KFRI Consultancy Report

PRODUCTIVITY OF TEAK AND EUCALYPT PLANTATIONS IN KERALA

Final Report of the Research Project No. KFRI 250/96
April 1996 to September 1996

A project sponsored by the World Bank

KERALA FOREST RESEARCH INSTITUTE
Peechi 680 653, Kerala, India
March 1997

KFRI Consultancy Report

PRODUCTIVITY OF TEAK AND EUCALYPT PLANTATIONS IN KERALA

Final Report of the Research Project No. KFRI 250/96
April 1996 to September 1996

A project sponsored by the World Bank

KERALA FOREST RESEARCH INSTITUTE
Peechi 680 653, Kerala, India
March 1997

Consultant Personnel

Project Leader	:	Dr. K.S.S. Nair, Director, Kerala Forest Research Institute,
Principal Investigator	:	Dr. K. Jayaraman, Scientist-in-Charge, Division of Statistics, Kerala Forest Research Institute
Associate Investigator	:	Mr. K. C. Chacko, Silviculturist-in -Charge, Division of Silviculture, Kerala Forest Research Institute

CONTENTS

Part II. Productivity of eucalypt plantations in Kerala

Part III. Strategies for enhancing the productivity of teak and eucalypt plantations in Kerala

ACKNOWLEDGEMENTS

Work of this nature is a pioneering one in Kerala and we record our appreciation to the Kerala Forest Department for awarding the consultancy to the Kerala Forest Research Institute. The task could not have been successfully completed without the unstinted co-operation received from the staff of the Kerala Forest Department and the Kerala Forest Development Corporation. We are thankful to Ms. K. Reji, Research Fellow and all other project staff who were involved in the collection and processing of the voluminous data. Scientists from different disciplines in the Institute gave their valuable input, particularly in formulating the strategies for improvement of the productivity of teak and eucalypt plantations. .Mr. M.R. Aravindakshan, Senior Manager (Forests), Hindustan Newsprint Limited, also made valuable suggestions on this aspect. Our appreciation is extended to Ms. Tegy Mathew and Mr. P.V. Santhoshkumar for the excellent word processing and related tasks associated with the project.

LIST OF TABLES

Part I

Part II

Part III

LIST OF FIGURES

Part I

Part II

LIST OF APPENDICES

ABSTRACT

The status of teak and eucalypt plantations in Kerala was assessed with respect to the site quality distribution and stocking through an objective sample survey and the current levels of productivity of these crops were ascertained. The plantations of teak and teak mixed with other species belonging to the Territorial Forest Divisions and the eucalypt plantations under the management of Kerala Forest Department and Kerala Forest Development Corporation formed the sampling frame. The plantations were stratified by regions (Divisions for teak and Circles for eucalypts) and by 5 yearly age groups within each region. Roughly 18 per cent of the plantations of teak and 8 per cent of eucalypt plantations were sampled. Measurements were taken from circular plots of 10 m radius laid along randomly placed transects in the selected plantations.

The extent of teak plantations under reference was 68,797 ha as on 1995. An assessment of site quality distribution of the area showed that only 5 per cent of the area fell under site quality class I. Nearly 38 per cent of the area was of site quality class II and 48 per cent was of site quality class III. Around 9 per cent of the area fell under site quality class IV. About 0.1 per cent of the total area was estimated as degraded. There was considerable variation in site quality distribution over the different Divisions. Achencoil, Konni and Kozhikode Divisions recorded major share of area under better site quality classes (SQ I and SQ II) whereas Thiruvananthapuram, Kottayam, Wayanad, and Kannur Divisions had larger area under poor site quality classes (SQ III and SQ IV). This in turn reflected in the MAI of commercial volume attained in these Divisions. Kozhikode and Achencoil Divisions recorded the highest MAI in the State, exceeding 3 m^3 ha^{-1} of standing volume including timber and smallwood at 60 years. Kottayam and Thiruvananthapuram had the lowest values of MAI which were less than 2 m^3 ha^{-1}. At the State level, the MAI of standing crop worked out to 2.423 m^3 ha^{-1} at 60 years. A comparison with potential MAI of 4.968 m^3 ha^{-1} at 60 years under site quality class I with full stocking as reported in the All India yield table for teak indicated the wide gap between the actual and potential yield levels. Nearly 86 per cent of the area falling under site quality classes II and III qualifies for improvement.

A study on past records of yield from thinning indicated an average MAI of 1.174 m^3 ha^{-1} for the State at an average final thinning age of 35 years. Although yield from thinning could not be estimated precisely due to inadequate data, the yield levels shown are substantially low when compared to the potential levels. The yield table figure for accumulated yield of thinning at 35 years under site quality class I with full stocking is 5.847 m^3 ha^{-1}. The MAI of total yield which includes main crop and accumulated yield of thinning at 60 years worked out to 3.110 m^3 ha^{-1} in the present study.

Based on basal area ha^{-1}, nearly 48 per cent of the plantation area was estimated as under-stocked. 26 per cent was classed as over-stocked and the remaining 26 per cent carried fully stocked stands. The corresponding figures based on number of trees were 64, 17 and 19. Among the under-stocked plantations 33 per cent of the area showed very poor stocking with stocking

ratio less than 0.5. Nearly 88 per cent of the plots showing under-stocking by basal area were under-stocked by number of trees also confirming that under stocking has resulted due to less than expected number of trees in many stands. The growing stock of teak in plantations older than 10 years estimated based on the updated list of plantations in 1996 was 3. 248 million m^3 of timber and 1.590 million m^3 of smallwood in 68,651 ha. The estimated total number of trees in plantations not older than 10 years as on 1996 came to 4.980 million in 4,516 ha.

The plantations of site quality I were mostly over-stocked. This was found to adversely affect the diameter of trees in later years. Plantations of lower site quality classes were found heavily under-stocked resulting in reduced overall volume. However, such variations were not found to affect the height growth of trees.

Compilation of observations on certain management and site features indicated the following. Plantation Journals were found available only in 51 per cent of the cases at the State level. Signs of external human interference in plantations were fairly common. Presence of loranthus, climbers, borer attack and water blisters could also be detected in many places. An analysis of the influence of some factors on crop growth revealed significant effects of human interference. climbers and loranthus on the crop growth other than that due to age and stocking.

As on 1995, eucalypts were reported to be grown in 30,641 ha belonging to the Territorial Divisions of the Kerala Forest Department and KFDC. Nearly 90 per cent of this area carried stands older than 10 years. Around 20 per cent of the stands have crossed 20 years of existence. *Eucalyptus tereticornis* was estimated to occupy around 67 per cent of the area under eucalypts and *Eucalyptus grandis* was found in the remaining area. The combined growing stock for the two species was estimated with the updated list of plantations as on 1996. The growing stock worked out to1.037 million m^3 in an area of 28,845 ha. Although the total extent under eucalypts as on 1996 was 33,054 ha. around 4,209 ha of plantations could not be located in the field which were mostly in North Nilambur Division.

