Relations Between Growth Traits and Wood Parameters of *Tectona grandis* L.f. in Even-Aged Plantations in Tamil Nadu

C. Buvaneswaran, M. George, K. Vinoth Kumar and R. Velumani

Abstract In the present study, the relation of stand growth parameters with the basic wood properties of the *Tectona grandis* L.f. in southern and western zone of Tamil Nadu was studied. The results revealed highly significant correlation between diameter and area of heartwood in southern zone ($r = 0.86$) and western zone ($r = 0.91$). There was no significant correlation between wood density and diametrical growth in both the zones. There was significant positive correlation between tree height and heartwood area. The result indicates that faster growth is associated with higher heartwood content and lower sapwood proportion disproving the general notion that faster-grown trees will always have greater sapwood content. This affirms that the heartwood production in the teak plantations is predictable from diameter measurement.

Keywords *Tectona grandis* · Heartwood · Sapwood · Diameter · Height · Age · Correlation

Introduction

Teak (*Tectona grandis* L.f.), a tropical timber species, is native to Indo-Malayan region. This multipurpose timber has favourable strength properties besides having resistance to termite and fungal attack by the presence of polyphenols. It has been described as one of the most durable timbers of the world. Teak is highly useful timber, which cannot be eclipsed by any other timber. Traditional use of teak poles for electricity transmission and timber for railway sleepers are a time-tested

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testimony of its suitability for outdoor uses. The persistent demand and continued shortfall of its availability make it one of the dearest species in the tropics. The natural teak forests of India are confined to peninsular India below 24°N latitude (Seth and Khan 1958). The most suitable soil for teak is deep and well-drained alluvium, with an optimum pH range of 6.5–8.0 and relatively high content of calcium and phosphorous (Seth and Yadav 1959). Teak grows from sea level to an altitude of 1200 m with precipitation range of 800–2500 mm. On a global basis, the total area under teak plantation extends to 5.79 million ha, of which 42.9% is in India (ITTO 2009).

In teak, the amount and distribution of heartwood and sapwood is an important determinant of wood value (Wiemann et al. 2002), and there is an increasing interest in heartwood yield of plantations (Bhat 1999; Climent et al. 2002). Of all the wood properties, density is the most significant in determining the end use and wood density is strongly correlated with strength properties of wood (Zobel and van Buijtenen 1989). In the present study, the relation of stand growth parameters with the basic wood properties of the *T. grandis* in southern and western zone of Tamil Nadu was studied.

Materials and Methods

Study Sites

Based on rainfall, temperature, soil type and other ecological conditions, seven agro-climatic zones have been identified in the state of Tamil Nadu in India (Anon 1993). Out of seven zones, the present study was carried out in two agro-climatic zones, viz. southern and western zones of Tamil Nadu which lie in Tirunelveli and Coimbatore forest divisions. Twenty sample plots of size 20 × 20 m were laid out in each age group, and all the trees were measured for girth at breast height (GBH). The whole girth range was divided into five different girth classes. Various measurements such as total height, basal girth, mid girth were recorded from the felled sample trees. Wood samples were collected from the sample trees and studied for wood properties such as density, heartwood (HW) and sapwood (SW) content. Density was estimated by adopting weight/volume method. Heartwood and sapwood thicknesses were measured, and HW/SW percentages were determined by area method (Bhat 1999). Pearsons's correlation, regression and other statistical analyses were performed using SPSS statistical software. Analysis of variance (ANOVA) was performed to test significant differences in the mean values of various parameters (Panse and Sukhatme 1985).

Results and Discussion

Southern Zone

Descriptive statistics on heartwood and sapwood area, percentage of heartwood and sapwood, and density for the 40 trees sampled in southern zone of Tamil Nadu, India, are summarized in Table 1. The heartwood area at breast height of sample trees ranged from 76.9 to 1157.5 cm^2, having the mean value of 449.7 cm^2. The sapwood area ranged from 8.0 cm^2 to 226.8 cm^2 with a mean value of 100.4 cm^2. The heartwood percentage ranged from 66.7 to 95.3, whereas the sapwood content varied from 4.7 to 33.3% of total disc area. By considering all the plantations (age ranging from 25 to 47 years) studied in this zone, the mean percentage values for heartwood and sapwood were 81.6 and 18.4, respectively. The sapwood percentage was found to have greater variation with coefficient of variation of 37% than the heartwood (CV = 9%). With regard to air-dry wood density, the minimum and maximum values recorded are 0.65 and 0.83 g/cc, respectively. The mean wood density was 0.73 g/cc. Variability in wood density was found to be lesser (CV = 9.4%) as compared to other wood traits (heartwood area, sapwood area and sapwood percentage).

