KFRI Research Report No. 233 **ISSN 0970-8103**

STAND DYNAMICS OF SELECTED FOREST PLANTATION SPECIES OF KERALA

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Peechi - 680 653, Kerala, India
July, 2002

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(Final Report of the Research Project No: KFRI 345/2000)

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A project sponsored by KERALA FOREST DEPARTMENT (WB)

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ABSTRACT OF PROJECT PROPOSAL

1. Project number	:	KFRI 345/2000
2. Title of the project	:	Stand dynamics of selected forest plantation species of Kerala.
3. Objective	:	To estimate the growth rate of trees in permanent sample plots of major plantation species *viz., Tectona grandis, Eucalyptus tereticornis, Acacia auriculiformis, Ailanthus triphysa, Gmelina arborea, Albizia falcataria and Acacia mearnsii.*
4. Expected outcome	:	The database generated will serve as a base for a long-term study on the stand dynamics in respect of the species considered. Any subsequent measurement will provide data on increment which will ultimately lead to the development of growth simulation models. The data will be useful in developing yield prediction models and thus the study will generate information on productivity of the plantations at different site quality and stocking levels. Information will also be obtained on several allometric relations at tree and stand level.
5. Date of commencement	:	April 2000
6. Scheduled date of completion	:	March 2002
7. Funding agency	:	Kerala Forestry Project (WB) Kerala Forest Department
8. Project team		
Principal Investigator	:	K. Jayaraman
Project Fellow	:	V. Praveen
		G. Sunilkumar

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ACKNOWLEDGEMENTS

The author is thankful to Dr. J.K. Sharma, Director, Kerala Forest Research Institute, under whose leadership, this study was initiated. The project was executed using funds obtained from the World Bank through the Kerala Forest Department. The unstinted cooperation obtained from the Department while carrying out the field work is gratefully acknowledged.

Mr. Praveen V and Mr. Sunilkumar G. served as Research Fellows for this project and did an excellent job in the collection and also in the analysis of the data. The author also wishes to thank the Editorial Committee members, Smt. P. Rugmini, Shri. K.C. Chacko and Dr. Jose Kallarackal for offering many constructive suggestions to improve the presentation.

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ABSTRACT

A total of 91 permanent sample plots were established in plantations of the following species *viz.*, *Tectona grandis* (50), *Eucalyptus tereticornis* (15), *Acacia auriculiformis* (15), *Ailanthus triphysa* (3), *Gmelina arborea* (3), *Albizia falcataria* (3) and *Acacia mearnsii* (2). The basic purpose of the work was to study the stand dynamics based on remeasured data over a number of years so that useful information on growth and mortality of trees under varying site and stand conditions is obtained. The sample plots network was also to form a base for growth related ecological studies in the future. This report refers to only the initial phase of a long term programme of establishment and monitoring a set of sample plots in forest plantations in Kerala.

Representative regions within each Territorial Circle in Kerala were selected and sample plots mostly of size 40 m x 40 m were laid out in these regions, in plantations belonging to different age groups. The locations of the plots were identified in terms of latitude, longitude, altitude and the site map, and their identity with respect to the Forest Division and Range was established.

Basic measurements on trees in the sample plots were made and the site features were recorded for each plot. The measurements on trees included girth at breast height, total height and crown diameter. Summary information on various stand attributes was generated and was documented in this report for future reference, in a systematic manner. These plots are to be remeasured periodically to generate information on growth rate. Certain guidelines for maintenance, future measurement and data analysis are also provided.

I. INTRODUCTION

The State of Kerala has a long history of raising plantations in large scale. Currently, forest plantations occupy around 1,72,000 ha (KFD, 1999) which constitutes about 20 per cent of the forest area in the State. Some of the plantations have been excluded from regular management operations as they are in wildlife sanctuaries and national parks. With the ban on felling operations in natural forests, plantations have become an important source of timber and other forms of wood in the State. However, the productivity levels of most of the plantations are on the decrease (KFRI, 1997).

Scientific management of the plantations requires the use of reliable growth and yield prediction models. Individual tree growth models are required for evaluating many silvicultural options whereas whole stand models become necessary for making many stand level management decisions. This project was proposed in the context of absence of any systematic information on growth rates of trees under different stand and site conditions, based on remeasured data. The idea of reorienting this study to estimate the changes in growing stock and productivity of plantations in the State *in toto,* although discussed from time to time, was abandoned for want of adequate funds. The latter would have required a well-designed statistical survey as part of a continuous forest inventory plan. It was also noted that growing stock estimation is being carried out on a decennial basis in individual Forest Divisions as part of preparation of Working Plans. After initial discussions, the present project was structured so as to enable establishment of a set of permanent sample plots for long term monitoring and measurement of growth rate of trees under varying stand and site conditions.

As specified in the proposal, the following species *viz., Tectona grandis, Eucalyptus tereticornis, Acacia auriculiformis, Ailanthus triphysa, Gmelina arborea, Albizia falcataria* (*Falcataria moluccana*) *and Acacia mearnsii* were identified by the Forest Department for laying out the sample plots. The plan was to have sample plots in plantations belonging to different age groups distributed in different Territorial Circles so that a cross section of the age-site combinations is included in the sample plots network. The efforts made in this regard are described in the following sections. A short description of the species considered is provided below for general reference.

Teak (*Tectona grandis* L.f) of Verbenaceae family is a valuable timber species in the tropics. It is indigenous to the South Asian and the Southeast Asian regions. Kerala has the history of growing teak in plantation scale over 150 years. Presently, teak plantations occupy nearly 75,883 ha which is about 50 per cent of the area under forest plantations in the State. Compared to plantation crops in the agricultural sector, teak receives very low levels of input. Virtually no post-planting operations take place other than initial tending, periodical thinning and occasional removal of mistletoes. However, the species has come up well in some pockets such as Nilambur, Achencoil and Thenmala (KFRI, 1997). Teak yields high quality timber and the demand for the same is expected to remain high in the future.

Eucalyptus tereticornis Sm. is a fast growing, versatile and strongly coppicing species of the family Myrtaceae. It has been a successful species in low land areas with summer rainfall followed by moderate dry season. The wood is used for a wide range of purposes including charcoal, paper, poles, posts, mining timber, hard board and particle board, while the tree is used for shelter belts, shade and in apiculture. The major use of eucalypts in Kerala is for pulpwood. The species was introduced in a plantation scale in the State in 1970's and the area occupied presently is expected to be around 24,458 ha. Although some criticism was raised against its planting due to the high water use, the species continues to be grown in Kerala. With

the good coppicing ability of the species, it is possible to take one or two coppice crops after the initial seedling crop. In the recent times, with the introduction of high yielding and disease resistant clones, the potential of increasing the yield levels to very high order has been demonstrated in Kerala.

Acacia auriculiformis A. Cunn. Ex Benth is a leguminous nitrogen-fixing tree of the subfamily Mimosoideae. It is a fast growing exotic, adapted to a variety of environments. It is an ideal firewood and is planted for this purpose in India and other parts of Asia. The species is also valued for its timber and high quality chemical pulp. Acacia entered as a major component in social forestry programmes in Kerala since 1980's. Acacia plantations are seen throughout the State both in forest and nonforest environments. No exact figures relating to the area under acacia in the State is available as it is many times planted in mix (in blocks) with other species. Of late, the paper mills in the State have started to utilize this species for making pulp.