Based on a survey, the MAI of the seedling crop of *E. tereticornis* was estimated as 7.653 m^3 ha^{-1} at 8 years. For the first coppice crop of the same species, the MAI worked out to 2.545 m^3 ha^{-1} at 8 years. Lack of data on crop age (year of coppicing) was a serious limitation in working out the MAI of *E. tereticornis* precisely. Comparison with the potential yield reported in the existing yield table which is 18 m^3 ha^{-1} with 1600 trees ha^{-1} under site quality class I indicated that current levels are poor both for seedling and coppice crops. One clear reason that could be attributed was poor stocking.

For want of data on year of coppicing, no estimate of MAI could be developed for *E. grandis* although, measurements were made in a number of sample plots. Past records had shown that seedling crop of *E. grandis* attains an MAI of 10 m^3 ha^{-1} in the State at 10 years. Potential yield levels indicated by yield table were found to be considerably higher. The maximum MAI reported in the yield table for the species was 36 m^3 ha^{-1} at 10 years with 1600 trees ha^{-1} under site quality class I.

Suggestions for proper management of teak and eucalypt plantations in Kerala for sustained productivity are given. For both species, it is recommended that plantation areas above 30^0 slope be converted to natural forests to avoid erosion and eventual permanent site deterioration. Both technical and administrative measures for proper management of the plantations in the remaining areas are suggested.

For teak, the technical measures include (1) management of very low productivity areas under SQ IV for pole production under simple coppice system on a short rotation of 20-25 years and (2) management of the remaining areas for timber production under low input but efficient management system which include appropriate silvicultural, and site, nutrient and pest management.

For eucalypts, technical measures include retention of only those plantations which satisfy minimum standards in terms of stocking and basal area and managing them with appropriate silvicultural site, nutrient and pest/disease management, for which guidelines are given. Use of improved clonal planting material in a phased manner is suggested for raising future plantations.

Administrative measures suggested for efficient management of both teak and eucalypt plantations include systematic maintenance of plantation records, organization of Plantation Productivity Workshops (PPWs) at Circle and Range levels, monitoring and evaluation procedures. To facilitate timely availability of funds for various plantation activities, a Treasury Public (TP) system of cash transaction is suggested.

PRELUDE

Teak and eucalypt plantations form the major share of the plantations managed by the Kerala Forest Department currently occupying around 100,000 ha in the State. Teak provides superior quality timber and eucalypts meet a large part of the pulpwood requirement of the State. There has been an ever increasing demand for both these products over the last many years. Options for any further increase in the land base for these plantations are limited in the State and hence enhancing the productivity of the existing lands under these crops is of utmost importance. Future investment in this line has been under consideration by the government for which baseline information of the current levels of productivity was required. The present project was taken up with the objective of evaluating the status of teak and eucalypt plantations raised by the Forest Department in Kerala with respect to the stocking and site quality distribution and thus assessing their current productivity levels. This was achieved through an objective sample survey of the plantations concerned. The list of plantations belonging to the Kerala Forest Department and the Kerala Forest Development Corporation updated to the year 1995 formed the sampling frame for the survey. Based on the observations made during the survey, certain guidelines for future management of these plantations were also formed. The survey provided information only about the standing crop. Information on intermittent yields had to be gathered from records kept by the Forest Department. The details of the methodology and the results are presented in three parts viz.,

Part I Productivity of teak plantations in Kerala
Part II Productivity of eucalypt plantations in Kerala
Part III Strategies for enhancing the productivity of teak and eucalypt plantations in Kerala

In the history of forest management in Kerala, this is the second major attempt in this direction. The first major attempt specific to Kerala was that of Chandrasekharan (1973) wherein a general assessment of the forest resources of Kerala was made including both man-made and natural forests and the need for making reappraisals from time to time was indicated. The authors hope that the information contained in this report will be of use in framing major policies and planning many activities related to the management of teak and eucalypt plantations in the State.

Before embarking on the details of the work executed, some remarks on the study area are in order here. The State of Kerala is situated on the South Western part of India. Kerala has an equable climate, the mean day temperature ranging from 20 to 35 ^{0}C. The region receives around 3000 mm of rainfall annually due to the monsoons with a short dry period stretching from December to March. With the warm tropical climate prevailing in the State coupled with high rainfall, there is every reason to expect fast rates of growth for trees in the region but is not seen fully realized in managed monoculture systems for the above crops. The state of affairs and also the reasons for the present status were thus worth investigating.

PART I. PRODUCTIVITY OF TEAK PLANTATIONS IN KERALA

1. INTRODUCTION

Teak (*Tectona grandis* L.f.) is indigenous to India. Although teak has been under planting in Kerala on a plantation scale since 1844, major expansion in area under the species in the State occurred during the period 1960 to 1980 as part of the Five Year Plans. Teak thrives best in fairly moist, warm, tropical climate and is best grown in well drained alluvial soil. Consonant with the fairly high variability in the soil, topographical and weather conditions in the State, there is a high degree of regional variation in the productivity of the plantations (Jayaraman and Rugmini,1993). Traditionally, teak is grown under rainfed conditions under a least intensive form of management. In Kerala, teak is worked on a 50 to 60 years of rotation.

2. MATERIALS AND METHODS

The list of plantations raised by the Forest Department in each Forest Division as of the year 1995 was obtained from the concerned Divisions. The plantations of teak belonging to the Territorial Circles were separated from the above list. Thus the target population was 68,797 ha of plantations of pure teak and teak mixed with other species in the State. The teak plantations belonging to the Wildlife and Social Forestry Wings and also those under the control of the Kerala Forest Development Corporation (KFDC) were excluded from the survey. The plantations belonging to the Wildlife Wing being inside the Wildlife Sanctuaries, do not fall under the regular management operations as in Territorial Circles. Teak stands of the Social Forestry Wing are of recent origin and are planted in nonforest areas of limited extent. The teak plantations managed by the KFDC are also of limited extent.

The survey of the plantations was initiated in April,1996. The plantations were stratified by Divisions and by age groups within each Division. The age groups formed were 1-5, 6-10, 11-15 and so on up to 60 years with reference to the year 1996. Plantations older than 60 years formed another additional stratum. Roughly 18 per cent of the plantations were selected at random from each of the strata keeping a minimum of one plantation from a stratum. In each of the selected plantations, plots were marked along a randomly laid out transect running through the center of the plantation. The transects were mostly along the longer direction of the plantation. The number of plots varied proportionally with the size of the plantations. Roughly one plot was taken for every 10 ha with a maximum of 10 plots in any one plantation. The plots were circular with a radius of 10 m. Measurements of girth at breast-height (gbh) of trees, measured at 1.37 m above ground level, in the plots were taken. Height (total height) was measured on a subset of trees in the plot using multimeter. Trees having the largest height, the smallest height and three trees in between the range were selected for measurement of height in each

plot. In the case of young plantations where many plants do not qualify for gbh measurement, height of all the plants in the plots was measured. Several ancillary features of the site like slope, soil condition, incidence of fire, pests and diseases were also recorded from each plot. In terms of actual area measured, the overall sampling intensity worked out to 0.06 per cent.

