Effect of Thinning on Stem Form and Wood Characteristics of Teak (*Tectona grandis)* in a Humid Tropical Site in Costa Rica

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The aim of the study was to evaluate the effects of thinning intensity on wood properties, such as heartwood proportion, wood basic density, and stem form of teak (*Tectona grandis* L.f.). The thinning trial was established on a teak plantation in a humid tropical site in northern Costa Rica.

The moderate and heavy thinnings yielded the highest percentage of heartwood volume (25 to 30% of total stem volume). The differences between stem form factors under different treatments were not statistically significant after separating thinning effects from timing effects. Both the highest (>0.65 g cm^{-3}) and the lowest (<0.50 g cm^{-3}) wood density values were observed under light thinnings, making it difficult to establish a relationship.

Large variations in wood properties found under different thinning regimes suggest that at early stages teak stands can be managed under different thinning programs without negatively affecting the quality of wood under humid tropical conditions.

Keywords stem taper, basic density, heartwood, sapwood, form factor
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1 Introduction

Despite the efforts made in planting *Tectona grandis* L.f. (teak) worldwide (according to FAO 2000, 5.7 million hectares had been planted through the year 2000), the supply of teak timber currently available is far below the needs of the market demand (Ball et al. 2000). The lack of superior quality trees was identified as the primary cause of teak timber deficit in the last TEAKNET (Asia-Pacific Network) meeting held in 1999 in Chiang Mai (Thailand).

Increased yield and higher uniformity from shorter rotations are key incentives for developing intensively managed teak plantations. However, no adequate data are available for teak timber production under intensive silvicultural practices in most teak producing countries (Bhat 1998). In the tropics, most of the tree plantations grown for saw timber require early, heavy and repeated thinnings in order to sustain rapid diameter growth of the selected trees (Galloway et al. 2001). However, it is not clear if such rapid diameter growth may be detrimental to certain wood properties.

Evidence of similar wood mechanical properties between 21- and 65-year-old teak trees offer scope for reducing the rotation age of this fast-growing species without affecting timber strength. Yet, the available data on the effects of spacing and thinning regimes on wood quality are insufficient for designing an efficient management system (Bhat 2000). Although *T. grandis* is an established high-value timber tree for commercial planting, the quality and yield of the timber from young-aged plantations often fail to meet expectations (Tze 1999).

The important property requirements of end-users in fast-grown teak are straight boles with cylindrical form, with few flutes/buttresses and knots, low proportions of juvenile and tension wood, high proportions of heartwood (>85%), optimum wood density (>0.675 $g\,cm^{-3}$), and sufficient strength (MOR > 135 $N\,mm^{-2}$) (Bhat 1998). Moreover, teak logs and saw timber are graded on the basis of the defect system, which depends on visual assessment (Kyaw Min 1996a). Teak log grading in depots considers bend, taper, hollowness, splits, sound and unsound knots, fluting, twist, surface and heart cracks, sapwood, and pith, among other defects (Kyaw Min 1996a, Kyaw Min 1996b, Suri 1974).

Available reports on teak wood quality include the heartwood content and the wood density variations from pith to bark, with stem height, age, stand density, and climatic conditions (Bhat 1995, Bhat et al. 2001, Brennan and Radomiljac 1998, Nair and Chavan 1985, Priya and Bhat 1999, Trockenbrodt and Josue 1998).

It is well known that wide spacing produces large diameter trees; however information on the effects of plantation density on wood properties such as heartwood content, stem form, and basic density is meager and fragmentary. The present study aims at evaluating the effects of thinning intensity on heartwood proportion, wood basic density, and stem form, based on the results of a thinning trial established on a teak plantation in a humid tropical site in northern Costa Rica.

2 Methodology

The thinning trial was established in San Carlos, Alajuela, on a site representing the typical warm, moist, and flat region of northwestern Costa Rica. The average annual temperature is 26.0 °C with minor daily and annual fluctuations. The mean annual precipitation is 2900 mm with three dry months (with less than 100 mm per month). At an altitude of 90 m.a.s.l., at 84°23´ W and 10°30´N, the site falls in the Tropical Wet Forest according to the Holdridge Life Zone System (Holdridge 1978). The soil texture is clay loam (>50% clay), with a pH of 5.2 and a slightly deficient nutrient status, particularly deficient in phosphorous.

