were coded as S, CD and D respectively and within a crown class trees were numbered as 1,2 and 3 according to the ascending order of DBH values. The diameter at breast height and tree heights of the selected trees are shown in Table 2.

Table 2 : Diameter at breast height and tree height of the sample trees

Tree code	DBH (cm)	Height (m)
Suppressed trees		
S1	18.8	10.0
S2	23.2	13.0
S3	28.3	13.0
Co-dominant trees		
CD1	34.2	14.0
CD2	38.4	15.0
CD3	42.9	19.0
Dominant trees		
D1	45.8	20.0
D2	48.1	23.0
D3	53.6	25.0

Investigation of wood properties

Initially, a 5 cm thick disk from each sample tree was cut at the breast height level, From this, a 2.5 cm thick disk was cut. The disks were planed and sanded. The growth rings were identified visually, using a hand lens. Rings were marked along 2 linear sections that go across the pith. Ring widths were measured to an accuracy of 0.1 mm using a hand lens. Rings widths were measured to an accuracy of 0.1 mm using a travelling microscope. Mean ring width was calculated for each ring using the readings taken from both sides from pith, in each linear section. The sampling procedure for linear sectioning is shown in figure 1.

Analysis of variance test and Turkey's pair-wise comparisons were carried out to find the difference of ring width in the three crown classes.

Measurement of specific gravity

Specific gravity values were measured for each ring in all the disk, except for disk S1. Rings were very close to each other and could not be separated in S1. Hence, three rings were considered as one ring for S1. Eight match-stick sized specimens (two specimens from both left and right of each linear section) were extracted and specific gravity was determined by using the maxium moisture content method (Smith, 1954)

