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EFFECT OF AGE AND LOCATION ON PULPWOOD QUALITY OF EUCALYPTUS GRANDIS

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ABSTRACT

Eucalyptus grandis is one of the most promising pulpwood species in Kerala that merits attention under the intensive short rotation management. The present study evaluates the wood quality differences of *E. grandis* among four age grcups (3, 5, 7 and 9 years) and three locations in the state. The properties investigated are wood density, percentage of bark and heartwood, and fibre length.

Trees attain the minimum wood density requirement of pulp industry at the age of 3 years and there is no significant wood density increase with an increase in age from 3 years to 7 or 9 years. On the other hand, 5-year-old trees produce the wood of lower density. This pattern of wood density variation with age indicates that there is no significant loss in pulp yield per unit volume of wood if 3-year-old wood is pulped as against 5-,7- or 9-year-old wood. Fibre length and heartwood percentage increase and bark percentage decreases with age from 3 to 9 years. Within each age group, tree growth parameters like height and diameter (DBH) have no marked effects on wood density, fibre length and heartwood percentage. Bark percentage is, however, negatively correlated with tree growth. These results suggest that silvicultural practices aiming at faster growth (higher yield) will not adversely affect the wood quality.

There is no appreciable wood property difference among the three locations of *E.grandis* growing areas in the state (Vandiperiyar, Munnar and Wynad), although fibre length and heartwood percentage are slightly greater in more rapidly grown 3-and 5-year-old trees in Vandiperiyar.

Analysis of variance reveals that both wood density and fibre length variations are significant within the trees but not between the trees. Along the stem, density declines initially from stump to BH level and then gradually increases towards the top while a somewhat reverse trend is noticed in fibre length. Fibre length increases considerably from pith to bark in all the age groups. Average tree density can fairly be predicted using BH density in 5, 7- and 9-year-old trees while stump density is a better predictor in 3-year-old trees.

Tree-to-tree variation is small in fibre length and wood density, modest in bark percentage and large in heartwood percentage as well as tree height and diameter in each of four age groups.

Key words: *Eucalyptus grandis,* rotation age, location and growth effects, wood density, bark content, heartwood percentage, fibre length.

1. INTRODUCTION

Over the past two and a half decades, eucalypts have been extensively planted in Kerala to meet the raw material demands of pulp and paper industries. The estimated annual requirement of eucalypt wood for the three pulping units is about 330,000 tonnes while the annual supply is in the order of 265,000 tonnes (Karunakaran 1982). The eucalypt plantations in Kerala todate account for about 40,000 ha, two main species being *Eucalyptus grandis* and E. *tereticornis*. The former is well suited for higher altitudes in the state while the latter grows better in low elevations. From the viewpoint of pulp-wood quality, *E. grandis* is superior to *E. tereticornis* (Bhat 1986). It has also been suggested that wherever *E. grandis* can be grown it is to be preferred to almost any other *Eucalyptus* species (Pryor 1970). In other tropical countries like Brazil, this species has been found to be one of the most economical timber crops and many profitable industries have been established because of large scale plantations (Kauman 1983). Zobel *et al* (1983) claim that the new plantations raised from selected trees propagated by rooted cuttings in Brazil now yield 70 m^3/ha/year at the age of 5.5 years. In some of the 18-year-old experimental plantations of *E. grandis* in Kerala, an annual increment of 20-28 m^3/ha has been reported (Anon 1982). There are also records of high yield as much as about 204 tonnes per ha with the average of 100 tonnes per ha in 8 years rotation cycle (Basha 1986). Apparently, *E. grandis* attracts the attention of both silviculturists and industrialists in obtaining the maximum yield of wood in each hectare of land under the intensive short rotation management.

Among the several intensive management practices, changing rotation age is one effective silvicultural tool to manipulate the quantity and quality of wood. One important consideration in fixing the rotation is the raw material suitability for different grades of pulp depending on the quality requirements of pulp and paper to be produced (FAO 1970).

An understanding of variations in wood properties with age is essential not only to determine the appropriate age of optimum wood properties desired by the industry but also to predict the effects of reducing rotation on wood quality. The main objectives of the present study are:

(a) to determine the age effects on wood properties such as wood density, fibre length, bark content and heartwood percentage by selecting the trees at the age of 3, 5, 7, and 9 years and

(b) to estimate the differences in the above wood properties among three locations in Kerala.

2. REVIEW OF LITERATURE

A general review of literature pertaining to the influence of wood properties. on pulp and paper making qualities has been made earlier by Bhat *et al* (1985). However, a breif review is desirable to examine more specifically the pulpwood quality of eucalypts, particularly *E. grandis.*

Numerous investigators agree with the view that wood density or specific gravity is one of the most useful parameters of measuring wood quality within the species (Zobel and Talbert 1984). It can also be used as a predictor of yield and quality of pulp and paper products (Dadswell and Wardrop 1959; Barefoot *et al* 1970). Any alteration in eucalypt wood density is, therefore, of great importance as it influences fibre properties and mechanical pulp qualities and consequently newsprint production (FAO 1970). Wood density determination is also of interest to the forester in preparing dry weight tables for prediction of productivity per unit land area (Zobel and Talbert 1984).

Wood density of *E. grandis* is known to be highly variable. It varies not only within and between the trees but also among the plots studied in South Africa and Zambia (Hans *et al* 1972; Taylor 1973a, 1973b; Hans 1976). On the contrary, no significant wood density difference is reported between two sites in Brazil (Brasil *et al* 1979) while two more Brazilian studies, indicate the between -provenance variations (Vital and Lucia 1980; Mendes *et al* 1980). Bamber and Humphreys (1963) show that seed source has significant effect on wood density,

Fibre length plays a significant role in paper making as it influences paper strength especially when short-fibred eucalypts are used as raw material (FAO 1970). Lower tear strength of paper made from *E. grandis* is attributed to shorter fibres as compared to bamboo fibres (FAO 1970). Duploy (1980) reports that besides density, fibre length/diameter ratio and fibre wall thickness/fibre diameter ratio are also important, as observed in S. Africa grown *E. grandis,* in the determination of pulp strength and surface properties. Brito et al (1978) state that determination of the percentage of eucalypt bark is important since inclusion of bark in whole tree chips is becoming common to increase the fibre content of the raw material.

