WOOD DENSITY AND FIBER LENGTH OF *EUCALYPTUS GRANDIS* GROWN IN KERALA, INDIA[1]

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ABSTRACT

Wood density and fiber length of *Eucalyptus grandis* were studied in trees of four age groups (3, 5, 7, and 9 years). The average basic density was 495 kg m^{-3} at 3 years and there was no significant increase from 3 to 9 years, whereas 5-year-old trees had a significantly lower value. Fiber length increased consistently with age and fibers of 3-year-old trees (mean 0.81 mm) were about 29% shorter than those of 9-year-old trees (1.15 mm). Density did not differ significantly between the locations, but fibers were longer in one location where trees had faster growth. Density declined from stump level to 25% of tree height and then gradually increased towards the top in a curvilinear manner, whereas fiber length commonly showed the reverse trend. In 5-, 7- and 9-year-old trees, average tree density could be predicted with reasonable accuracy using breast height density, but stump level density was a better predictor of average tree density in 3-year-old trees.

Keywords: Wood density, fiber length, within-tree variation, age effect, *Eucalyptus.*

INTRODUCTION

Eucalyptus grandis is widely planted in the tropics under intensive short rotation management. To meet the growing raw material demands of the pulp and paper industry, there is continuous pressure to reduce the harvesting age from the currently accepted age of 8–9 years. This calls for an immediate scrutiny of wood properties of younger trees. In their preliminary study of *E. grandis,* Bamber and Humphreys (1963) found that the fiber length of wood laid down in the fifth year was similar to that of adult wood while basic density was much lower. In contrast to the marked effect of age on density reported by Ferreira (1972) from Brazil in older trees (11–16 years), Ladrach (1986) concluded that wood density did not vary with age from 4 to 7 years in Colombia-grown *E. grandis.*

We report in this paper data on basic density and fiber length of *E. grandis* of four ages (3, 5, 7, and 9 years) grown in Kerala.

MATERIALS AND METHODS

Wood samples were collected from three upland locations (altitudinal range of 900–1,100 m) where *Eucalyptus grandis* plantations were established in large scale in Kerala. Twenty-five trees were randomly selected from each age group (3, 5, 7, and 9 years) in one of the three locations, viz. Munnar (location 1). The adequacy of sample size was determined using the formula given by Rastagi (1983). The preliminary analysis showed that 20–21 trees per plantation would be adequate

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TABLE 1. *Density and fiber length values of* E. grandis *at four ages in location 1.*

Age (yr)	Density (kg m^{-3})			Fiber length (mm)		
	Average	Range	cv%	Average	Range	cv%
3	494.5	433–547	6.6	0.812	0.789–0.835	2.4
5	419.6	358–503	8.3	0.995	0.984–1.017	1.9
7	484.5	420–561	8.5	1.086	1.049–1.114	2.2
9	496.7	429–620	8.9	1.147	1.106–1.221	3.8
Test of significance among age groups		$5\ \overline{7\ 3\ 9}$			$\bar{3}\ \bar{5}\ \bar{7}\ \bar{9}$	

Note: Age groups under single bar not significantly different at 1% level.

to estimate wood density and 5 trees for fiber length, with an allowable error of 5% as indicated by Hans et al. (1972).

Cross-sectional disks 3 cm thick were removed from the stump (15 cm from ground level), and 25%, 50%, and 75% of the tree heights, in addition to the one at breast height. Unextracted basic density (o.d. weight to green volume basis) was determined using radial wedges in the northern cardinal direction of the standing tree. The average tree density was calculated using the weighted volume of the wood samples represented in the tree. For fiber length measurements, small segments (slivers), having radial and tangential dimensions of 2 and 5 mm, respectively, were removed from three positions of the wedges in a radial line, representing the portions 2 mm from the pith, 2 mm from the bark, and midpoint between pith and bark. Fibers were macerated by Franklin's method (1945). The lengths of a minimum of 25 randomly selected fibers per segment were measured after ascertaining the number of fibers required per sample by Stein's procedure (1945). The average fiber length of the disk was calculated by weighting the individual segment fiber lengths with radial distance of the sample from the pith.