Ailanthus triphysa (Dennst.) Alston of family Simaroubaceae is comparatively rare but occurs throughout India in evergreen and seasonal forests. It is a fast growing tree reaching up to a height of 45 m, which produces a lightweight soft wood. It is the preferred wood for match splints and is also used for furniture parts, laminated wood assemblies, toys, and plywood cores and as plywood. It is also used for fuel wood and charcoal and is raised in plantations. The extent under pure stands of ailanthus in Kerala is around 500 ha. It is also found planted in mix with teak.

Gmelina arborea Roxb., belonging to family Lamiaceae, produces an important and valuable creamy-white timber which is sometimes called white teak. It is a fast-growing species that demands good site conditions. *G. arborea* is a medium-sized tree which produces a clear, but frequently bent, bole. It reaches 30 m tall on favourable sites. However, it can become shrubby in drier environments, such as in Punjab and other parts of India. *G. arborea* has low, obscure buttress and a yellowish-grey, smooth bole. The branches are numerous which spread to form a large shading crown. The corky bark is yellow inside and greyish-white outside when young, turning brown with age. The old bark then sheds, producing patches of paler bark on the bole. When the timber of *G. arborea* is adequately protected, it is excellent for house posts, boat decks, furniture, boxes, musical instruments, cars, railway carriages, matches, curing tobacco, building, panels and general carpentry work. It has also been used to manufacture plywood. *G. arborea* can easily be pulped and used for producing paper for various uses including wrapping, writing and printing. Plantations of gmelina are rare in Kerala.

Albizia falcataria, renamed as *Falcataria moluccana* (Miq.) Barneby & J. W. Grimes, is one of the fastest growing multipurpose tree species and coupled with other positive attributes, it is a suitable species for plantation programmes and agroforestry applications in the humid tropics. It has many uses but it is commonly planted as an ornamental and shade tree. Other uses of the species being tested include alley farming, intercropping in forest plantations and reforestation. The thin crown of *A. falcataria* provides partial shade to tea, cocoa and coffee. When managed as hedges, this species is able to produce 2-3 tonnes of green leaf manure/ha/year. Because of its fast growth, *A. falcataria* is often used in reforestation and afforestation of denuded lands, for firewood and charcoal production, and as an ornamental tree. Pure stands give a good protective cover in preventing erosion on slopes. The ability to coppice fairly well makes it suitable for pulpwood production. *A. falcataria* is also commonly used in agroforestry systems throughout its range.

A. mearnsii De Wild. is a native wattle of southeastern Australia. It is a fast-growing, nitrogen-fixing tree adapted to a wide range of sites, from the temperate and subtropical lowlands to tropical highlands. It yields bark extractives high in tannin, cellulose for rayon and paper, charcoal, and fuel wood. The use of *A. mearnsii* tannin for production of waterproof wood adhesives for reconstituted-wood industries is expanding. *A. mearnsii* grows to a large shrub or small tree, typically in the height range of 5-15 m but at times reaching 20 m with a breast-height diameter up to 45 cm but normally in the range of 10-35 cm. It is also a useful species for erosion control, soil improvement, shade and shelter, and ornament. In Kerala, plantations of *A. mearnsii* are restricted to High Ranges, which are mostly used as a source of firewood for tea estates. Most of these plantations happen to be in a poor state due to irregular harvests and human interference.

2. MATERIALS AND METHODS

The overall plan was to take representative Divisions from each of the Territorial Circles in Kerala and lay out plots in each of these selected Divisions for the species concerned in varying age groups, depending upon the availability of the area. Accordingly, plantations were selected from Kannur, Wayanad, Thrissur, Munnar and Thenmala Forest Divisions representing the five Territorial Circles *viz.*, Northern, Olavakkode, Central, High Range and Southern circles. However, the selection could not be restricted to these Divisions due to nonavailability of plantations of desired age group or the species. Plot size of 40 m x 40 m was adjudged to be of convenient size both in terms of technical requirement and practical feasibility. In practical terms, plot size of 40 m x 40 m is convenient that it is possible to lay out or realign such a plot and finish all the required measurements in one full day unless the plantation is too young to be having large number of trees. Technically the largest spacing expected between trees is in teak plantations which have reached rotation age. The expected number of trees under site quality I at 60 years is around 16, in 40 m x 40 m plot which is good enough for developing individual tree growth models. However, slight changes in the plot size were made in certain cases depending upon the local conditions.

Sample plots were established in each of the selected plantations. Girth at breast-height *i.e.*, at 1.37 m above ground level, was measured for all the trees qualifying for the same in the plots. For trees having height less than 1.37 m or having girth at breast-height below 10 cm, actual height was recorded. Height was recorded on a subsample of five trees covering the range of girth values in each plot. Crown diameter was measured for a sub-sample of 5 to 10 trees covering the range of diameter at breast-height, in two directions, one in the direction of maximum width and the other perpendicular to the previous one. Tree position was identified by coordinates with origin as one of the corners of the plot. The proforma used for recording the measurements is given in Appendix 3.

The trees in the sample plots were marked with white paint at breast-height level. Also the border trees were marked with red paint. A board containing information regarding the project number, size of the plot, plot number etc. was hung on one of the corner trees and a concrete post was put at the same corner of the plot. No other markings were made on trees except the expanding coiled wires fixed on the four corner trees. The plots are expected to be under the regular management operations of the Department.

Computer programmes were prepared to process the above data and to generate plot level summary reports, providing information related to various aspects of the crop growth. The computations involved in generating the various summary statistics are detailed below.

The basic set of biometrical measurements recorded at the tree level included girth at breast-height, total height and crown diameters in two directions. Let n denote the number of trees in the plot, g_i the girth at breast-height of ith tree in the plot in cm, h_i the height of the ith tree in the plot in m, and A the area of the plot in m^2.

Density : Observations on the number of live trees in the plot at the time of data collection were utilized to compute the stocking per ha for each plot.

$$N = \frac{n \times 10000}{A} \qquad (1)$$

Crop diameter : Crop diameter was calculated as the diameter corresponding to mean basal area of trees in the plot.

$$\bar{d} = \frac{1}{100 \times \pi} \sqrt{\frac{\sum_{i=1}^{n} g_i^2}{n}} \qquad (2)$$

Basal area : Basal area ha^{-1} for each plot was worked out using the formula,

$$B = \frac{\sum_{i=1}^{n} g_i^2}{4 \times \pi} \times \frac{10000}{A} \qquad (3)$$

Crop height : Crop height was computed as the mean predicted or actual height of trees in the plot as the case may be.

$$\bar{h} = \frac{\sum_{i=1}^{n} \hat{h}_i}{n} \qquad (4)$$

where $\hat{h}_i$ is the predicted height of the *i*th tree.

Tree height for each tree was predicted, when needed, using a local height-diameter relationship developed for each plot. A linear regression equation of the following form was utilized for the purpose.

$$\ln h = a + b \ln d \qquad (5)$$

where ln indicates natural logarithm
h = height of the tree (m)
d = diameter at breast-height (m)
a, b are the parameters to be estimated

The coefficients of the equation worked out for the different plots are given in Appendix 1.

Volume : The commercial volume of trees was calculated using the following prediction equations which were available. The volume was not computed for species for which such equations were not available for the region.