No adequate information is available regarding the effect of age on eucalypt pulpwood quality, Some preliminary studies conducted in India are based on *E. tereticornis* (Guha *et al* 1970; Misra *et al* 1976; Unkalkar *et al* 1977; Bhat and Bhat 1984). In Brazil-grown *E. grandis,* wide variation of wood density is reported at different ages like 11, 12, 13, 14 and 16 years (Ferreira 1972). On the other hand, Ladrach (1986) finds no variation of density with age from 4 to 7 years in Colombia. Regarding the influence of growth rate, literature reveals different findings. According to Bamber *et al* (1982), wood density and fibre length of *E. grandis* are independent of growth rate while a couple of studies show that rapid growth results in longer fibres (Higgs 1969; Taylor 1973b).

3. MATERIALS AND METHODS

E. grandis plantations in Munnar and Wynad are fairly good in growth performance (Karunakaran 1982). To study the age effect, plantations of the different ages (3, 5, 7, and 9 years) were located in Devicolam Range, Munnar Division. For age classes of 3 and 5 years, trees were sampled from 1981 · plantation at Kottiyar and for those of 7 and 9 years, 1977 plantation at Papathishola .and I976 plantation at Shenkulam respectively. Twenty five trees were selected randomly from each age group. Adequacy of the sample size per plantation 'was ascertained using the following formula given by Rastagi (1983).

$$n = K\alpha + \frac{Z^2 S^2}{E^2}$$

Where n = calculated sample size,

E = allowable error,

S = estimation of population standard deviation,

Z = modified t value ,

$K\alpha$ = table value at $(1-\alpha)$ confidence level.

This preliminary analysis showed that 20-21 trees would be adequate per plantation to estimate wood basic density with an allowable error of 5%.

About 10 cm thick transverse discs were removed at stump and BH levels as well as 50 and 75% of tree heights represeting 4 different height levels of an individual tree. Each disc was transversely cut into two halves. 'One half was used for estimation of bark and heartwood percentage following the procedure given in an earlier report (Bhat *et al* 1985). The other half was used for the determination of wood basic density and fibre length. The methods used to measure these properties were essentially similar to those described in the earlier study (Bhat *et al* 1985) except that wood density of the disc was determined using radial wedges. Weightage was however given to calculate the average disc and tree densities using the volume of wood these samples represented in disc and trees respectively.

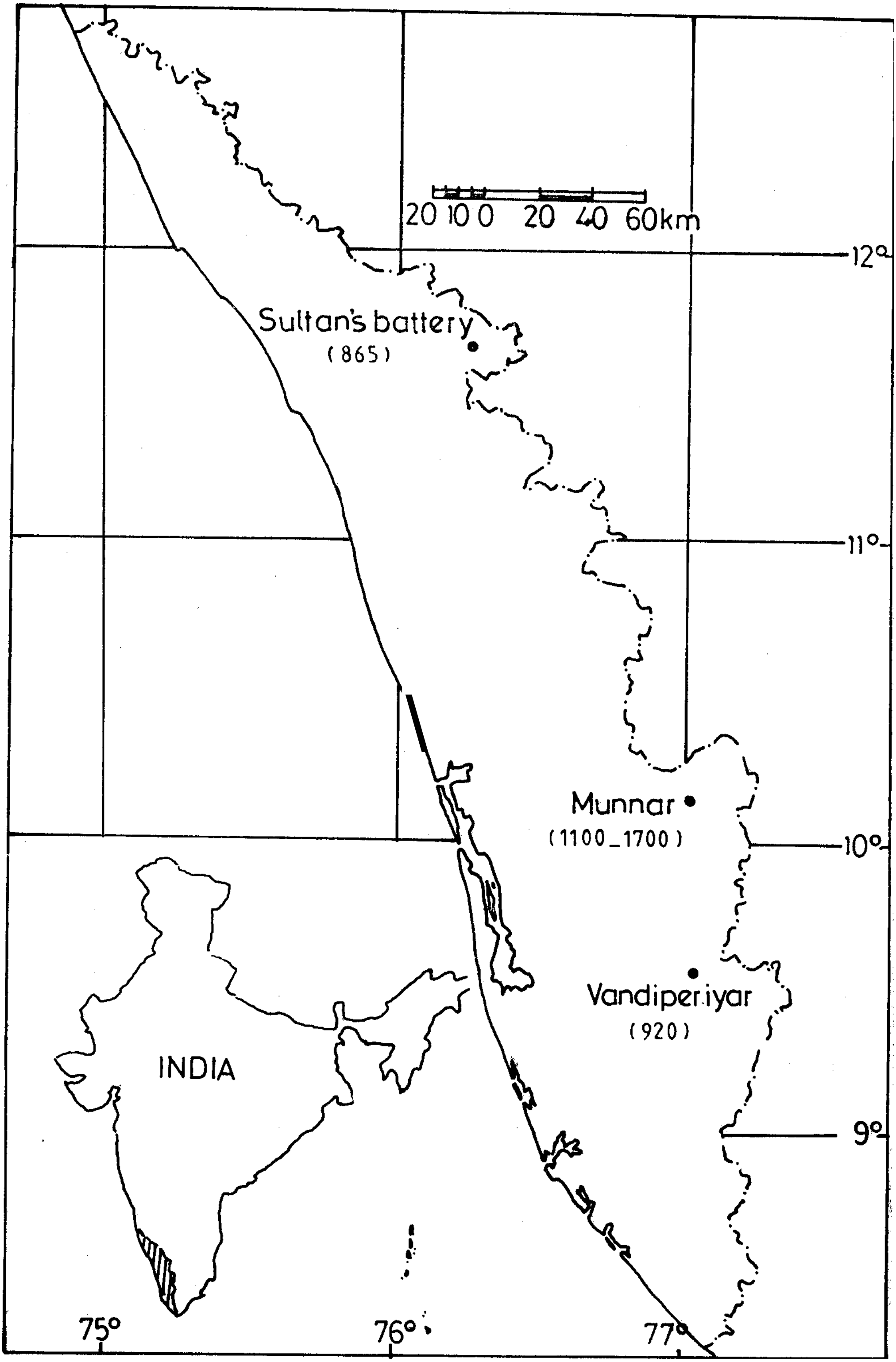

Fig. 1. Sampling locations of *E. grandis* plantations in Kerala with their respective altitudes (m)

For fibre length measurement, about 2 mm thick slivers (segments) were removed from three positions of the wedges in such a way that they represent the wood near to pith, near to bark and intermediate between pith and bark. Fibres were macerated and length measurements were made in accordance with the. procedure given earlier (Bhat *et al* 1985). Twentyfive randomly selected fibres per segment were measued after noting the number of fibres required per segment using Rastagi's method (1983). Number of trees required for the estimation of site means of fibre length was five as recommended by Hans *et al* (1972). This necessitated the measurement of 1500 fibres for each age group. Weighted average vaiue was obtained to consider average disc and tree fibre lengths as mentioned elsewhere (Bhat *et aI* 1985).