In addition, 3- and 5-year-old plantations in Vandiperiyar (location 2) and a 9-year-old plantation in Sultan's Battery (location 3) were also sampled to estimate the between-location differences at breast height, following the procedure adopted in location 1. The seed source of all plantations of the three locations was the seed production area at Coimbatore, South India.

Statistical treatment

Analysis of variance (ANOVA) was carried out to identify the sources of variation in density and fiber length. The method of analysis used for density was two-way, with multiple observations per cell. For fiber length, a split-plot design (Gomez and Gomez 1984) was used, where disks form main plot treatments and segments form sub-plot treatments, repeated over four age groups. Fixed effects were attributed to ages, disks, segments, and their interactions. The clustering method of simultaneous testing (Calinski and Corster 1985) was done to clarify the differences among age groups. Simple regression was used to compare the predictive capacity of breast height and stump level density for average tree values, while a quadratic regression model, with height level (percentage of total tree height) as independent variable, was found suitable for explaining longitudinal variation in the stem. Simple correlation coefficients were computed to examine the relationships of average wood properties with tree size in each age class of location 1.

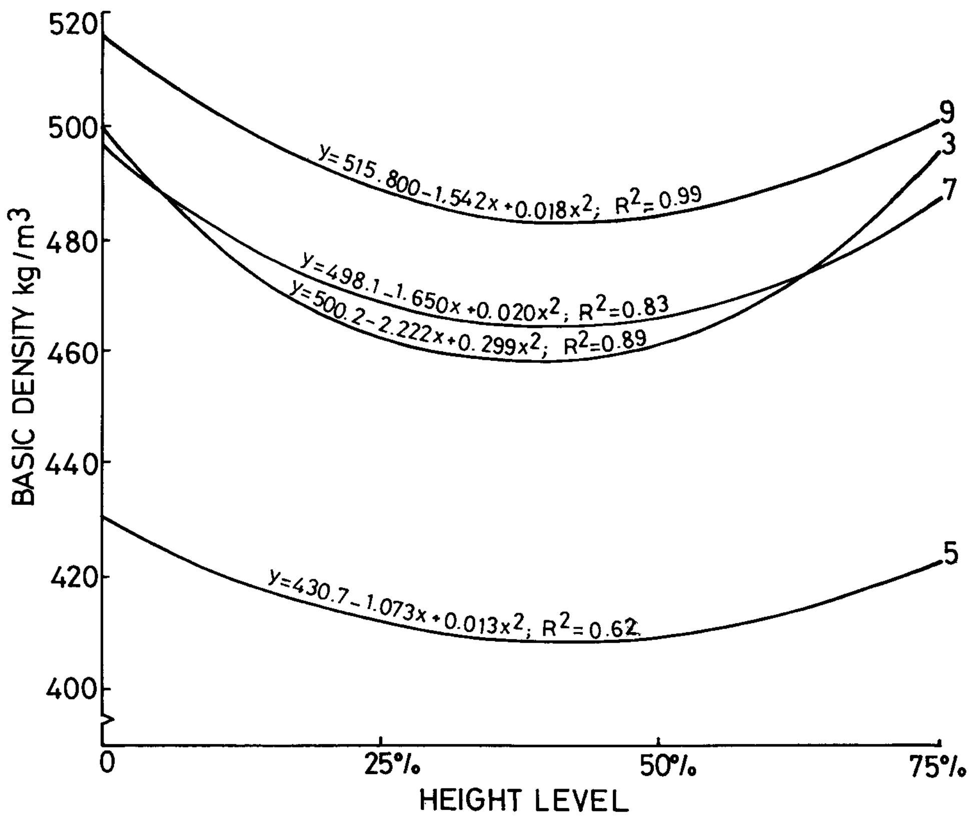

FIG. 1. Variation in average basic density as a function of percent of total tree height (height level) at four ages (number denotes years) in location 1.

RESULTS AND DISCUSSION

Between the ages of 3 and 9 years the average height increased from 4.9 to 23.9 m and dbh from 6.5 to 21.2 cm. Tree size varied considerably from location to location. Three- and 5-year-old trees in location 2 showed very good growth performance with a marked increase in height and diameter as compared to those grown in location 1. Similarly, height growth of 9-year-old trees in location 3 was significantly greater than that of similar age in location 1.