Volume equation for *Tectona grandis* (Chaturvedi, 1973a)

$$\sqrt{v} = -0.1825 + 3.1679d \qquad (6)$$

where *v* = Volume of timber and smallwood (m^3)
d = Diameter at breast-height (m)

Volume equation for *Eucalyptus tereticornis* (Chaturvedi, 1973b)

$$\sqrt{v} = -0.0840 + 2.511d \qquad (7)$$

where *v* = Volume of wood over bark up to a limit of 10 cm girth over bark (m^3)
d = Diameter at breast-height (m)

Volume equation for *Acacia auriculiformis* (Jayaraman and Rajan, 1991)

$$\ln v = 1.0683 + 0.8680 \ln d - 0.3699 (\ln d)^2 \quad (8)$$

where v = Volume of wood over bark up to a limit of 10 cm girth over bark (m^3)
d = Diameter at breast-height (m)

Top height : Top height was computed as the height corresponding to the quadratic mean diameter of the largest 250 trees (by diameter) per hectare as read from the height diameter relation of Equation (5) developed for each plot.

Site quality: For teak, the top height obtained for each plot was compared with the age vs top height table given in the yield table for *Tectona grandis* (FRI and Colleges, 1970) and site quality of each plot was ascertained. For *Acacia auriculiformis,* the table reported in Jayaraman and Rajan (1991) was utilized for the purpose. For other species, reference tables for evaluating site quality were not available.

Crown diameter : Crown diameter was measured for a sub-sample of trees in two directions perpendicular to each other. Crown diameter1 (cw_1) is the maximum width of the crown measured on the ground by dropping perpendiculars from the edges of the crown and crown diameter2 (cw_2) is the crown diameter measured in the diametrically opposite direction to that of maximum width. The mean crown diameter (w) for each tree was calculated as

$$w = \sqrt{\sum_{i=1}^{n} \frac{\left(cw_1^2 + cw_2^2\right)}{2}} \quad (9)$$

A prediction equation of the following form was developed to predict mean crown diameter at the tree level based on diameter at breast height, for each species.

$$\ln w = a + b \ln d \quad (10)$$

where w = Mean crown diameter of the tree (m)
d = Diameter at breast-height (cm)

The coefficients of the equation worked out for the different species are given in Appendix 2.

Developing such a prediction equation for each plot was not attempted because the relation between crown diameter and diameter at breast-height was found weak. Using the prediction equation established for each species, mean crown diameter for each tree was predicted. Quadratic mean crown diameter for each plot was then computed using the formula,

$$\overline{w} = \sqrt{\frac{\sum w_i^2}{n}} \quad (11)$$

where $\overline{w}$ = Mean crown diameter of the stand (m)
w_i = Predicted mean crown diameter of the ith tree (m)
n = Number of trees in the plot

Basal area and number of trees per hectare of trees other than the planted species in each plot were also calculated using formulae similar to those reported above.

3. RESULTS AND DISCUSSION

3.1. Details of sample plots

The lists of permanent sample plots established for each species along with the details are given below. A necessary adjunct of this report is the original data which is not reproduced here but provided separately in a CD.

3.1.1. *Tectona grandis*

Table 3.1. Status of sample plots established in *Tectona grandis* plantations in Kerala

Sl No.	Plot no.	Circle	Division	Range	Name of plantation	Extent (ha)	Year of planting
1	13	Central	Chalakudy	Vellikulangara	Chokkanna	40.20	1954
2	12	Central	Chalakudy	Pariyaram	Mullapana	200.40	1960
3	20	Central	Malayatoor	Kodanad	Kaprikad B	4.05	1950
4	17	Central	Malayatoor	Kodanad	Thodakayam	14.60	1983
5	21	Central	Thrissur	Machad	Kalapara	64.35	1944
6	57	Central	Thrissur	Pattikkad	Kuthiran	45.02	1965
7	6	Central	Thrissur	Pattikkad	Pullamkandom	71.26	1978
8	14	Central	Vazhachal	Vazhachal	Choozhimeedu	100.00	1973
9	16	Central	Vazhachal	Vazhachal	Ponjanamkttu	4.48	1990
10	70	High Range	Kothamangalam	Kothamangalam	Thattekad	40.89	1956
11	35	High Range	Kothamangalam	Thodupuzha	Valiyakandam	12.85	1957
12	36	High Range	Kothamangalam	Kothamangalam	Thadikulam	25.92	1963
13	73	High Range	Kothamangalam	Mullaringad	Chattamattom	10.00	1965
14	43	High Range	Kothamangalam	Kothamangalam	Charupara	104.90	1973
15	72	High Range	Kothamangalam	Kothamangalam	Avolichal	125.40	1978
16	71	High Range	Kothamangalam	Kothamangalam	Thattekad	52.76	1996
17	40	High Range	Kottayam	Ayappankovil	Kallar	12.14	1941
18	41	High Range	Kottayam	Ayappankovil	Ayappankovil	130.50	1967
19	42	High Range	Munnar	Neriyamangalam	Neriyamangalam	8.82	1952
20	45	High Range	Munnar	Neriyamangalam	Neendapara	13.60	1984
21	87	Northern	Kannur	Kasaragod	Parappa	19.59	1946
22	86	Northern	Kannur	Kasaragod	Parappa	41.93	1958
23	85	Northern	Kannur	Kasaragod	Baluvanthadukka	38.00	1999
24	38	Northern	Wayanad	Tholpetti	Camp road	27.12	1953
25	79	Northern	Wayanad (N)	Begur	Shanamangalam	66.62	1963
26	81	Northern	Wayanad (N)	Begur	Alathur	3.65	1965
27	89	Northern	Wayanad (N)	Begur	Alathur	6.07	1974
28	37	Northern	Wayanad (S)	Chedalath	Bhoodanam	50.00	1978
29	77	Northern	Wayanad (S)	Chedalath	Padiri north	55.00	1983
30	105	Olavakkode	Mannarkkad	Attappady	Pottikal	19.93	1960
31	104	Olavakkode	Mannarkkad	Mannarkkad	Panakadan	7.89	1960
32	31	Olavakkode	Nilambur (N)	Nilambur	Panayamkode	11.76	1950
33	22	Olavakkode	Nilambur (N)	Nilambur	Valluvassery	29.40	1952
34	1	Olavakkode	Nilambur (N)	Vazhikadavu	Nellikuthu	3.80	1957
35	19	Olavakkode	Nilambur (N)	Vazhikadavu	Punchakolli	51.00	1977
36	3	Olavakkode	Nilambur (N)	Nilambur	Valluvassery	12.87	1982
37	2	Olavakkode	Nilambur (N)	Vazhikadavu	Nellikuthu	61.12	1986
38	4	Olavakkode	Nilambur (N)	Nilambur	Valluvassery	55.00	1995
39	5	Olavakkode	Nilambur (N)	Nilambur	Karimkoramanna	7.84	1999
40	15	Olavakkode	Nilambur (S)	Karulai	Churulipotti	20.04	1949
41	33	Olavakkode	Nilambur (S)	Karulai	Sankarankode	81.08	1961
42	32	Olavakkode	Nilambur (S)	Karulai	Poolakkappara	55.14	1969
43	44	Olavakkode	Nilambur (S)	Karulai	Nedumkayam	24.59	1974
44	63	Southern	Achenkovil	Achenkovil	Muthalathodu	11.49	1957
45	61	Southern	Punalur	Anchal	Kadamankadu	30.35	1948
46	58	Southern	Punalur	Pathanapuram	Mukkadavu	6.50	1976
47	102	Southern	Ranni	Ranni	Pampa Valley	10.00	1984
48	56	Southern	Thenmala	Arienkavu	Thalappara	14.43	1964
49	53	Southern	Thenmala	Arienkavu	Palaruvi	29.50	1985
50	55	Southern	Thenmala	Arienkavu	Karimpinthotam	9.10	1995

Table 3.1. (Contd.)

