Evaluation of Provenances for Seedling Attributes in Teak (*Tectona grandis* LINN.F.)

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Summary

A provenance trial in teak (*Tectona grandis* LINN.F.) involving seven provenances from Kerala (India) was conducted during the period from June 1995 to January 1997. Data were compiled on germination characteristics and seedling performance in the nursery,and also on root growth potential and field establishment using stumps. Germination characteristics did not vary significantly among the provenances in the nursery. Analysis of variance demonstrated profound variation in seedling growth rates among the provenances. Parambikulam, Nilambur and Malayattur provenances consistently recorded better shoot and root growth, biomass allocation and relative growth rate, while the local provenance (Trichur) was poorest. Application of MAHALANOBIS' D^2 statistics revealed that a close similarity exists in among the fastest growing provenances. Root growth potential of the provenances was highly variable in most of the attributes like number of lateral and tertiary roots, length of three longest lateral roots and dry weight of lateral roots. Nilambur and Malayattur provenances were superior in this respect, while the local provenance (Trichur) produced the lowest means. Performance of the provenances in the field followed nursery growth patterns, confirming that growth is under strong genetic control. Grading of seedlings based on their height and collar diameter at an early age is recommended for selection of best preforming seedlings in the main field. Parambikulam, Nilambur and Malayattur are the best provenances suited for planting in Trichur District of Kerala, India.

Key words: Provenance variation, seedling attributes, *Tectona grandis.*

Introduction

Tectona grandis LINN.F., teak, is a tropical tree species with a wide natural distribution in southeastern Asia (KAOSA-ARD, 1981). In addition to fine growth characteristics and superior timber qualities, the species is reported to have a mean annual increment (MAI) of 4 to 18 m^3 ha^{-1} yr^{-1} on good sites (EVANS, 1982). Presently, teak is an important component of many plantation programs throughout the tropical world.

Naturally distributed in different climatic and edaphic zones, teak has developed different ecotypes during the processes of evolution. Wide variation in the performance of different ecotypes has been previously recognized (KEOGH, 1982; WHITE, 1993). Therefore, it is desirable to delineate and select the best available geographic source of seeds as planting materials in teak plantation programmes (KERTADIKARA and PRAT, 1995).

Although the Indian state of Kerala is relatively small (38,863 km^2), there appears to be considerable variation in teak trees growing in different regions (KADAMBI, 1972). The genetic component of this variation can be identified by provenance testing and exploited through selection of superior populations for seed collecting to improve yields (DUPUY and VERHAEGEN, 1993). Correspondingly, a study was conducted to identify provenances of teak from different agro-climatic regions of Kerala, that show superior vigor and growth attributes.

Materials and Methods

Nursery and field studies involving seven provenances of teak were conducted at the College of Forestry, Kerala Agricultural University, Vellanikkara, Kerala (India) during the period from June 1995 to January 1997. The location has a warm humid climate with a mean annual precipitation of 254 cm (1995 to 1996), most of which (78%) falls during June to September. The mean maximum monthly temperature ranges from 28.8°C (July) to 36.4°C (March) and minimum temperatures occur from 21.1°C (January) to 25.2°C (May). Soils at the experimental locations are oxisols.

Seven teak growing geographical regions, Arienkavu, Konni, Malayattur, Nilambur, Parambikulam, Wynad and Trichur (local provenance), in Kerala were selected as provenances *(Figure 1)* (VENKATESH et al., 1986; BEDELL, 1989). Six middle aged plantations (25 to 30 years) of local seed source were identified in each provenance, and seeds were collected from ten phenotypically superior trees in each plantation. Dominant or codominant trees with clear bole, well developed crown and devoid of infestations were selected as seed trees.

After collection,the seeds were bulked by provenance and subjected to alternate wetting and drying treatments for one week prior to sowing. Three nursery beds (12 m x 1.2 m x 0.5 m), each representing a replication, were prepared and randomly divided into seven plots of size 1.5 m x 1 m for sowing the seeds from seven provenances, i.e., a randomized complete block design. The pretreated seeds were dibbled in nursery beds at a spacing of 5 cm x 5 cm, so that each plot had 600 seeds in it.