Western Zone

Table 2 presents descriptive statistics on various parameters for the 35 trees sampled in western zone. While considering all the plantations studied, the heartwood area ranged from 50.2 to 776.5 cm^2 (mean value of 346 cm^2) and sapwood area ranged from 60.9 to 283.3 cm^2 (mean value of 121.8 cm^2). The percentage of heartwood ranged from 45.2 to 90.8. The mean percentage values for heartwood and sapwood were 71.5 and 28.5, respectively, with age ranging from 20 to 34 years. It was observed that sapwood percentage exhibited greater variation (CV = 33%) than the heartwood (CV = 14%). The wood density ranged from 0.65

Table 1 Descriptive statistics on properties of wood in teak plantations of southern zone

Characteristics	DBH (cm)	HW area (Sq cm)	SW area (Sq cm)	HW (%)	SW (%)	Density (g/cc)
Mean	25.93	449.7	100.4	81.6	18.4	0.73
Standard error	0.96	38.80	9.50	1.10	1.10	0.009
Standard deviation	6.07	245.0	59.8	7.1	7.1	0.059
CV %	23.40	54.5	59.9	8.8	37.2	9.4
Minimum	14.65	76.9	8.0	66.7	4.7	0.65
Maximum	42.65	1157.5	226.8	95.3	33.3	0.83

Table 2 Descriptive statistics on properties of wood in teak plantations of western zone

Characteristics	DBH (cm)	HW area (Sq cm)	SW area (Sq cm)	HW (%)	SW (%)	Density (g/cc)
Mean	24.04	346.0	121.8	71.5	28.5	0.72
Standard error	0.91	29.98	9.13	1.63	1.63	0.006
Standard deviation	5.38	177.4	54.0	9.7	9.7	0.038
CV %	22.38	51.3	44.3	13.7	33.1	5.2
Minimum	12.5	50.2	60.9	45.2	9.2	0.65
Maximum	34.1	776.5	283.3	90.8	54.8	0.79

to 0.79 g/cc with a mean value of 0.72 g/cc. Similar to southern zone, variability in wood density was lesser compared to other parameters in western zone.

Between the zones, heartwood proportion was higher in trees of southern zone (82% of total disc area) than in western zone (72% of total disc area). However, there was no significant difference in the mean wood density (0.01).

Relations Between Growth and Wood Parameters

Diameter and Wood Properties

In southern zone, dbh exhibited highly significant positive correlation with heartwood area ($r = 0.864$) and sapwood area ($r = 0.717$) and non-significant correlation with wood density ($r = 0.26$) (Table 3), whereas in western zone, the correlation was found to be highly significant between dbh and heartwood area ($r = 0.91$) (Table 4). The correlation between dbh and area of sapwood was also observed to be significant, but with moderate *r*-value of 0.64. However, there was significant correlation between wood density and dbh ($r = 0.48$).

Tree Height and Wood Properties

In southern zone, the correlation analysis revealed statistically significant positive relation of height with heartwood area ($r = 0.60$) and a moderate correlation with sapwood area ($r = 0.49$). On the contrary, there existed non-significant correlation between wood density and height ($r = 0.17$) (Table 3). The observations on axial variation revealed that the heartwood area gradually decreased from bottom (587–642 cm^2) to top (13–48 cm^2) height of the trees, while heartwood percentage ranged from 74 to 88 at the base and from 22 to 43% in the top of the trees. Sapwood percentage gradually increased up to 3/4th of tree height (ranging from 30 to 78%). The observations also revealed highly significant variations in wood density at

Table 3 Correlation coefficient (r) for various growth parameters and mean heartwood and sapwood area in teak plantations of southern zone

Parameters	Age (yr)	DBH (cm)	Height (m)	Sapwood area (cm^2)	Heartwood area (cm^2)
Age (yr)	1				
DBH (cm)	0.173	1			
Height (m)	0.143	0.754*	1		
Sapwood area (cm^2)	0.188	0.717*	0.493*	1	
Heartwood area (cm^2)	0.203	0.864*	0.599*	0.371	1
Wood density (g/cc)	0.051	0.259	0.171	0.071	0.279

*Correlation is significant at the 0.001 level

Table 4 Correlation coefficient (r) for various growth parameters and mean heartwood and sapwood area in teak plantations of western zone