A total of 314 ha of teak plantations were established in June, 1994, on land originally cleared for farming, with an initial spacing of 2.5 m × 2.5 m (1600 trees ha^{-1}). The origin of the seeds is unknown. When the thinning trial began (June 1998, 4 years of age), most of the trees had attained a DBH of 12.0 cm, an average height of 14.5 m, and a density varying between 1450 and 1550 trees ha^{-1}. The stand presented a full canopy closure but extreme competition was not evident (basal area varying between 13.5 and 21.0 $m^2\,ha^{-1}$). The first pruning (up to 3 m high) was the only silvicultural intervention that had been applied to the plantation before the trial establishment. The experimental design consisted of randomized complete blocks, with 8 treatments and 3 replicates. Each treatment consisted of 80 trees in square blocks of 500 m^2 each. Two lines of trees were left between treatments, each of them thinned according to the treatment they were bordering.

The trial consisted of different thinning intensities applied at 4 and 6 years of age. The treatments were:

1) Unthinned (Control)
2) Early light thinning; removal of 25% of the original trees (1600 trees ha^{-1}) in the 4th year (25% 4th)
3) Early moderate thinning; removal of 25% of the original trees in the 4th year and 25% of the original trees in the 5th year (25% 4th & 5th)
4) Early moderate thinning; removal of 40% of the original trees in the 4th year (40% 4th)
5) Early heavy thinning; removal of 60% of the original trees in the 4th year (60% 4th)
6) Late light thinning; removal of 25% of the original trees in the 6th year (25% 6th)
7) Late moderate thinning; removal of 40% of the original trees in the 6th year (40% 6th)
8) Late heavy thinning; removal of 60% of the original trees in the 6th year (60% 6th)

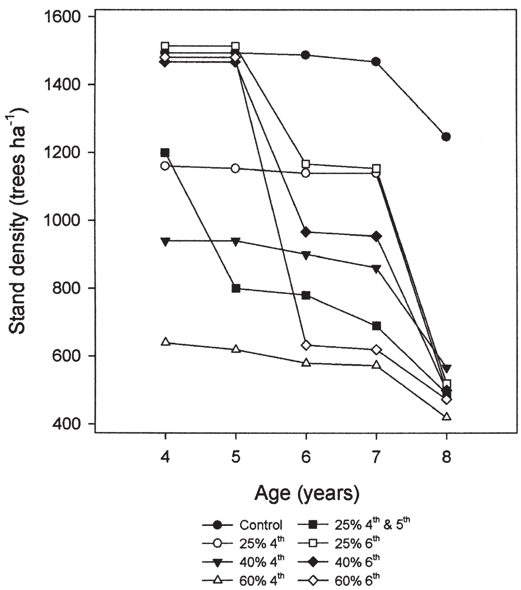

Fig. 1. Stand density after the thinning interventions from the ages 4 to 8 years for the different thinning treatments of the thinning trial established on a *T. grandis* plantation in Costa Rica.

The density management scheme resulting from the different thinning intensities is presented in Fig. 1. Permanent sample plots were established for each treatment and for each replicate. All standing trees were recorded and numbered with red paint. DBH (cm) and total height (m) were measured annually, using a diameter tape and a Suunto altimeter. On each thinning, preference was given to the retention of the most vigorous trees, although trees were selected trying to keep a relatively even spacing. The last measurement was carried out at 8 years of age.

A total of 24 trees (one per treatment on each replicate) were harvested for stem analysis. Stem cross-sectional samples (disks) were taken from each felled tree at 0.3 m and at 1.3 m from the ground base. From the height of 2.0 m onwards, sections were taken along the stem at 2.0 m intervals. Firstly, heartwood diameter and total mean diameter (with and without bark) were calculated as the average of two cross-sectional measurements (in direction North-South and East-West). Secondly, heartwood, sapwood and bark cross-sectional areas (m^2) were calculated as geometric circles. Finally, the total volume (m^3) of sapwood, heartwood and stem (with and without bark) were calculated using the Smalian formulae (Clutter et al. 1983). The last stem section, i.e. that section from the last-taken disk to the tip of the tree, was calculated as a geometric cone.