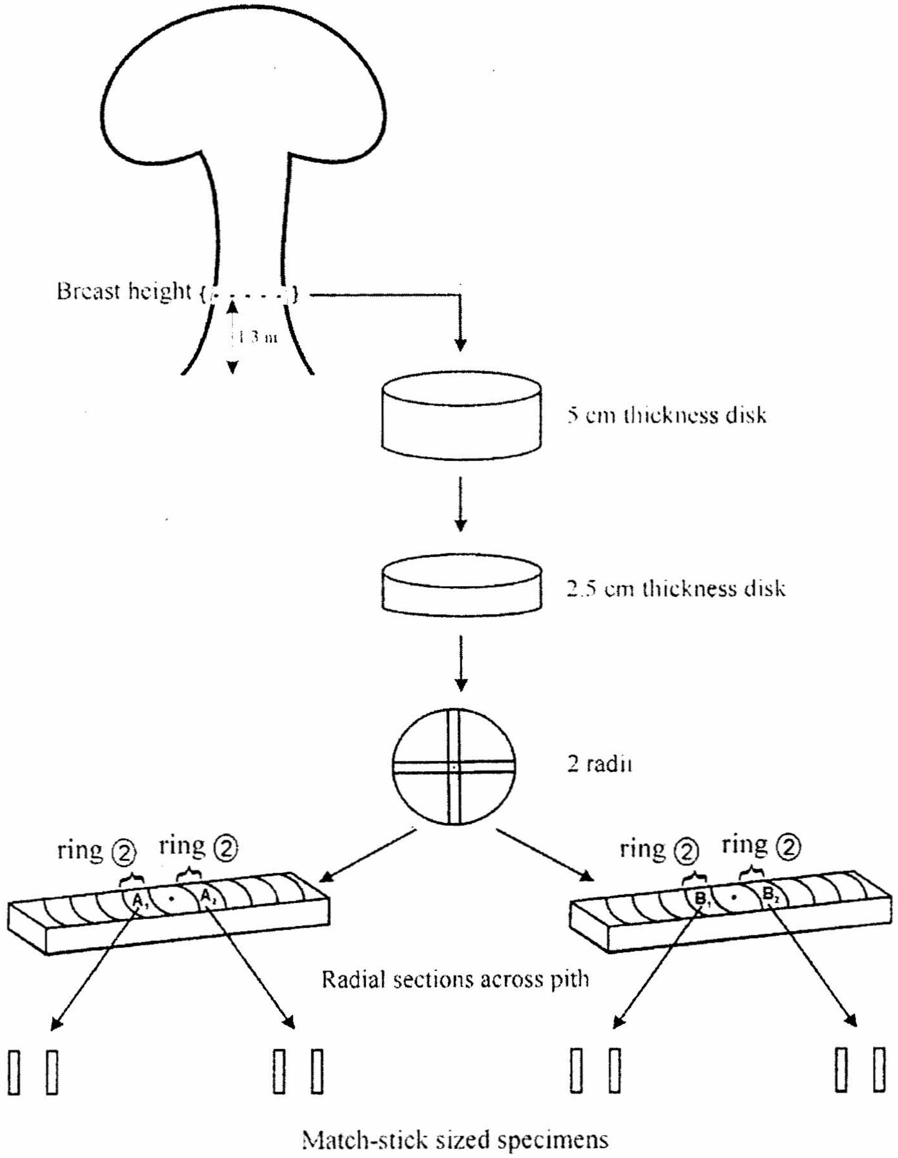


Figure 1: Sampling procedure for each tree and procedure for sampling preparation for the measurement of specific gravity.

The mean specific gravity values of the eight specimens of each ring, was calculated to give the specific gravity of a particular ring. In S1 disk, three rings were considered as one ring as the rings were very close to each other and could not be separated.

Specimen samples were immersed in distilled water and a vacuum applied until they absorbed water to a maximum moisture content. The green weights of samples were measured having removed excess water using absorbent paper using an electric balance. The specimens were then dried in an oven to 103± 2 ^{0}C until a constant weight was achieved. Then samples were transferred rapidly to a desiccator charged with a moisture absorbent and were allowed to reach an equilibrium temperature. The oven dry weights of samples were recorded.

The specific gravity of wood (SG) was calculated using the equation defined by smith (1954).

$$SG = \frac{1}{\frac{Mm - Mo}{Mo} + \frac{1}{1.53}}$$

Where, Mm= Green weight of the specimens (g)
Mo= Oven dry weight of the specimens in (g)
1.53 is the specific gravity of the wood cell wall substances

Analysis of Variance test and Turkey's pair-wise comparisons were carried out to find the difference of specific gravity in the three crown classes. Pearson correlations tests were carried for each class to investigate the relationship between the variables ring width and specific gravity.

Measurement of the percentage of heartwood

Figure 2 indicates schematic diagram of obtaining radii and widths of four radii (R_1, R_2, R_3 and R_4) were measured along the two linear sections taken across the pith. Widths (r_1, r_2, r_3, r_4) of heartwood along those four radii were also measured. Heartwood was determined as a percentage of the total cross sectional area of the disks.

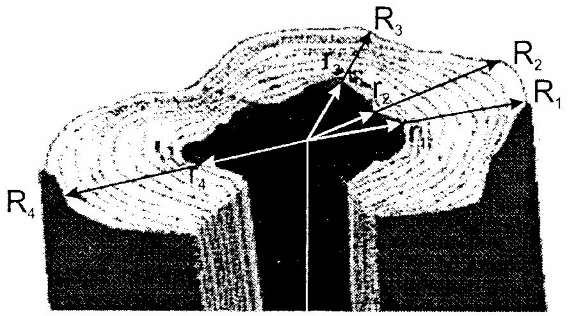


Figure 2: A scheme of a disk illustrating the axes along which measurements were made (Black colour arrows indicate R while, white colour arrows indicate r)

Heartwood percentage of the each sample disk was calculated using equations defined by *Kokutse et al,* (2004).

Cross sectional area of the disks (S_1) $$S_1 = \frac{\pi(\ \Sigma_{i=1}^{4} R_i^2}{4}$$

Cross sectional area of the heartwood (S_{HW}) $$(S_{HW}) = \frac{\pi(\Sigma_{i=1}^{4} R_i^2}{4}$$

Where,

R= the distance between the pith and the bark

r= the axis between the pith and the heartwood boundary

Finally, the heartwood percentage was calculated as follows,

$$\text{Heartwood percentage} = \frac{S_i}{S_{HW}} \times 100\%$$

Determination of the colour

The colours of the heartwood and sapwood were determinied usiing the Munsel soil Colour chart.

Results

Ring width

Variations of ring width for the nine studied individual trees and variations of ring width based on mean values for the three crown classes studied are illustrated in Figures 1 and 2 respectively.

All three suppressed trees (S1-S3) showed a similar radial tend [Figure 3 (A)}: ring width fluctuated in the initial rings close to the pith and thereafter from ring number 33 it remained more or less constant towards the bark.