	Age (yr)	DBH (cm)	Height (m)	Sapwood area (cm^2)	Heartwood area (cm^2)
Age (yr)	1				
DBH (cm)	0.490*	1			
Height (m)	0.172	0.651*	1		
Sapwood area (cm^2)	0.154	0.631*	0.040	1	
Heartwood area (cm^2)	0.437*	0.913*	0.580*	0.078	1
Wood density (g/cc)	0.511*	0.476*	0.043	0.206	0.494

*Significant at p value of 0.05

different heights of the trees. In general, wood density decreased from base (ranging from 0.66 to 0.71 g/cc at base) to the top (ranging from 0.58 to 0.62 g/cc at top). The trend in wood density at different heights indicated a slight decrease up to 1/4th of the tree height from base and thereafter gradual increase up to 3/4th height and subsequently a sharp decline at the top 1/4th height of the trees (Fig. 1).

In western zone, the results of correlation analysis showed a statistically significant relation of height with heartwood area ($r = 0.58$), but a non-significant correlation with sapwood area ($r = 0.04$). Likewise, there existed non-significant correlation between wood density and height ($r = 0.043$) (Table 4). The observations on axial variation revealed that area of heartwood gradually decreased from bottom (225–446 cm^2) to top (10–63 cm^2) of the trees. Correspondingly, heartwood content ranged from 76 to 79% at the base and from 22 to 39% at the top of the trees. SW% gradually increased up to 3/4th of tree height (varying from 22 to 32%) and rapidly increased at the top 1/4th height (varying from 40 to 79%). With reference to axial variation, wood density decreased from base (0.71–0.74 g/cc) to the top (0.64–0.66 g/cc). In this zone, there was a slight decrease in wood density