Wood basic density was determined by taking samples of stem sections (4 cm × 2 cm × 12 cm) at DBH (1.3 m high). The volume of each sample was determined from the volume of water it displaced when submerged, according to ASTM standard norms (ASTM 1986). Basic density was calculated as oven-dry weight (24 hours at 105 °C until constant weight) divided by green volume.

In order to evaluate the effect of stand density on heartwood content at stand level, stand volume (m^3 ha^{-1}) was generalized for each treatment based on the average percentage of heartwood volume of the sampled trees. Analysis of variance (ANOVA) was carried out in Systat 6.0 for the different treatments, using the initial stand density of each plot as covariate for the reduction of variations caused by initial stand differences (initial BA varied from 13.5 to 21.0 $m^2 ha^{-1}$). ANOVA was carried out in two-way analysis, i.e. the three thinning regimes (light, moderate, and heavy) and the two timings (early and late) were compared to separate one effect from the other.

3 Results

Heartwood content varied considerably among treatments (Fig. 2). The ANOVA analysis showed no significant differences between treatments ($P<0.05$) even after separating the thinning effect from the timing effect, as for instance the moderate and heavy thinnings yielded the highest heartwood volume (between 25 and 30% of the tree total volume) but also the lowest (below 10%). In general, the light thinnings and the Control yielded slightly higher heartwood contents than heavy and moderate thinnings (16.8–18.0% vs. 14.7–15.9%, respectively). The Control also showed higher heartwood contents than the late and early thinnings (Control > Late > Early).

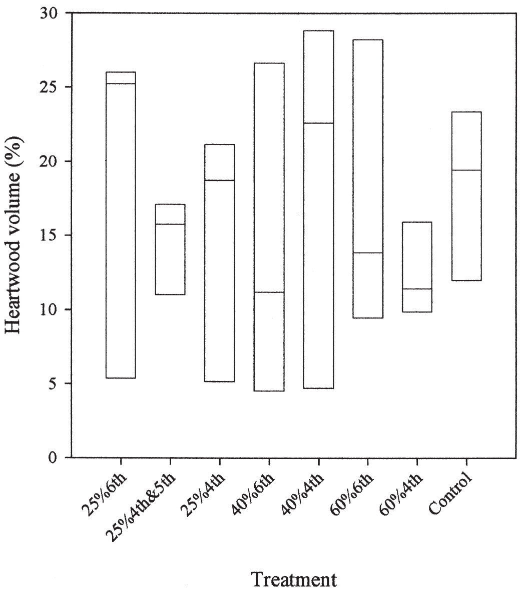

Fig. 2. Heartwood volume (%) at the age of 8 years for the different treatments of the thinning trial. Box middle line corresponds to the average, and box edges refer to the Percentiles 25 and 75 (lower and upper edges, respectively).

Moderate and early executed thinnings (25% 4th & 5th and 40% 4th), yielded more cylindrical trees (average form factor of 0.46) than some late thinnings (40% 6th) and the Control (average form factor of 0.43 and 0.44, respectively) (Fig. 3). The ANOVA indicated that the stem form factor was not statistically different ($P<0.05$) between treatments even after separating the thinning effect from the timing effect.

The DBH/total height ratios (cm to m relationship) increased with increasing age in all treatments (Fig. 4). In the moderate and heavy thinnings, the yearly increments in DBH (cm) were greater than those in total height (m), reaching final ratios greater than 0.95. The DBH/total height ratios were higher in the heavy thinnings than in the moderate and light thinnings ($P<0.05$), while the moderate thinnings showed significantly higher values ($P<0.05$) than the light thinnings and the Control (Heavy > Moderate > Light > Control).

