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EVALUATION OF HIGH INPUT MANAGEMENT ON GROWTH AND TIMBER PRODUCTION IN TEAK

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ABSTRACT

Growing teak in high input plantations for timber production is relatively a new concept. Given the time and resource constraints, attempt has been made in the present short-term study to assess the effects of certain silvicultural inputs on growth and quality of juvenile teak wood.

Fertilization with irrigation had a significant effect on tree height and volume. Debudding, although helped formation of clear bole, was suspected to reduce the tree volume. Absence of lower side branches facilitated deer damage which is an adverse outcome of producing clear boles in areas rich in deer population. An observation of phyllotaxy variants in the experimental plantation revealed that 99.3% showed normal opposite decussate phyllotaxy, 0.6% whorled phyllotaxy and 0.07% alternate phyllotaxy; the phyllotaxy variants reverted to normal phyllotaxy when the leading shoot was damaged.

The results showed that wood density, maximum bending and longitudinal compressive stresses of 5-year-old teak grown under high input management (HIM) were not significantly inferior while stiffness of wood (modulus of elasticity) was only 76% of the Standard teak value due to its severe juvenility. Faster growth due to fertilization with irrigation in one-year-old seedlings increased the latewood width and fibre percentage resulting in higher density of wood.

The five-year-old trees grown under high input management showed higher heartwood percentage than the trees of similar age from forest plantations. While the sapwood of these juvenile trees was comparable to heartwood in the values of fibre stress at elastic limit and static bending, the former had higher stiffness and longitudinal compression strength. Wood figure (colour, grain, texture) was slightly different in view of the tendency of losing typical ring porosity during the initial three years of vigorous growth in juvenile teak. However, timber displayed the resumption of ring-porous character after the initial three years' growth, delimiting the wood figure differences only to the inner core. These observations imply that the differences in market value of the timber are expected to be minimal in older trees of 15-20- year-old plantations.

Five-year-old juvenile wood from HIM was less decay resistant than the mature teak wood of forest plantations. However, it was comparable in natural durability to the juvenile wood of forest plantations and to the inner heartwood of very old teak, as it belonged to Class II of resistant timbers in contrast to Class I of very resistant outer heartwood of mature timber. There were significant tree-to-tree variations in decay resistance against the white rot fungi indicating scope for selection in genetic improvement of timber durability.

1. INTRODUCTION

Teak (*Tectona grandis* L.f.) occupies 14.2% of the tropical forest plantations (Evans, 1992) and 45.9% of the forest plantations in Kerala (Kerala Forest Department, 1998, 1999). Traditionally teak is harvested at a rotation age of 50 to 80 years. Due to high demand and price, there are efforts to grow it on short rotations with high inputs, especially fertilizers and irrigation. Teak wood production in high input plantations (teak wood farming) is therefore relatively a new concept. The plantations established under such management are yet to attain the harvestable age. However, in order to assess the economic returns of investments made on intensively managed plantations, it was felt necessary to forecast the timber quality from such plantations before establishing large-scale plantations.

It was in this context that the present study was taken up with the following objectives.

(i) To determine the effects of spacing, irrigation, fertilizer application and pruning on yield and quality of timber

(ii) To evaluate the economics of high input management.

2. MATERIALS AND METHODS

2.1. FIELD WORKS

A field experimental plot was laid out over an area of 2.419 ha during June 1997 at the KFRI Field Research Centre, Velupadam (Fig. 1). The site was a teak final felled area sparsely regenerated with coppice growth of teak and miscellaneous trees, shrubs and herbs. The area was located on a foot-hill and had a slope of 3^{o} to 15^{o} with south-west aspect. The locality received a mean annual rainfall of 2980 mm during 1984-1994. The rainfall pattern during the study period is given in Fig. 2.

2.1.1. Soils

Soil samples were collected from 0-20, 20-40 and 40-60 cm deep layers from ten localities representing the experimental area. Ten soil pits were taken. The soil samples were sieved and particles > 2 mm (gravel) were separated. Particle-size separation, soil pH, organic carbon, exchangeable bases, available N, P, K, Ca and Mg contents were found out as per standard procedures in ASA (1965) and Jackson (1958). The mean values of soil properties in different layers are given in Table 1.

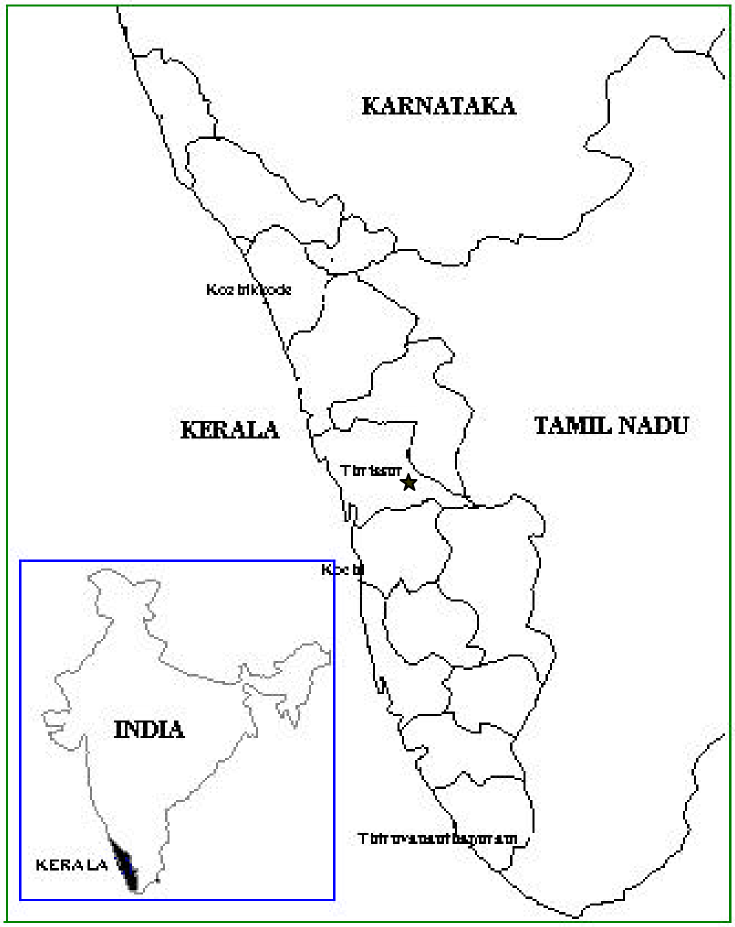
The soil was loamy sand in the surface and sandy loam in deeper two layers. It was strongly acidic in all layers. The organic carbon content was low in the surface and very low in deeper layers. The available nutrient contents (N, K, Ca and Mg) and exchangeable bases were also low in all layers. The available P contents were only traces. The soils in general are highly degraded (Table 1).