All three trees in the co- dominant class (CD1-CD3) showed similar radial trend [Figure 3 (B)]. The initial rings close to the pith ring width showed fluctuations. Thereafter, generally in CD1 from growth ring 39, in CD2 from growth ring 34 and in CD3 from growth ring 30 ring widths were more or less a constant towards the bark.

All three dominant trees (D1-D3) also showed a similar tend [(Figure 3 (C)]. Ring width showed a slight decline in the initial rings of D2 and D3 and then increased, after which ring width showed a fluctuation in the middle growth rings. The D2 ring width showed slight fluctuations towards the bark while in the D3 ring width declined towards the bark. In D1, the ring width showed a drastic decline from ring number 1 to 2 and then increased again to growth ring number 3. The D1 ring width showed fluctuation in the middle growth rings following which it attained a more or less a constant value from ring number 34 toward the bark.

Tend of radial variation is roughly similar in the three classes (Figure 4); ring width fluctuated in the initial rings close to the pith and then decreased to nearly a constant towards the bark.

Analysis of mean ring width values of three crown classes revealed significant differences among crown classes (Table 3). It is clear from Table 3 that, dominant trees had significantly wider rings compared to co-dominant and suppressed trees.

Table 3 : Mean ring width values of three crown classes

Crown class	Mean ring width (mm)
Suppressed	2.65 ± 0.139 a
Co-dominant	3.54 ± 0.119 b
Dominant	4.67 ± 0.190 c

(Values with different letters are significantly different at P≤0.05 according to Turkey's test)

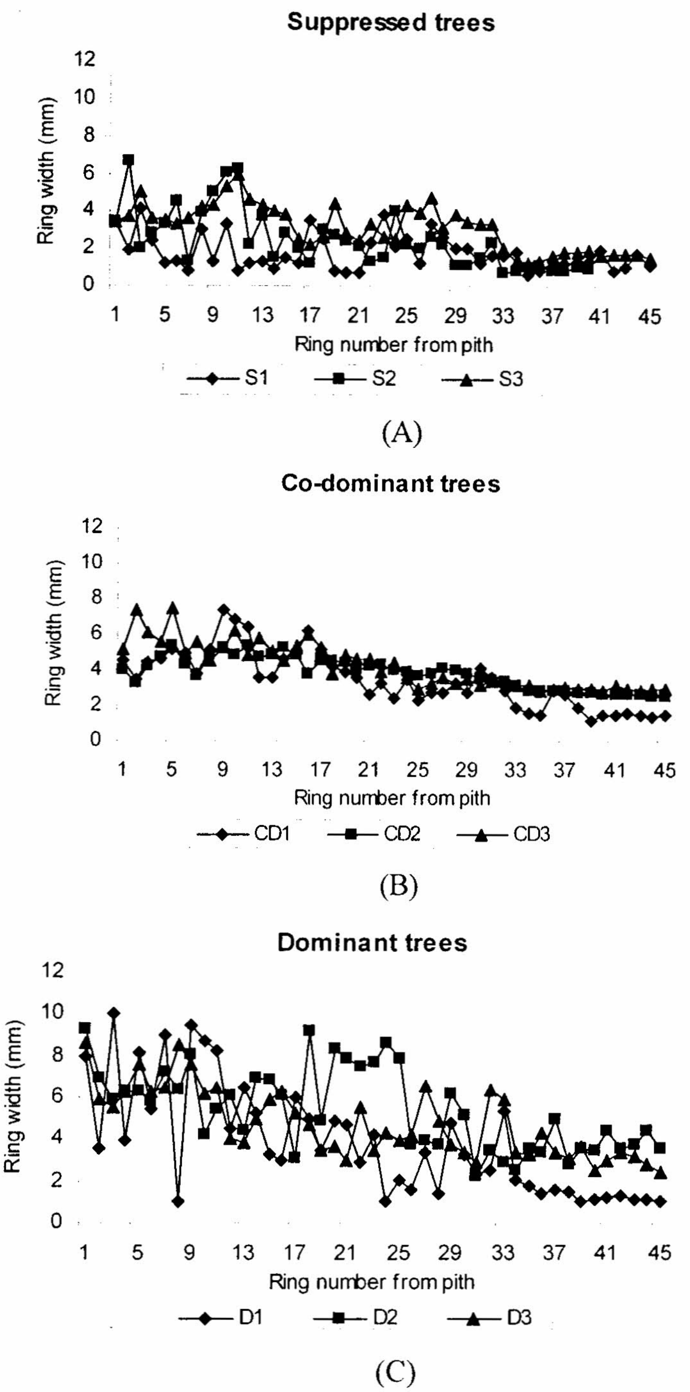


Figure 3 : Radial variation of ring width of three (A) suppressed trees (S1-S3) (B) Co-dominant trees (CD1-CD3) and (C) dominant trees (D1-D3)