Wood basic density varied considerably within and between treatments (Fig. 5). In general, light thinnings presented high (>0.60 $g\,cm^{-3}$) as well

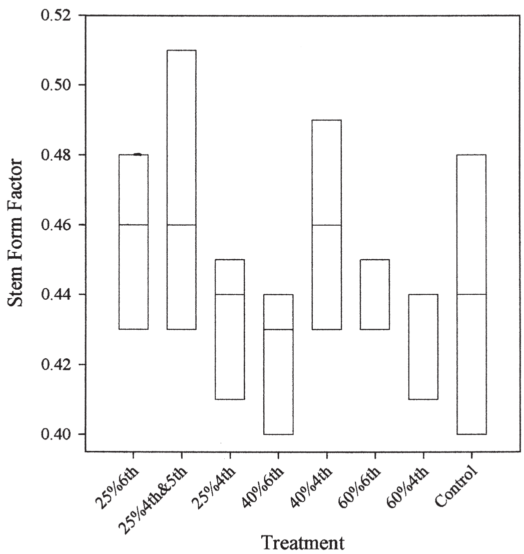

Fig. 3. Stem form factor at the age 8 years for the different treatments of the thinning trial.

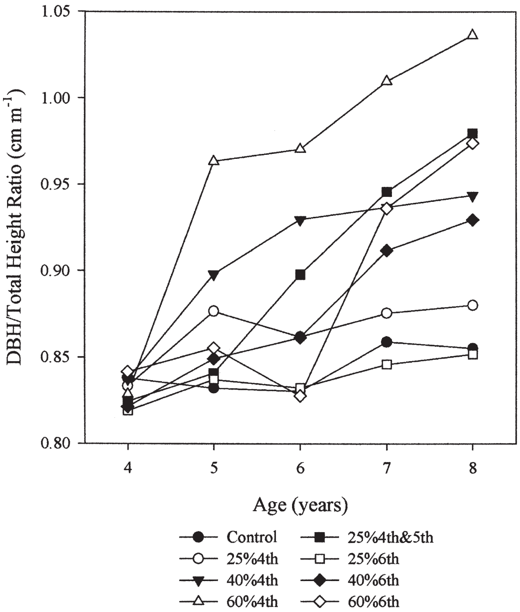

Fig. 4. Ratio DBH / Total height ratio from ages 4 to 8 years for the different treatments of the thinning trial.

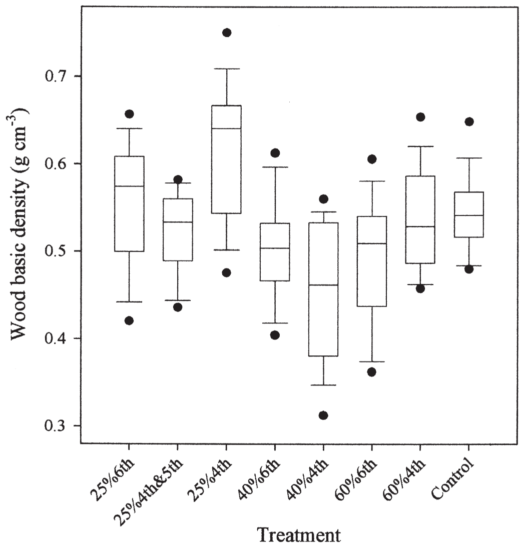

Fig. 5. Wood basic density at the age of 8 years for the different treatments of the thinning trial. Box middle line corresponds to the average, box edges refer to the Percentiles 25 and 75 (lower and upper edges, respectively), and outer fences indicate the minimum and maximum values. Dots correspond to outliers.

as low wood density values (<0.50 g cm^{-3}), while the heavy and the early thinning treatments presented high wood densities.

Heartwood volume (%) showed no clear relationship with stand density (Fig. 6a). Trees on heavy thinned treatments yielded between 10 to 30% of heartwood volume at BA between 15 and 20 m^2 ha^{-1}. Moderate and on time thinnings yielded similar values at BA of 20 to 25 m^2 ha^{-1}, while light and late thinnings showed heartwood contents varying between 20 and 25% at BA $>$ 25 m^2 ha^{-1} (Fig. 6a). Wood basic density varied between 0.45 and 0.65 g cm^{-3} but showed no relationship with stand BA, although the lowest values were found at BA $<$ 20 m^2 ha^{-1} and the highest values at BA $>$ 25 m^2 ha^{-1} (Fig. 6b).