Table 1. Physical and chemical properties of soils in different layers of pits

Depth (cm)	G	S	Si	Cl	pH	Oc	Eb	N	P	K (%)	Ca	Mg
	(------------------%-------------)					(%)	(me/ 100g)	(%)			(--------%------)	
0-20	17	81	10	9	5.1	1.01	5.5	0.041	Trace	0.0141	0.125	0.036
20-40	20	79	10	11	5.2	0.62	4.5	0.039	Trace	0.0104	0.062	0.024
40-60	24	73	10	17	5.2	0.48	6.0	0.032	Trace	0.0096	0.090	0.010

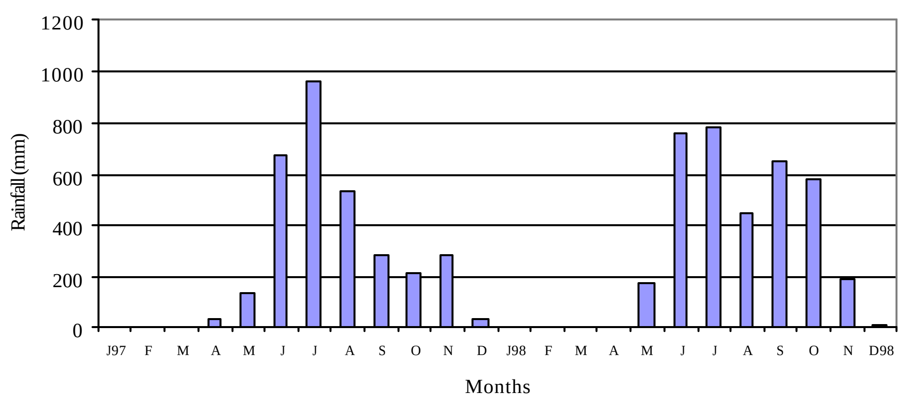
G = Gravel; S = Sand; Si = Silt; Cl = Clay; pH = Soil pH; Oc = Organic carbon; Eb = Exchangeable bases; N = Available Nitrogen; P = Available Phosphorus; K = Available Potassium; Ca = Available Calcium and Mg = Available Magnesium

Fig 1. Location of experimental area



★ **FRC Velupadam**

Fig. 2. Rainfall of the experimental area during January 1997 to December 1998



2.1.2. Site preparation

The entire coppice growth of teak and miscellaneous regeneration was cut and slash burned. After aligning and staking, the area was planted with one-year-old teak stumps brought from Nedungayam nursery of Karulai Range, Nilambur North Forest Division. The seeds from Karulai seed stands were used for raising the seedlings.

Contour trenches were made uniformly all over the experimental area at one metre vertical interval to prevent water run-off through the plots. The trenches were 30 cm wide and 30 cm deep, located at one meter vertical interval. In addition to trenching, the seedlings were provided with 60 cm square platform with hill ward slope to enable soil and moisture conservation. Details of the activities are provided in Table 2.

Table 2. Details of various operations carried out during the study period

Operations	Months after planting																					
	First year													Second year								
	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Apr 1997	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan 1998	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan 1999	Feb
Coppice slash	*																						
Alignment and staking		*																					
Planting			*																				
Knife weeding		*	*		*		*			*						*						*	
Scrape weeding					*			*							*					*			
Fertilization					*			*								*				*			
Irrigation (drip)											*	*	*	*									
Debudding *									*	**		**	**	**	*	**	**				*	*	*

* Two debuddings were done in a month

* Number of stars in columns indicate number of time debudding done

2.1.3. Treatments and experimental layout

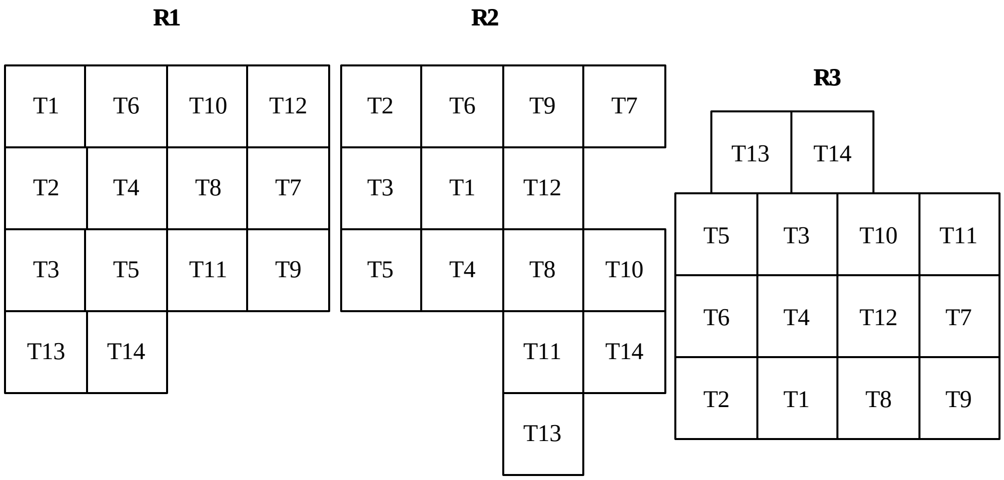
The factorial experiment laid out under Randomized Block Design with three replicates had three levels of spacing (3 m x 3 m; 2.5 m x 2 m; 2 m x 2 m), two levels of Fertilization (fertilization and irrigation given; fertilization and irrigation not given), and two levels of debudding of stem (continuous debudding; no debudding). The details of various treatments are given in Table 3. Stump planting in crowbar holes as practiced by the Forest Department with debudding (T13) and without debudding as control.

Table 3. Details of various silvicultural treatments

Treatment combination code	Treatment combination			
	Method of planting	Spacing	Fertilization (Fertilization + irrigation)	Debudding of main stem
T1	Stumps planted in pits	2 m x 2 m	Fertilization given	Debudding done
T2	’’	’’	’’	Debudding not done
T3	’’	2.5 m x 2.5 m	’’	Debudding done
T4	’’	’’	’’	Debudding not done
T5	’’	3 m x 3 m	’’	Debudding done
T6	’’	’’	’’	Debudding not done
T7	’’	2 m x 2 m	Fertilization not given	Debudding done
T8	’’	’’	’’	Debudding not done
T9	’’	2.5 m x 2.5 m	’’	Debudding done
T10	’’	’’	’’	Debudding not done
T11	”	3 m x 3 m	’’	Debudding done
T12	’’	’’	’’	Debudding not done
T13	Stumps planted in crowbar holes	2 m x 2 m	’’	Debudding done
T14	’’	’’	’’	Debudding not done

The layout of the experiment is shown in Figure 3. Except in T13 and T14, stump planting was done in 30 cm x 30 cm x 30 cm pits to overcome the compactness of the soil. Casualty replacements were done during the initial three months after planting using pre-sprouted stumps raised in polythene bags so as to make up the growth of replaced plants with the growth of the initially planted stumps.

Fig. 3. Experimental layout



Each plot measures 20 m x 20 m

R1, R2 and R3 are three replications

T1, … T14 are different treatments

In fertilization treatments (T1 to T6), the fertilizer application schedule followed is given in Table 4.

Table 4. Fertilizer application schedule

Fertilizer	Doze at different application (g / plant)					
	First year			Second year		
	Aug 97	Nov 97	Total	Jul 98	Nov 98	Total
Urea (46% N)	15	15	30	43	43	86
Muriate of potash (50% K)	15	15	30	38	38	76
Mussori rock phosphate (20% P)	75	75	150	100	100	200
Magnesium sulphate (10% Mg)	Nil	Nil	Nil	100	100	200
Calcium carbonate* (40% Ca)	Nil	Nil	Nil	28	28	56

* Applied 15 days after application of other fertilizers in order to increase soil pH

Drip irrigation was provided to all the plants in the fertilizer-applied plots through an improvised method using plastic pots connected with intra -venal injection sets. Irrigation was provided at the rate of six litres of water per plant once in ten days during February - May 1998. A pot had a capacity of 12 liters and irrigated two plants simultaneously. Entire pot water was used up for irrigation with 24 hours of filling.