2.1. Spatial distribution and age structure

The area falling under different Divisions and the age structure of the plantations of pure teak and teak mixed with other species as of 1995 was generated from the above data base.

2.2. Site quality distribution

Site quality level of each plot carrying stands of age greater than 5 years was ascertained by first computing the top height for each plot and then referring the top height by age table for teak (Anonymous, 1970). The height-diameter relation for computing the top height was worked out from the data on height and diameter at breast-height (dbh) of trees, pooled for each Division. The height-diameter equation fitted was of the following form.

$$\ln (h-1.37) = a + b \ln D \qquad (1)$$

where h = Total height of the tree (m)
D = Dbh of the tree (m)
ln indicates natural logarithm
a and b are parameters

The proportions of area belonging to each site quality class in different Divisions and for the State as a whole were then estimated through the formulae applicable to stratified sampling using ratio estimator. The size of individual plantations formed the auxiliary variable. The exact formulae used are given in Appendix 1. In addition to the standard set of four All India site quality classes, a class of degraded stands and one of super quality class were considered in the above computations to capture the variation outside the predefined limits.

2.3. Stocking

Basal area ha^{-1} and number of trees ha^{-1} were worked out for each plot carrying stands above 10 years of age. The stocking status was determined based on basal area ha^{-1} and number of trees ha^{-1} as expected by the yield table for teak (Anonymous,1970). In particular, the stocking ratio for each plot was obtained by dividing the observed basal area or the number of trees by the corresponding basal area or number of trees as expected by the yield table for the particular age and site quality class pertaining to the

plot. A deviation of 10 per cent on either side from the expected basal area or number of trees was allowed for fully stocked stands.

Having assessed each plot for the stocking status, the proportions of area belonging to each stocking class in different Divisions were estimated through the formulae applicable to stratified sampling using ratio estimator. The size of individual plantations formed the auxiliary variable.

In addition to the above, estimates of growing stock in volume were developed for each Division through the formulae applicable to stratified sampling, using ratio estimator with size of the plantations as auxiliary variable.. For this purpose, estimates of timber and smallwood volume in each plot were obtained first by applying the following equations reported by Chaturvedi (1973a) on each tree in the plots and added up to the plot level. The plot level estimates of volume formed the observations at the basic sampling unit in the sampling scheme.

$$V_T = -0.0645 + 0.2322\ D^2h \quad (2)$$

$$V = 0.1217 + 0.2257\ D^2h \quad (3)$$

$$V_S = V - V_T$$

where V_T = Volume of timber from the tree (m^3)

V = Volume of timber and smallwood from the tree (m^3)

V_S = Volume of smallwood from the tree (m^3)

D = Dbh of the tree (m)

h = Total height of the tree (m)

Timber refers to wood under bark with diameter greater than 20.32 cm over bark. Wood including bark between 20.32 cm and 5.08 cm diameter over bark constitutes smallwood. Since the height was not measured on each tree, it had to be predicted using equation (1) developed for each Division. For plantations not older than 10 years, the growing stock was computed in terms of number of trees. Unlike the estimates of other parameters, the estimates of growing stock were based on the list of plantations updated to the year 1996.

2.4. Productivity

2.4.1. Main crop

2.4.1.1. Mean Annual Increment (MAI)

One of the measures of productivity in the case of forest plantations is the MAI in commercial volume. The MAI is supposed to vary with age, site quality and the thinning schedule followed. For a particular region, the marginal distribution of MAI over age can be obtained by condensing the variation of MAI over the site quality and stocking levels existing in that region.

In a cross sectional survey like the present one, the MAI can be obtained only with respect to the standing volume in the field for a particular age. Plot specific information on yield from thinning will not be obtainable. The existing volume at any age is technically comparable to final yield which is the sum of the main crop volume and current year's thinning yield. Since the selected plots need not fall in all the age-site quality-stocking combinations, a prediction function for MAI was to be developed. For this purpose, an estimate of commercial volume (timber and smallwood) for each plot was obtained through equations (2) and (3). A prediction equation of the following form was used for prediction of commercial volume at the stand level, after making trials with a number of models on the data.

$$\ln V = a + b A^{-1} + c \ln H + d A^{-1} \ln H \qquad (4)$$

where V = Volume of timber and smallwood ha^{-1}

A = Age (year)

H = Top height (m)

In the above equation, top height was used instead of site index because, for a given age and stocking, the variation in volume is proposed to be due to variation in top height which is identical with that of the site index. Site index refers to the top height projected to a base age. Top height has the advantage of being a direct measure from the plot without involving a projection on to a base age. The MAI for any age-site quality-stocking combination can be obtained by dividing the corresponding predicted volume by age. Since information on stocking is not utilized in predicting the volume at any age, the predictions of volume at any age and particular site quality level would represent the average position with respect to the variation in stocking for that combination of age and site quality level.

Equation (4) was utilized for getting estimates of the expected volume and therefrom MAI for the age of 60 for the different site quality levels. The age of 60 was chosen because final felling centers around the age of 60 in the State. The expected MAI for any particular Division for the chosen age was then obtainable by taking the weighted average of the predicted MAI for the different site quality classes taking weights as the proportion of area in that Division under different site quality classes.

2.4.1.2. Average size and number of trees

The following equations were additionally fitted to predict the average size of trees in a stand with respect to dbh and height, for any age, site quality and stocking level.

$$\ln \bar{d} = a + b A^{-1} + c \ln H + d \ln N \qquad (5)$$

$$\ln \bar{h} = a + b A^{-1} + c \ln H + d \ln N \qquad (6)$$

where $\bar{d}$ = Crop diameter (m)

$\bar{h}$ = Crop height (m)
N = number of trees ha^{-1}
A = Age (year)
H = Top height (m)
N = Number of trees ha^{-1}

Additionally, the expected number of trees as per the thinning schedule followed in the region was predicted by estimating the parameters of the following function.

$$\ln N = a + b A^{-1} + c \ln H \quad (7)$$

where A,H,N are as defined earlier

2.4.2. Yield from thinning

In order to obtain information on yield from thinning operations, data were gathered from Plantation Journals and Felling Registers maintained at the Range Offices of the Department. Although the data were planned to be obtained from randomly selected Ranges in each of the Territorial Divisions in the State, data could not be obtained from some Divisions due to nonavailability of proper records. Also the number of units for which data were available was few. Hence, the data were pooled to arrive at a single set of figures for the State. Individual plantations formed the basic unit. The data were classified by the type of thinning like I Mechanical thinning, II Mechanical thinning, I Silvicultural thinning, II Silvicultural thinning etc. and the average yield obtained in the region for each operation were computed by giving weightage to the extent of individual plantations. The harvested material was of different classes of poles and logs. The yield of poles was found recorded in numbers in many cases and hence the following conversion factors KFRI (1979) were used for arriving at the volume estimates.