Sl no.	Plot no.	Initial spacing (m x m)	Date of measurement	Plot size (m x m)	*Slope category	Aspect	Rotation	Longitude East (degree)	Latitude North (degree)	Altitude (m)	Site quality
1	13	2 x 2	01/12/00	40 x 40	G		I	76.415	10.390	100	IV
2	12	2 x 2	30/11/00	40 x 40	G	SE	I	76.479	10.347	100	II
3	20	2 x 2	21/12/00	40 x 40	G	SE	II	76.552	10.009	100	III
4	17	2 x 2	04/01/01	40 x 40	S	NW	I				III
5	21	2 x 2	28/12/00	40 x 40	S	W	II	76.352	10.655	100	IV
6	57	2 x 2	02/02/01	50 x 50	M	N		76.359	10.595	118	II
7	6	2 x 2	24/10/00	40 x 40	S	NW	I	76.314	10.595	100	III
8	14	2 x 2	12/12/00	40 x 40	M	SE	I	76.634	10.308	100	IV
9	16	2 x 2	13/12/00	40 x 40	G	SW	II	76.599	10.305	100	III
10	70	2 x 2	12/11/01	40 x 40	G	SW	I	76.676	10.132	292	II
11	35	2 x 2	27/03/01	50 x 50	P		I	76.830	10.409		II
12	36	2 x 2	30/03/01	50 x 50	G	S	I	76.725	10.176		III
13	73	2 x 2	15/11/01	40 x 40	G	NE	I	76.739	10.019	56	III
14	43	2 x 2	24/04/01	50 x 50	M	W	I	76.895	10.210		III
15	72	2 x 2	14/11/01	40 x 40	M	N	I	76.745	10.074	84	II
16	71	2 x 2	13/11/01	40 x 40	G	SW	II	76.674	10.111	73	
17	40	2 x 2	18/04/01	50 x 50	S	E	I				IV
18	41	2 x 2	19/04/01	50 x 50	S	SE	I				IV
19	42	2 x 2	23/04/01	50 x 50	G	SE	I	76.545	10.161		III
20	45	2 x 2	05/09/01	40 x 40	S	N	I	76.837	10.023	150	II
21	87	2 x 2	29/12/00	50 x 50	M	E		75.259	12.572	64	IV
22	86	2 x 2	10/05/00	40 x 40	M	SW	I	76.267	12.575	117	IV
23	85	3 x 3	03/01/02	40 x 40	S	NE	II	75.186	12.528	100	
24	38	2 x 2	07/04/01	50 x 50	G	W	I	76.067	11.924	824	III
25	79	2 x 2	08/12/01	40 x 40	M	SW	I	76.097	11.849	824	III
26	81	2 x 2	09/12/01	40 x 40	M	NE	I	76.077	11.880	824	II
27	89	2 x 2	05/01/02	40 x 40	G	E	I	76.074	11.866	824	II
28	37	2 x 2	06/04/01	50 x 50	G	S		76.134	11.799	824	III
29	77	2 x 2	05/12/01	40 x 40	G	NW	I	76.137	11.823	824	III
30	105	2 x 2	27/02/01	50 x 50	P		I	76.555	11.070	104	II
31	104	2 x 2	01/03/01	50 x 50	G	S		76.394	11.018	112	
32	31	2 x 2	15/03/01	40 x 40	G	P		76.245	11.316	56	II
33	22	2 x 2	15/02/01	50 x 50	G			76.262	11.302	61	IV
34	1	2 x 2	12/10/00	40 x 40	G			76.354	11.354	61	I
35	19	2 x 2	06/02/01	50 x 50	M	NE		76.383	11.386	140	III
36	3	2 x 2	17/10/01	40 x 40	G			76.261	11.331		IV
37	2	2 x 2	13/10/00	40 x 40	G			76.350	11.357	54	I
38	4	2 x 2	17/10/00	40 x 40	G	S		76.262	11.328	57	I
39	5	3 x 3	19/10/00	40 x 40	G		II	76.275	11.326	56	
40	15	2 x 2	10/02/01	50 x 50	P			76.359	11.284		III
41	33	2 x 2	09/03/01	40 x 40	G		II	76.324	11.310	56	II
42	32	2 x 2	14/03/01	40 x 40	G		I	76.367	11.354	61	I
43	44	2 x 2	08/02/01	50 x 50	G	N		76.351	11.289	56	IV
44	63	2 x 2	07/10/01	40 x 40	S	N		77.132	9.087	264	III
45	61	2 x 2	10/03/01	50 x 50	G	E		77.053	8.894	209	III
46	58	2 x 2	08/10/01	40 x 40	G	S	I	77.017	9.023	264	II
47	102	2 x 2	25/01/01	20 x 20	M	S					I
48	56	2 x 2	22/09/01	40 x 40	S	SE	II	77.140	8.973	333	III
49	53	2 x 2	18/09/01	40 x 40	S	N	II	77.149	8.955	272	III
50	55	2 x 2	21/09/01	40 x 40	P		II	77.157	8.980	285	I

*Slope category : G –Gentle, M- Moderate, S- Steep, P - Plain

Aspect : N – North, S – South, E – East, W – West, NE – North East, NW- North West, SE-South East, SW- South West.

Table 3.1. (Contd.)