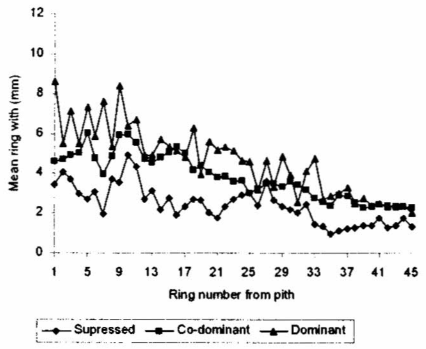


Figure 4: Radial variation of mean ring width in the three crown classes (each data is based on values from three trees)

Specific gravity

Radial variations of specific gravity for the nine individual trees studied are illustrated in Figure 5. Radial variations of mean specific gravity for the studied three crown classes are illustrated in Figure 6.

In tree S1, specific gravity increased up to ring number 33 and in tree S2 increased up to ring number 6 and thereafter remained more or less constant towards the bark. In tree S3, specific gravity gradually increased up to growth ring 35 and then showed a gradual decline towards the bark [Figure 5 (A)].

In the case of the co-dominant trees (CD1-CD3), in CD1 specific gravity generally increased up to growth ring number 5, then showed fluctuations up to growth ring 36 and thereafter remained nearly constant towards the bark. In CD2 generally higher specific gravity values were observed with fluctuations near the pith. After an initial reduation and a decrease was seen but finally becoming nearly constant towards the bark. In CD3, after an initial reduction up to growth ring 5, specific gravity showed high fluctuations in the middle growth rings from 6-25. From growth ring 36, specific gravity remained almost constant towards the bark [Figure 5 (B)].

The variation of specific gravity in the dominant trees (D1-D3) showed a slight decline in specific gravity in first few rings from pith, then an increase towards the middle growth sheaths and finally showed an almost constant specific gravity towards bark [Figure 5 (C)]. The highest specific gravity was observerd in tree S3 (0.4687).

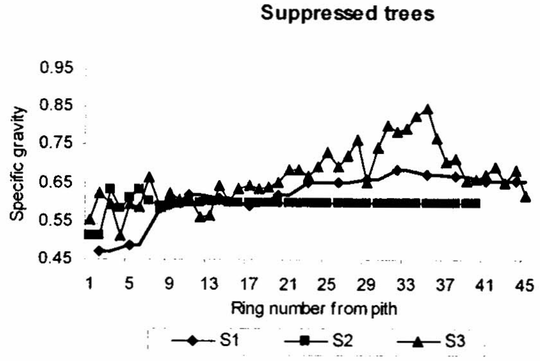
A similar trend in specific gravity was observed in accordance with the radial pattern of variation of mean specific gravity in the crown classes (Figure 6). Specific gravity varied relatively little form pith to bark.

Analysis of specific gravity values revealed that mean specific gravity values are not statistically different among these crown classes.

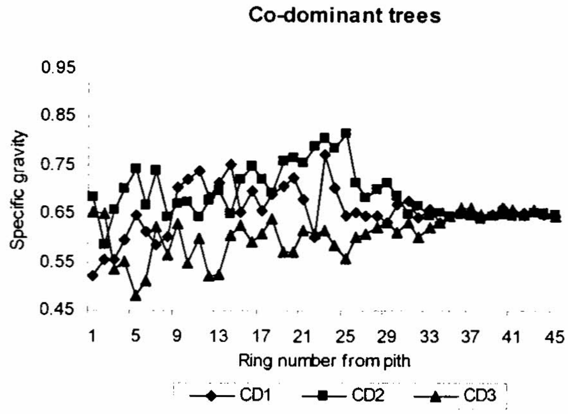
Table 4 : Mean specific gravity values of three crown classes.