4.2	Class I	poles make	1 m^3 of wood
8.5	Class II	poles make	1 m^3 of wood
14.1	Class III	poles make	1 m^3 of wood
35.3	Class IV	poles make	1 m^3 of wood
70.6	Class V	poles make	1 m^3 of wood
142.9	Class VI	poles make	1 m^3 of wood

Since the volume of logs was recorded in quarter girth volume the corresponding round wood volume was obtained by dividing by 0.785. Later, the mean yield from different operations was summed up to obtain the total yield from thinning and then divided by the average age at final thinning to arrive at the MAI for thinning yield.

2.4.3. Total yield

The MAI of total yield (standing crop + accumulated yield of thinning) was found out as follows.

MAI of total yield = (Rotation age x MAI of standing crop at rotation age) + (Average age at final thinning x MAI of thinning yield) / Rotation age.

2.5. Factors affecting productivity

Information on certain factors related to the management and site features were gathered during the survey. These factors were slope of the site, human interference in the plot, presence of climber, loranthus and borer in the plot, etc. The proportions of area under the different levels of these factors were estimated in accordance with the sampling plan used, in order to assess their status. For instance, area falling under different slope classes, different levels of human interference, etc. were estimated. Additionally, influence of these factors on growth of trees was investigated through analysis of variance. Basal area ha^{-1} was chosen as the dependent variable in the analysis of variance so as to avoid any error created while predicting the volume of trees based on diameter and thus to assess the influence of the factors on the crop more precisely. The basal area had to be converted to logarithmic scale to break the dependence of conditional variance of basal area on the corresponding mean. The partial coefficient of determination was computed for each factor so as to evaluate the relative magnitude of influence of different factors on crop growth.

2.6. Potential productivity

The above works were mainly directed in estimating the current levels of productivity and the status of plantations with respect to certain aspects like stocking and site quality distribution. A related question is that of comparison of the existing productivity levels with certain standards available. Information on productivity of teak in other States in the country is scant. Hence, comparisons were effected in relation to the variations depicted in the yield tables for teak (Anonymous, 1970) which was developed based on the data from all teak growing States in India. The objective of such comparisons was mainly to assess the current levels in relation to maximum potential productivity possible under comparable growing conditions. The maximum standing volume observed during the survey also served as a basis in this regard.

3. RESULTS AND DISCUSSION

3.1. Spatial distribution and age structure

The extent of teak plantations in the different Forest Divisions as on 1995 is shown in Table 1. The plantations of teak and teak mixed with other species were found to occupy about 68,797 ha in the State as on 1995. Although species like bombax, ailanthus, etc. are grown mixed with teak, their share in the stand is very small exerting practically no influence on the growth and yield of teak. The proportion of such miscellaneous species including natural regeneration was found to be less than 25 per cent on an average except

in few Divisions. Teak is grown in all Territorial Divisions. The Central and Southern Circles held larger shares of the teak area. At the Divisional level, Chalakkudy and Malayattoor had the largest extent under teak, Kozhikkode had the least extent.

The age structure of the plantations as of 1995 is indicated in Table 2 and Figure 1. Nearly 72 per cent of the area is below 35 years of age.

During the course of the survey, the list of plantations was updated to the year 1996 including the minor changes that had happened since 1995 and also correcting some of the earlier entries on year of planting, extent etc. of the plantations. The updated list with the reference year 1996 is furnished in Appendix 15 along with the summary tables. However, all the parameter estimates except that of growing stock had to be developed based on the 1995 list of plantation because that list constituted the sampling frame for the survey. Once the samples were drawn, changes in the sampling frame would alter the selection probabilities for sampling units. Nevertheless, growing stock was estimated based on the revised list of plantations as it is very sensitive to the extent of plantations.

3.2. Site quality distribution

The estimates of parameters of the height-diameter relation obtained for the different Divisions are given in Appendix 3. The adjusted R^2 varied from 0.4807 to 0.9349. While fitting the height-diameter equations, defective trees like those with broken tops or dried up stems were excluded. In spite of such refinements, the variation in height in individual diameter classes was fairly high. In the data set, the values of height ranged from 1 m to 40 m and the values of dbh ranged from 1.05 cm to 81.17 cm. The estimates of height-diameter relation in respective Divisions were utilized in the computation of top height from the survey plots taken from each Division and in turn for obtaining the site quality distribution of area for each Division.

The estimates of the proportion of area in different site quality classes in respect of the different Divisions are given in Table 3. Some of the best plantations are available in Kozhikode Division with a unique incidence of 8 per cent area carrying super quality plantations. Achencoil, Konni and Kozhikode Divisions recorded major share of area under better site quality classes (SQ I and SQ II) whereas Thiruvananthapuram, Kottayam, Wayanad, and Kannur Divisions had larger area under poor site quality classes.

At the State level, nearly 86 per cent of the area fell in medium site quality classes. The extremes were rare.

Table 1. Area under teak plantations belonging to Territorial Divisions of Kerala as on 1995

Circle/ Division	Area under teak (ha)	Percentage of area
Northern		
Kannur	1792.47	2.6
Kozhikode	289.49	0.4
North Wayanad	1490.04	2.2
South Wayanad	3091.29	4.6
Central		
Chalakkudy	5778.85	8.5
Malayattoor	5758.79	8.5
Thrissur	3604.14	5.3
Vazhachal	5514.43	8.2
Southern		
Achencoil	4779.50	7.1
Konni	4308.25	6.4
Punalur	1289.95	1.9
Ranni	4451.21	6.6
Thenmala	2808.87	4.1
Thiruvananthapuram	656.96	1.0
Olavakkode		
Mannarkkad	2046.42	1.3
Nemmara	1145.05	1.7
North Nilambur	4047.13	6.0
Palakkad	1900.22	2.8
South Nilambur	5024.68	7.4
High Range		
Kothamangalam	4971.74	7.4
Kottayam	3535.13	5.2
Munnar	512.42	0.8
Total	68797.03	100.0

Table 2. Age structure of teak plantations in Kerala as on 1995

Age group (years)	Area (ha)	Percentage of area	Cumulative percentage of area
0 - 4	2311.70	3.4	3.4
5 - 9	1017.79	1.5	4.9
10 - 14	4214.92	6.2	11.1
15 - 19	11610.09	17.2	28.3
20 - 24	10001.09	14.8	43.1
25 - 29	9250.71	13.7	56.8
30 - 34	10619.19	15.7	72.5
35 - 39	5274.98	7.8	80.3
40 - 44	2492.97	3.7	84.0
45 - 49	3437.67	5.1	89.1
50 - 54	2511.32	3.7	92.8
55 - 59	2212.65	3.3	96.1
>59	2666.95	3.9	100.0
Unknown	1175.00	--	--
Total	68797.03	--	--