Data were recorded on the days taken for first seedling emergence as characterized by the emergence of the radicle, the number of seedlings emerging on each day, and daily seedling mortality for 60 days after sowing (International Seed Testing Association, 1976). The germination data were expressed as germination capacity (GC), peak value (PV), and germination value (GV). Germination capacity was calculated from the percentage of seeds that had germinated at the end of the test; peak value was the maximum quotient derived by dividing daily the accumulated number of germinants by the corresponding number of days. This represents the mean daily germination of the most vigorous component of the seed lot, which is a mathematical expression of the tangent drawn through the origin of the sigmoid curve representing a typical course of germination (CZABATOR, 1962). Germination value is the combination of both the speed and completeness of germination into a single value and is the product of peak value and mean daily germination (CZABATOR, 1962).

Destructive sampling of three seedlings per provenance from each replication was conducted at intervals of 60 days over a

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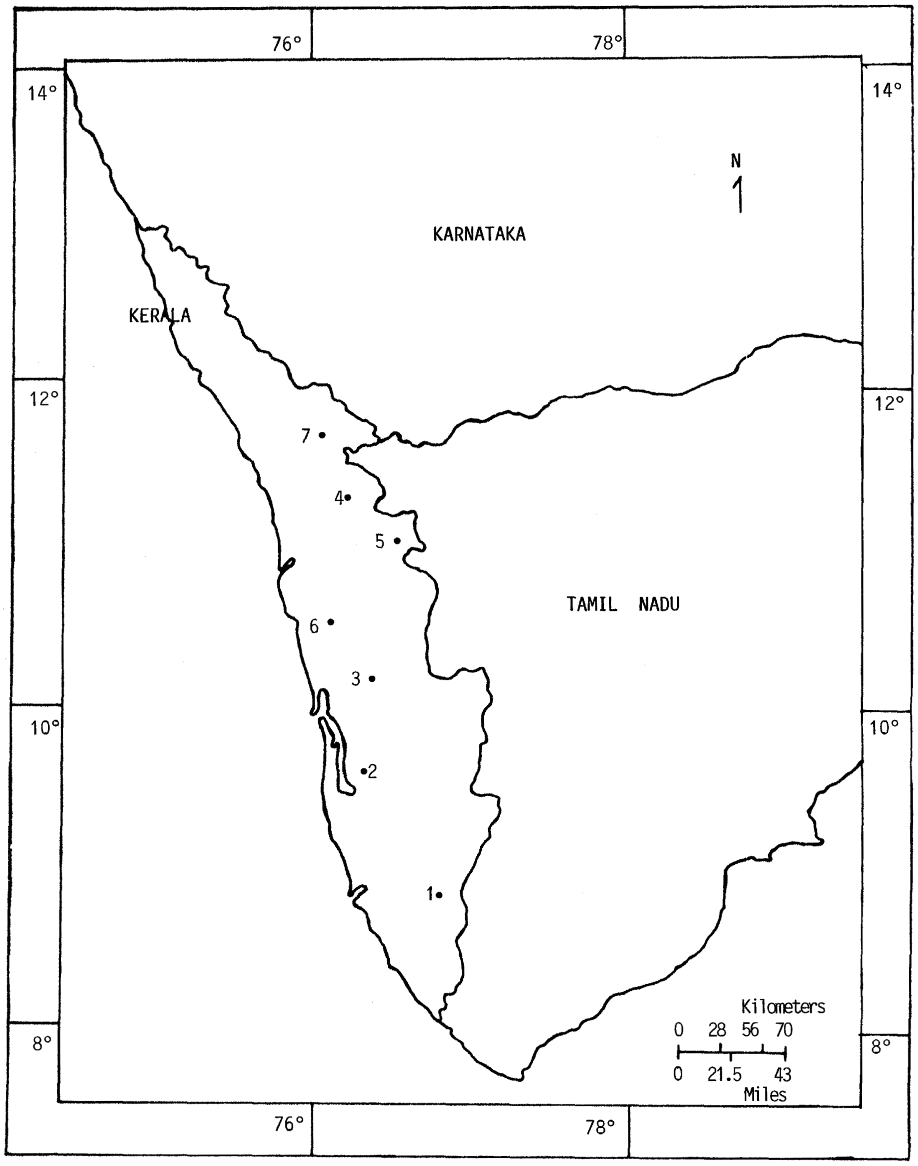


Figure 1. – Map showing the location of different provenances of *Tectona grandis* in the state of Kerala, India (o: 1-Arienkavu, 2-Konni, 3-Malayattur, 4-Nilambur, 5-Parambikulam, 6-Trichur, 7-Wynad).