Crown class	Mean specific gravity
Suppressed	0.632 ± 0.0066 a
Co-dominant	0.647 ± 0.0069 a
Dominant	0.635 ± 0.0047 a

(Values with same letters are not significant different at $P \leq 0.05$ according to Turkey's test)



(A)



(B)

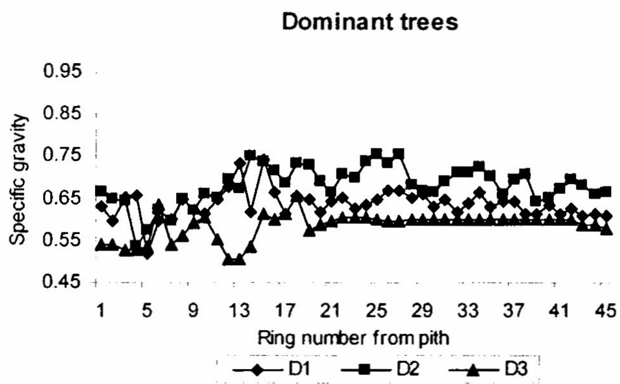


Figure 5: Radial variation of specific gravity of three (**A**) suppressed trees (S1-S3) (**B**) co-dominant trees (CD1-CD3) and (**C**) dominant trees (D1-D3)

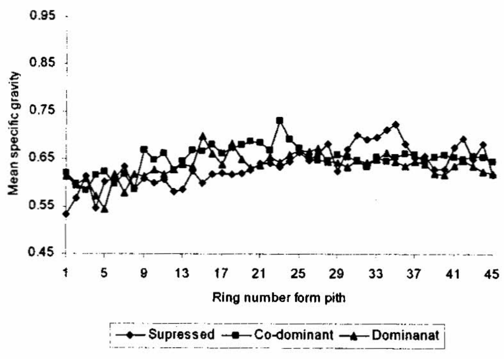


Figure 6: Radial variation of specific gravity in the three crown classes (each data is based on values from three trees)

Relationship between ring width and specific gravity

The variations of ring width and specific gravity versus ring number from pith for each crown class are illustrated in Figure 7,. Generally, ring width values gradually decreased towards the bark while specific gravity remained nearly constant in all three crown classes.

Correlation coefficients between ring with and specific gravity are shown in Table 5. It is clear from Table 5 that there is no significant relationship between ring width and specific gravity in these crown classes.

Table 5 : Correlation coefficients between ring width and specific gravity for the three crown classes

Class	Correlation	P value	Significance
Suppressed	0.144	0.153	NS
Co-dominant	0.009	0.922	NS
Dominant	-0.012	0.887	NS