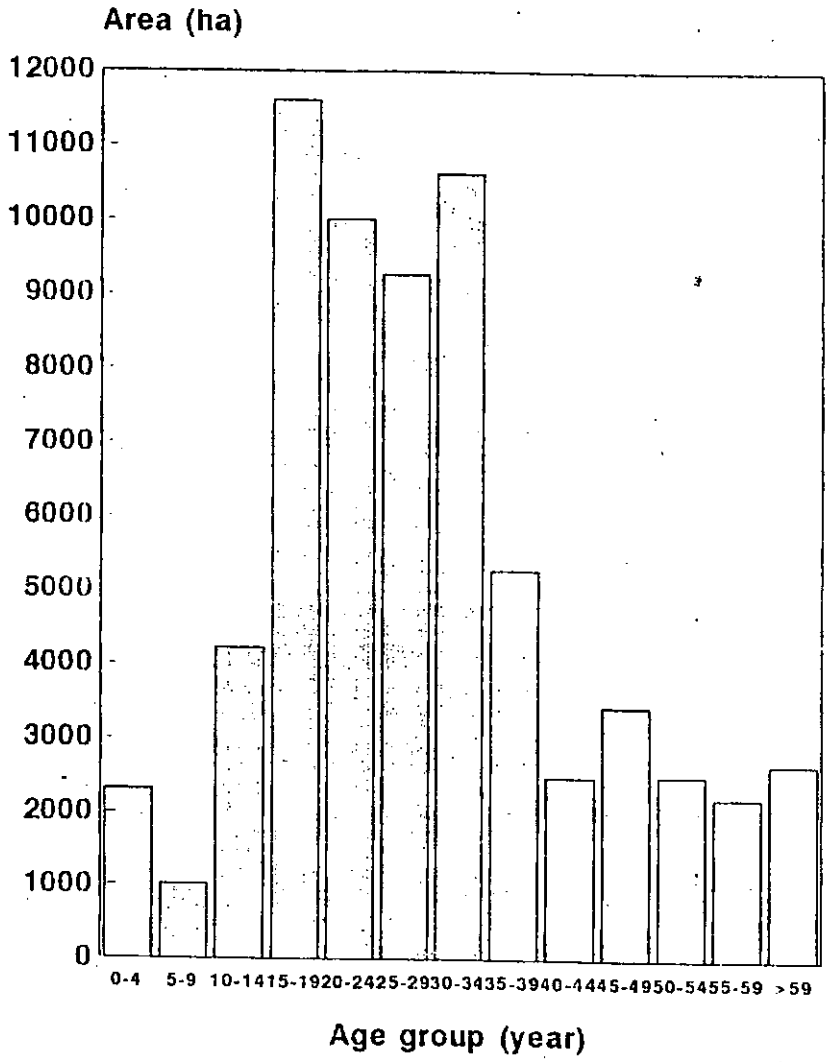

Figure 1. Age structure of teak plantations belonging to Territorial Divisions in Kerala as on 1995

Table 3. Site quality distribution of area under teak in different Divisions

Circle / Division	Percentage of area in different site quality classes						Total
	SC	I	II	III	IV	DC	
Northern							
Kannur	0	0	13	62	25	0	100
Kozhikode	8	38	23	26	5	0	100
North Wayanad	0	0	13	72	15	0	100
South Wayanad	0	0	7	75	18	0	100
Central							
Chalakkudy	0	2	49	49	0	0	100
Malayattoor	0	6	28	64	2	0	100
Thrissur	0	9	22	40	18	11	100
Vazhachal	0	2	46	51	1	0	100
Southern							
Achencoil	0	18	66	16	0	0	100
Konni	0	1	70	29	0	0	100
Punalur	0	1	32	63	4	0	100
Ranni	0	9	33	53	5	0	100
Thenmala	0	1	36	57	6	0	100
Thiruvananthapuram	0	0	0	56	39	5	100
Olavakkode							
Mannarkkad	0	1	34	46	17	2	100
Nemmara	0	3	53	42	2	0	100
North Nilambur	0	5	56	36	3	0	100
Palakkad	0	7	16	57	20	0	100
South Nilambur	0	12	45	42	1	0	100
High Range							
Kothamangalam	0	3	30	52	15	0	100
Kottayam	0	0	3	46	51	0	100
Munnar	0	9	51	38	0	2	100
Overall	0	5	38	48	9	0	100

Note : SC = Super quality class, DC = Degraded class

3.3. Stocking

Plantations having a stocking ratio between 0.9 and 1.1 were taken as fully stocked. Considering teak alone, based on basal area, nearly 48 per cent of the plantation area was under-stocked, 26 per cent fully stocked and 26 per cent over-stocked (Table 4) indicating that the growth was poor in many plantations in the State. The corresponding figures based on number of trees (Table 5) were 64, 19 and 17. Nearly 88 per cent of the plots showing under-stocking by basal area were also under-stocked by number of trees confirming that the under-stocking has resulted due to less than expected number of trees in many stands. The above estimates were obtained excluding the coppice shoots in the computation of stocking.

Based on basal area density, under-stocked plantations were more common in Punalur Konni, Kozhikode, Thrissur and Kannur Divisions and this was mostly due to the reduced number of trees in the stands. The case of over-stocked plantations occurred more frequently in Mannarkkad, Nemmara and the two Wayanad Divisions. The over-stocking was found partly due to the presence of larger number of trees in the stand rather than due to the better growth of trees.

Finer gradation of stocking in under-stocked plantations are given in Tables 6 and 7. In terms of basal area, 5 per cent of the plantation area in the State showed stocking ratio less than or equal to 0.25 and 11 per cent had stocking ratio between 0.26 - 0.50. About 19 per cent of the area fell in the class of 0.51 - 0.74 and 13 per cent of the area had stocking ratio 0.75 - 0.80. In terms of number of trees, the corresponding percentages were 5, 20, 29 and 10.

The estimates of growing stock of teak in terms of timber and smallwood for plantations of age greater than 10 years are furnished in Table 8. The plantations under reference (based on the list of plantations updated to the year 1996) in the State were found to carry 3.248 million m^3 of timber and 1.590 million m^3 of smallwood in 68,651 ha. The growing stock of plantations up to 10 years of age expressed in number of trees is reported in Table 9. In many Divisions, there are no plantations younger than 11 years. The total number of trees in the State in the age group of 1 to 5 years worked out to 3.790 million. The corresponding number in the age group of 6 to 10 years was around 1.190 million. The combined extent of plantations up to 10 years of age was 4,516 ha.