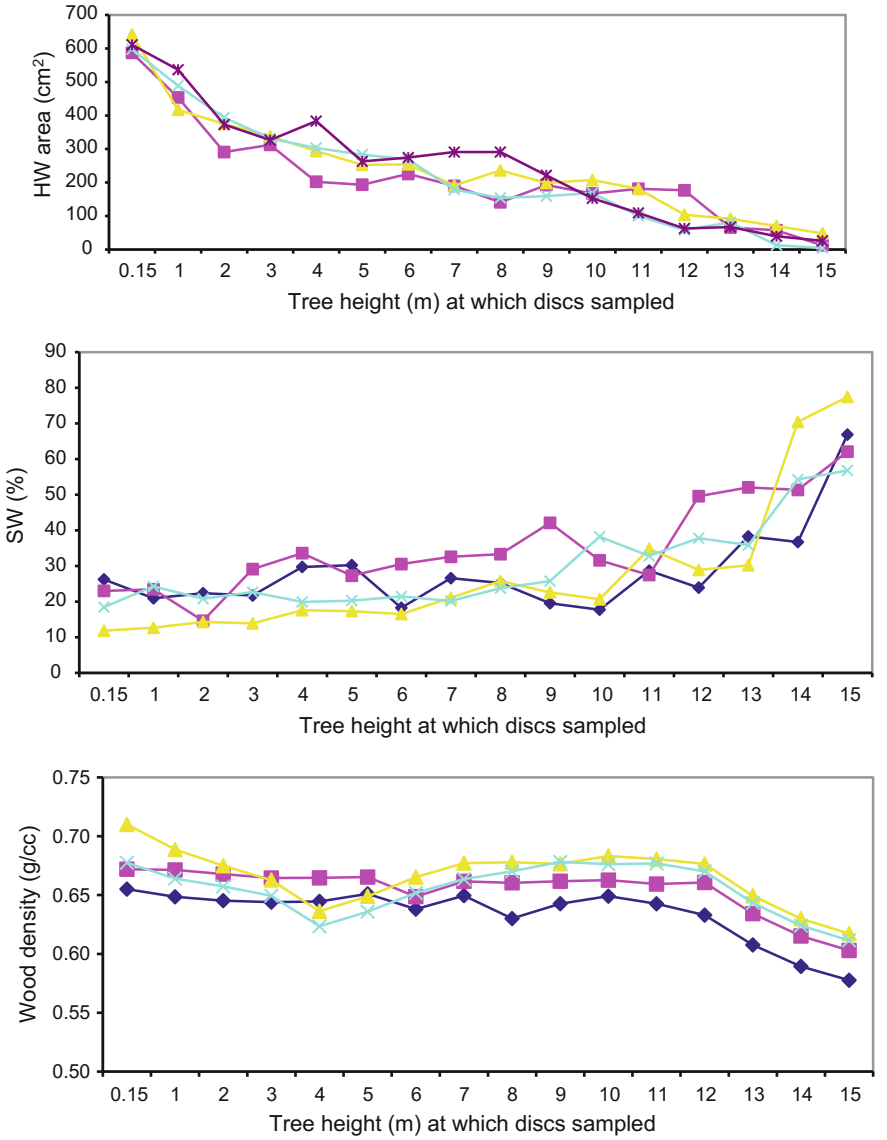

Fig. 1 Axial variation in heartwood area (cm^2), sapwood (%) and wood density (g/cc) at different heights of four representative trees in southern zone

from base up to 3/4th height followed by sharp decrease at the top 1/4th height of the trees (Fig. 2).

Within a tree, the axial variation in wood density was statistically significant in both southern and western zones (Tables 5 and 6).

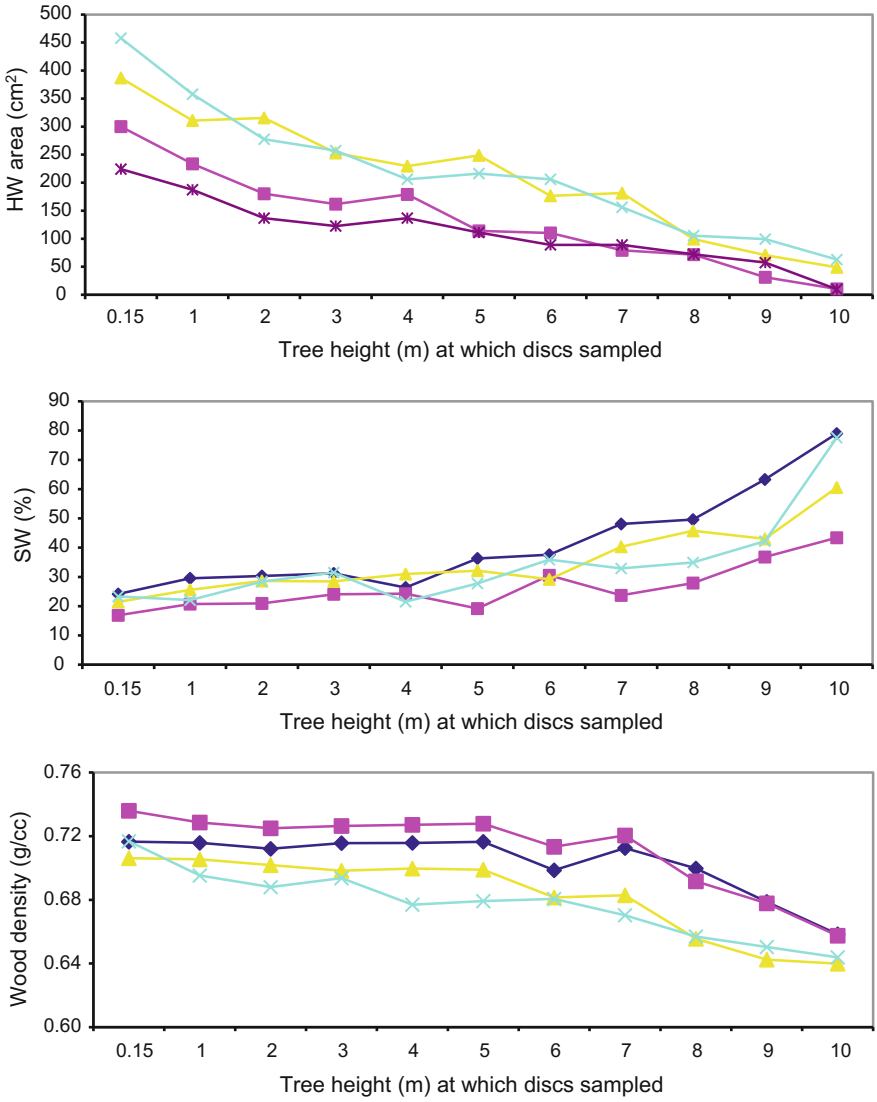

Fig. 2 Axial variation in heartwood area (cm^2), sapwood (%) and wood density (g/cc) at different heights of four representative trees in western zone