360 day period. Seedling height, tap root length, collar diameter, leaf area, and also dry weight of root, shoot and leaf were recorded.

From the observations of shoot dry weight, relative growth rate (RGR), which is the rate of increase in size per unit of size (HUNT, 1990), was calculated using the formula:

$$RGR = (Log_e W_2 - Log_e W_1)/t_2\text{-}t_1$$

where W_2 is the dry weight estimate at time t_2 and W_1 is the dry weight estimate at time t_1.

The experimental data were statistically analysed by applying the technique of analysis of variance for factorial experiment using a randomised complete block design. Significant differences were detected by 'F' tests ($\alpha = 0.05$), and DUNCAN's Multiple Range Test was used for comparison of means (SNEDECOR and COCHRAN, 1967) using MSTATC statistical package.

Multivariate analysis was employed to examine the pattern of provenance variation considering a group of characters (seedling height, tap root length, collar diameter, shoot and root dry weight) simultaneously. MAHALANOBIS' "generalised distance function" (D^2 statistics), as outlined by RAO (1952), was used for estimating the genetic divergence among the seven provenances at 360 days after sowing. Provenances were appropriately grouped into different clusters on the basis of the square root of the average D^2 values, which gave the genetic distance 'D' between the provenances. For determining clusters, TOCHER's method was followed, as suggested by RAO (1952).

Growth behaviour of stumps in polythene bags

One year old seedlings (3 per provenance) from each replication were randomly selected to investigate root growth potential (RGP). Using a sharp knife, the shoot and tap root of each seedling were reduced retaining only 3 cm and 20 cm to 22 cm portion of the shoot and tap root, respectively, from the collar. All the lateral roots also were carefully removed without damaging the bark of the tap root.

Immediately afterwards, the modified seedlings (stumps) were planted in polythene bags (250 gauge) of size 35 cm x

16 cm filled with rooting medium of sand and soil in the 1 : 1 ratio. After 28 days the sprouted stumps were carefully removed and the number of sprouts per stump, number of lateral roots per stump, tertiary roots per stump, length of three longest lateral roots per stump and dry weight of lateral roots were recorded.

Field establishment

One year old seedlings were used to prepare stumps for field planting, which is the normal way of planting teak. The seedlings from each treatment were randomly selected for stump preparation as described above. Stumps were planted in a randomized complete block design (5 blocks) at a 2 m x 2 m spacing between 24 and 28 July 1996. There were 7 provenances and 9 stumps per provenance in each replication. Individual stumps were considered as plots. A single row boundary of teak stumps belonging to respective provenances were planted around the experimental planting to decrease edge effect. Observations of height of seedlings, number of functional leaves and collar diameter were recorded six months after planting.