In order to study the location effects on wood properties, 3-and 5-year-old plantations at Munnar and Vandiperiyar (Wallardie Estate) as well as 9-year-old plantations at Munnar and Wynad (Mavinhalla) were utilised for sampling (Fig. 1). All the sample plantations had the espacement of 2 x 2 m except that 9-year-old plantation at Wynad, where espacement was 3x3 m. Sample discs were removed at BH level for wood property comparison. The method of measurement of properties is similar to that mentioned above.

3.1 Limitation of sampling

An ideal programme of wood quality assessment should have wide-spread plantation trials in order to cover the variations due to diverse environmental factors. But, at least in the near future, it may not be possible to obtain sample material of different age groups in more than one location in Kerala. Although the original plao was to select different age groups from multi-location trials, non-availability of plantations of desired age classes necessitated to confine to one location (Munnar) to study the age effect on wood properties. Nevertheless, an initial assessment with extrapolated results could provide enough information, atleast for that area where *E. grandis* has been extensively grown, until better meterial becomes available. It is with this view that the present study has been initiated in this line

3.2 Statistical methods

To examine the effects of age, individual tree, positions (discs) within the tree and their interactions on wood properties, analyses of variances (ANOVA) were carried out using both split-plot and split-split-plot designs. Within-stem variation in density and fibre length was explained using parabolic curves obtained from quadratic regression models. Simple correlation and regression analyses were performed to examine the interrelationships of certain parameters.

4. RESULTS AND DISCUSSION

4.1 Tree Size

Mean values of tree height and DBH with their standard deviation are presented in Table 1. There is a marked increase in tree size from 3-to- 9-year-old trees. The coefficients of variation show that tree-to-tree variation is greater in diameter than in height. However, there is highly significant positive correlation between height and diameter, although the relationship weakens with the increase in age from 3 to 9 years (Table 1).

Table 1. Mean height and diameter of sample trees ($\bar{x}$=mean, SD=standard deviation, CV= coefficient of variation, r=coefficient of correlation between height and DBH)

Age (yr)	Tree height (m)			DBH (cm)			
	$\bar{x}$	SD	cv%	$\bar{x}$	SD	cv%	r
3	4.9	1.0	21.6	6.5	1.5	24.3	0.903**
5	9.8	1.6	16.6	11.2	3.0	27.4	0.832**
7	12.3	2.3	18.7	14.1	3.2	23.1	0.690**
9	23.9	3.0	12.9	21.2	3.9	18.8	0.638**

** Significant at 1% level

Tree size varies considerably from location to location. The performance of 3-and 5-year-old-trees in Wallardie Estate at Vandiperiyar, with marked increase in height and diameter, is good as compared to the 3-and 5-year-old trees at Munnar (Table 2). Similarly height growth of 9 year-old trees in Wynad is significantly greater than that of the 9-year-old trees of Munnar plantation. As the seed source of these plantations is not precisely known, the exact role of genetic and environmental factors ,in growth differences cannot be assessed in this study.

Table 2. Comparison of mean tree *size* among three locations in Kerala

Age (yr)	Growth parameter	Location			Significanc of t-test
		Vandiperiyar	Munnar	Wynad	
3	Height (m)	15.6	4.9	—	**
	Diameter (cm)	13.0	6.5	—	**
5	Height (m)	23.3	9.8		**
	Diameter (cm)	15.5	11.2	—	**
9	Height (m)	—	23.9	29.0	**
	Diameter (cm)	—	21.2	22.6	ns

** Significant at level

ns Not significant

4.2 Wood density

Five-year-old trees have lowest and 9 -year-old trees have highest wood density values (Table 3). The analysis of variance reveals that there is significant variation in wood density among the age groups (Table 4). However the clustering method of testing (Calinski and Corster 1985) confirms that no significant difference exists among the age groups of 3,7 and 9 years and only 5-year-old trees have significantly low wood density (Table 3).

Table 3. Wood density values for ***E. grandis*** at different ages

Age (yr)	Average (kg/m^3)	cv%	Range (kg/m^3)
3	494.5	6.6	433–547
5	419.6	8.3	358–503
7	484.5	8.5	420–561
9	496.7	8.7	429–620

Test of significance (Bar diagram)	5 Years	7 years	3 years	9 years

(In the bar diagram a bar is drawn over 7 years, 3 years and 9 years.)

Note : Ages under bar not significantly different

In each of four age groups studied there is no significant tree-to-tree variation as the F-ratio is not significant (Table 4). The cv value for between -tree variation is quite small as it ranges from 6.6 to 8.7 (Table 3). Similarly Purkayastha *et al* (1979) report small cv values for between-tree variation among 8-9-year old trees of *E. tereticornis* grown in different parts of India.

Table 4. Analysis of variance of wood density (split-plot design)

Source of variation	df	MSS	F
Age	3	88428.9	15.9**
Tree	18	7140.8	1.3ns
Error[1]	54	5576.2	–
Disc	3	18669.5	29.2**
Disc x age	9	776.7	1.2ns
Error[2]	216	638.8	–
Total	303		

** Significant at 1% level
Not significant

Along the stem, density declines initially from the bottom to BH level and then gradually increases towards the crown in all the four age classes. This within-tree (between-disc) variation is considerable since the F-value for between -disc variation is found significant (Table 4). Based on the average values at 4 height levels, the variation pattern could be adequately explained using quadratic regression models, where R^2 value ranges from 62% (in 5-year- old trees) to 99% in 9-year-old trees (Fig 2).