3.4. Productivity

3.4.1. Main crop

3.4.1.1. Mean Annual Increment (MAI)

The equation for predicting the commercial volume including timber and smallwood at the stand level worked out to be the following.

$$\ln V = 0.8287 - 139.7739\ A^{-1} + 1.1629 \ln H + 46.9783\ A^{-1} \ln H \qquad (8)$$
$$(0.5403)\quad (15.2053)\quad (0.1805)\quad (5.3075)\quad (\text{Adj. } R^2 = 0.5762)$$

The figures in brackets are standard errors. The commercial volume for a given age and top height combination was computable from equation (8). The values of volume as per the equation (8) for different age and site quality levels are tabulated in Table 10. In Kerala, commercial volume is usually expressed in terms of quarter girth volume. The values in Table 10 are converted to quarter girth volume and reported in Table 11 for easy reference. However, all further discussions are based on round wood volume. A graphical representation of the volume curves under different site quality classes along with that reported under the yield table for teak is given in Figure 2. For site quality class I, the volume of the standing crop was found to increase faster than expected under the yield table, initially. This was due to the larger number of trees retained in those plantations. However, the initial advantage disappeared in the later stages due to overcrowding resulting in reduced size of the trees as could be seen in the graphs following. At 60 years, there was as much as 9 per cent loss in volume compared to yield table figures (Table 12). In site quality class IV, the observed volume growth was less than the expected due to poor stocking with great losses initially and around 20 per cent in later years. In other site quality classes (SQ II and SQ III), the loss in volume amounted to around 10 per cent at 60 years.

The change in MAI with age under different site quality classes is discernible from Table 13. Under better site quality classes MAI attains to the maximum at younger ages and vice versa in poor site quality classes.

For the computation of regional average, the age at which MAI is to be expressed was taken as 60. The volume attained at 60 years for different site quality classes was first predicted using equation (8) and the corresponding MAI was obtained by dividing the predicted volume by 60. The weighted average MAI at 60 years computed for the different Divisions is reported in Table 14. Considering the values of MAI obtained three productivity classes were identified viz., MAI < 2 $m^3 ha^{-1}$, MAI of 2-3 $m^3 ha^{-1}$, MAI >3 $m^3 ha^{-1}$. The identity of the different Divisions with respect to the productivity classes is also indicated in Table 14. Kozhikode and Achencoil Divisions qualified for the high productivity group. The low productivity group included Kannur, North Wayanad, South Wayanad, Kottayam and Thiruvananthapuram Divisions. The rest of the Divisions fell into the medium group but places like Nilambur, Konni and Munnar retained their relative superiority within the medium group. The middle group is the one which is supposed to respond to treatment and holds promise for the future.

Table 4. Stocking status of area under teak in different Divisions, based on basal area ha^{-1}, excluding coppice shoots

Circle / Division	Percentage of area in different stocking classes		
	Under stocked	Fully stocked	Over stocked
Northern			
Kannur	70	18	12
Kozhikode	79	17	4
North Wayanad	18	19	63
South Wayanad	12	18	70
Central			
Chalakkudy	55	22	23
Malayattoor	52	35	13
Thrissur	78	12	10
Vazhachal	45	27	28
Southern			
Achencoil	37	45	18
Konni	78	13	9
Punalur	91	9	0
Ranni	55	34	11
Thenmala	50	38	12
Thiruvananthapuram	51	32	17
Olavakkode			
Mannarkkad	22	1	77
Nemmara	21	16	63
North Nilambur	45	38	17
Palakkad	52	24	24
South Nilambur	42	26	32
High Range			
Kothamangalam	48	22	30
Kottayam	21	23	56
Munnar	24	29	47
Overall	48	26	26

Table 5. Stocking status of area under teak in different Divisions, based on number of trees ha^{-1}, excluding coppice shoots

Circle / Division	Percentage of area in different stocking classes		
	Under stocked	Fully stocked	Over stocked
Northern			
Kannur	86	10	4
Kozhikode	33	8	59
North Wayanad	67	21	12
South Wayanad	29	37	34
Central			
Chalakkudy	50	22	28
Malayattoor	65	16	19
Thrissur	59	12	29
Vazhachal	61	19	20
Southern			
Achencoil	85	6	9
Konni	84	12	4
Punalur	99	0	1
Ranni	74	20	6
Thenmala	84	8	8
Thiruvananthapuram	57	25	18
Olavakkode			
Mannarkkad	26	26	48
Nemmara	23	28	49
North Nilambur	49	31	20
Palakkad	60	30	10
South Nilambur	49	22	29
High Range			
Kothamangalam	77	14	9
Kottayam	75	14	11
Munnar	52	19	29
Overall	64	19	17

Table 6. Finer gradations of under stocking in teak plantations in different Divisions, based on basal area ha^{-1}, excluding coppice shoots

Circle / Division	Percentage of area in different under stocking classes			
	Stocking ratio			
	<=0.25	0.26 - 0.50	0.51 - 0.74	0.75 - 0.89
Northern				
Kannur	7	27	23	13
Kozhikode	11	24	35	9
North Wayanad	0	7	5	6
South Wayanad	0	7	2	3
Central				
Chalakkudy	3	17	22	13
Malayattoor	6	13	11	22
Thrissur	15	6	30	27
Vazhachal	3	7	25	10
Southern				
Achencoil	0	5	23	9
Konni	7	27	29	15
Punalur	15	43	24	9
Ranni	0	6	24	25
Thenmala	0	12	28	10
Thiruvananthapuram	15	0	0	36
Olavakkode				
Mannarkkad	8	10	2	2
Nemmara	5	1	11	4
North Nilambur	4	9	21	11
Palakkad	11	9	18	14
South Nilambur	3	12	18	9
High Range				
Kothamangalam	7	8	18	15
Kottayam	0	5	15	1
Munnar	6	4	8	6
Overall	5	11	19	13

Table 7. Finer gradations of under stocking in teak plantations in different Divisions, based on number of trees ha^{-1}, excluding coppice shoots

Circle / Division	Percentage of area in different under stocking classes			
	Stocking ratio			
	<=0.25	0.26 - 0.50	0.51 - 0.74	0.75 - 0.89
Northern				
Kannur	13	28	40	5
Kozhikode	6	9	18	0
North Wayanad	6	12	34	15
South Wayanad	2	8	15	4
Central				
Chalakkudy	1	14	26	9
Malayattoor	7	14	22	22
Thrissur	17	22	20	0
Vazhachal	3	17	33	8
Southern				
Achencoil	2	27	44	12
Konni	3	33	45	3
Punalur	22	35	42	0
Ranni	5	23	33	13
Thenmala	6	41	36	1
Thiruvananthapuram	15	19	10	13
Olavakkode				
Mannarkkad	12	8	3	3
Nemmara	5	2	9	7
North Nilambur	5	9	23	12
Palakkad	13	16	19	12
South Nilambur	1	13	27	8
High Range				
Kothamangalam	12	26	23	16
Kottayam	1	26	37	11
Munnar	6	7	20	19
Overall	5	20	29	10

Table 8. Estimated growing stock of teak in teak plantations of age greater than10 years belonging to Territorial Divisions of Kerala as on 1996