The plots were kept under weed control by knife weeding close to ground during the study period. Scrape weeding to a diameter of 30 cm around each plant was also done except for T13 and T14. A general view of the experimental plot at 15 months after planting is given in Figure 4 and view of treatment T1 (spacing 2 m x 2 m; fertilization and pruning) is given in Figure 5.

2.1.4. Growth observations

Height, girth at breast height and 15 cm clear bole length of trees as well as damage to clear bole due to animal attack were recorded periodically and given in Table 5. Although not envisaged in the project, phyllotaxy variants were identified and monitored to see their performance.

2.1.5. Data analysis

From the values of girth, diameter was calculated. Using the height and diameter measurements, mean tree conical volume was worked out using the formula used for *Eucalyptus grandis* by Cameron *et al*. (1989).

$$\text{Conical volume} = \frac{\Pi D^2}{4} H$$

$$\text{Where D (Basal diameter of the tree)} = \frac{d}{(H-h)}$$

d = Diameter measured at a height of h above ground level

H = Total height of the tree

h = Distance between base and height at which diameter was measured

The values of height, diameter and conical volume were subjected to analysis of variance to test for significant differences.

Fig. 4. View- of treatment TI (spacing 2 m X 2 m; fertigation and pruning

Fig. 5. General view of the experimental area at 15 months after planting

Table 5. Details of observations recorded during the study period

Type of observation	Months after planting																				
	First year												Second year								
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Jun 97	Jul	Aug	Sep	Oct	Nov	Dec	Jan 98	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan 99	Feb
Height			*			*			*			*	*		*			*			*
Girth at breast height						*			*			*	*		*			*	*		
Leaf number			*			*			*			*									
Shape of stem									*			*									
Leaf angle to stem									*			*									
Petiole characteristics									*			*									
Internodal height									*			*									
Clearbole height													*		*			*			*

2.1.6. Economics of cultivation

Cost of cultivation and maintenance per hectare were worked out for each treatment in terms of total amount and as percentage of control (T14).

2.1.7. Wood quality evaluation

High input plantations older than the age of 5 years were not available for timber sampling The study has therefore resorted to sample the 5 -year-old juvenile trees of teak plantation established in a farm land in Kerala that was given high inputs of fertiliser (NPK) and irrigation. Another reason for selection of this age group was that teak poles are available from the first mechanical thinning of forest plantations in Kerala. The average tree size with a diameter at beast height of 11 cm in farm grown trees was greater than that of Site Quality I given in the All-India Yield Table for teak. Nine dominant or co-dominant trees falling within a breast height (BH) diameter class of 11-14 cm were selected for studying the wood properties.

To study the effects of various silvicultural inputs on wood formed during the first year's growth after field planting , one-year-old plants were also sampled from the experimental plantation plot laid out in Velupadam under this project. Fourteen seedlings that have been irrigated and treated with fertiliser were compared with control plants of the same experimental plot.

2. 2. LABORATORY WORK

2.2.1. Anatomy

To study the wood anatomy, 15-20 μm thick cross sections were taken on a sliding microtome comprising different rings from pith to periphery so as to cover the radial variation. Standard microtechnique procedure was followed to prepare the sections for microscopic observation. Important anatomical properties studied are ring width, vessel diameter, fibre length, fibre wall thickness and proportions of fibres, vessels and parenchyma (ray and axial parenchyma combined). Leica Image Analysis System (Quantimet 500+) was employed for precise quantification of wood anatomical features. For the estimation of fibre and vessel dimensions, at least 50 largest cells were measured to obtain mean values per ring. Heartwood percentage was estimated following the procedure described in an earlier report (Bhat *et al.* 1985).

2.2.2. Decay resistance

To study natural decay resistance, seven dominant or co-dominant trees were selected for cutting the cross sectional discs at breast height level. The BH diameter of heartwood cylinder varied from 5.5-8.0 cm. The inner heartwood cylinder was separated from the outer sapwood region for preparing the test blocks radially from the pith confining to only heartwood region as per the ASTM D2017-71 (1978). From each tree, inner and outer radial samples (with 6 replicates) were selected for testing. Sample blocks were also prepared from the heartwood of three dominant trees each of 13-, 21- and 55-year old plantations for comparative purpose.

The test (white-rot) fungi consisted of cultures of two species, viz. *Polyporus hirsutus* Wulf. ex Fries and *P. versicolor* L. ex Fries. which are known to be the common fungi causing decay in converted wood in India (Bakshi et al.,1967). The fungal cultures were obtained from Forest Research Institute, Dehra Dun. As the cultures of brown rot fungi were not available, the present study has confined only to white rot fungal tests. The procedure described in ASTM Standard (1981) for accelerated laboratory test was followed. The test fungi were grown in 2% malt agar in petri-dishes. An agar disc of 8 mm diameter cut from the margin of an actively growing colony of the test fungi was placed aseptically on the feeder strips. After 2-3 weeks, when the feeder strip was almost covered with the fungus, the sterilized test blocks and the reference blocks were transferred aseptically. Of the two blocks from each bottle, adjacent blocks were kept on the un-inoculated feeder strips.

The test blocks were prepared according to the procedure described by Bakshi et al (1967). Billets of 60-cm length were taken from the butt-end of the logs in such a way that they had 30-cm portion above and 30-cm portion below the breast height point. From these billets, planks of 2.5 cm thickness were sawn across the diameter. Battens of 2.0 cm width were obtained from the heartwood portion and test blocks of 2.0 x 2.0 x 1.0 cm size alongthe grain direction were prepared. Six defect-free blocks from each tree randomly assigned were tested against each test fungus. Four blocks were used as adjustment blocks. Reference blocks, similar to the test blocks in size were prepared from mature trees of *Bombax ceiba* Linn., a highly perishable timber, as described earlier for feeder strips.

After 8 weeks exposure to the test fungi, two reference blocks for each test fungus were taken out, the fungal mycelium removed, oven dried and weighed to determine the weight loss. This was continued every week until a weight loss of 60% was recorded in the reference blocks. Once 60% weight loss was reached, the reference blocks and test blocks were removed from the bottle and their oven dry weight determined. If the adjustment blocks had suffered any weight loss due to any reason, necessary corrections were made in the oven dry weight of the test blocks. The weight loss of the test blocks due to the decay was calculated and their decay resistance graded. The relative resistance of each test block to decay was measured as the percentage loss in oven dry weight during two-month exposure to attack by the two aggressive wood decay fungi mentioned earlier.

2.2.3. Mechanical testing

The basal billets of 1.4 m length were converted into scantlings of 3 x 3 cm cross section to prepare test samples from pith to periphery in one radial direction selected randomly just below the breast height. From each radius, samples (with the size of 2 x 2 x 30 cm) were tested for static bending (fibre stress at elastic limit-FSEL, modulus of rupture-MOR, modulus of elasticity-MOE) and compression parallel to grain (maximum crushing stress - MCS). The sample size of 2 x 2 x 10 cm has been used for compression test. Small pieces from tested samples were cut to determine the wood density in air dried condition.