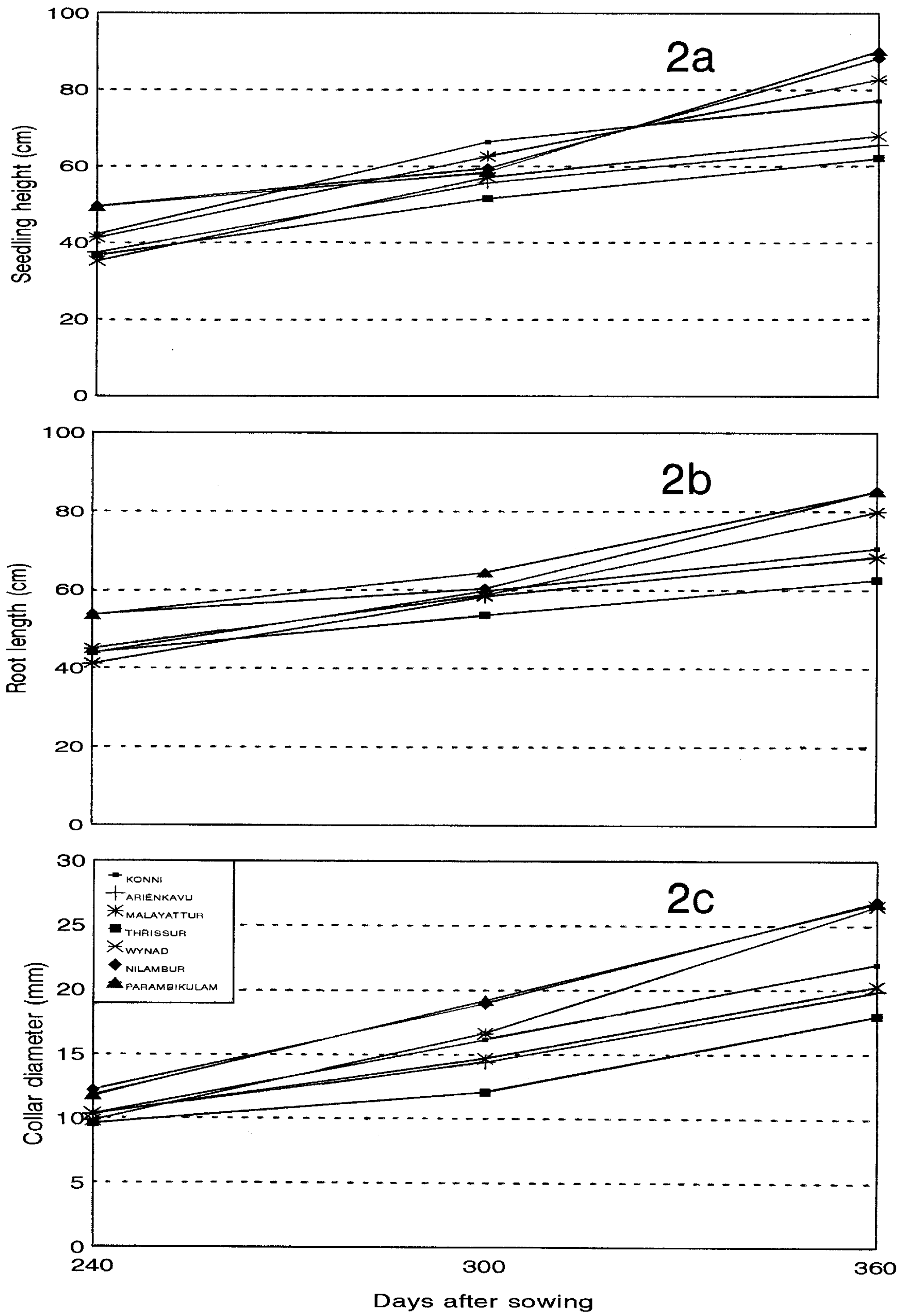


Figure 2. – Seedling characteristics of seven teak provenances at various stages of growth (2a-Seedling height, 2b-Root length, 2c-Collar diameter).

Correlation analysis

Correlation between the sboot height and collar diameter of seedlings at 360 days after sowing (DAS) in the nursery was calculated (P = 0.05 level). In root growth potential studies, dry weight of the lateral roots were correlated with the root dry weight of the seedlings prior to modifying them into stumps. The height and collar diameter of the sprouts in the field were also correlated with the seedling height and collar diameter of the seedlings determined prior to modifying them into stumps (P = 0.05 level).

Results and Discussion

Germination behaviour of seeds in the nursery was not significantly influenced by the provenances. Significant differences in seedling height and tap root length were observed among provenances at 60, 180, 240 and 360 DAS. Height and tap root length means were largest in the seedlings of the Parambikulam and Nilambur provenances at most observation intervals, followed by the Malayattur provenance at the final interval *(Figure 2a and b)*. These provenances also were characterised by significantly superior collar growth at 240, 300 and 360 DAS *(Figure 2c)*. Parambikulam, Nilambur and Malayattur provenances recorded the highest shoot dry weight during most of the period and were significantly superior to other provenances at 240, 300 and 360 days after sowing (*Figure 3a*). Root dry weight was also significantly superior in these provenances at 240 and 360 days after sowing *(Figure 3b)*.

The performance of a provenance depends partly on the site and seed source (GLOVER, 1987; CHADHAR, 1994). The prove-