Sl no.	Plot no.	Age (year)	Density (no. ha^{-1})	Basal area (m^2ha^{-1})	Crop diameter (cm)	Crop height (m)	Crown diameter (m)	Volume (m^3ha^{-1})	MAI of volume (m^3 ha^{-1} yr^{-1})	Density of other trees (no. ha^{-1})	Basal area of other trees (m^2ha^{-1})
1	13	46	200	14.61	30.50	17.02	6.74	122.25	2.66	150	1.70
2	12	40	225	15.94	30.00	23.94	6.82	134.31	3.36	112	3.30
3	20	50	275	18.92	29.60	19.16	6.78	158.02	3.16	0	0.00
4	17	18	1063	11.68	11.80	10.26	3.33	11.31	0.67	212	3.68
5	21	56	331	16.42	25.10	15.90	5.98	125.94	2.25	49	3.60
6	57	36	164	12.08	30.60	20.82	6.86	102.85	2.94	52	2.25
7	6	22	969	13.60	13.40	9.76	3.56	44.52	2.02	619	2.81
8	14	27	131	5.55	23.20	12.99	5.59	40.74	1.51	176	6.87
9	16	10	1531	9.45	8.90	6.12	2.68	1.04	0.10	13	0.74
10	70	45	106	13.02	39.50	27.42	8.44	121.69	2.77	6	0.39
11	35	44	188	19.40	36.20	25.51	7.87	176.99	4.12	0	0.00
12	36	38	288	11.82	22.90	17.66	5.54	83.07	2.25	36	0.27
13	73	36	200	8.44	23.20	16.69	5.61	58.38	1.67	30	0.51
14	43	28	592	15.49	18.20	13.66	4.59	86.98	3.22	240	2.98
15	72	23	263	12.07	24.20	21.45	5.80	88.79	4.04	61	1.15
16	71	5	2600	4.47	4.70	3.56	1.66	0.00	0.00	12	0.04
17	40	60	352	18.04	25.50	16.27	6.01	139.14	2.36	76	2.29
18	41	34	508	14.84	19.30	12.30	4.89	82.15	2.49	0	0.00
19	42	49	188	23.88	40.20	18.10	7.51	225.71	4.70	60	9.74
20	45	17	488	10.46	16.50	13.99	4.29	49.44	3.09	112	4.17
21	87	54	236	5.45	17.10	11.99	4.47	20.84	0.39	40	0.98
22	86	42	325	7.79	17.50	13.55	4.43	32.60	0.78	50	2.11
23	85	3	1394	1.52	3.70	4.34	1.46	0.00	0.00	25	0.02
24	38	48	120	17.88	43.60	23.20	9.20	173.31	3.69	16	0.05
25	79	38	231	15.56	29.30	16.19	6.73	128.99	3.49	95	0.73
26	81	36	188	20.55	37.30	26.07	8.06	188.77	5.55	88	4.44
27	89	28	394	18.04	24.20	18.58	5.78	133.67	5.14	169	4.01
28	37	23	628	14.31	17.00	13.31	4.45	59.19	2.69	28	0.89
29	77	18	1006	17.26	14.80	12.32	3.89	77.75	4.57	37	0.13
30	105	41	336	35.66	36.80	24.45	7.94	327.75	8.19	4	0.03
31	104	41	272	21.20	31.50	0.27	7.08	182.74	4.57	0	0.00
32	31	51	175	20.65	38.80	26.80	8.30	192.29	3.85	6	0.02
33	22	49	196	12.02	27.90	11.85	6.48	97.99	2.04	0	0.00
34	1	43	131	16.83	40.40	28.93	8.54	159.36	3.71	0	0.00
35	19	24	336	6.74	16.00	13.18	4.20	28.15	1.22	108	1.52
36	3	19	1025	6.66	9.10	6.34	2.70	5.03	0.28	0	0.00
37	2	14	1069	11.24	11.60	12.69	3.26	22.27	1.59	0	0.00
38	4	5	1981	12.90	9.10	8.46	2.76	4.73	0.95	0	0.00
39	5	1	1044	0.51	2.50	2.30	1.05	0.00	0.00	0	0.00
40	15	52	164	20.93	40.30	20.48	8.52	198.21	3.89	120	2.18
41	33	40	188	13.79	30.60	23.91	6.95	116.92	3.00	0	0.00
42	32	32	169	14.74	33.30	25.97	7.41	129.97	4.06	24	0.51
43	44	27	316	8.92	19.00	11.94	4.82	50.25	1.93	248	3.39
44	63	44	300	21.32	30.10	19.07	6.65	188.69	4.39	186	1.42
45	61	53	308	9.05	19.30	19.08	4.91	48.92	0.94	96	5.24
46	58	25	525	17.27	20.50	16.59	5.08	106.62	4.44	6	0.03
47	102	17	575	11.00	15.60	14.67	4.15	43.93	2.75	200	0.41
48	56	37	563	14.93	18.40	15.70	4.51	101.77	2.83	113	2.52
49	53	16	988	11.53	12.20	8.13	3.35	30.38	1.96	37	1.11
50	55	6	2081	15.37	9.70	9.67	2.91	0.00	0.00	0	0.00

3.1.2. *Eucalyptus tereticornis*

Table 3.2. Status of sample plots established in *Ecalyptus tereticornis* plantations in Kerala

Sl no.	Plot no.	Circle	Division	Range	Name	Extent (ha)	Year of planting
1	90	Central	Thrissur	Wadakkanchery	Chittenda	23.42	1965
2	94	Central	Thrissur	Wadakkanchery	Arissery	58.20	1975
3	24	Central	Thrissur	Wadakkanchery	Konnanatthukunnu	91.39	1981
4	93	Central	Thrissur	Pattikkad	Pampoorampara	13.20	1983
5	7	Central	Thrissur	Wadakkanchery	Wadakkanchery hill	43.00	1989
6	92	Central	Thrissur	Wadakkanchery	Kozhikunnu	23.00	1991
7	8	Central	Thrissur	Wadakkanchery	Thayoor-Pazhayoor	64.00	1994
8	91	Central	Thrissur	Wadakkanchery	Wadakkanchery hill	4.00	1995
9	88	Northern	Wayanad (N)	Begur	Campumalla	10.00	1996
10	78	Northern	Wayanad (N)	Begur	Thirunelli	96.50	1999
11	76	Olavakkode	Mannarkkad	Agali	Thova Bit I	48.00	1995
12	29	Olavakkode	Nenmara	Nelliyampathi	Padagiri	58.50	1982
13	34	Olavakkode	Nenmara	Alathur	Chanthanathode	11.00	2000
14	30	Olavakkode	Nilambur (N)	Vazhikadavu	Manjakode	34.76	1990
15	51	Southern	Thenmala	Thenmala	Kattilappara	37.12	1997

Table 3.2. (Contd.)

Sl no.	Plot no.	Initial spacing (m x m)	Date of measurement	Plot size (m x m)	Slope category	Aspect	Rotation	Longitude East (degree)	Latitude North (degree)	Altitude (m)
1	90	2 x2	21/11/00	40 x40	S	NE	II	76.199	10.691	100
2	94	2 x2	15/11/00	40 x40	G	SE	III	76.249	10.690	100
3	24	2 x 2	15/02/00	20 x 20	M	W	I	76.249	10.676	100
4	93	2 x2	22/01/01	40 x 40	G	NW		76.254	10.597	100
5	7	2 x 2	31/10/00	40 x 40	S	NE	II	76.210	10.665	100
6	92	2 x2	22/01/00	40 x 40	M	S	III			
7	8	2 x 2	18/11/00	40 x 40	S	N	II	76.178	10.672	100
8	91	2 x2	21/01/02	40 x40	M	NE	II	76.254	10.660	93
9	88	2 x2	01/06/02	40 x40	G	NW	I	75.974	11.865	838
10	78	2 x2	12/06/01	40 x 40	M	W	III	76.002	11.911	824
11	76	2 x 2	28/11/01	40 x 40	S		II	76.740	11.085	
12	29	2 x 2	17/03/01	20 x 20	G	SE	II			
13	34	3 x 3	22/03/01	20 x 20	G	E	I	76.571	11.674	
14	30	2 x 2	15/03/01	20 x 20	G	S	II	76.326	11.430	108
15	51	2 x 2	15/09/01	40 x 40	M	S	II	77.098	8.924	272

Table 3.2. (Contd.)