3. RESULTS AND DISCUSSION

3.1. Silvicultural inputs

The experiment had 14 treatments with planting methods, spacing, fertilization (fertilization and irrigation) and debudding in different combinations. As growth data for 20 months are insufficient to comment on the effect of spacing, the results deal only with the effect of fertilization and debudding. Table 6 gives the mean values of height, diameter at 15 cm, diameter at breast height of 137 cm, mean conical volume, mean clear bole length, and bole length percentage for the 14 treatment combinations. Table 7 summarises the overall performance in fertilization and pruning treatments.

Summary of analysis of variance of treatment effects is provided in APPENDIX I.

3.1.1. Effect of fertilization

The effect of fertilisation is significant on height, diameter and volume growth of trees at 17 and 20 months after planting (Tables 6 and 7). At 20 months, the fertilization treatments registered an overall mean dbh of 3.5 cm against 2.8 cm in no fertilization, height of 376.9 cm against 299.5 cm, and a conical volume of 338.5 cm^3 against 212.7 cm^3.

3.1.2. Effect of debudding

The effect of debudding done up to a height of 2 m was reflected on the clear bole length (Tables 6 and 7).

As debudding was continued till the last observation, the carry over effect of debudding need to be observed for more time for a correct assessment of the effect.

The debudding treatments gave clear bole up to 295.9 cm at 20 months in fertilization treatment as against 266.8 cm in case of no fertilization treatments. Debudding treatment invariably gave a clear bole to main stem ratio of above 75 percent.

Table 6. Height, diameter, clear bole length and conical volume of *Tectona grandis* in different treatments

Treatment	Mean height (cm)*					Mean diameter at 15 cm (cm)*				Mean diameter at 137 cm (cm)*		Mean tree conical volume (cm^3)*				Mean clear bole length (cm)**	
	Months after planting					Months after planting				Months after planting		Months after planting				Months after planting	
	2	6	12	17	20	6	12	17	20	17	20	6	12	17	20	17	20
T1	14.6	56.4	116.7	330.0	365.4 (115.2)	1.30	1.9	4.7	5.1 (100.0)	2.9	3.3 (117.9)	4.87	16.7	219.4	287.1 (118.5)	161.7 (49.0)	319.5 (87.4)
T2	15.8	62.7	114.7	322.8	368.6 (116.2)	1.39	2.0	4.8	5.3 (103.9)	2.9	3.3 (117.9)	5.95	17.2	233.5	317.4 (131.0)	15.7 (4.9)	16.0 (4.3)
T3	16.9	73.1	139.0	353.1	389.6 (122.9)	1.60	2.2	5.0	5.4 (105.9)	3.3	3.6 (128.6)	8.07	23.3	263.6	340.1 (140.2)	108.8 (30.8)	337.2 (86.6)
T4	16.2	80.7	133.8	339.0	379.7 (119.7)	1.71	2.3	5.6	5.7 (111.8)	3.3	3.6 (128.6)	9.68	24.3	310.6	368.3 (152.1)	7.7 (2.3)	12.0 (3.2)
T5	13.9	65.3	128.8	344.3	391.0 (123.3)	1.49	2.1	5.2	5.5 (107.8)	2.7	3.6 (128.6)	6.85	20.9	272.7	347.0 (143.3)	89.7 (26.1)	231.0 (59.1)
T6	15.5	59.6	104.9	315.6	367.1 (115.8)	1.43	2.0	5.2	5.8 (113.7)	2.8	3.5 (125)	5.98	16.2	250.0	371.1 (153.2)	6.4 (2.0)	11.0 (3.0)
T7	17.3	64.2	117.7	262.4	314.8 (99.3)	1.44	2.0	4.0	4.6 (90.2)	2.3	2.9 (103.6)	6.04	16.2	132.3	210.5 (86.9)	155.5 (59.3)	246.5 (78.3)
T8	15.3	74.8	115.7	236.6	282.3 (89.0)	1.56	2.1	4.3	5.0 (98.0)	2.2	2.8 (100)	8.74	19.8	145.7	225.7 (93.2)	9.8 (4.1)	12.0 (4.3)
T9	13.1	43.0	73.5	272.5	302.8 (95.5)	1.09	1.5	4.1	4.6 (90.2)	2.5	2.7 (96.4)	3.32	7.6	135.7	186.3 (76.9)	150.0 (55.0)	278.4 (91.9)
T10	18.1	70.7	106.7	253.2	299.6 (94.5)	1.53	2.1	4.5	5.2 (101.9)	2.4	3.1 (110.7)	7.76	17.6	153.0	242.5 (100.1)	6.0 (2.4)	9.0 (3.0)
T11	16.9	57.5	98.0	276.6	320.1 (100.9)	1.33	1.8	4.2	4.8 (94.1)	2.5	2.8 (100)	4.97	12.3	143.7	213.5 (88.2)	91.9 (33.2)	275.4 (86.0)
T12	16.6	61.0	95.5	227.6	275.0 (86.7)	1.47	2.0	4.3	4.8 (94.1)	2.2	2.5 (89.3)	6.41	14.2	134.8	197.7 (81.6)	7.1 (3.1)	11.0 (4.0)
T13	15.5	42.6	74.1	260.4	301.5 (95.1)	1.03	1.5	4.1	4.8 (94.1)	2.4	2.8 (100)	3.01	7.4	131.6	207.5 (85.7)	116.4 (44.7)	252.1 (83.6)
T14 (Control)	13.5	32.2	57.3	269.5	317.1 (100)	0.84	1.2	4.4	5.1 (100.0)	2.4	2.8 (100)	2.61	5.3	152.8	242.2 (100)	9.4 (3.5)	11.0 (3.5)

* Figures in parenthesis give the percentage over control
** Figures in parenthesis give clear bole length as a percentage of total height

Table 7. Overall mean of treatments with and without fertilization and debudding

Treatment	Mean height (cm)					Mean diameter at 15 cm (cm)				Mean diameter at 137 cm (cm)		Mean tree conical volume (cm^3)				Mean clear bole length (cm)*	
	Months after planting					Months after planting				Months after planting		Months after planting				Months after planting	
	2.5	6	12	17	20	6	12	17	20	17	20	6	12	17	20	17	20
F1P1	15.2	64.9	128.2	342.5	382.0	1.5	2.1	5.0	5.4	3.0	3.5	6.6	20.3	251.9	324.8	120.1 (35.1)	295.9 (77.7)
F1P0	15.8	67.6	117.8	325.8	371.8	1.5	2.1	5.2	5.6	3.0	3.4	7.2	19.2	264.7	352.3	9.9 (3.0)	13.0 (3.5)
F0P1	15.8	54.9	96.4	270.5	312.6	1.3	1.8	4.1	4.7	2.5	2.8	4.8	12.0	137.2	203.4	132.5 (49.0)	266.8 (85.4)
F0P0	16.7	68.8	106.0	239.1	285.6	1.5	2.0	4.4	5.0	2.3	2.8	7.6	17.2	144.5	222.0	7.6 (3.2)	10.7 (3.8)
F1	15.5	66.3	123.0	334.1	376.9	1.5	2.1	5.1	5.5	3.0	3.5	6.9	19.8	258.3	338.5	65.0 (19.4)	154.5 (40.6)
F0	16.2	61.9	101.2	254.8	299.1	1.4	1.9	4.2	4.8	2.4	2.8	6.2	14.6	140.9	212.7	70.0 (27.5)	138.7 (44.6)
P1	15.5	57.5	106.8	299.9	340.7	1.3	1.9	4.5	5.0	2.7	3.1	5.3	14.9	185.6	256.0	124.9 (41.6)	277.2 (81.3)
P0	15.8	63.1	104.1	280.6	327.0	1.4	1.9	4.7	5.3	2.6	3.1	6.7	16.4	197.2	280.7	8.9 (3.2)	11.7 (3.6)