Circle/Division	Timber (m^3)	Smallwood (m^3)
Northern		
Kannur	78,964	28,609
Kozhikode	17,337	4,547
North Wayanad	61,748	51,843
South Wayanad	95,108	93,273
Central		
Chalakkudy	348,841	132,441
Malayattoor	233,913	138,514
Thrissur	84,097	42,333
Vazhachal	203,288	146,798
Southern		
Achencoil	284,219	113,709
Konni	419,917	147,608
Punalur	23,022	18,806
Ranni	255,481	95,664
Thenmala	104,172	47,746
Thiruvananthapuram	17,931	11,933
Olavakkode		
Mannarkkad	79,079	39,032
Nemmara	68,064	35,157
North Nilambur	191,151	92,864
Palakkad	117,989	28,614
South Nilambur	212,607	107,311
High Range		
Kothamangalam	180,699	96,774
Kottayam	130,090	97,148
Munnar	40,523	19,493
Total	3,248,240	1,590,217

Table 9. Estimated number of trees of teak in teak plantations of age up to 10 years in Territorial Divisions of Kerala as on 1996

Circle/Division	Number of trees	
	Plantations of age 1 to 5 years	Plantations of age 6 to 10 years
Northern		
Kannur	—	—
Kozhikode	—	—
North Wayanad	—	38,536
South Wayanad	—	—
Central		
Chalakkudy	32,970	—
Malayattoor	122,250	—
Thrissur	178,000	—
Vazhachal	253,396	161,369
Southern		
Achencoil	271,026	55,969
Konni	839,105	—
Punalur	—	—
Ranni	608,701	79,495
Thenmala	504,900	81,128
Thiruvananthapuram	39,105	—
Olavakkode		
Mannarkkad	—	—
Nemmara	891	1,241
North Nilambur	407,929	427,939
Palakkad	204,712	30,254
South Nilambur	252,845	107,742
High Range		
Kothamangalam	—	206,877
Kottayam	74,379	—
Munnar	—	—
Total	3,790,209	1,190,550

Table 10. Estimates of commercial volume (round wood) of teak at different age and site quality levels

Age (year)	Volume of timber and smallwood (m^3 ha^{-1})			
	SQ I	SQ II	SQ III	SQ IV
10	38	9	1	0
15	114	43	12	2
20	174	78	28	6
25	204	105	44	13
30	224	124	58	20
35	236	137	71	29
40	248	153	83	37
45	254	160	92	42
50	261	171	101	50
55	263	178	109	55
60	271	184	114	60

Table 11. Estimates of commercial volume (quarter girth volume) of teak at different age and site quality levels

Age (year)	Quarter volume of timber and smallwood (m^3 ha^{-1})			
	SQ I	SQ II	SQ III	SQ IV
10	30	7	1	0
15	89	34	9	2
20	137	62	22	5
25	160	82	35	10
30	176	97	46	16
35	185	108	56	23
40	195	120	65	29
45	199	126	72	33
50	205	134	79	39
55	206	140	86	43
60	213	144	89	47

3.4.1.2. Average size and number of trees

The equations for predicting the average size of trees with respect to dbh and height were the following.

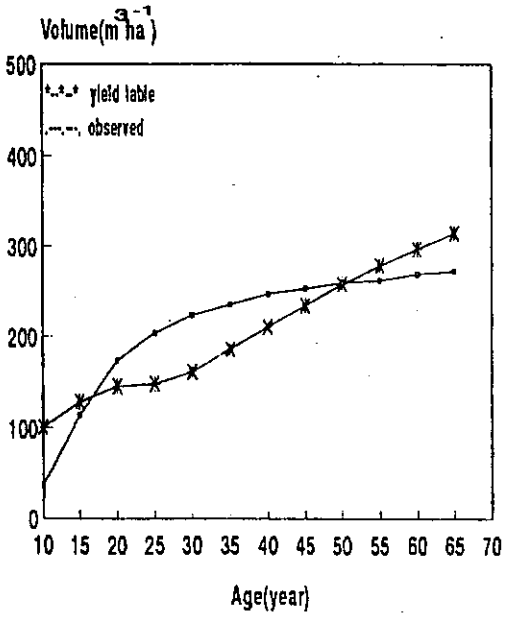

Figure 2a. Site Quality I

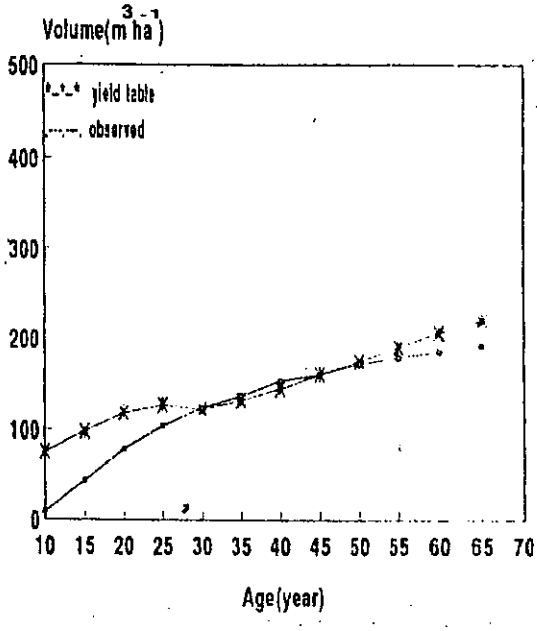

Figure 2b. Site Quality II

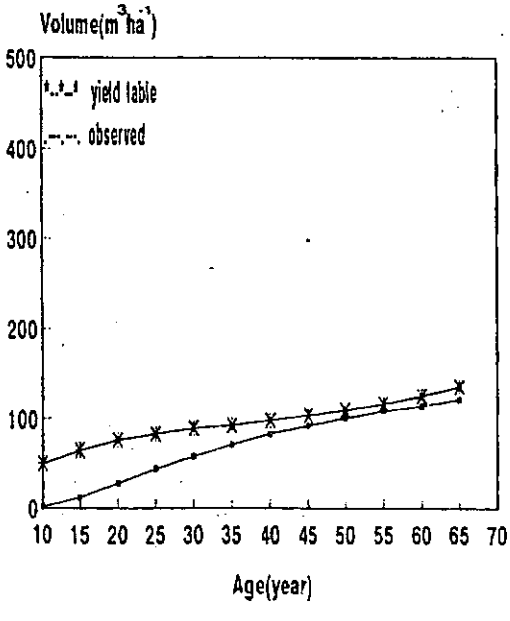

Figure 2c. Site Quality III

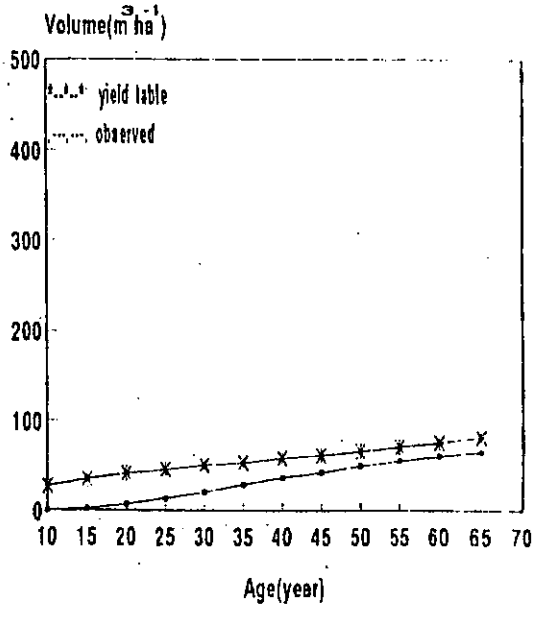

Figure 2d. Site Quality IV

Figure 2. Change in commercial volume of teak with age under different site quality classes