Age and Wood Properties

The age of plantation in southern zone ranged from 25 to 47 falling in eight age groups, and the correlation was made between age and area of sapwood and heartwood. It is noted that the correlation was non-significant and the observed

Table 5 *F*-value from ANOVA test for wood density in teak plantations at different heights of samples trees in southern zone

Wood traits	Source of variation	df	Sum of squares	Mean square	*F*-value	Statistical significance
Density	Within tree	15	0.0247	0.0016	15.8	Significant at the 0.01 level
	Between trees	3	0.0084	0.0028	26.7	
	Error	45	0.0047	0.0001		
	Total	63	0.0378			

Table 6 *F*-value from ANOVA test for wood density in teak plantations at different heights of samples trees in western zone

Wood traits	Source of variation	df	Sum of squares	Mean square	*F*-value	Statistical significance
Density	Within tree	10	0.0189	0.0019	27.4	Significant at the 0.01 level
	Between trees	3	0.0095	0.0032	46.1	
	Error	30	0.0021	0.0001		
	Total	43	0.0305			

r-values for heartwood and sapwood area were 0.203 and 0.188, respectively (Table 3). There was a non-significant correlation between age and density as well in southern zone ($r = 0.05$).

The age of plantations in western zone ranged from 21 to 34, falling in seven age groups. A significant correlation was observed between age and heartwood area ($r = 0.44$), whereas it was non-significant between age and sapwood area ($r = 0.15$) (Table 4).

However, ANOVA indicated statistically significant differences among different age groups with reference to heartwood area and wood density in both the zones (Tables 7 and 8). This significant variation observed among plantations may be brought out by the locality factors rather than age as such.

Table 7 *F*-value from ANOVA test for wood density in teak plantations of different age groups in southern zone

Wood traits	Source of variation	df	Sum of squares	Mean square	*F*-value	Statistical significance
Heartwood area	Age of the plantations	7	1,402,093	200,299	6.83	0.00005
	Error	32	939,119	29,347		Significant at the 0.01 level
	Total	39	2,341,213			
Density	Age of the plantations	7	0.075	0.011	3.14	0.0121
	Error	32	0.109	0.003		Significant at the 0.01 level

Table 8 *F*-value from ANOVA test for wood density in teak plantations of different age groups in western zone

Wood traits	Source of variation	df	Sum of squares	Mean square	*F*-value	Statistical significance
Heartwood area	Age of the plantations	6	386,858	64,476	2.64	0.037
	Error	28	682,800	24,386		Significant at the 0.01 level
	Total	34	1,069,658			
Density	Age of the plantations	6	0.038	0.0063	16.00	0.0000
	Error	28	0.011	0.0004		Significant at the 0.01 level
	Total	34	0.049			

The mean values observed with reference to heartwood in the present study are comparable with that reported for teak by Bhat et al. (1985) that is 76.6% at 51–52 years. The present results are also in tune with that reported by Bhat (2001) who recorded 58–65% of heartwood at age between 13 and 21 years and 85–88% at age between 55 and 65 years in teak plantations from Nilambur, Kerala. While comparing the wood traits observed in southern zone with that in western zone, it is found that on an average basis, the heartwood produced was in greater proportion in trees of southern zone (82%) than in western zone (72%). For the purpose of comparison, plantations of similar ages in these two zones were selected and the overall mean values were worked out. While comparing heartwood percentage in teak plantations of two zones studied at comparable ages (from 30 to 35 years), mean heartwood percentage for southern zone (83%) was greater than that of western zone (76%). This difference could be attributed to the eco-climatic variation between the zones.

Observation on variation among trees in wood traits in the present study is well within the range reported by Bhat (2001) who recorded CV range of 6.5–13.5% for specific gravity in teak. This result is also in consonance with Bhat et al. (1990) who observed CV values ranging from 6.6 to 8.9% for wood density in *Eucalyptus grandis* plantation. Varghese et al. (2000) also reported low CV (6.2%) for wood density in samples tested across nine plantations of teak in various locations from peninsular India.

With reference to correlation and regression relations of growth traits with wood properties, Todorovski (1966) reported that stem diameter was one of the first variables used to predict heartwood diameter in *Pinus sylvestris* and *Pinus nigra*. Ihara (1972) also observed highly significant correlation between heartwood diameter and stem diameter for *Cryptomeria japonica*. Bhat (1995) also observed statistically significant positive correlation between heartwood and breast height diameter in teak plantation and inferred that faster growth is associated with higher heartwood content and lower sapwood proportion disproving the general notion that faster-grown timber always has higher sapwood content. Mukerji and Bhattacharya (1963) reported that the correlation between the rate of diametrical

growth (in terms of number of rings per 2.5 cm) and specific gravity is not statistically significant in teak.