* Figures in parenthesis give clear bole length as a percentage of total height

F1 Mean of six treatments with Fertilization (see Table 6 for details)
F0 Mean of six treatments with no Fertilization
F1P1 Mean of three treatments with Fertilization and debudding
F1P0 Mean of three treatments with Fertilization and no debudding
P1 Mean of six treatments with debudding
P0 Mean of six treatments without debudding

It is interesting to note from the data at 17 and 20 months that debudding has a decreasing effect on volume of the tree. This may be due to suppression of foliage production which in turn may have affected the growth. This aspect needs detailed investigation.

Another interesting aspect is that the longer clear bole of stems, in debudding treatments, has favoured extensive damage caused by spotted deer (Chacko and Herald John, 1999). Heavy branching on stem prevents easy access of animals to the main stem and hence remains undamaged by spotted deer population.

3.1.3. Observation on phyllotaxy variants

It was incidental that the phyllotaxy variants in the experimental area were observed. Of the 4509 plants in the experiment plot, 99.33% showed normal opposite decussate phyllotaxy, 0.6% whorled phyllotaxy and 0.07% alternate phyllotaxy. The phyllotaxy variants revert back to normal phyllotaxy when the leading shoot is damaged (Chacko *et al.*, 2000).

3.2. ECONOMICS OF CULTIVATION

Economics of cultivation can be worked out only when the crop starts yielding products. However, at this point of time, the cost of cultivation per hectare in the case of each treatment (Table 8) provides an idea of the cost variation under different input levels.

Large cost variation is mainly due to spacing which determines the number of plants. The increase in cost due to debudding is only 2%.

3.3 Timber quality

3.3.1. Wood colour

Colour of the wood is generally referred to that of heartwood due mainly to extractives although cell wall components often contribute to the colour of exposed surface by oxidation. Colour interpretation of wood may also vary according to individual perceptions or visually based description. More precise measurements can be made only through spectrophotometer which records the amount of light reflected from a surface in the various parts of spectrum and hence not practicable in trade practices.

Table 8. Cost of cultivation and maintenance of teak plantation for 20 months under different treatments

Treatment	Site preparation (Rs.)	Cost of planting material (Rs.)	Cost of planting (Rs.)	Knife weeding (Rs.)	Scrape weeding (Rs.)	Lemon grass uprooting (Rs.)	Clipping of multiple shoot (Rs.)	Fertilization (Rs.)	Irrigation (Rs.)	Debudding (Rs.)	Pesticide (Rs.)	Watch and Ward (Rs.)	Total (Rs.)	Total as a percentage of total expenditure in control
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T1	1510	800	1619	2101	1538	547	119	2246	5833	212	190	2106	18821	219
T2	1510	800	1619	2101	1538	547	119	2246	5833	-	190	2106	18609	217
T3	1510	768	1035	2101	984	547	114	1437	3731	203	122	2106	14658	171
T4	1510	768	1035	2101	984	547	114	1437	3731	-	122	2106	14455	169
T5	1510	533	718	2101	682	547	79	997	2589	141	84	2106	12087	141
T6	1510	533	718	2101	682	547	79	997	2589	-	84	2106	11946	139
T7	1510	800	1619	2101	1538	547	119	-	-	212	-	2106	10552	123
T8	1510	800	1619	2101	1538	547	119	-	-	-	-	2106	10340	121
T9	1510	768	1035	2101	984	547	114	-	-	203	-	2106	9368	109
T10	1510	768	1035	2101	984	547	114	-	-	-	-	2106	9165	107
T11	1510	533	718	2101	682	547	79	-	-	141	-	2106	8417	98
T12	1510	533	718	2101	682	547	79	-	-	-	-	2106	8276	97
T13	1510	800	527	2101	866	547	119	-	-	212	-	2106	8788	102
T14 (Control)	1510	800	527	2101	866	547	119	-	-	-	-	2106	8576	100

Explanation

Column 2: Coppice cutting and transporting the materials outside the experimental area
Column 3: Cost of teak stumps
Column 4: Pitting and planting (crowbar planting in T13 and T14)
Column 5: Six knife weedings
Column 6: Scraping of weeds and maintenance of platform around plants
Column 7: Lemon grass uproot and removal of uprooted materials from the plot
Column 8: Clipping of multiple shoots retaining one healthy shoot
Column 9: Cost of fertilizers and application costs
Column 10: Cost of hose pipe and wages of labours
Column 11: Debudding up to 2 m height
Column 12: Cost of pesticides and wages of application

Compared to the geographic source of variation, wood colour differences between managed stands and control trees are small (Fig. 6). For instance, teak grown in Nilambur location in India is golden brown or yellow while that from another location of Kerala (Konni) is darker in colour as in Burma teak. The figure shows that heartwood of 5-year-old teak of managed stand with fertiliser treatment and irrigation is almost similar in colour to that of Nilambur grown teak as type IV d escribed by Pearson and Brown (1932).

3.3.2. Grain and texture

The term 'grain' refers to the longitudinal alignment of cells, more to the vessel (pore) lines in medium or course textured woods. Wood texture varies according to the size (diameter) of cells more pronounced in pores. Grain can be determined by the type of cleavage produced when wood is split. Straight grained teak wood is generally flat while the interlocked or wavy grained wood has wavy or curly face of cleavage and figure. The main factors that determine the beautiful figure of teak wood are heartwood colour and black lines of extractives / organic substances, grain, texture and the pattern of growth ring marks that will be displayed depending on plane of cutting (Figs. 6 and 7). Teak being a ring porous wood, pores are non-uniform in size, larger ones in the earlywood region along with soft tissues (longitudinal parenchyma) form continuous concentric bands while the smaller pores with thicker walled fibres in the latewood region form denser and darker coloured zones. Therefore teak wood is generally un-even in texture displaying non-homogeneous and varied patterns of figures. In contrast, five-year-old wood from HIM, with fertilization and irrigation, showed slight differences in grain and texture because of more uniform sized pores in the wood laid down during the initial period of three years (Fig 8). This is mainly due to the tendency of teak to loose the typical ring-porosity of wood during extremely fast growing period resulting in diffuse porous condition with more even-textured wood (Figs. 6 and 7). However, it was observed that teak resumed its normal ring porous nature after the initial period of 3 years' rapid growth and the wood figure changes got minimized with advancement of tree age from 3 to 5 years. The implication is that the changes in wood figure have only localised effects when larger cylinder of wood is formed in older trees, i.e. at the age of 15-20 years. However, wood laid down during the initial period of 1- 2 years is likely to be very fine-textured due to smaller sized pores as displayed in Figure 9 (Bhat et al. 1999).