The average tree density can fairly be predicted by measuring the density at BH. Using stump level or BH density as an independent variable the derived predictive equations are presented in Table 5. It may be seen that in 3-year -old trees stump disc with higher r^2 values is a better predictor than BH sample disc and the deviation from the predicted value is only about 16 kg/m^3. Whereas in 5-,7-and' 9-year old trees, BH sample is more useful to predict the average tree density with the standard deviation range of 11-24 kg/m^3 (Table 5).

Table 5. Predictive equations for the average tree density (kg/m^3) using the density at breast height (BH) and stump level

Age (yr)	Sample location	Regression equation	r^2%	sy.x
3	Stump level	y= 134.016+ 0.730x	73.1	16.4
	BH ,,	y = 186.117+ 0.680x	48.3	23.9
5	Stump level	y = 28.318+0.902x	87.6	12.5
	BH ,,	y= 117.297+0.750x	90.1	11.3
7	Stump level	y=108.713+0.750x	59.2	27.0
	BH ,,	y = 154.0+0.716x	69.1	22.0
9	stump level	y= 78.428+0.813x	69.0	24.2
	BH ,,	y 119.050+0.777x	79.5	19.6

Tree size (height, DBH or volume) has little influence on wood density as tree growth parameters are not consistently correlated with the latter. However, at the age of 9 years, there is a weak positive correlation between tree size and density (Table 6).

Table 6. Correlation coefficients for the relationships of wood density with tree growth parameters

Age (yr)	Tree height	DBH	Tree volume
3	0.052ns	0.025ns	0.100ns
5	0.075ns	-0.133ns	-0.052ns
7	0.327ns	0.391ns	0.481*
9	0.433*	0.462*	0.520**

** Significant at 1% level
* 5% level
ns Not significant

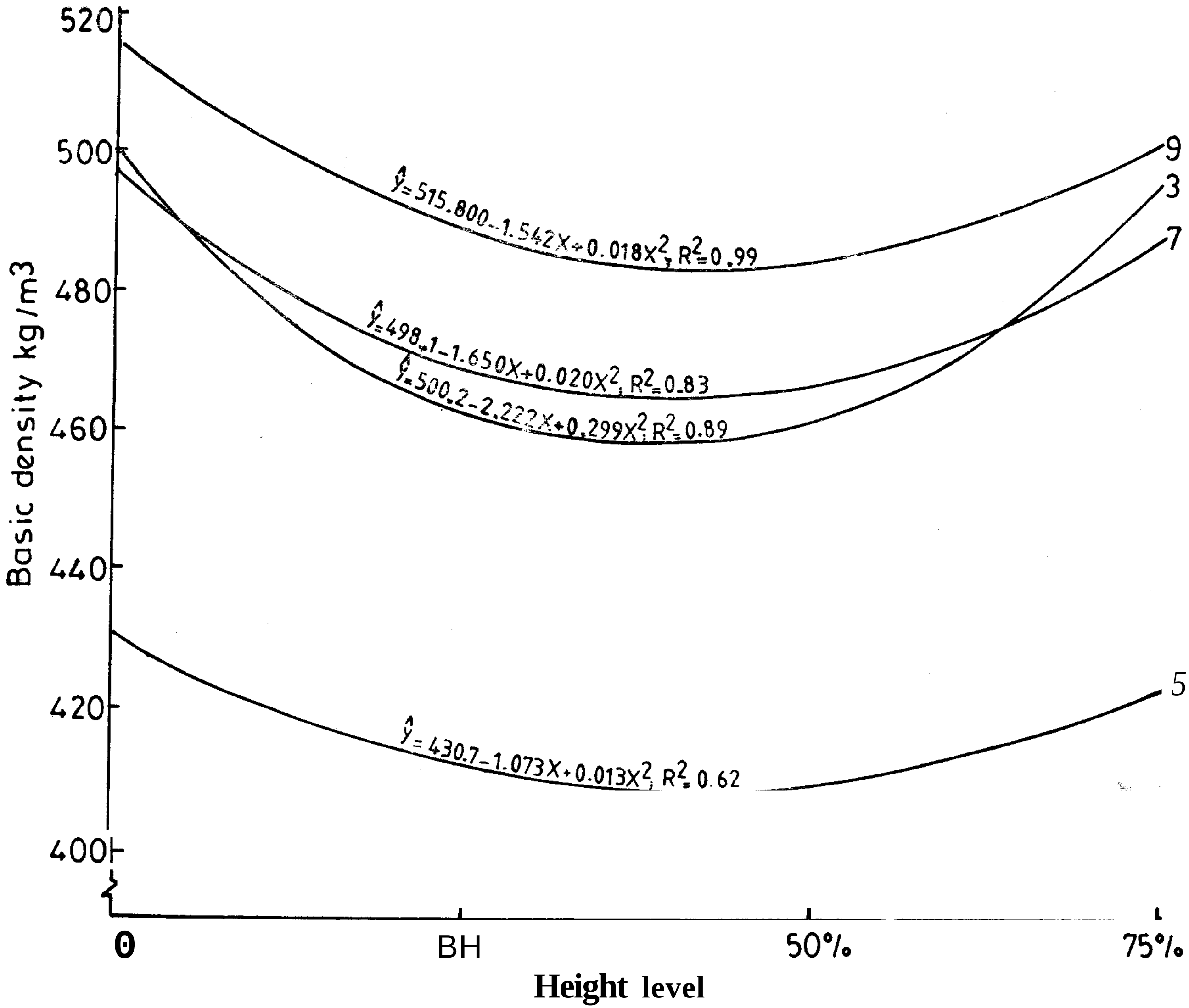

Fig. 2. Within-tree variation in wood density as a function of height level (stump and BH levels and 50 and 75% of tree heights) in 3-,5-,7-and 9-year-old trees.

Wood density values of 3-and 5-year-old trees, as measured at BH, grown in Vandiperiyar are slightly lower than the wood density values of those grown in Munnar (Table 7). Similarly 9-year-old trees grown in Wynad have lower mean value than that of the 9-years-old trees grown in Munnar. However, these wood density differences between locations are not statistically significant despite the differences in growth factors. This indicates that no appreciable difference could exist in wood density of trees grown in different locations in Kerala.