Large-size trees presented higher percentages as well as higher absolute values of heartwood than small-size trees, being both absolute and relative values significantly correlated ($r = 0.98$). However, no clear relationship could be established between heartwood content and intensity or timing of thinning, as the size of the tree and not the thinning regime of the plot seems to be determining the content and proportion of heartwood volume (Fig. 7). Treatments with moderate intensity or late executed, e.g. "40% 4th", "40% 6th", "25% 6th", presented the highest heartwood contents (25–30%, 0.05–0.06 m^3 per tree), however results were inconsistent as one of the three replicates differed considerably from the other two.

Treatments "25% 4th" and "60% 4th" presented the highest per-hectare heartwood volumes (between 35 and 40 m^3 ha^{-1}); treatments "25% 6th" and "40% 6th" yielded middle values of 25–35 m^3 ha^{-1}, while the remaining treatments (including the Control) showed heartwood volumes of 20 m^3 ha^{-1} and less, at 8 years of age (Fig. 8). Light thinnings differed significantly ($P<0.05$) from the Control and from moderate thinnings, but not from the heavy thinnings. Late and early executed thinnings tended to produce higher per-hectare heartwood volumes than the Control (25–27 m^3 ha^{-1} vs. 15.0 m^3 ha^{-1}), however differences were not statistically significant ($P<0.05$).

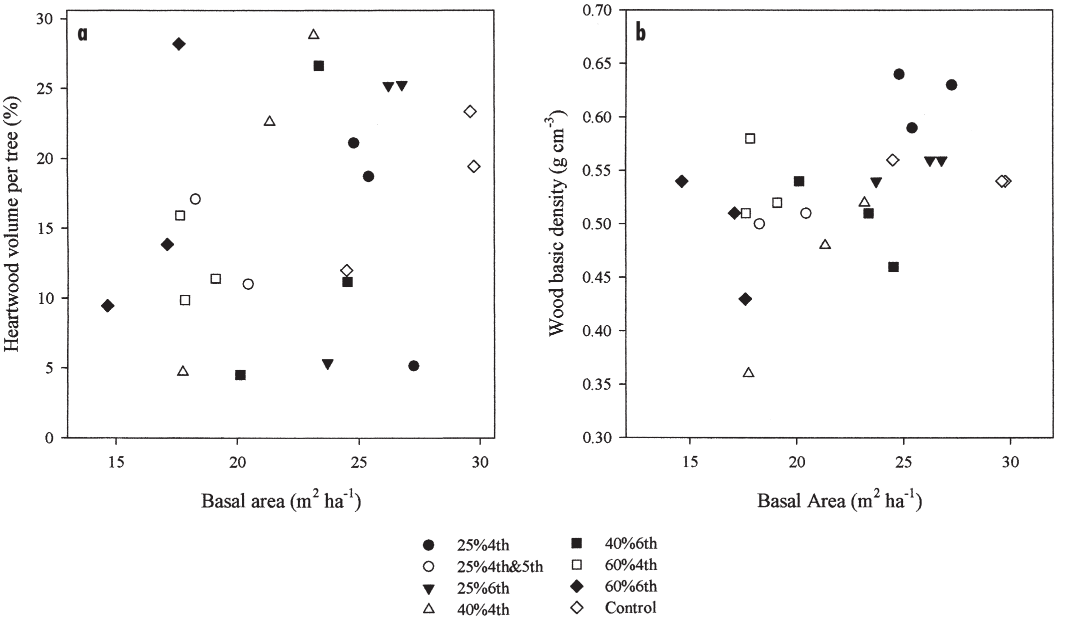

Fig. 6. Relationship between (a) individual-tree heartwood volume (b) wood basic density and stand basal area at the age of 8 years for the different treatments of the thinning trial.