It is clear from the above results that any change in wood figure due to rapid growth has only localized effects and the differences in market value of the timber are expected to be minimal in older plantations of 15-20 years. Accordingly, market is likely to be standardized in future as the customers / teak wood users will be aware of these small differences and learn to use value-added products from fast grown plantations.

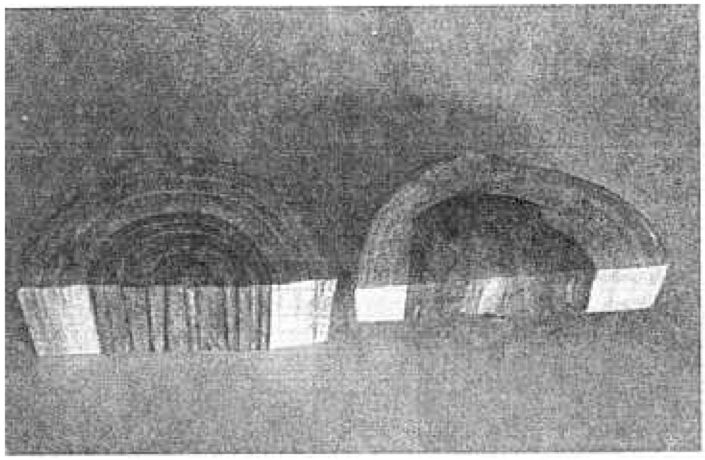


Fig. 6. Cross sectional disc of 5-year-old teak from high input plantation (right) compared with 8-year-old teak (left) grown in forest plantation in Nilambur; note higher proportion of heartwood in fast grown teak with slight differences in colour, grain and texture

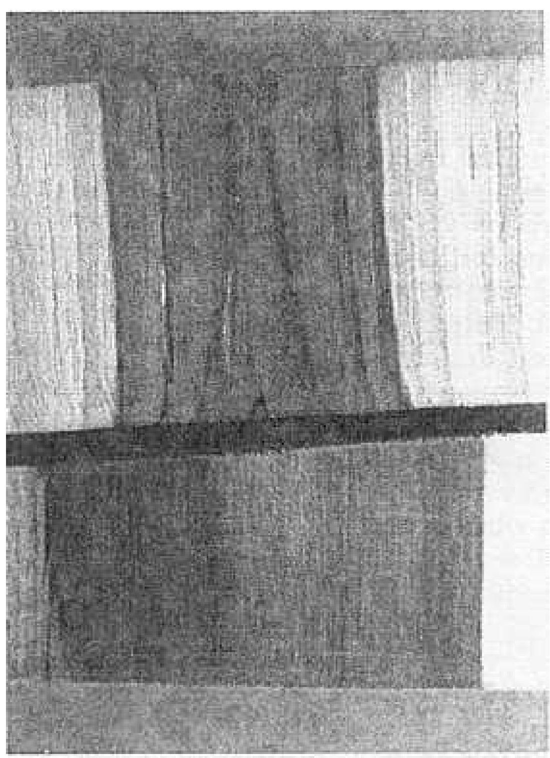


Fig. 7. Wood figure as displayed from plain sawn wood materials of traditional plantation (above) and high input management (below).

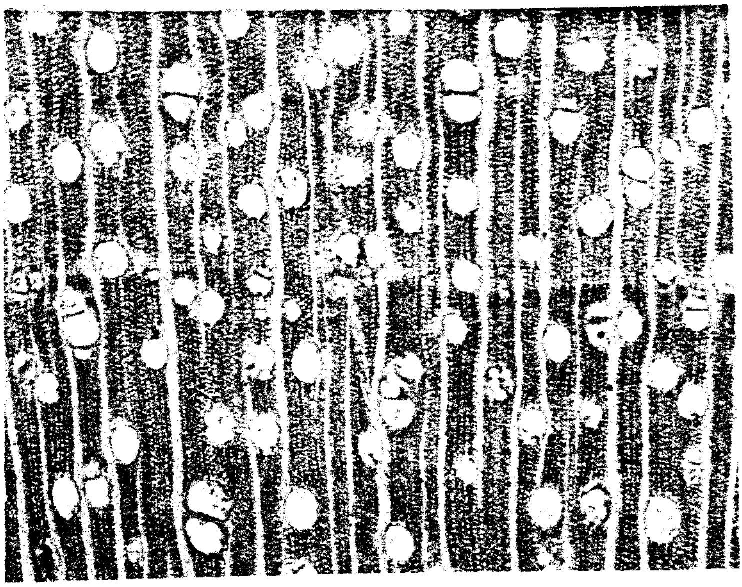


Fig. 8. Transverse section of fast grown wood from high input management showing the absence of typical ring-porous nature of teakwood.

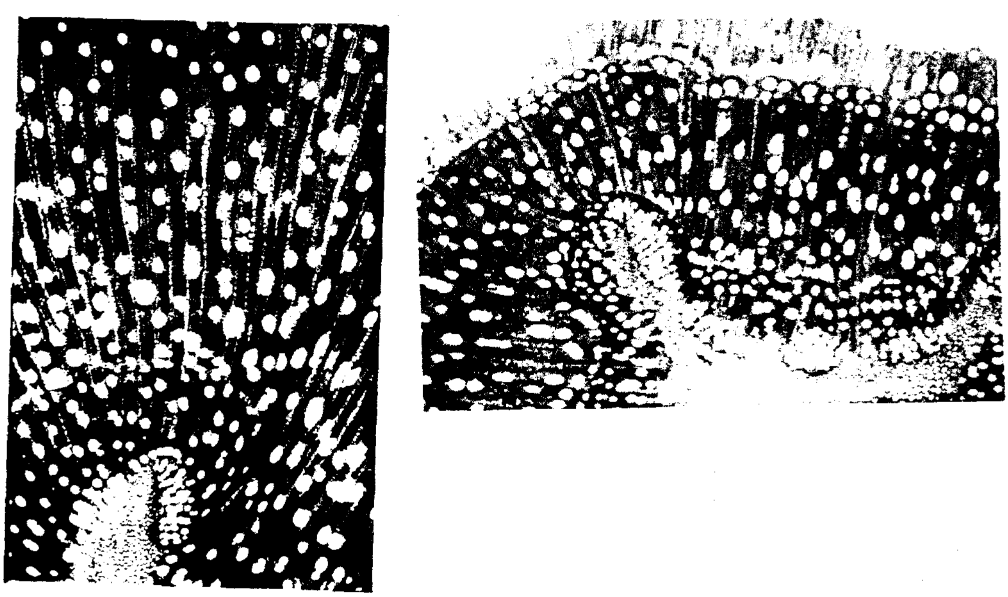


Fig. 9. Growth ring structure of one-year-old teak wood of high input management (left) and control plant (right) as seen from transverse sections

3.3.3. Anatomical and mechanical properties of 5-year-old wood

Air dry specific gravity and maximum bending and compression strength values in HIM were not found inferior, although due to the severe juvenility of 5-year-old trees, the stiffness (modulus of elasticity) was 76% of the standard teak value (Table 10). This suggests that there is no cause for concern with regard to the timber strength in 15-20 year old high input plantations when mechanical maturity is attained in teak (Bhat 2000).