Within-tree and age-related variation: basic density

The average density value varied from 420 to 497 kg m^{-3} among the four age groups (Table 1). Density was lowest in 5-year-old trees and highest in 9-year-old trees. No significant differences existed among the age groups of 3, 7, and 9 years, and only 5-year-old trees had significantly lower wood density (Table 1).

The probable explanations for the relatively low density of 5-year-old wood are: (a) definite pattern of age-related density variation; with distance from the pith in *E. grandis* it is common for the density curve to decrease initially before the gradual rise towards the bark (Bamber and Humphreys 1963; Taylor 1973a), and (b) age-environment-genotype related variation. Nevertheless, the density

TABLE 2. *Comparison of predictive equations for average tree density (kg m⁻³) using density at breast height (bh) and stump level (n = 25).*

Age group (yr)	Sample position	Regression equation	r^2(%)	Sy.x
3	Stump level	Y = 134.0 + 0.736X	73.1	16.4
	bh level	Y = 186.1 + 0.680X	48.3	23.9
5	Stump level	Y = 28.3 + 0.902X	87.6	12.5
	bh level	Y = 117.3 + 0.750X	90.1	11.3
7	Stump level	Y = 108.7 + 0.750X	59.2	27.0
	bh level	Y = 154.0 + 0.716X	69.1	22.0
9	Stump level	Y = 78.4 + 0.813X	69.0	24.2
	bh level	Y = 119.1 + 0.777X	79.5	19.6

value at 5 years is in agreement with the finding of Bamber and Humphreys (1963) in 5-year-old wood of different seed sources. The average density of 495 kg m^{-3} observed in 3-year-old wood is also closer to that of 3-year-old progenies of plus trees selected in Brazil (Mendes et al. 1980), which is greater than the density of not only 1.4-year-old plants of a half-sib progeny test done in Florida (Wang et al. 1984), but also of older trees belonging to the age groups ranging from 15 to 20 years grown in South Africa (Taylor 1973b).

Both age and relative position of the stem were important sources of variation in density. Along the stem, density declined initially from stump level to 25% of tree height and then gradually increased towards the top. Based on the average values at four height levels, the longitudinal variation could be explained using quadratic regression models as R^2 values ranged from 62% (in 5-year-old trees) to 99% in 9-year-old trees (Fig. 1). This pattern of longitudinal variation supports the observation (Bamber et al. 1969) that in 1- and 5-year-old wood, density is lowest somewhere between breast height and 50% of tree height.

The predictive equations derived, using density at stump or breast height level as an independent variable, for average tree density are presented in Table 2. In 3-year-old trees, stump disk density was found to be the better predictor, and the deviation from the predicted value was only about 16 kg m^{-3}. In 5-, 7- and 9-year-

TABLE 3. *Analysis of variance of fiber length of* E. grandis *trees of four age groups grown in location 1.*

Source of variation	d.f.	m.s.s.	*F*
Age	3	8,372,371	932.1**
Error (1)	16	8,982	
Disk	3	39,604	15.8**
Disk × age	9	3,424	1.4 ns
Error (2)	48	2,502	
Segment	2	1,849,217	1,519.5**
Disk × segment	6	5,956	4.9**
Age × segment	6	63,815	52.4**
Disk × age × segment	18	2,169	1.8*
Error (3)	128	1,217	
Total	239		