Table 7. Comparison of BH wood density at 3 locations ($\bar{x}$=mean, SD=standard deviation, cv=coefficient of variation)

Age (Yr)		Vandiperiyar	Munnar	Wynad	Significance of t-test
3	$\bar{x}$	418.8	456.8	—	ns
	cv%	14.0	7.2		
5	$\bar{x}$	398.0	402.9	—	ns
	cv%	5.6	10.9		
9	$\bar{x}$	—	488.0	457.4	ns
	cv%	—	10.0	9.1	

ns Not significant

4.3 Bark percentage

Age has a marked effect on bark percentage as the F-value is highly significant (Table 8). Bark percentage decreases consistently with the increase in age. 3-year-old trees have the average value of 19.5 as against 9.2 of 9-year-old trees (Table 9)., Analysis of variance reveals that both within-tree and between -tree variations in bark percentage are not significant (Table 8). No definite pattern of bark percentage variation could be established within the trees although a small increasing trend towards tree top is noticed.

Table 8. Analysis of variance of bark percentage (split-plot design)

Source of variation	df	MSS	F
Age	3	1310.390	57.119 **
Trees	17	17.851	0.778 ns
Error 1	51	22.941	—
Disc	3	79.809	0.274 ns
Age x Disc	9	46.784	0.160 ns
Error 2	204	290.852	—
Total	287		

** Significant at 1% level

ns Not significant

Table 9. Bark Percentage values of *E. grandis* at different ages

Age (yr)	Average	CV%	Range
3	19.5	16.1	13.8-25.3
5	14.6	13.0	11.3-20.0
7	12.9	15.1	10.0-15.9
9	9.2	15.6	6.7-12.0

There is a significant difference in bark content of 3-and 5-year-old trees between Vandiperiyar and Munnar locations (Table 10). However, no significant difference is noticed in 9-year-old trees between Munnar and Wynad plantations. The difference between Vandiperiyar and Munnar plantations is attributed to the marked differences in tree size as bark percentage is often negatively correlated with tree height and DBH (Table 11).

Table 10. Comparison of BH bark percentage at three locations

.Age (yr)		Vandiperiyar	Munnar	Wynad	t-test
3	$\bar{x}$	13.2	18.2	—	*
	cv%	40.9	20.0	—	
5	$\bar{x}$	10.4	15.1	—	*
	cv%	21.4	17.2	—	
9	$\bar{x}$	—	9.4	10.2	ns
	cv%	—	23.4	12.7	

* Significant at 5% level
ns Not significant

Table 11. Correlation coefficients for the relationships of bark percentage with tree growth parameters

Age (yr)	Tree height	DBH	Tree volume
3	-0.526**	-0.544**	-0.548**
5	-0.527**	-0.302ns	-0.344ns
7	-0.230ns	-0.587**	-0.495*
9	-0.269ns	-0.156ns	-0.209ns

* Significant at 5% level
** Significant at 1% level
ns Not significant

4.4 Heartwood percentage

Heartwood percentage increases with the increase of tree age, The average value for 3-year-old tree is 36.8 in contrast to the average value of 66.4 in 9-year-old trees (Table 12). It varies so much that many trees at the age of 3 years are either completely devoid of heartwood or often contain only at the basal portion. At the age of 5 and 7 years, heartwood is not distinct in most of the trees at 75% of the tree height while it is invariably found in all the sample trees at the age of 9 years in all the 4 height levels. Tree size within the age group, has no marked effect on heartwood percentage (Table 13) although in 3-and 5-year old trees the correlation between tree volume and heartwood percentage is slightly greater.

Table 12. Heartwood percentage of *E. grandis* at different ages

Age (yr)	Average Heartwood percentage	CV%	Range of Heartwood percentage
3	36.8	32.5	0-50.0
5	39.0	23.8	23–55.0
7	52.5	10.4	48–60.0
9	66.4	20.7	55–77.1

Table 13. Correlation coefficients for the relationships of heartwood percentage with tree growth parameters

Age (yr)	Tree height	DBH	Tree volume
3	0.636^{ns}	0.498^{ns}	0.646^{ns}
5	0.340^{ns}	0.329^{ns}	0.334^{ns}
7	0.238^{ns}	-0.036^{ns}	0.089^{ns}
9	-0.169^{ns}	-0.022^{ns}	-0.075^{ns}

ns Not significant

BH heartwood proportion is significantly greater in Vandiperiyar-grown trees than in Munnar-grown trees at the age of 3 and 5 years (Table 14) Similarly it is significantly higher in 9-year-old trees of Wynad than in the trees of Munnar at the same age. Since tree size within the age group has no influence on heartwood percentage, these between-location differences in heartwood are attributable to locality factors as indicated by Purkayastha *et al* (1979) for *E. tereticornis.*

Table 14. Comparison of heartwood percentage at BH between the three locations

Age (yr)		Location			t-test
		Vandiperiyar	Munnar	Wynad	
3	$\bar{X}$	45.5	36.8	—	**
	SD	13.6	11.9	—	
	CV%	30.0	32.5	—	
5	$\bar{X}$	59.8	39.0	—	**
	SD	2.6	10.6	—	
	CV%	4.4	27.5	—	
9	X	—	74.8	79.2	**
	SD	—	5.7	4.4	
	CV%	—	7.6	5.6	

** Significant at 1% level

4.5 Fibre length

The average fibre length increases from 0 812 mm to 1.147 mm with the increase of age from 3 to 9 years in Munnar area (Table 15). The fibre length variation with age is considerable as the F-value is highly significant (Table 16). The clustering method of testing (Calinski and Corster 1985) reveals that each one of the age groups is significantly different from the other.