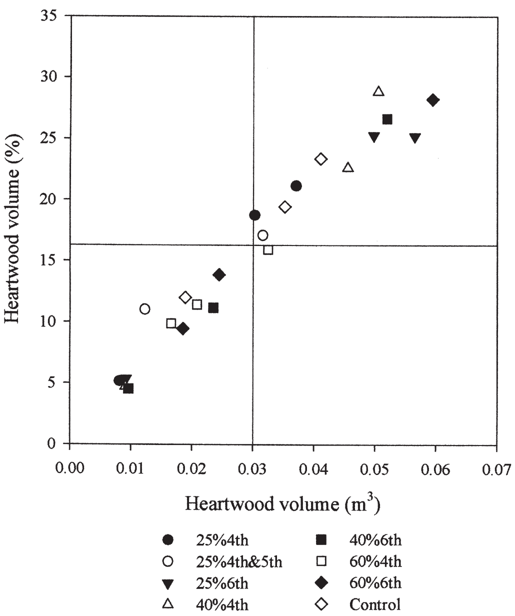

Fig. 7. Relationship between relative and absolute heartwood volume for the different treatments of the thinning trial. Horizontal and vertical lines correspond to the mean of the corresponding variable.

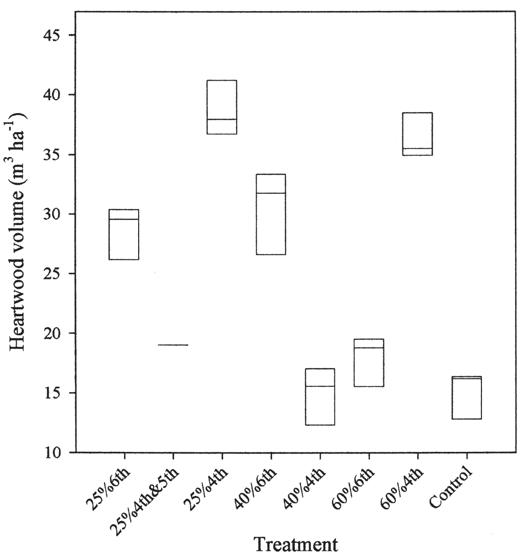

Fig. 8. Per hectare heartwood volume at 8 years of age for the different treatments of the thinning trial.

4 Discussion

After thinning, plantation density ranged from 1550 to 640 trees ha^{-1}. Although heavy thinnings were performed, the stand density in some treatments was still higher than that recommended for young teak stands in Costa Rica. Initial densities of 1600 trees ha^{-1} are no longer implemented in the country; instead a density of 1111 trees ha^{-1}, i.e. 3 m × 3 m spacing, is now commonly accepted. In addition, the number of trees extracted in the heavy thinnings was considerably higher, causing a drastic and difficult-to-recover reduction in basal area.

No clear relationship could be established between the thinning intensity-timing and the heartwood content. While moderate and heavy thinnings yielded the highest heartwood contents, light thinnings and the Control yielded higher average values. The Control showed a higher heartwood content than the early and late thinnings, suggesting that the age for the first thinning has no effect on heartwood content in this particular experiment. Hillis (1987) suggests that heartwood content varies considerably among trees within the same stand and of the same age.

The study on heartwood content gave different results than anticipated, i.e. high stand densities (light thinnings) would yield more heartwood than low stand densities as trees in dense stands have less crown area and grow slower, requiring, therefore, less sapwood which decays and begins to turn into heartwood (Bamber 1976). According to the present results, 8-year-old trees in the north Pacific region of Costa Rica produce a maximum of 30% heartwood volume. Similar results have been reported previously for 8-year-old teak trees growing in different regions of Costa Rica by Pérez Cordero and Kanninen (2003). The authors reported that the heartwood volume of 8- to 47-year-old trees increased with increasing DBH and age, and decreased with increasing stand density, even after eliminating the effect of age. It is suspected that the high variability within treatments and the poor relationship between plantation densities and heartwood volume are normal conditions at young stages in this particular humid region of Costa Rica rather than a result of insufficient sample size.

The differences in stem form (form factor) between treatments were not statistically significant (i.e. $P < 0.05$), even after separating the timing effect from the thinning intensity. Contrary to this, Adegbeihn (1982) reports slight increases (0.39–0.41) in the stem form factor with increasing stand density on a spacing trial for teak in Nigeria. In conifer species, such as Jack Pine (*Pinus banksiana*), the stem form factor has been reported to increase with decreasing stand density (Morris et al 1994).