Sl no.	Plot no.	Age (year)	Density (no. ha^{-1})	Basal area (m^2ha^{-1})	Crop diameter (cm)	Crop height (m)	Crown diameter (m)	Volume (m^3ha^{-1})	MAI of volume (m^3ha^{-1} yr^{-1})	Density of other trees (no. ha^{-1})	Basal area of other trees (m^2ha^{-1})
1	90	15	281	5.38	15.60	11.94	3.05	26.77	0.76	826	5.17
2	94	25	1369	7.49	8.30	8.60	2.42	25.59	1.02	432	1.13
3	24	3	1225	0.41	2.10	5.61	1.88	0.30	0.00	175	0.00
4	93	18	181	2.49	13.20	15.20	3.32	11.43	0.22	975	14.75
5	7	11	1456	2.28	4.50	4.78	1.69	2.46	0.00	0	0.00
6	92	9	1088	6.39	8.70	8.76	2.37	25.03	1.56	13	0.10
7	8	6	550	6.08	11.90	8.73	2.97	28.27	4.71	0	0.00
8	91	7	406	8.05	15.90	18.92	3.36	37.98	0.49	18	0.24
9	88	6	750	4.21	8.50	11.72	2.38	15.67	3.92	343	3.30
10	78	2	1356	1.99	4.30	4.47	1.53	5.28	0.23	49	0.82
11	76	6	1219	6.33	8.10	10.30	2.16	20.86	0.26	0	0.00
12	29	19	1625	21.33	12.90	18.71	3.12	98.55	0.23	375	0.68
13	34	1	1575	0.00	0.00	1.81	0.00	0.00	0.00	0	0.00
14	30	11	525	7.26	13.30	12.02	3.24	33.48	2.44	0	0.00
15	51	4	1838	7.98	7.40	10.71	2.28	23.29	7.76	162	0.41

3.1.3. *Acacia auriculiformis*

Table 3.3. Status of sample plots established in *Acacia auriculiformis* plantations in Kerala

Sl no.	Plot no.	Circle	Division	Range	Name of plantation	Extent (ha)	Year of planting
1	25	Central	Chalakkudy	Vellikulangara	Kavanadu	15.00	1995
2	103	Central	Thrissur	Wadakkanchery	Poolakunnu	34.00	1987
3	10	Central	Thrissur	Machad	Cheppilakode	105.00	1988
4	98	Northern	Kannur	Kasaragod	Karadukka	7.20	1986
5	84	Northern	Kannur	Kasaragod	Kuttimunda	18.00	1998
6	101	Northern	Kannur	Kasaragod	Madathumkad	19.84	1998
7	97	Northern	Kannur	Kasaragod	Guddaduakka	8.00	1999
8	100	Northern	Kannur	Kasaragod	Annapadi	22.00	1999
9	96	Northern	Kannur	Kasaragod	Tharia	33.25	2000
10	99	Northern	Kannur	Kasaragod	Kuttimunda	2.39	2000
11	82	Northern	Wayanad (S)	Periya	Chanthanathode	3.00	1996
12	27	Olavakkode	Nenmara	Alathur	Veezhumala	17.50	1991
13	28	Olavakkode	Nenmara	Alathur	Poothamala	30.00	1998
14	50	Southern	Thenmala	Thenmala	Villumala	10.15	1995
15	54	Southern	Thenmala	Thenmala	Kottavasal	26.40	1999

Table 3.3. (Contd.)

Sl no.	Plot no.	Initial spacing (m x m)	Date of measurement	Plot size (m x m)	Slope category	Aspect	Rotation	Longitude East (degree)	Latitude North (degree)	Altitude (m)	Site quality
1	25	2 x 2	20/02/01	20 x 20	G	S		76.330	10.370	100	II
2	103	2 x 2	11/01/01	40 x 40	S	N	II	76.330	10.740	100	III
3	10	2 x 2	14/02/01	20 x 20	M	S		76.280	10.660	100	IV
4	98	2 x 2	01/02/02	40 x 40	G	SE	II	75.160	12.510	164	I
5	84	2 x 2	02/01/02	40 x 40	S	N	II	75.300	12.590	101	
6	101	2 x 2	03/02/02	40 x 40	G	NE	II	75.200	12.530	216	
7	97	3 x 3	30/01/02	40 x 40	G	SE	II	75.270	12.550	136	
8	100	3 x 3	02/02/02	40 x 40	M	NE	II	75.250	12.510	153	
9	96	3 x 3	31/01/02	40 x 40	S	W	III	75.140	12.510	140	
10	99	3 x 3	29/01/02	40 x 40	S	W	II	75.300	12.600	160	
11	82	2 x 2	12/12/01	40 x 40	S	S	II	75.820	11.840	786	II
12	27	2 x 2	21/03/01	20 x 20	M	W	I	76.560	10.620		II
13	28	2 x 2	20/03/01	20 x 20	G	P	I				
14	50	2 x 2	13/09/01	40 x 40	G	W	II	77.080	8.910	266	II
15	54	2 x 2	19/09/01	40 x 40	S	S	II	77.170	8.990	328	II

Table 3.3. (Contd.)

Sl no.	Plot no.	Age (year)	Density (no. ha^{-1})	Basal area (m^2ha^{-1})	Crop diameter (cm)	Crop height (m)	Crown diameter (m)	Volume (m^3ha^{-1})	MAI of volume (m^3ha^{-1} yr^{-1})	Density of other trees no. ha^{-1})	Basal area of other trees (m^2ha^{-1})
1	25	6	1200	4.67	7.00	12.03	2.76	35.27	7.05	0	0.00
2	103	14	4731	10.71	5.40	7.43	2.52	49.25	3.79	124	0.37
3	10	13	1650	2.96	4.80	6.10	2.48	11.71	0.98	25	0.02
4	98	16	1775	19.36	11.80	15.96	2.76	150.01	10.72	13	0.14
5	84	4	2156	2.47	3.80	5.25	2.41	7.92	3.96	68	6.98
6	101	4	1988	4.81	5.50	6.42	2.48	19.80	9.90	13	0.02
7	97	3	1725	5.01	6.10	7.19	2.53	24.27	24.27	25	2.26
8	100	3	1463	1.69	3.80	5.88	2.43	5.19	5.19	57	10.27
9	96	2	1450	0.44	2.00	3.03	2.24	0.19	0.00	25	0.57
10	99	2	1519	0.01	0.30	2.14	2.07	0.00	0.00	56	0.96
11	82	5	1425	7.87	8.40	8.38	2.61	49.47	12.37	38	0.68
12	27	10	575	9.81	14.70	14.56	2.71	81.62	9.07	550	2.12
13	28	3	2425	6.54	5.90	7.21	2.52	27.94	13.97	0	0.00
14	50	6	3456	13.42	7.00	8.79	2.64	79.93	15.98	543	5.17
15	54	2	2419	5.85	5.50	5.94	2.50	24.23	23.75	0	0.00

3.1.4. *Ailanthus triphysa*

Table 3.4. Status of sample plots established in *Ailanthus triphysa* plantations in Kerala

Sl no.	Plot no.	Circle	Division	Range	Name of plantation	Extent (ha)	Year
1	46	High Range	Kothamangalam	Neriyamangalam	Chembankuzhi	10.70	1985
2	83	Northern	Kozhikode	Peruvannamuzhi	Peruvannamuzhi	64.00	1984
3	75	Olavakkode	Palakkad	Ottapalam	Maringodan mala	3.00	1985

Table 3.4. (Contd.)

Sl no.	Plot no.	Initial spacing (m x m)	Date of measurement	Plot size (m x m)	Slope category	Aspect	Rotation	Longitude East (degree)	Latitude North (degree)	Altitude (m)
1	46	2 x 2	09/07/01	20 x 20	G	NE	I	76.810	10.030	150
2	83	3 x 3	13/12/01	40 x 40	S	W	I	75.820	11.600	32
3	75	2 x 2	27/11/00	40 x 40	M	NE	I	76.440	10.870	111

Table 3.4. (Contd.)