Table 15. Fibre length values of *E. grandis* at different ages

Age (yr)	Average fibre length (mm)	CV%	Range (mm)
3	0.812	2.4	0.789—0.835
5	0.995	1.9	0.984—1.017
7	1.086	2.2	1.049 1.114
9	1.147	3.8	1.106—1.221

Table 16. Analysis of variance of fibre length (Split-split-plot design)

Source of variation	df	MSS	F
Age	3	837237.1	85.76**
Tree	4	6641.7	0.68ns
$Error_1$	12	9761.7	
Disc	3	39604.0	15.82**
Disc x Age	9	3424.2	1.36**
$Error_2$	48	2502.8	
segment	2	1849217.8	1519.32**
Disc x Segment	6	5956.9	4.89**
Age x Segment	6	63815.3	52.43**
Disc x age x segment	18	2169.1	1.78**
$Error_3$	128	1217.1	
Total	239		

** Significant at 1% level
ns Not significant

The ANOVA reveals that tree-to-tree variation in fibre length is not significant although within-stem (between-disc) variation is considerable in all the ages (Table 16) Along the stem, fibre length increases initially from stump to BH level and then gradually decreases towards the top. This pattern of longitudinal variation could be best explained using quadratic regression models derived on the basis of average values. The explained variance ranges from 98-99% (Fig.3) Across the stem, fibre length increases considerably from the pith to the bark region as between-segment fibre length variation is found significant (Table 16 and Fig. 4). The interaction terms of disc and age, disc and segment, age and segment as well as disc, age and segment are all sigaificant sources of fibre length variation and hence all these factors are important in the determination of fibre length. The longest fibres occur near the bark in radial diretion (Figs. 4 and 5) and somewhere near BH in longitudinal direction (Fig. 3). BH fibre length has little predictive value in the estimation of average tree fibre length as can be seen from small correlation coefficients (Table 17).

Table 17. Correlation of average tree fibre length with BH, and stump level fibre length values

Age (yr)		Correlation coefficient
3	Stump	0.579ns
	BH	0.758**
5	Stump	0.695*
	BH	0.289ns
7	Stump	0.530*
	BH	0.613*
9	Stump	0.838**
	BH	0.698*

** Significant at 1% level
* Significant at 5% level
ns Not significant

Fibre length has no consistent relationship with the tree size (either height or diameter) although fibre length is positively correlated with tree volume in 9 -year-old trees (Table 18).

Table 18. Correlation coefficients for the relationship of fibre length with tree growth parameters

Age (yr)	Tree height	DBH	Volume
3	0.412ns	.314ns	.489ns
5	–0.104ns	–.388ns	-. 156ns
7	–0.618ns	–.392ns	-. 552ns
9	–0.072ns	–.767*	–.726*

* Significant at 5% level
Not significant

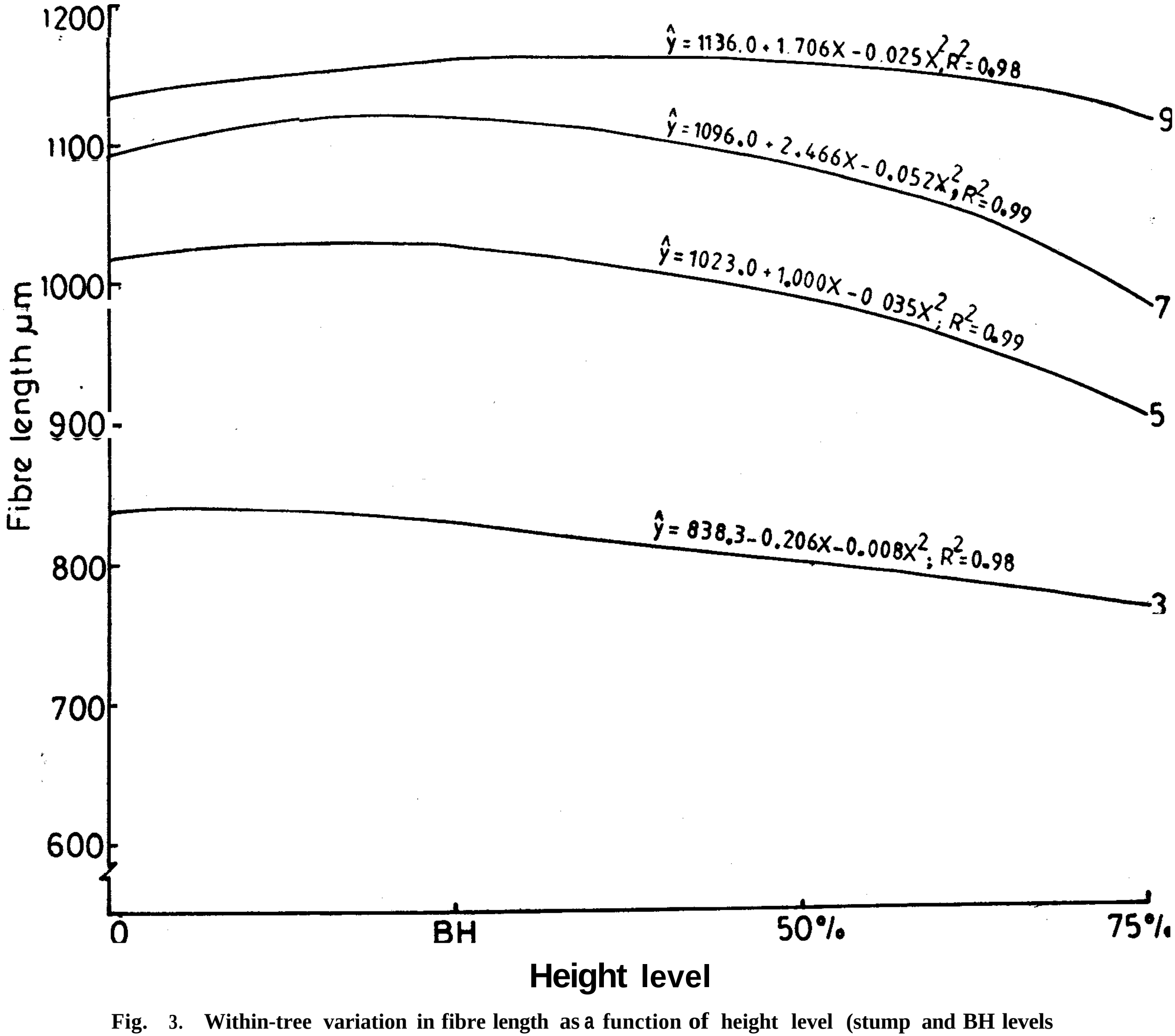

Fig. 3. Within-tree variation in fibre length as a function of height level (stump and BH levels and 50 and 75% of tree hights) in 3-,5-,7-and 9-year-old