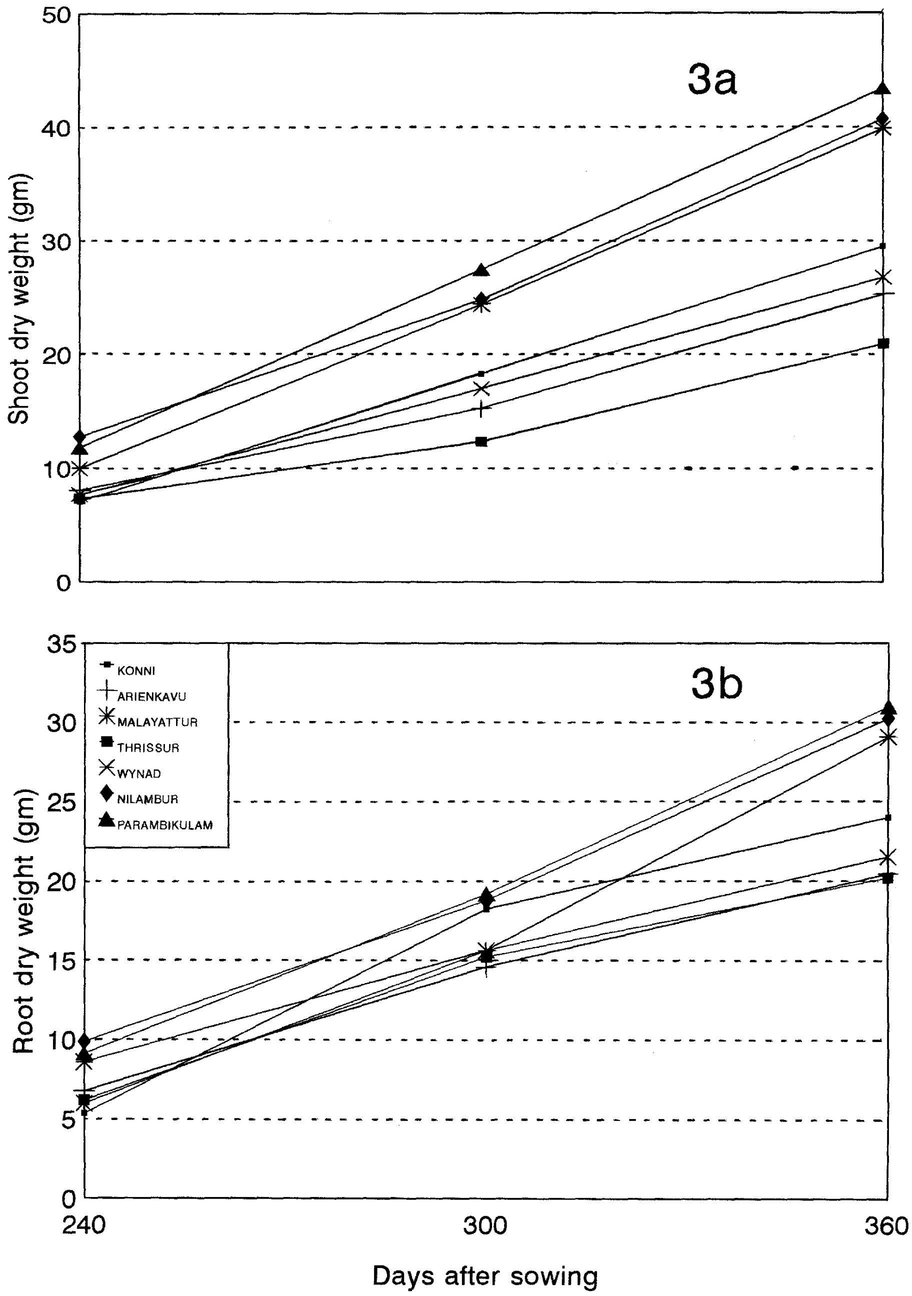


Figure 3. – Shoot and taproot dry weights of seedlings from seven teak provenances at various stages of growth (3a-Shoot dry weight, 3b-Taproot dry weight).

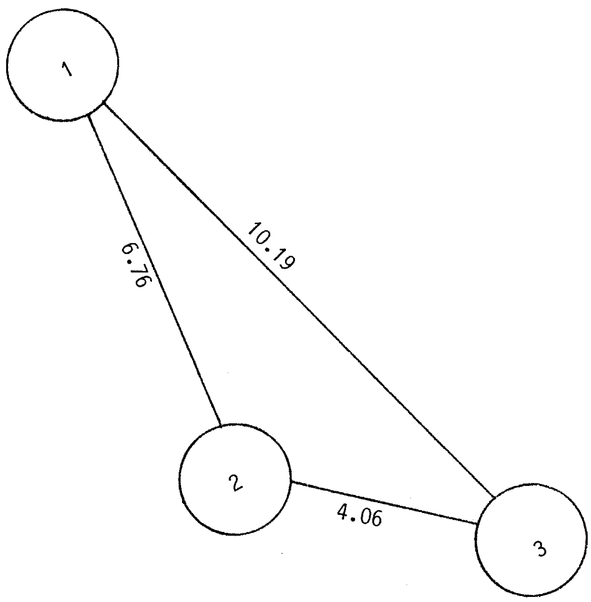
Table 1. – Mean Leaf area (cm^2) of seedlings from seven teak provenances (Least square mean separations are shown by letters. Means with same letters are not significantly different).