Table 9. Comparison of anatomical, physical and mechanical properties of 5-year-old teak, grown under HIM and forest plantations (control), with the reported average values of mature and standard teak wood

PROPERTY	HIM MEAN	HIM S	CONTROL MEAN	CONTROL S	MATURE WOOD	STD TEAK
Ring width, mm	7.7	3.2	2.8	1.1	2.5[a]	
Vessel diameter, µm	118	16	136	7	196[a]	
Vessel, %	11.8	1.8	18.5	3.9	18.5[a]	
Fibre, %	50.0	1.6	63.5	3.2	51.1[a]	
Fibre wall thickness, µm			4.3	0.6		
Microfibrillar angle, ^{o}	21	1	19	1	10[a]	
Parenchyma (ray) , %	22.8	1.7	18.0	2.0	20[a]	
Heartwood %	33.0	3.4	18.0	2.0		
Basic SG	0.522	0.03	0.444[b]	0.03	0.570[a]	
MC, %	117.3	11.7				
Radial shrinkage, %	4.1	2.0			2.3[c]	
Tangential shrinkage, %	5.9	1.2			4.8[c]	
Vol. shrinkage, %	10.0	2.9			7.0[c]	
FS-EL, N/mm^2	86.3	10.7				
MOR, N/mm^2	111.0	12.3			124.2[a]	86.6[b]
MOE, N/mm^2	8141	2612			15746[a]	10753[b]
MCS, N/mm^2	45.9	5.5			47[a]	48[b]

[a]Bhat et al. 2000; [b]Rajput and Gulati 1983; [c]Nazma et al. 1981.

3.3.4. Heartwood and sapwood contents

The heartwood percentage increased with growth rate of the trees at age 5 years. As compared to the forest plantations, the 5-year-old trees of HIM yielded significantly higher heartwood percentage. However, heartwood proportion being small in very young trees (Table 10), longer than 5-year-rotation is recommended for higher heartwood volume per tree. The greater volume of sapwood (67%) available from juvenile trees will find application only after preservative treatment. Another important observation is that strength properties of sapwood are not inferior to those of heartwood even in juvenile wood (Table 11) although often sapwood of mature timber can be slightly weaker due to the definite pattern of radial variation in strength which often decreases with age along with the growth rate of the trees. The results of this study show that sapwood has often significantly higher stiffness (modulus of elasticity) and compression strength (parallel to grain). However, reduced natural durability of sapwood can pose problems in structural / solid wood uses unless the material is adequately treated with environment-friendly preservatives. With higher penetrability, sapwood is easier to treat with preservatives than the refractory heartwood.

Table 10. Comparison of inner (heartwood) and outer radii (sapwood) strength properties in 5-year-old teak grown under high input management (HIM)

PROPERTY	INNER RADII		OUTER RADII		SIGNIFICANCE
	MEAN	SD	MEAN	SD	
FS-EL, N/mm^2	82.8	4.8	92.0	13.9	ns
MOR, N/mm^2	107.7	11.1	117.1	11.5	ns
MOE, N/mm^2	7104	1861	9883	2496	*
MCS, N/mm^2	42.8	4.1	48.1	6.1	*

* Significant at 5% level; [ns] non-significant; [SD] Standard deviation

3.3.5. Anatomy and basic density of one-year-old wood

Comparison of properties of wood formed in the first year after planting in high input plantation with those of control plants showed that there was significant increase in ring width (and hence the stump diameter) associating with wider latewood (Fig. 9) and higher density (Table 12). The greater density is possibly due to higher cell wall percentage and slightly longer fibres of latewood. In contrast, earlywood width and vessel size (diameter) did not differ appreciably. This observation supports the view that fast grown juvenile teak produces wider latewood resulting in greater density of timber (Bhat 2000).

Table 11. Comparison of quantitative anatomy and specific gravity of treated seedlings under high input management with control seedlings (1-yr-old plots, Velupadam)

PROPERTY	TREATED		CONTROL		T-VALUE
	Mean	SD	Mean	SD	
Stump diameter , cm	6.2	2.8	4.8	2.2	*
Ring width (mm)	3.86	1.0	2.96	0.6	*
Earlywood width, mm	0.41	0.13	0.46	0.11	ns
Latewood width, mm	3.45	1.10	2.50	0.75	*
Vessel Diameter (µm)	92.6	12.0	81.6	9.9	ns
Vessel number per mm2	161	56.0	212	77.0	ns
Vessel (%)	13.6	2.8	13.9	3.3	ns
Fibre (%)	58.7	4.6	55.7	4.4	ns
Parenchyma (%)	28	4.2	30.6	5.6	ns
Cell wall (%)	56	5.0	48.0	6.7	*
Earlywood Fibre length (mm)	0.73	0.04	0.70	0.03	ns
Latewood Fibre length (mm)	0.78	0.02	0.75	0.03	*
Earlywood Fibrillar angle	28	1.7	28	2.0	ns
Latewood Fibrillar angle	27	2.0	27	1.9	ns
Basic density (kg/m3)	479	90	424	78	*

n = 14; Significant at 5% level; ns = Non-significant

3.3.6. Natural durability

The weight loss data of the test blocks exposed to the decay fungi are recorded in Table 14. The mean values indicate that weight loss of wood specimens due to attack of both the test fungi was 21% at the age of 5 years as against 7-12% in older and more mature timbers sampled from 13-, 21- and 55-year-old plantations. The 5-year-old juvenile teak wood falls under Class II (Resistant Timbers) while mature wood generally belongs to Class I (Highly Resistant Timbers) as per the general classification system (Bakshi et al., 1967; ASTM 1981). The present finding of relatively low decay resistance of 5-year-old wood is supported by the previous observations on lower durability of young plantation teak and inner heartwood of older trees (Da Costa et al. 1958; 1961; Bakshi et al., 1967). This is attributed to the lower extractive content of juvenile wood and its radial increase towards the outer heartwood region with age. According to Narayanamurti et al. (1962), the middle to outer heartwood which is richest in total extractives is the most durable part. Simatupang and Yamamoto (1999) suggest that determination of extractive content gives ample information on the natural durability of teak. Similarly, Bakshi et al (1967) made the observation that the decay resistance of inner heartwood of even very mature trees falls under Class II as against the outermost heartwood (in the region of 54 -97 rings from pith) under Class I as per the general classification of timbers against decay resistance (ASTM 1981).

The implication is that the juvenile wood grown in intensively managed plantations is not always inferior in natural durability to that grown in traditional plantations. However, compared to very mature timber, the lower decay resistance of juvenile wood restricts its utilisation to some extent although it is still superior to many other moderately resistant or less resistant timbers like eucalypts (Da Costa et al., 1958) raised in fast growing plantations. More detailed bio-deterioration studies, including decay resistance against brown rot-fungi, are suggested to evaluate the natural durability of short rotation teak timber harvested particularly before 20 years.

The analysis of variance was carried out using GLM procedure of SAS software to test the between- and within tree differences in decay resistance. The data had non-orthogonal structure due to missing observations on account of infection of other organisms. In the mixed effects linear model, the effects due to trees and radii (different directions) within trees were identified as random and the effect due to position (inner and outer) was considered as fixed. The adjusted sum of squares along with expected values of mean squares are shown in Table 15. Tree-to-tree differences in decay resistance against *Polyporus versicolor* were highly significant though not against *P. hirsutus*. The variation among the different radial directions was non-significant. There were also no systematic differences between inner and outer segments within the radii. (Tables 14 and 15). These results support the observations made by Da Costa et al., (1958) that some trees of teak commence to form durable heartwood at a very early age, whilst others to continue to produce non-durable heartwood for many years. This offers the probable explanation for Tree No. 7 showing distinctly low decay resistance to both the white rot fungi.