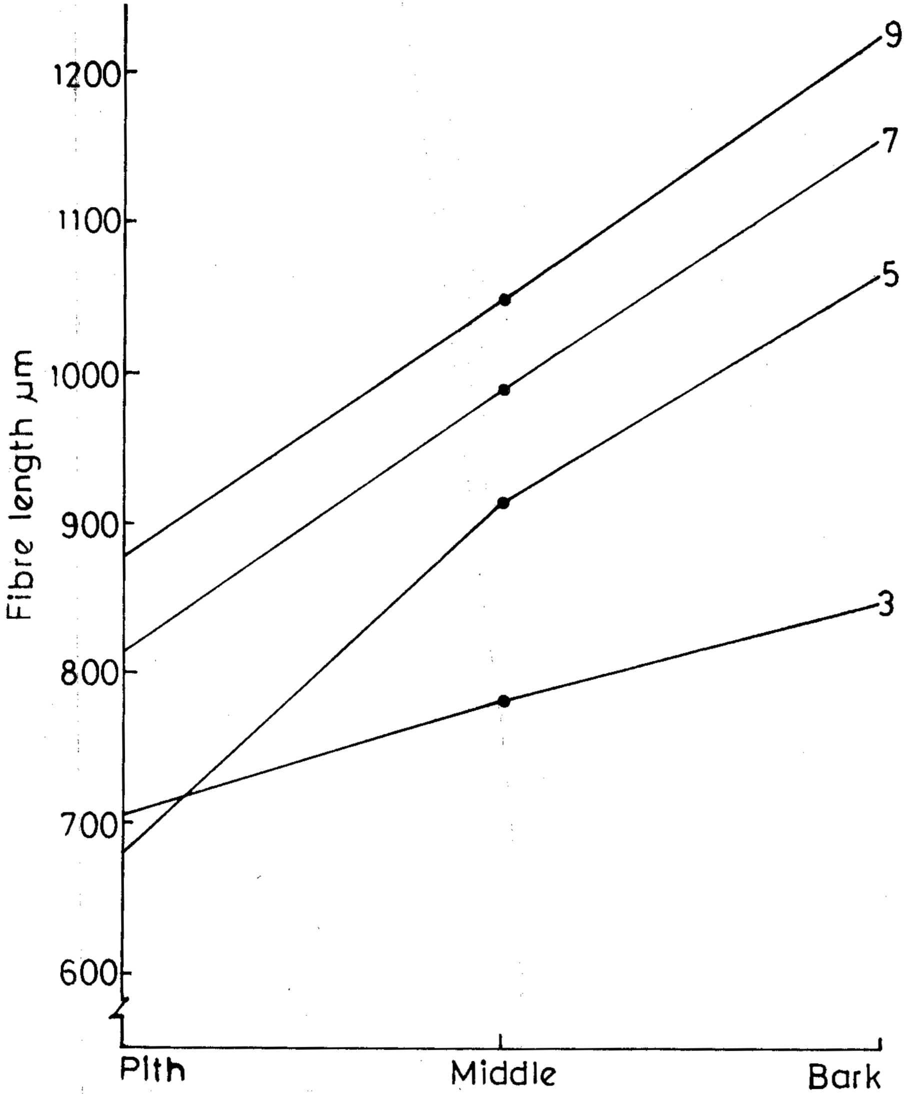

Fig. 4. Average fibre length in relation to three radial positions (height levels combined) in 3-, 5-,7, and Y-year-old trees.