Provenance	Days after sowing		
	240	300	360
Konni	522.4^{AB}	2253.3^{AB}	2979.6^{BC}
Arienkavu	585.8^{AB}	1613.5^{B}	2937.9^{BC}
Malayattur	724.3^{A}	2910.1^{A}	3935.5^{AB}
Trichur	445.9^{B}	1228.0^{B}	2003.9^{C}
Wynad	439.9^{B}	2343.4^{AB}	2482.1^{C}
Nilambur	721.4^{A}	2944.6^{A}	4428.4^{A}
Parambikulam	678.9^{A}	3456.8^{A}	4663.6^{A}
CD (0.05)	214.32	1097.9	929.40
SEM (±)	75.38	385.81	396.16
CV (%)	28.43	20.17	18.92

nances which exhibited better performance during the initial stage of growth were found to be better throughout the growth observation period confirming the results of RAI *et al.* (1982) and GUPTA *et al.* (1992). Root growth patterns generally follow the same trend of height growth patterns (GLOVER, 1987). Experiments conducted by AMARA (1987) showed that the provenance which exhibited faster height growth was also characterized by quicker collar growth. The present study also indicated a positive relationship between height and collar diameter (r = 0.698), which is supported by the studies of AMARA (1987) and SUBRAMANIAN *et al.* (1991).

Leaf area per plant was significantly different among provenances only during the leaf shedding period (240 DAS) characteristic of deciduous species during dry summer season (during which period about 50% to 100% of the leaves are shed) and afterwards (300 and 360 intervals) *(Table 1).* Parambikulam, Nilambur and Malayattur provenances have significantly more leaf area per plant than other provenances tested during these periods. Significant variation in leaf dry weight among provenances was not evident until the 360 interval. Seedlings from Parambikulam provenance produced the largest amount of dry weight (17.237 g plant^{-1}), followed by the Nilambur Provenance (14.711 g plant^{-1}). In contrast, the Wynad Provenance (12.395 g plant^{-1}) produced the lowest amount of dry weight per seedling. Malayattur and Trichur provenances had similar dry weights (14.395 g plant^{-1}), whereas Konni recorded 13.432 g plant^{-1} in this respect. HAZARA and TRIPATHI (1986) reported that biomass production is a function of the photosynthetically active radiation on the leaves. As optimal leaf mass levels increase, biomass production would substantially increase. Due to higher leaf area and leaf dry weight, Parambikulam, Nilambur and Malayattur provenances may have higher potential for photosynthetic carbon fixation. This was reflected by the larger amount of dry matter production (shoot and root) by seedlings from these provenances in comparison to other provenances.

Relative growth rate (RGR – g g^{-1} week^{-1}x 10^{-2}) of the provenances were not significantly different at most of the stages except during the leaf shedding time (240 DAS). Nilambur provenance had the largest RGR (1.417) at that time, while seedlings of Konni provenance had lowest RGR (-4.456). The RGR of seedlings of the provenances decreased considerably during dry summer months due to shedding of leaves. Seedlings from Nilambur, Parambikulam (0.275) and Malayattur (0.402) provenances, however, exhibited a small decrease in RGR because of the reduced amount of leaf shedding when compared to Arienkavu (-3.366), Wynad (-3.222), Trichur (-3.188) and Konni Provenances. These results imply that the



Not to scale

Figure 4. – Diagramatic representation of provenance clusters of teak according to average between-cluster Mahalanobis' D^2 values (1-Malayattur, Nilambur and Parambikulam, 2-Arienkavu and Wynad, 3-Konni and Trichur).

Table 2. – Mahalabobis D^2 Values between the seven provenances of *Tectona grandis* (1. Arienkavu, 2. Konni, 3. Malayattur, 4. Trichur, 5. Wynad, 6. Nilambur, 7. Parambikulam).