Sl no.	Plot no.	Age (year)	Density (no. ha^{-1})	Basal area (m^2 ha^{-1})	Crop diameter (cm)	Crop height (m)	Crown diameter (m)	Density of other trees (no. ha^{-1})	Basal area of other trees (m^2ha^{-1})
1	46	16	1775	18.56	11.50	9.55	3.04	6	0.11
3	83	17	725	16.69	17.10	12.50	2.53	325	5.39
2	75	15	1425	11.68	10.20	3.78	2.08	156	6.71

3.1.5. *Gmelina arborea*

Table 3.5. Status of sample plots established in G*melina arborea* plantations in Kerala

Sl no.	Plot no.	Circle	Division	Range	Name of plantation	Extent (ha)	Year of planting
1	65	Central	Vazhachal	Charpa	Kannamkuzhy	63.87	1977
2	64	Central	Malayatoor	Kodanad	Paniley	76.00	1977
3	67	Olavakkode	Nilambur (N)	Vazhikadavu	Karim Muriyam	20.00	1977

Table 3.5. (Contd.)

Sl no.	Plot no.	Initial spacing (m x m)	Date of measurement	Plot size (m x m)	Slope category	Aspect	Rotation	Longitude East (degree)	Latitude North (degree)	Altitude (m)
1	65	2 x 2	30/10/01	40 x 40	G	NW		76.590	10.340	472
2	64	2 x 2	28/10/01	40 x 40	G	E	II	76.610	10.160	2031
3	67	2 x 2	6/11/01	40 x 40	M	E	I	76.300	11.390	140

Table 3.5. (contd.)

Sl no.	Plot no.	Age (year)	Density (no. ha^{-1})	Basal area (m^2ha^{-1})	Crop diameter (cm)	Crop height (m)	Crown diameter (m)	Density of other trees (no. ha^{-1})	Basal area of other trees (m^2ha^{-1})
1	65	24	494	25.12	25.40	17.22	4.80	6	0.24
2	64	24	2675	142.17	26.00	15.49	4.72	0	0.00
3	67	24	769	23.90	19.90	16.23	4.05	31	1.51

3.1.6. *Albizia falcataria*

Table 3.6. Status of sample plots established in *Albizia falcataria* plantations in Kerala

Sl no.	Plot no.	Circle	Division	Range	Name of plantation	Extent (ha)	Year of planting
1	52	Southern	Thenmala	Thenmala	Neduvanoorkadavu	9.10	1992
2	74	High Range	Kothamangalam	Mullaringad	Chullikandom	55.00	1996
3	66	Central	Vazhachal	Kollathirumedu	Annamukku	19.65	1989

Table 3.6. (Contd.)

Sl no.	Plot no.	Initial spacing (m x m)	Date of measurement	Plot size (m x m)	Slope category	Aspect	Rotation	Longitude East (degree)	Latitude North (degree)	Altitude (m)
1	52	2 x 2	17/09/01	40 x 40	S	NW	II	77.070	8.930	272
2	74	2 x 2	16/11/01	40 x 40	M	E	III	76.750	10.040	92
3	66	2 x 2	29/10/01	40 x 40	M	N	II	76.680	10.300	473

Table 3.6. (Contd.)

Sl no.	Plot no.	Age (year)	Density (no. ha^{-1})	Basal area (m^2ha^{-1})	Crop diameter (cm)	Crop height (m)	Crown diameter (m)	Density of other trees (no. ha^{-1})	Basal area of other trees (m^2ha^{-1})
1	52	9	1775	18.56	11.50	9.550	2.77	325	5.40
2	74	5	725	16.69	17.10	12.500	3.19	156	6.71
3	66	12	1425	11.69	10.20	3.780	3.25	6	0.11

3.1.7. *Acacia mearnsii*

Table 3.7. Status of permanent sample plots established in *Acacia mearnsii* plantations in Kerala

Sl no.	Plot no.	Circle	Division	Range	Name of plantation	Extent (ha)	Year of planting
1	49	High Range	Munnar	Devikulam	Pazhathotam	9.00	1983
2	47	High Range	Munnar	Marayoor	Perumala	9.00	1989

Table 3.7. (Contd.)

Sl no.	Plot no.	Initial spacing (m x m)	Date of measurement	Plot size (m x m)	Slope category	Aspect	Rotation	Longitude East (degree)	Latitude North (degree)	Altitude (m)
1	49	2 x 2	18/08/01	20 x 20	S	N		77.2112	10.18473	2481
2	47	2 x 2	21/08/01	20 x 20	G	NE	I	77.1892	10.20132	1323

Table 3.7. (Contd.)

Sl no.	Plot no.	Age (year)	Density (no. ha^{-1})	Basal area (m^2ha^{-1})	Crop diameter (cm)	Crop height (m)	Crown diameter (m)	Density of other trees (no. ha^{-1})	Basal area of other trees (m^2ha^{-1})
1	49	18	825	11.46	13.3	19.24	2.75	0	0.00
2	47	12	975	11.35	12.2	13.00	2.73	25	0.03

3.2. Guidelines for future measurements

The sample plots established especially for *Tectona grandis*, *Eucalyptus tereticornis* and *Acacia auriculiformis* are of sufficient range with respect to age and site conditions. Data on the tree characteristics like girth at breast height, total height and crown width are to be collected periodically from these plots. An interval of two to three years would be optimal for the species considering the expected growth rate and expenditure for remeasurement. The measurements are so structured to enable the development of distance dependent individual tree growth models. However, other classes of models such as diameter class models or whole stand models can be developed depending upon the requirements. Records of all operations carried out in the sample plots need to be gathered at the time of remeasurement. The plots are supposed to be subjected to regular management operations undertaken by the forest department. No differential operations need be given to the stands, from that of the surrounding area in the plantation.

4. CONCLUSIONS

The project was initiated with the objective of establishing a set of permanent sample plots for some of the important forest plantation species in Kerala so as to estimate the growth rate of trees under varying stand and site conditions, based on remeasured data. Representative regions within each Territorial Circles were selected and sample plots were laid out in these regions, in plantations belonging to different age groups. The locations of these plots were identified in terms of latitude, longitude, altitude and the site map, and their identity with respect to the Forest Division and Range was established. The number of plots established for each species was respectively, *Tectona grandis* (50), *Eucalyptus tereticornis* (15), *Acacia auriculiformis* (15), *Ailanthus triphysa* (3), *Gmelina arborea* (2), *Albizia falcataria* (3) *and Acacia mearnsii* (2).

The number of plots taken for *Ailanthus triphysa, Gmelina arborea, Albizia falcataria and Acacia mearnsii* was less than the targets fixed. For *Ailanthus triphysa* and *Albizia falcataria,* most of the plantations available were of higher age groups and were thus not suitable for establishing permanent sample plots. For *Gmelina arborea,* only a few plantations were available and plots were laid out in all the available plantations. In the case of *Acacia mearnsii,* most of the plantations were failed plantations and some good ones were inaccessible.

Basic measurements on trees in the sample plots were made and the site features were recorded for each plot. Summary information on the stand attributes was generated and was documented in this report for future reference, in a systematic manner. These plots are to be remeasured periodically to generate information on growth rate. A few points as regards the relevance of the study are noted here.

(i) The permanent sample plots now established will form a base for long term monitoring of the growth and mortality of trees under varying site and stand conditions.
(ii) The sample plots network can offer a base for growth related ecological studies in future.
(iii) The remeasured data from these plots will enable construction of growth models through which questions on optimum spacing required between trees can be answered.