** Significant at 1% level; * significant at 5% level; ns, not significant.

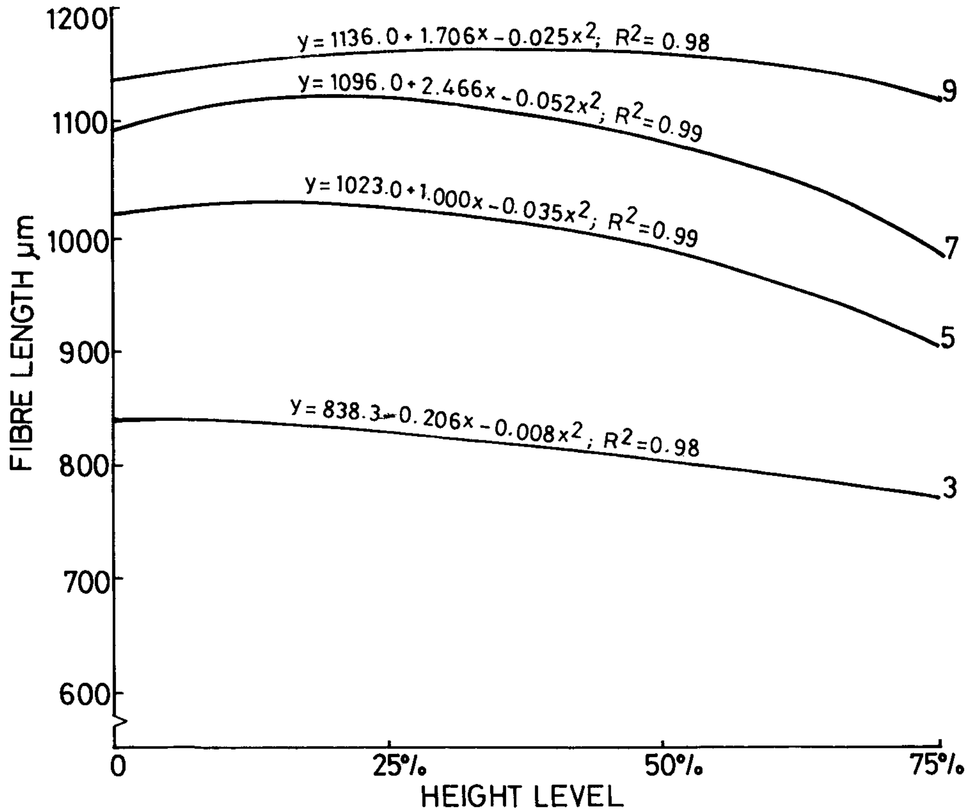

FIG. 2. Variation in average fiber length as a function of total tree height (height level) at four ages in location 1.

old trees, the average tree density could be predicted more accurately by breast height density, with the standard deviation being in the range of 11–24 kg m^{-3}.

Fiber length

Average fiber length increased by 42% from 0.81 mm at 3 years to 1.15 mm at 9 years (Table 1). Age was a very important source of variation (Table 3) and each age group was significantly different from the other. However, the rate of increase in fiber length with age declined from 18.4% (3 to 5 years) through 8.4% (5 to 7 years) to 5.3% (7 to 9 years). This supports Ranatunga's observation (1964) that fiber length reaches a constant value somewhere near the age of 8–9 years in *E. grandis.* This probably accounts for the fact that fiber length in older trees (15–20 years) and adult wood (Bamber and Humphreys 1963; Taylor 1973b) is not considerably greater than in young trees.

Within-tree (both disk-to-disk and segment-to-segment) variation was significant (Table 3). Longitudinally, fiber length showed a small increase from stump level to 25% of tree height level and then decreased towards the top. The quadratic regression models, on the basis of average values, explained 98%–99% of the variation (Fig. 2). This longitudinal pattern of variation supports the observation

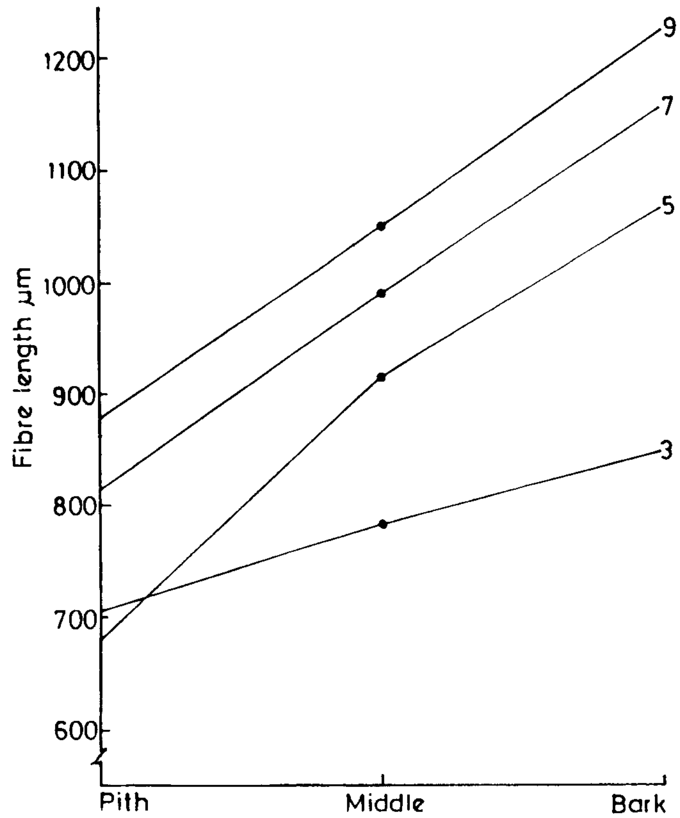

FIG. 3. Average fiber length in relation to three radial positions of the trees at four ages (height levels combined) in location 1.