With regard to relations between height and wood traits, Nicholls and Matheson (1980) also reported that there were significant differences in heartwood between 7-year-old trees of *Eucalyptus obliqua* and those showing better height growth which have a greater proportion of heartwood. Bhat et al. (1990) observed that wood density is not significantly related to height in *Eucalyptus grandis* when the age of the plantations was between three and seven years.

Axial variation in wood density was studied in selected trees in both zones. The observations revealed that there exist highly significant variations in wood density at different heights of trees. In general, wood density decreased from base to the top in both southern and western zones. Sekhar and Negi (1966) studied variation of strength properties along the length of stem in teak and they found that strength properties were higher at the bottom. However, the differences in wood density in actual values were relatively small. On average, wood density was 0.7 at the base and 0.63 at the top of trees.

Conclusions

The present study confirms a significant correlation between tree diameter and heartwood content and affirms that the heartwood production in the teak plantations is predictable from diameter measurement. The study also corroborates with earlier studies that increased diametrical growth owing to genetics or environmental factors will not bring change in heartwood production. On the other hand, the proportion of sapwood production is influenced by site factors. Specific gravity remains unaltered in teak after the reported wood maturation age of 20 years and beyond.

References

Anon (1993). Manual on agroforestry in dry lands. Directorate of Agriculture, Madras, 600 005

Bhat KM (1995) A note on heartwood proportion and wood density of 8-year old teak. Indian For 112:514–517

Bhat KM (1999) Is fast grown teak inferior in wood quality?—an appraisal from plantations of low input management. Wood News 8:27–31

Bhat KM (2001) Breeding for improved wood quality of teak. In: Mandal AK, Ansari SA (eds) Genetics and silviculture of teak. International Book Distributors, Dehra Dun, pp 147–163

Bhat KM, Bhat KV, Dhamodaran TK (1985) Wood and bark properties of branches of selected tree species growing in Kerala. KFRI research Report, 29. Kerala Forest Research Institute, Peechi, Kerala, India

Bhat KM, Bhat KV, Dhamodaran TK (1990) Wood density and fibre length of *Eucalyptus grandis* grown in Kerala, India. Wood Fiber Sci 22(1):54–61

Climent J, Chambel MR, Pérez E, Gil L, Pardos J (2002) Relationship between heartwood radius and early radial growth, tree age and climate in *Pinus canariensis*. Can J For Res 32:103–111
Ihara N (1972) A dendrometrical study on heartwood formation of forest trees. Bull Kyushu Univ For 46:123–129
ITTO (2009) Encouraging industrial forest plantations in the tropics. Report of a global study. International tropical timber organization technical series, vol 33. P 97
Mukerji HK, Bhattacharya PK (1963) A study of the correlation between different pairs of physical and mechanical properties of teak grown in various localities of India and Burma. Indian For 89:207–217
Nicholls JWP, Matheson AC (1980) Variation in wood characteristics in thinning from a field trial of *Eucalyptus obliqua*. Aust For Res 10:239–247
Panse VG, Sukhatme PV (1985) Statistical methods for agricultural workers, 4th edn. ICAR, New Delhi, pp 58–62
Sekhar AC, Negi GS (1966) Variation of some mechanical properties along the length of teak trees. Indian For Bull 251
Seth SK, Khan WMA (1958) Regeneration of teak forest. In: Proceeding of all India teak study tour and symposium. Forest Research Institute, Dehra Dun, p 108
Seth SK, Yadav JPS (1959) Teak soils. Indian For 85(1):2–16
Todorovski S (1966) Effect of certain factors on the proportion of sapwood and heartwood in the stem of *Pinus sylvestris* and *Pinus nigra*. For Abstr 1968:2908
Varghese M, Nicodemus A, Ramteke PK, Anbazhagi G, Bennet SSR, Subramanian K (2000) Variation in growth and wood traits among nine populations of teak in Peninsular India. Silvae Genet 49:201–205
Wiemann MC, Brown JP, Bennett ND (2002) Comparison of methods to determine disk and heartwood areas. Research paper NE-720. USDA, Forest Service, North Eastern Research Station
Zobel BJ, van Buijtenen JP (1989) Wood variation—its causes and control. Springer-Verlag, Berlin, Heidelberg, Germany