The plots are supposed to be subjected to regular management operations of the forest department. Records of all operations carried out in the plots need to be gathered during the time of remeasurement.

5. REFERENCES

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6. APPENDICES

Appendix 1. Coefficients of plotwise height prediction equations for different species

Tree height was predicted using a local height-diameter relationship established for each plot. The equations were of the following form.

$$\ln h = a + b \ln d$$

where ln indicates natural logarithm

h = Height of the tree (m)

d = Diameter at breast height (m)

The values of the coefficients a and b for each plot for the different species are given below.

Tectona grandis

Plot no.	*a*	*b*	R^2
1	3.76599	0.42736	0.7526
2	4.94294	1.07498	0.9354
3	3.01229	0.46106	0.9193
4	4.32433	0.89486	0.9950
5	3.93548	0.83448	0.9596
6	3.92501	0.75823	0.9047
12	3.22317	0.03769	0.0203
13	3.57761	0.59073	0.6342
14	3.18018	0.39787	0.9570
15	3.36645	0.3613	0.8048
16	4.66619	1.14955	0.9335
17	4.2696	0.8813	0.9715
19	4.8958	1.23568	0.9417
20	3.76278	0.65499	0.9695
21	3.97238	0.85871	0.9865
22	3.59479	.86605	0.9596
31	3.82698	0.55554	0.8944
32	4.13447	0.78405	0.8552
33	3.49306	0.26419	0.4122
35	4.01554	0.74499	0.9494
36	3.71319	0.55069	0.9860
37	3.14033	0.30333	0.5531
38	3.50928	0.44238	0.6391
40	3.56865	0.54751	0.9171
41	3.65842	0.684	0.9225
42	3.74792	0.91086	0.9358
43	3.03318	0.22376	0.8929
44	3.68824	0.70884	0.9906
45	4.10281	0.77681	0.9536
53	3.42385	0.69115	0.7867
56	3.64364	0.45408	0.6733
57	3.80741	0.63328	0.7135
58	4.01637	0.73443	0.7539
61	3.64523	0.41639	0.8535
63	3.75634	0.5842	0.9380
70	3.83521	0.55697	0.7698
71	3.55296	0.72264	0.6620
72	3.83154	0.52544	0.9465
73	3.66877	0.56772	0.9657
77	3.14148	0.29613	0.8555
79	3.51613	0.5884	0.9852

Tectona grandis

Plot no.	*a*	*b*	R^2
81	3.77911	0.51161	0.9492
85	4.9524	1.05706	0.7072
86	4.1066	0.84136	0.9157
87	3.71995	0.68603	0.6723
89	3.69934	0.52839	0.9765
102	6.14885	1.85914	0.9760
103	5.55917	1.19636	0.6482
105	3.74339	0.52454	0.9630

Eucalyptus tereticornis

Plot no.	*a*	*B*	R^2
7	3.85039	0.71349	0.9791
8	3.89957	0.75047	0.9659
24	2.88607	0.38766	0.3828
29	3.96457	0.46765	0.8717
30	4.28472	0.85699	0.7778
51	4.72312	0.87366	0.8552
76	4.86184	0.89882	0.8382
78	3.45717	0.55798	0.7332
88	4.60643	0.80388	0.8826
90	4.1960	0.8926	0.9943
91	4.96675	0.99826	0.8356
92	3.84979	0.61799	0.2302
93	3.56274	0.39371	0.4057
94	4.66243	0.97175	0.7312

Ailanthus triphysa

Plot no.	*a*	*b*	R^2
46	3.28436	0.42665	0.8243
75	2.77514	0.57299	0.9377
83	3.92537	0.72525	0.9326

Acacia auriculiformis

Plot no.	*a*	*b*	R^2
10	2.42924	0.19985	0.0742
25	3.14629	0.29727	0.3382
27	3.21448	0.26313	0.8060
28	4.27982	0.77087	0.7576
50	3.67224	0.54273	0.6478
54	3.55799	0.5814	0.8041
82	4.00385	0.70842	0.8702
84	4.31637	0.79102	0.6454
96	3.1269	0.50454	0.7640
97	3.54378	0.53138	0.8408
98	4.36238	0.72614	0.9395
99	1.13049	0.07724	0.4185
100	3.96336	0.66142	0.7659
101	3.85493	0.6391	0.8987

Gmelina arborea

Plot no.	*a*	*b*	R^2
64	3.44644	0.47301	0.9419
65	4.0719	0.87014	0.8886
67	3.42279	0.37801	0.9105

Albizia falcataria

Plot no.	*a*	*b*	R^2
52	4.13883	0.69652	0.8168
66	3.96463	0.78152	0.9536
74	3.41285	0.26343	0.6708

Acacia mearnsii

Plot no.	*a*	*b*	R^2
47	4.55751	0.90475	0.9907
49	3.53817	0.26169	0.9618

Appendix 2. Coefficients of prediction equations for crown diameter for different species

The following equation form was used for establishing a relation between crown diameter and diameter at breast-height for each species.

$$\ln w = a + b \ln d$$

where ln indicates natural logarithm

w = Crown diameter of the tree (m)

d = Diameter at breast height (cm)

The values of the constants, a and b for each species are given below

Species	a	b	R^2
Tectona grandis	-0.628	0.752	0.8493
Eucalyptus tereticornis	-0.340	0.601	0.5509
Acacia auriculiformis	0.7421	0.114	0.7400
Ailanthus triphysa	-0.689	0.662	0.4537
Gmelina arborea	-0.931	0.776	0.4930
Albizia falcataria	0.201	0.490	0.5375
Acacia mearnsii	-0.678	0.767	0.4576

Appendix 3. Proforma used for recording the measurements

KFRI PROJECT 345/2000: ESTABLISHMENT OF PSP'S IN PLANTATIONS
(Measurements on trees in permanent sample plots)

Lat [ ] **Longi** [ ] **Alti** [ ] **Plot Number:** [ ]

I. Plantation details

1. Forest Division :
2. Forest Range :
3. Name of plantation :
4. Species planted :
5. Total extent of the plantation (ha) :
6. Initial espacement (m x m) :
7. Year of planting :
8. Date of measurement :
9. Location map :

II. Plot measurements

1. Plot size (m x m) :
2. Slope category (G, M, S) :
3. Aspect (N, NE, E, SE, S, SW, W, NW) :
4. Rotation phase (I/II/III/IV/V) :
5. Previous vegetation :

G = Gentle < 6% (0-3^0), M = Moderate 6 - 25% (3.1-15^0), S = Steep > 25% (>15^0)

III. STEM CHART

Direction: **Name of plantation:** **Plot Number:**

III. Past operations done/Occurrence of natural calamities:

Year/Month	Operations/Calamities	Details/Remarks

IV. Measurements on trees in the plot **Plot Number:**

Grid no.		Distance(m)		Tree no.	Species	Ht. (m)	GBH (cm)	CHt. (m)	CW1 (m)	CW2 (m)	Remarks
GR	GC	X	Y								

DD = Dead/Dry, TB = Top broken, FR = Forking, CR = Crooked, CP = Coppice,
WB = Water blister, LR = Loranthus, VA = Vanda, CL = Climber, BR = Borer,
DF = Defoliator, SK = Skeletoniser, DS = Disease

Date of measurement: Signature of the Field Staff