S : Significant at P ≤0.05 NS: Not significant at P≤0.05

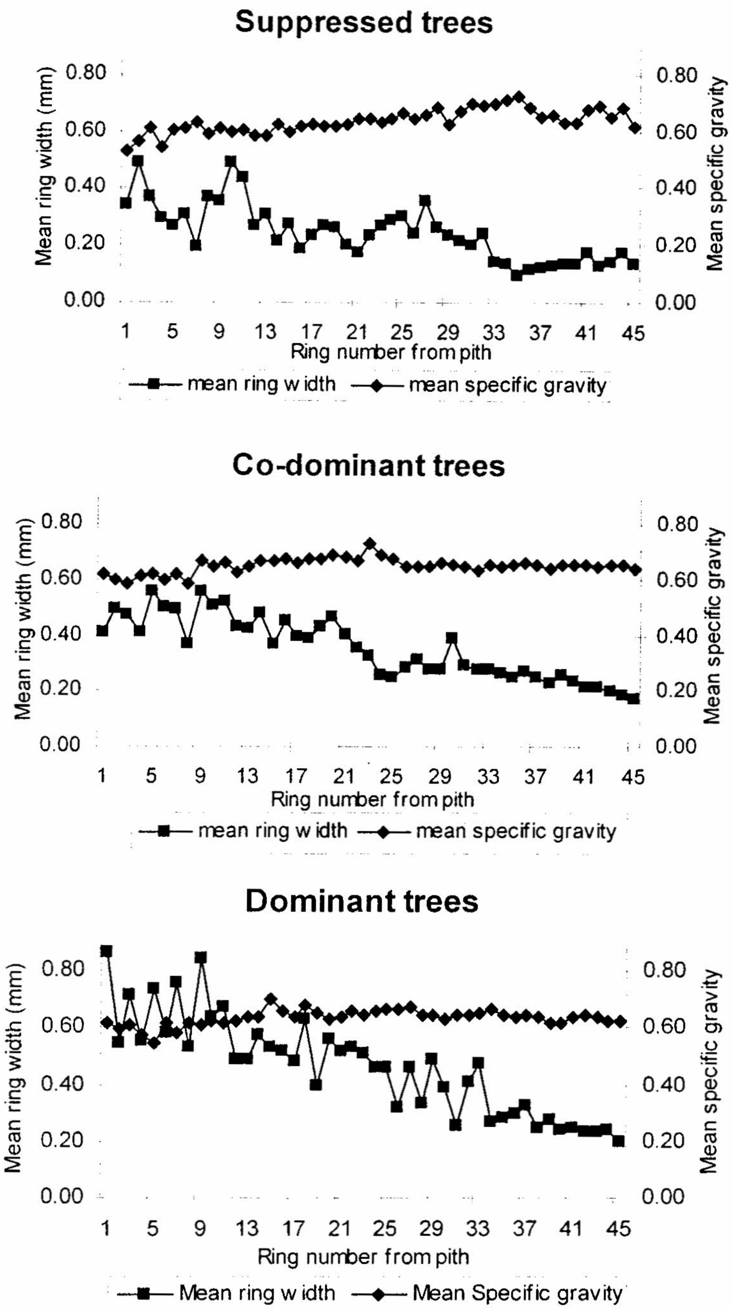


Figure 7 : Variation of mean ring width and mean ring specific gravity with ring number from pith in studies classes.

Percentage of Heartwood

Results obtained for the Heatrwood percentage of the studies trees are shown in Table 6.

Table 6 : Heartwood percentage of the studies trees.

Tree Code	DBH (cm)	No. of rings	Heartwood width (cm)	% Heartwood
Suppressed trees				
S1	18.8	39	7.1	70.89
S2	23.2	34	9.2	59.71
S3	28.3	33	11.4	57.59
Co-dominant trees				
CD1	34.2	38	10.8	75.99
CD2	38.4	40	10.0	70.70
CD3	42.9	32	11.2	70.95
Dominant trees				
D1	45.8	34	15.6	86.25
D2	48.1	35	20.4	84.63
D3	53.6	36	18.4	71.97

The highest percentage of heartwood was obtained for the dominant trees and the lowest for suppressed trees. Generally, the heartwood was observed up to the growth ring 35.

As summarized in Table 7, analysis of heartwood percentage in different crown classes revealed that there is a significant difference in the heatrwood perecntages of suppressed and dominant trees.

Table 7 : Diffenance of heartwood percentage in different crown classes.

Crown Class	Mean % Heartwood	P value
Suppressed	62.73 ± 4.125 a	0.153
Co-dominant	72.55 ± 1.723 a	
Dominant	80.95 ± 4.514 c	

(Values with different letters are significantly different at $P \leq 0.05$ according to Turkey's test)

Analysis of correlation between the variables heartwood percentage and crown class shown in Table 8 revealed that this relationship is significant.

Table 8 : Correlation between heartwood percentage and crown class

Relationship	Correlation	P value	Significance
% Heartwood and crown class	0.820	0.007	S

S: Significant at $P \leq 0.05$

Colour

The colour of the heartwood was light brown for all the trees except for trees CD1 and D3 where the colours observed were brown and dark brown respectively. The colour of the sapwood; pale yellow was common to all the trees.

Discussion

Growth rings are annual in teak, because teak is deciduous, where each growth ring represents one wet season's growth. Therefore the number of rings present in the wood corresponds to the age of the tree (Bhat 1998). Growth rings in teak are distinct therefore the rings were clearly visible in the sample disks. Discontinuous and false rings were present. They were easily identified, as they did not completely surround the stem when examined along different radial directions.

Ring width data were plotted according to a radial sequence. Ring width fluctuated in the initial rings close to the pith and then decreased showing almost a constant towards the bark (Figure 4). This indicates the fluctuation of growth rate at the early years of tree growth while becoming constant after maturation of the cambium. This pattern was observed in all classes, indicating that it is an inherent trend, independent of crown class effects. Rahman *et. al.*, (2005) has also reported a similar trend for teak, where ring width was greater during the initial rings and then decreased towards the bark.