Table 12. Mean values of weight loss percentage of juvenile teak wood as compared with older trees against the attack of two white-rot fungi

Tree No.	Position in heartwood	*P. hirsutus*	*P. versicolor*
5-yr		% Weight Loss	% Weight Loss
1	Inner	18.1	19.3
	Outer	19.0	19.4
2	Inner	13.8	18.2
	Outer	18.9	18.7
3	Inner	21.3	16.5
	Outer	12.2	11.4
4	Inner	18.9	20.9
	Outer	21.2	22.1
5	Inner	22.0	22.0
	Outer	25.0	22.4
6	Inner	17.2	17.2
	Outer	12.4	17.8
7	Inner	30.1	36.5
	Outer	40.4	39.6
	Mean	20.8	21.4
	SD	7.0	7.8
	CV%	33.7	36.5
Control			
13-yr	mean	12.0	11.0
21-yr	mean	13	11.8
55-yr	mean	9.0	7.6

Table 13. ANOVA of decay resistance (% weight loss) of 5-year-old juvenile teak wood to two white-rot fungi

SOURCE OF VARIATION	D.F.	SUM OF SQUARES	MEAN SQUARE	F-VALUE
Polyporus hirsutus				
Between-tree	6	791.38	131.89	1.92 ns
Radii (Within-tree)	11	787.44	71.59	1.04 ns
Position (inner-outer heart wood)	1	7.05	7.05	0.1 ns
P. versicolor				
Between-tree	6	2134.87	355.81	8.62**
Radii (Within-tree)	18	459.88	25.55	0.62 ns
Position (inner-outer heart wood)	1	0.008	0.008	0.00 ns

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

4. CONCLUSIONS

Given the situation of time and resource constraints, not anticipated in the original study design, the present short-term study draws the following conclusions.

a) Fertilization and irrigation had significant effects on tree height and volume. Although d ebudding resulted in the formation of a clear bole, a small reduction in tree volume was observed. This aspect needs further investigation.

b) Absence of lower side branches facilitated deer damage which again is an adverse outcome of having clear bole in areas rich in deer population.

c) An observation of phyllotaxy variants in the experimental plantation revealed that 99.33% showed normal opposite decussate phyllotaxy, 0.6% whorled phyllotaxy and 0.07% alternate phyllotaxy; the phyllotaxy variants revert back to normal phyllotaxy when the leading shoot is damaged.

d) Wood density, maximum bending and longitudinal compressive stresses of 5-year-old teak grown under high input management (HIM) were not significantly inferior while stiffness of wood (modulus of elasticity) was only 76% of the Standard teak value. Faster growth due to irrigation and fertilisation in one-year-old seedlings increased the latewood width and fibre wall percentage resulting in higher wood density.

e) The five-year-old trees grown under HIM showed higher heartwood percentage than the trees of similar age from traditional forest plantations.

f) Wood figure (colour, grain, texture) was slightly different in view of the tendency of 1-3-year-old juvenile teak to loose the ring-porous nature of wood under extremely fast growing conditions. However, these wood figure changes had only localised effects and the differences in market value of the timber are expected to be minimal in older plantations of 15-20 years.

g) Five-year-old juvenile wood from high input plantations was less decay resistant than the mature teak wood of forest plantations. However, it was comparable in natural durability to the inner heartwood of very old teak and to the juvenile wood grown in relatively low input forest plantation. There was significant tree-to-tree variation in decay resistance against the white rot fungus, *P. versicolor*, indicating scope for genetic selection in developing wood of higher natural resistance in high input plantations.

The above results, though indicative in nature, may offer useful information to the agencies, which are concerned with tree farming particularly plantation entrepreneurs, farmers and the State Forest Departments / Forest Development Corporations.

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APPENDIX I

Analysis of variance for height, diameter at 15 cm, diameter at 137 cm and conical volume

Source of variation	DF	Height Aug 97 (2 months)		Height Nov 98 (17 months)		Height Feb 99 (20 months)		D15 Nov 98		D15 Feb 99	
		F value	P value*	F value	P value*	F value	P value*	F value	P value*	F value	P value*
Spacing	2	0.07	0.928	0.56	0.579	0.12	0.885	1.42	0.261	0.74	0.489
Fertilization (and irrigation)	1	0.65	0.427	34.11	0.000	21.61	0.000	30.11	0.000	13.64	0.001
Debudding	1	0.80	0.379	3.13	0.088	1.23	0.277	2.77	0.108	2.89	0.101
Spacing x Fertilization (and irrigation)	2	0.98	0.388	0.02	0.979	0.08	0.924	0.80	0.459	0.64	0.538
Spacing x debudding	2	0.70	0.504	0.30	0.744	0.24	0.785	0.75	0.482	0.23	0.792
Fertilization (and irrigation) x debudding	1	0.02	0.895	0.29	0.593	0.25	0.621	0.00	0.978	0.05	0.833
Spacing x fertilization (and irrigation) x debudding	2	2.48	0.104	0.03	0.970	0.14	0.872	0.14	0.871	0.31	0.734
T13 vs T14	1	0.87	0.359	0.07	0.788	0.12	0.736	0.68	0.416	0.42	0.522
(T13 + T14) vs rest	1	1.43	0.242	2.70	0.112	1.58	0.219	4.46	0.045	0.84	0.369
Replication	2	1.17	0.327	3.03	0.066	1.68	0.206	3.54	0.044	4.65	0.019
M square error	26	6.89		1660.78		2521.79		0.23		0.30	

* Significant at $P \leq 0.05$

(Continued …..)

Appendix 1 (continued)

Source of variation	DF	D137 Nov 98		D137 Feb 99		CV Nov 98		CV Feb 99	
		F value	P value*	F value	P value*	F value	P value*	F value	P value*
Spacing	2	1.23	0.310	0.35	0.708	0.87	0.430	0.27	0.768
Fertilization (and irrigation)	1	13.79	0.001	14.09	0.001	33.08	0.000	17.68	0.000
Debudding	1	0.30	0.586	0.00	0.950	0.24	0.627	0.59	0.449
Spacing x Fertilization (and irrigation)	2	0.58	0.565	0.59	0.561	0.62	0.544	0.50	0.611
Spacing x debudding	2	0.01	0.990	0.36	0.704	0.47	0.630	0.13	0.875
Fertilization (and irrigation) x debudding	1	0.41	0.530	0.03	0.875	0.02	0.892	0.02	0.882
Spacing x fertilization (and irrigation) x debudding	2	0.16	0.857	0.28	0.757	0.10	0.907	0.11	0.897
T13 vs T14	1	0.00	0.987	0.00	0.994	0.18	0.674	0.22	0.640
(T13 + T14) vs rest	1	1.77	0.195	1.66	0.209	4.51	0.043	1.64	0.211
Replication	2	2.29	0.121	3.39	0.049	2.62	0.092	3.21	0.057
M square error	26	0.26		0.28		3752.38		8057.55	

* Significant at $P \leq 0.05$