Intensive thinnings had a positive effect on the stem form, inducing the development of trees with desired proportions of DBH and total height. Trees under high competition in the Control and light thinning treatments will hardly reach the desired DBH/total height ratio of 1:1. Adegbeihn (1982) found the DBH/Total height ratio to increase with decreasing stand density in a study on density management of teak. In this study, all treatments presented ratios greater than 1.0, suggesting a general good stem form despite the stand density variations (748–2660 trees ha^{-1}).

Wood basic density was found to be higher at high stand densities (light thinnings). Nevertheless, only one treatment ("25% 4th") showed statistically significant differences from the other treatments ($P < 0.05$). Variations within treatments negatively affected the relationship between wood basic density and stand density. Similar results were found by Pérez Cordero and Kanninen (2003) when studying teak plantations in different regions of Costa Rica, where wood basic density varied between 0.50 and 0.65 $g\,cm^{-3}$ at 8 years of age.

As wood basic density is an important indicator of wood quality and strength, present results from a trial carried out in a humid tropical site of Costa Rica offer a scope for developing high intensity thinning programs elsewhere by implementing similar management guidelines and evaluation tools under different stand conditions. In other tropical plantation species, wood basic density has been reported to decrease with increasing thinning intensity. Malende and Ringo (1987) concluded that different thinning schedules are unlikely to reduce wood density in *Cupressus lusitanica* grown in Northern Tanzania. Tewari (1999) mentions several studies on teak in India where wood specific gravity did not vary at different DBH growth rates and stand densities.

Moya et al. (2003) report an increase in wood basic density (from 0.38 to 0.69 $g cm^{-3}$) with increasing age of cambium for 10-year-old teak grown in Guanacaste, Costa Rica. Differences in stand densities had no permanent effect on wood density, as significant differences found at cambium ages of 6, 7, and 8 years disappeared at 10 years. According to studies carried out on 27-year-old teak plantations in India, wood density increases from pith to bark but decreases near the bark (Tewari 1999).

Present results were not determining for the development of a density management diagram towards significant gains on wood properties of teak plantations in the northwest Atlantic region of Costa Rica. As significant variations in wood properties were found under different thinning regimes, it is suspected that the teak stands on this region can be managed under different thinning programs at early stages without negatively affecting the quality of wood.

Trees with the highest heartwood proportions (%) presented the highest heartwood volumes (m^3 per tree) but no correlation with thinning treatments was evident, suggesting that the size and dominance of the tree rather than the thinning regime of the plot determines the heartwood content. At stand level, the highest heartwood volume ($m^3 ha^{-1}$) was found on the light and on the heavy thinnings executed at 4 years of age. On the former, the stand density influenced a higher volume formation and consequently a higher heartwood content, while on the latter fewer trees but with larger size and higher heartwood contents yielded similar per hectare heartwood volumes. Based on these findings, intensive management systems for teak growing in a humid tropical site of Costa Rica can concentrate on maximizing either the individual tree or the stand total volume in order to maximize not only the heartwood percentage but also the absolute heartwood volume.

Teak wood quality is of considerable importance when classified according to international grading rules. The present study reports the preliminary results about the effect of thinning (intensity and timing) on certain wood properties for teak growing in a humid tropical site of Costa Rica. Heavy thinnings positively affected wood quality variables such as heartwood content, wood basic density, and stem form, however most results could not be strongly supported by statistical tests.

5 Conclusions

1) At young stages, teak plantations in a humid tropical site of Costa Rica show no clear relationship between stand density (and thinning regimes) and certain wood properties.
2) High variability on certain wood properties was observed. It is suspected that this is normal at young stages in teak plantations under similar growing conditions in a humid tropical site of Costa Rica.
3) Intensive thinnings have a positive effect on stem form even at young stages, producing trees with desired DBH/total height proportions.
4) Large variations at early stages in wood properties under different thinning regimes open a scope for managing teak stands in a humid tropical site of Costa Rica under different thinning programs without negatively affecting wood quality properties. The establishment and follow up of similar studies in different regions of Costa Rica are strongly recommended by the authors.

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