According to the results, the differences of ring width (S=2.65 mm, CD= 3.53 mm, D= 4.67 mm) were significant ($P \leq 0.05$) between the crown classes, suggesting that the dominant class showed a significantly higher growth rate than the others. The differences in growth rate of the even aged trees growing in the same site can be attributed to variations in site environmental conditions. These results suggest that it is possible to increase or decrease growth rate of teak, by changing extrinsic environmental factors such as silvicultural manipulations.

Specific gravity changed relatively little from pith to bark. Bhat and Indira (1997) in their studies has also observed a similar trend for teak. Therefore, the pattern of variation of specific gravity in teak is an inherent trend, resulting from cambial ageing. Therefore it will not increase or decrease on changing of the growth rate by extrinsic environmental factors.

Accroding to the results, the differences of specific gravity (S=0.6321, CD= 0.6473, D= 0.6346) were not significant ($P \leq 0.05$) between the crown classes. Therefore, although there was a significant difference in growth rates a significant change in specific gravity did not result between the crown classes.

Generally a similar relationship was observed between the variation of specific gravity and ring width in all the crown classes (Figure 7), ring width decreased towards bark while specific gravity remained almost constant, indicating that specific gravity is independent of the effect of growth rate. Bhat (1997) has reported a similar trend, indicateing a decrease in ring width while specific gravity varied relatively little from pith to bark

Poor relationships between growth rate and specific gravity can also be explained by the very low regression coefficients between ring width and specific gravity. Therefore, the differences in specific gravity in the crown classes cannot be explained by the difference in growth rate, again confirming that there is no effect of growth rate on specific gravity.

The effect of growth rate on specific gravity has been subjected to many investegations and much controversy. The relationship between the effect of growth rate and specific gravity of *T. grandis* was judged to be inconclusive by several authors. Taylor and Wooten (1973) cited by Zobel and van Buijetenen (1989) have stated that there is no significant relationship between growth rate and specific gravity in many hardwoods. Studies by Sanwo (1986) tested on dominant, co-dominant and subdominant trees from 27-year old plantation in Nigeria showed that the growth rate has no significant influence on specific gravity. Findings of the present study are in line with these observation as well as those of Chat *et al.*, (1987), Harris (1981), Rajput *et al.*, (1996) cited by Bhat (2000) and Yolanda (1992) who also found that wood specific gravity, is independent of growth rate.

However, a negative relationship between growth rate and specific gravity for teak is also reported in the literature Chowdhury 1953; Thor 1964; Bryce 1966; Strickland and Godbard, 1966; Canticon, 1976a; Zobel and McElace, 1958 cited by Zobel and van Buijtenen 1989), that fast growth resulted in lower specific gravity.

Based on the results of the present study, it was observed that specific gravity shows an insignificant relationship with growth rate in the three crown classes, of *T. grandis*. Therefore, as there is very remote possibility that wood density of *T. grandis*, can be changed by varying the growth rate. Futher it is clear that silvicultural treatments designed to increase growth rate would not necessarily affect the quality of wood with regared to specific gravity in teak.

When considering heartwood, it was observed that it was produced generally up to growth ring number 35. This suggests that the transformation from sapwood to heartwood has taken place, up to the 35 years. The effect of growth rate on the percentage of heartwood was also studied.

The heartwood percentage differed significantly between the crown classes ($P \leq 0.05$). The mean heartwood percentage of the dominant trees was significantly higher than in the other two classes. Bhat (1988) found that increased tree growth rate does not retard the formation of heartwood in Teak. In fact from the present study, it was observed that higher growth rates result higher percentage of heartwood Therefore, according to the present study, it is possible that heartwood percentage can be increased by higher growth rates. Similar results were obtained by Bhat (1998) where he showed a positive correlation of heartwood percentage with ring width, indicating that faster growth rates were associated with higher heartwood content.

The colour of the heartwood was light brown for all the trees except for tree CD1 and D3 where the colour observed were brown and dark brown respectively. However, the literature reveals that the heartwood of teak is often dull yellowish when freshly cut but it turns golden brown or sometimes dark greyish-brown after exposure. The colour of the sapwood was found to be pale yellow and was common to all the trees.

In conclusion, it can be stated that the patterns of variation of ring width and specific gravity are inherent to *Tectona grandis*. The results indicated that specific gravity values do not change significantly between crown classes. Hence it is likely that specific gravity is independent of growth rate. Fouthermore, no siginficant relationship could be found between growth rate and specific gravity for each crown class. However, it was found that percentage heartwood can be increased by higher growth rates.

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