made by Bamber et al. (1969) that in 1- to 5-year-old wood the longest fibers occur below 50% of tree height. Radial variation (between-segment) was highly significant as fiber length increased considerably from the pith to the bark (Fig. 3). Interaction terms such as disk × segment, age × segment, and disk × age × segment were also important determinants of fiber length (Table 3). These results contrast with those of Brasil and Ferreira (1979) who did not detect significant radial variation in fiber length at breast height level in 3-year-old trees. Fiber length at the stump and breast height levels was of little value in the estimation of average tree fiber length (r^2 = 9% to 64%).

Between-tree variation

Neither density nor fiber length (Table 3) showed significant between-tree variation in each of four age groups. The density variation coefficient was only in the range of 7% to 9%. These findings deviate from the general view that in eucalypts density and fiber length variations between the trees can exceed 50 and 25%, respectively (Wilkes 1988). Whether this is due to the difference in sampling technique or genotypic uniformity of the seed source is not clear since in the present study only four disks per tree were sampled.

TABLE 4. *Comparison on mean values of* E. grandis *properties (at breast height level) in selected age groups between two locations.*

Property	Age group (yr)	Location 1	Location 2	Location 3	Test of significance
Density	3	456.8	418.8		ns
kg m^{-3}	5	402.9	398.0		ns
	9	488.0		457.4	ns
Fiber length	3	0.833	1.043		**
mm	5	1.031	1.116		*
	9	1.160		1.104	ns

** Significant at 1% level; * significant at 5% level; ns, not significant.

Between-location difference

The comparison of breast height density among the locations revealed that no statistically significant difference existed between the locations despite the marked growth differences among the three locations (Table 4). This suggests that no practical difference may exist in wood density among different upland locations within the geographic limits of Kerala. Fibers at the breast height level of 3- and 5-year-old trees in location 2, where trees had faster growth, were significantly longer than those of similar ages grown in location 1 (Table 4). This supports the finding of Taylor (1973b) that rapidly elongating stems had longer fibers in South Africa-grown *E. grandis.* However, there was no appreciable difference in the fiber length of 9-year-old trees between location 1 and location 3.

Correlations between wood properties and tree vigour

Wood density was not consistently related either to tree height or diameter, although at 9 years there were weak positive correlations (Table 5). This supports the observation that faster growth in general does not necessarily affect the wood density in young trees of *E. grandis* (Bamber et al. 1982). Similarly, fiber length had no consistent relationship with tree height or diameter although there was a significant negative correlation with dbh in 9-year-old trees (Table 5).

Implications of results

It was found that *E. grandis* trees attain the minimum wood density requirements of the pulp industry (Ikemori et al. 1986) at the age of 3 years, and then there is no significant increase with age from 3 to 9 years. The results imply that pulp yield per unit volume of wood from 3-year-old trees is not necessarily low

TABLE 5. *Correlation coefficients for the relationships of wood properties with tree height and dbh at four age groups in location 1.*

Correlating variables	3-year	5-year	7-year	9-year
Height vs. dbh	0.90**	0.83**	0.69**	0.63**
Height vs. density	0.05 ns	0.07 ns	0.32 ns	0.43*
Height vs. fiber length	0.42 ns	−0.10 ns	−0.61 ns	0.07 ns
dbh vs. density	0.02 ns	−0.13 ns	0.39 ns	0.48*
dbh vs. fiber length	0.31 ns	−0.33 ns	−0.39 ns	−0.76*

** Significant at 1% level; * significant at 5% level; ns, not significant.

compared to 5-, 7- and 9-year-old trees. Fiber length, however, increases with age, although the rate of increase declines even before 7 or 9 years. Thus, there exists opportunity for reducing the rotation age in pulpwood plantations of *E. grandis* below 9 years.

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