Provenances	1	2	3	4	5	6	7
1	0.00	7.39	30.24	27.76	4.64	42.57	47.22
2		0.00	62.53	8.38	5.19	80.48	87.89
3			0.00	111.43	41.48	1.65	4.69
4				0.00	25.52	135.82	145.24
5					0.00	54.79	58.34
6						0.00	1.47
7							0.00

negative effect of leaf shedding and water stress on the RGR of these provenances was negligible. RAJESH et al. (1997) observed that negative effect of water stress on RGR was negligible in teak compared to *Pterocarpus marsupium* ROXB., *Acacia mangium* WILLD. and *Swietenia macrophylla* KING. RGR is a function of the dry matter production (MAGUIRE et al., 1990) and is an important factor determining linear increment pattern in teak (AKINDELE, 1989). However, seedlings showing low values in RGR when the soil moisture was limiting will exhibit slow growth (KOZLOWSKI, 1982).

Application of MAHALANOBIS D^2 analysis and TOCHER's clustering method resolved the seven provenances into three clusters. Malayattur, Nilambur and Parambikulam were the provenances in cluster I, Arienkavu and Wynad were in cluster II, Konni and Trichur provenances were in cluster III. The weighted mean of intracluster D^2 was 4.168. *Figure 4* shows the intercluster distances based on the average D^2 and D values which revealed that the maximum divergence occurred between clusters I and III and the minimum between II and III. Average D^2 values showing the genetic distance between provenances is furnished in *table 2*. It is clear that the genetic distance between provenances Parambikulam and Trichur (D^2 = 145.24) is largest, while there is a close proximity between provenances Parambikulam and Nilambur (D^2 = 1.47).

Application of MAHALANOBIS' D^2 statistics to evaluate the genetic divergence in tree crops is somewhat recent (PARAMATHMA, 1992). The inclusion of geographically divergent provenances of teak in the same cluster may be attributed to the fact that the factors other than geographic distribution might be responsible for their genetic similarity (SUBRAMANIAN et al., 1994). The studies of MANOJKUMAR (1994) in *Santalum album* L. and SINGH and CHAUDHARY (1992) in *Prunus armeniaca* LINN. support this conclusion.

The attributes related to root growth potential of stumps of the various provencences were highly variable *(Table 3)*. In the case of number of fresh lateral roots produced and length of 2nd and 3rd longest lateral roots per stump, Malayattur and Nilambur provenances had significantly more and longer lateral roots than other provenances. The local provenance (Trichur) recorded the lowest number of roots and Arienkavu provenance recorded the lowest root length. With respect to the total number of tertiary roots, the differences were significant and ranged from 106.3 (Trichur) to 255 (Malayattur). Nilambur provenance was characterized by relatively higher amount of dry weight from lateral roots per stump while the local provenance (Trichur) registered the lowest dry weight.

Generally, plants with high root growth potential (RGP) establish easily and perform well because of their ability to produce new roots promptly after planting (WAKELEY, 1959). RITCHIE (1982) reported that carbohydrates, growth regulators, or both are produced by shoots and are necessary for root growth. There was a positive relationship between stored carbohydrates or photosynthates present in the stumps and the development of healthy root system that resulted in better establishment. It is natural that the stumps with higher amount of reserve food materials performed well in subsequent evaluations (DAVIS et al., 1990; LEBOT, 1996). Variation in RGP was positively correlated with original root dry weight (r = 0.783). The high degree of expression in RGP probably resulted in the rapid root development as shown by LARSEN et al. (1986).

Statistically significant variation was observed in the establishment of stumps of the provenances in the field *(Table 4)*. An examination of the number of leaves produced per stump revealed that Malayattur and Nilambur provenaces had significantly higher means. Trichur provenance recorded relatively lower means in this respect. Parambikulam provenance was characterized by relatively higher rate of shoot height, closely followed by Nilambur and Malayattur provenances and was statistically superior to others tested. Again, the local provenance (Trichur) recorded the lowest mean.

Establishment of stumps of seven provenances in the field was similar to the nursery performance of the seedlings. Provenance performance appears to be under strong genetic control as suggested by GLOVER (1987). Experiments conducted by TEWARI (1994) showed that the quality and genetic potential of the seedlings used to prepare stumps have a strong influence on the performance of the stumps. The present study also indicated that height and collar diameter of plants from the stumps had a positive relationship between height and collar diameter of the seedlings prior to modifying them into stumps (r = 0.807 and r = 0.613 respectively). The study shows that selection of best performing seedlings in the field can be accomplished by grading seedlings at an early age by height and collar diameter. Based upon the study, it may be concluded that Nilambur, Parambikulam and Malayattur provenances are suited for planting in Trichur District of Kerala State, India.