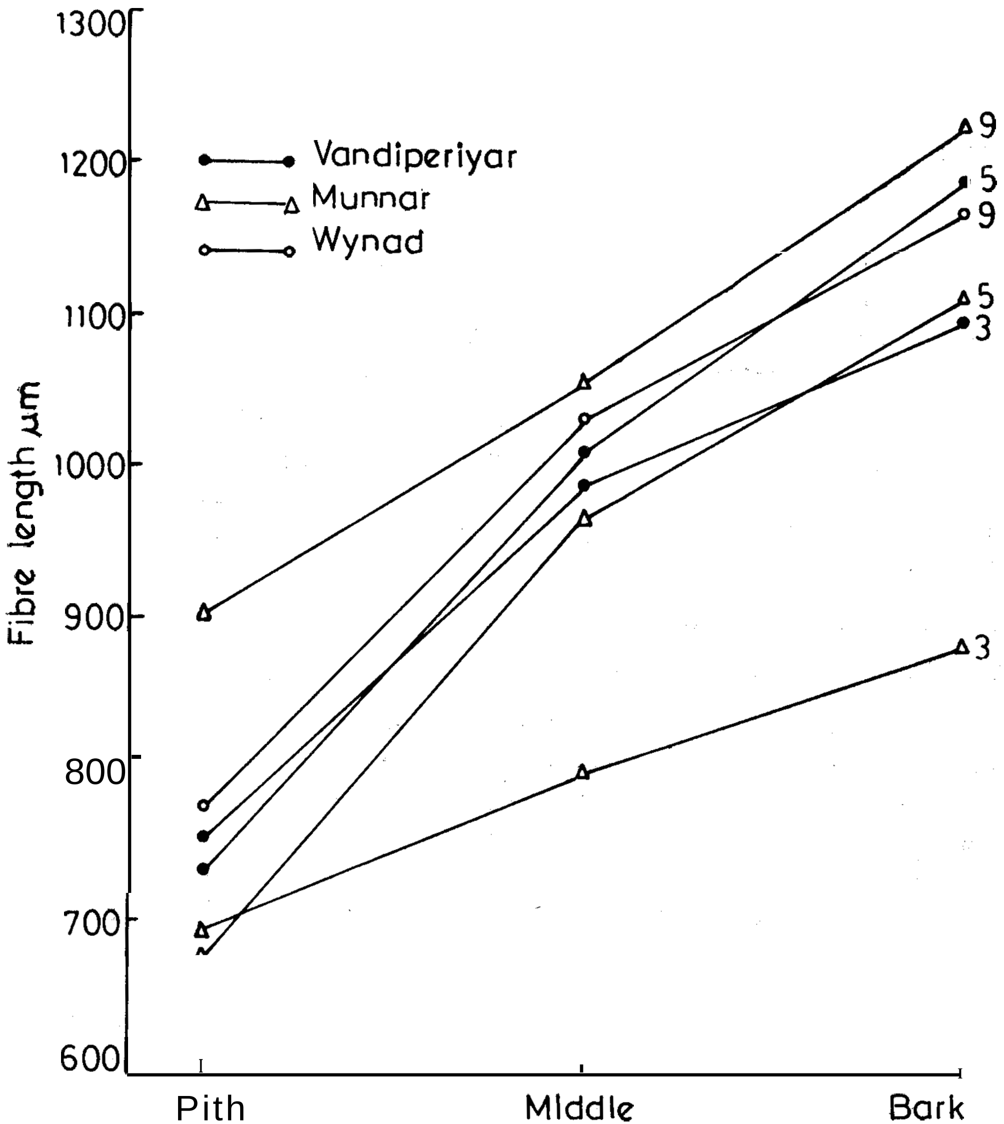

Fig. **5.** Mean fibre length in relation to three radial positions at BH level of 3-,5-,and 9-year-old trees grown in three sampling locations in Kerala.

Average BH fibre lengths of 3-and 5-year-old trees grown in Vandiperiyar are significantly greater than those of the trees of similar ages, grown in Munnar (Table 19). This supports the finding of Taylor (1973b) that rapidly elongating stems have longer fibres in South Africa-grown *E. grandis*. However, there is no significant difference in fibre length of 9-year-old trees between Munnar and Wynad locations.

Table 19. Comparison of BH Fibre length at three locations

Age (yr)		Location			Significance of t-value
		Vandiperiyar	Munnar	Wynad	
3	AV	1.043	0.833		**
	CV%	6.0	2.9		
5	AV	1.116	1.031		*
	CV%	4.5	3.0		
9	AV	—	1.160	1.104	ns
	CV%	—	3.5	4.9	

* Significant at 5% level; ** Significant at 1% level
ns Not significant

4.6 Practical significance of results

4.6.1 Tree age and wood quality

The results clearly show that *E. grandis* trees attain the desired wood density at the age of 3 years, as the minimum wood density requirement of pulp industry is in the range of 480-570 kg/m3 (Ikemori *et al* 1986). There is no increase in wood density, if the trees are harvested at later ages like 5, 7 and 9 years. On the other hand, delayed harvesting, say at the age of 5 years, may affect the pulp yield per unit volume of wood as there is significantly low average wood density. For example, pulp yield and strength are higher when 3-year old wood is pulped as against 6-year-old wood of *E. tereticornis* due to higher cellulose and lower lignin content in the former (Guha *et al* 1970). Similarly. younger trees of *E tereticornis* are known to give the pulp of better yield and strength when 7 and 8 year old trees are compared (Misra *et al* 1976). Further, no significant differences are noticed in wood and pulping properties in pilot-scale testing of *E. tereticornis* among trees of5-,7- and 10-year age groups in West Coast Paper Mills in Karnataka (Unkalkar *et al* 1977). Another finding of the present study that supports the idea of early harvesting is the lower proportion of coloured heartwood in younger ages. Of the 30 sample trees of the age class 3 years, twenty trees do not show the presence of heartwood at all whereas in 5-, 7- and 9-year-old trees all the sample trees have heartwood with a steady increase in proportion from 5 to 9 years.

Two properties, which do not favour early harvesting are fibre length and bark content. Fibre length consistently increases and bark proportion decreases with an increase in age from 3 to 9 years. Strength properties like tear factor of paper may be adversely affected when younger wood with shorter fibres and higher bark content is pulped. However these limitations cannot be over emphasised in the current situation of growing demands for different grades of pulps. For instance, the major pulp industries requirements in Kerala are rayon-grade and newsprint-grade pulps where fibre length has little role in influencing the product quality. Similarly, the higher bark content (average of 19.5%) noticed in 3-year-old trees need not be a constraint because of the fact that up to 18 -20% bark is permitted in the eucalypt wood chips as it increases the fibre content of raw material (Brito *et al* 1978) Considering these facts, one of the short rotation methods adopted in the United States is to harvest the trees at the age of 1,2 or 3 years and then regenerate the stand with sprouts (Jett and Zobel 1975). The sprouts are again cut at young age and the cycle is repeated 4 to 6 times before the stand is replanted. The younger wood with many desirable features like modest density, less frequent kino veins, more thin walled fibres, lower proportion of coloured heartwood and fewer phenolic deposits has better pulpwood value than mature wood (Bamber and Humpreys 1963; Zobel 1981).

4.6.2 Influence of location and tree growth on wood quality

Faster grown trees in Vandiperiyar (at the age of 3 and 5 years) and Wynad (at the age of 9 years) do not produce the wood of significantly different density than the trees of similar ages grown in Munnar. However, fibres are significantly longer, heartwood percentage greater and bark content lower in the trees grown in Vandiperiyar. After studying the wood of *E. grandis* grown in South Africa, Taylor (1973b) reports that rapidly elongating stems produce wood with lower density and with longer fibers than trees which grow more slowly in height. However, by and large, tree growth parameters like height and DBH or tree volume are' not consistently related with the wood properties of different ages studied. This indicate.; that any treatment for faster growth (higher volume) of *E.grandis* trees will have no adverse effect on wood density and fibre length. On the other hand, faster grown trees may produce lower bark percentage which is desirable for pulp industry.

5. CONCLUSIONS AND RECOMMENDATIONS

a. Wood density does not improve with age from 3 years to 7 or 9 years. On the other hand, 5-year-old trees have lower density wood. As indicated by wood density, there is no significant loss in pulp yield per unit volume of wood if 3-year-old trees are pulped as against 5, 7 or 9-year-old-trees,

b. Fibre length and heartwood percentage increase and bark percentage decreases consistently with an increase in age from 3 to 9 years.

c. As measured by tree height and DBH, faster growth is not consistently related to wood density, fibre length and heartwood percentage in each age group. By and large, it is negatively correlated with bark percentage, This suggests that any intensive silvicultural practice for faster growth should be encouraged.

d. Within-tree variations in wood density and fibre length are considerable while between-tree variations are not significant.

e. Tree-to-tree variation is small in fibre length and density, modest in bark percentage and large in tree size and heartwood percentage.

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