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Table 3. – Variability in the growth characteristic of teak stumps from different provenances in polythene bags at 28 days after planting (Least square mean separations are shown by letters. Means with same letters are not significantly different).

Provenance	Sprouts per stump	Lateral roots per stump	Tertiary roots per stump	Dry weight of lateral roots (g $stump^{-1}$)	Length of three largest lateral roots per stump (cms)		
					First	Second	Third
Konni	2.55	9.77^{B}	166.4^{AB}	0.070^{B}	14.68	11.14^{BC}	9.76^{C}
Arienkavu	2.55	6.66^{BC}	123.0^{B}	0.058^{BC}	14.08	9.82^{C}	8.18^{C}
Malayattur	2.66	13.77^{A}	255.0^{A}	0.071^{B}	17.83	14.03^{AB}	13.21^{AB}
Trichur	2.11	6.00^{C}	106.3^{B}	0.046^{BC}	13.72	9.88^{C}	8.24^{C}
Wynad	3.88	7.00^{BC}	146.0^{B}	0.062^{BC}	13.84	11.22^{BC}	10.61^{C}
Nilambur	3.44	13.22^{A}	201.2^{AB}	0.129^{A}	16.86	15.54^{A}	13.97^{A}
Parambikulam	2.66	9.00^{BC}	153.6^{B}	0.088^{AB}	18.85	13.05^{AB}	10.08^{BC}
CD (0.05)	NS	3.373	89.12	0.042	NS	4.07	3.116
SEM (±)	0.500	1.186	31.34	0.015	1.773	1.432	1.095
CV (%)	62.87	28.06	27.11	28.97	33.88	25.51	20.89

Table 4. – Variation in stump growth of teak provenances grown in the field.(Least square mean separations are shown by letters. Means with same letters are not significantly different).

Provenance	Shoot height (cm)	Leaves per stump	Collar girth (cm)
Konni	33.3^{BCD}	5.9^{AB}	3.9^{B}
Arienkavu	33.9^{BCD}	5.5^{AB}	4.1^{B}
Malayattur	37.2^{ABC}	6.9^{A}	4.7^{A}
Trichur	30.8^{D}	5.2^{B}	3.8^{B}
Wynad	32.5^{CD}	6.1^{AB}	4.1^{B}
Nilambur	37.8^{AB}	6.7^{A}	5.1^{A}
Parambikulam	39.7^{A}	6.1^{AB}	4.9^{A}
CD (0.05)	4.802	1.344	0.406
SEM (±)	1.302	0.151	0.068
CV (%)	24.9	16.7	2.69

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A Nucleus Breeding Plan for Radiata Pine in Australia

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Abstract

The Southern Tree Breeding Association Inc. (STBA), consisting of 20 private companies and government agencies working cooperatively to breed improved varieties of radiata pine *(Pinus radiata)* for Australia, has adopted the concept of a nucleus breeding strategy entailing a total breeding population of 300 selections subdivided into two components: a nucleus population (which receives more emphasis in terms of breeding and testing and consists of the best 10% or so of the population) and a main population consisting of the remainder of the breeding population. This paper describes and compares three different plans for operational implementation of a nucleus breeding strategy by the STBA. The first option (Option 1) is the simplest entailing open-pollinated management of the main population and unified nucleus and main populations. The second two plans (Options 2a and 2b) employ complementary mating designs with pollen-mix management of the main population and a breeding population (consisting of the main and nucleus populations) that is further sub-divided into three unrelated lines. These lines serve as unrelated breeding groups to manage inbreeding in the deployment population. Options 2a and 2b differ only in the use of seedlings (Option 2a) or rooted cuttings (Option 2b) in unreplicated full-sib family plots used for within-family selection. The three options are compared in terms of costs, logistics, and detailed genetic gains predictions. In general, costs are similar for all three options and relatively small when compared with the overall STBA budget. Similarly, all three options are logistically feasible given the staffing and resources of the STBA. Thus, comparison of genetic gains represents the most meaningful criterion for deciding among the three options and in this regard, both Options 2a and 2b are clearly superior to Option 1. This is largely due to the pollen-mix management of the main population and the use of

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