$$\ln \bar{d} = -4.0251 - 3.7695\ A^{-1} + 1.0914 \ln H - 0.0911 \ln N \quad (9)$$
$$(0.0693)\ (0.2851) \qquad (0.0178) \qquad (0.0061) \qquad (\text{Adj. } R^2 = 0.8918)$$

$$\ln \bar{h} = 0.3072 - 1.1011\ A^{-1} + 1.0131 \ln H - 0.0703 \ln N \quad (10)$$
$$(0.0477)\ (0.1956) \qquad (0.0122) \qquad (0.0042) \qquad (\text{Adj. } R^2 = 0.9231)$$

Table 12. Percentage change in observed commercial volume of teak in relation to yield table values at different age and site quality levels

Age (year)	Percentage change in volume of timber and smallwood (%)			
	SQ I	SQ II	SQ III	SQ IV
10	-63	-88	-97	-100
15	-11	-56	-81	-94
20	19	-34	-63	-84
25	37	-18	-47	-71
30	38	1	-35	-60
35	27	4	-23	-45
40	17	6	-15	-37
45	8	0	-11	-31
50	1	-2	-8	-24
55	-6	-6	-6	-22
60	-9	-10	-9	-20

Table 13. Estimated MAI of commercial volume (round wood) of teak at different age and site quality levels

Age (year)	MAI of commercial volume ($m^3\ ha^{-1}$)			
	SQ I	SQ II	SQ III	SQ IV
10	3.757	0.914	0.141	0.012
15	7.620	2.877	0.815	0.135
20	8.698	3.929	1.404	0.326
25	8.177	4.184	1.770	0.531
30	7.478	4.128	1.929	0.670
35	6.755	3.912	2.028	0.830
40	6.204	3.832	2.087	0.916
45	5.652	3.563	2.054	0.939
50	5.219	3.423	2.018	0.995
55	4.785	3.230	1.982	1.000
60	4.508	3.068	1.898	1.001

Table 14. Estimates of MAI of teak at 60 years excluding yield from thinning for the different Divisions

Circle/Division	MAI ($m^3 ha^{-1}$)	Productivity class
Northern		
Kannur	1.826	Low
Kozhikode	3.323	High
North Wayanad	1.916	Low
South Wayanad	1.818	Low
Central		
Chalakkudy	2.524	Medium
Malayattoor	2.364	Medium
Thrissur	2.130	Medium
Vazhachal	2.479	Medium
Southern		
Achencoil	3.140	High
Konni	2.743	Medium
Punalur	2.263	Medium
Ranni	2.474	Medium
Thenmala	2.291	Medium
Thiruvananthapuram	1.503	Low
Olavakkode		
Mannarkkad	2.131	Medium
Nemmara	2.578	Medium
North Nilambur	2.657	Medium
Palakkad	2.088	Medium
South Nilambur	2.729	Medium
High Range		
Kothamangalam	2.193	Medium
Kottayam	1.476	Low
Munnar	2.712	Medium
Overall	2.423	Medium

Crop diameter corresponded to the quadratic mean diameter for each plot. The values of crop diameter expected under different site quality classes as per the equation (9) are given in Table15. Graphical representation of the equation (9) is given in Figure 3 in comparison with that of the yield table. The average diameter of the stands under reference was mostly in conformity with the yield table except the reduction in diameter growth due to over-stocking in site quality I plantations in later years. The lateral size of logs in teak is of importance and this is not to be sacrificed for the higher volume that might accrue initially on account of over-stocking.

Crop height for each plot was obtained as mean of predicted tree heights obtained using equation (10) a tabular presentation of which under different site quality and age levels is made in Table 16. A graphical representation of the values in Table 16 is given in Figure 4 in comparison to that of the yield table. There seems to be near perfect agreement of the fitted height curves in the present case with that expected under the yield table. The over-stocking or under-stocking do not seem to have affected the height growth and this confirms the general observation that height is less affected by variations in stand density.

The reduction in number of trees with increasing age was characterized by the following equation.

$$\ln N = 6.1281 + 15.2603\ A^{-1} - 0.4224 \ln H \qquad (11)$$
$$(0.2756)\quad (1.2734)\quad (0.0833) \qquad (\text{Adj. } R^2 = 0.2462)$$

The output of equation (11) for different age and site quality combinations is provided in Table 17. A comparison of the fitted functions with that of the yield table for teak is given in Figure 5. It can be seen from Figure 5 that the plantations of site quality class I are slightly over-stocked whereas plantations of site quality IV are heavily under-stocked. Thinning rates in other site quality classes agreed more or less closely with that proposed in the yield table.

In the data set used for estimating the parameters of equations (8), (9), (10) and (11), the ranges of variables were the following.

Variable	Minimum	Maximum
A	10 years	78 years
H	4 m	40 m
N	32 trees ha^{-1}	2133 trees ha^{-1}
V	3 m^3 ha^{-1}	303 m^3 ha^{-1}
$\overline{d}$	6.6 cm	67.4 cm
$\overline{h}$	4 m	40 m

Table 15. Estimates of crop diameter of teak at different age and site quality levels

Age (year)	Crop diameter (cm)			
	SQ I	SQ II	SQ III	SQ IV
10	14.9	11.4	7.9	4.9
15	22.4	17.4	12.5	7.8
20	28.5	22.1	15.8	9.9
25	33.0	25.7	18.7	12.0
30	36.9	28.8	21.0	13.6
35	40.1	31.4	23.3	15.6
40	43.3	34.3	25.5	17.2
45	45.8	36.2	27.3	18.3
50	48.3	38.5	29.0	19.8
55	50.3	40.4	30.7	20.9
60	52.7	42.2	31.9	22.0

Table 16. Estimates of crop height of teak at different age and site quality levels

Age (year)	Crop height (m)			
	SQ I	SQ II	SQ III	SQ IV
10	13.6	10.6	7.6	4.9
15	18.2	14.3	10.6	6.8
20	21.7	17.1	12.6	8.2
25	24.2	19.2	14.3	9.5
30	26.4	21.0	15.7	10.5
35	28.1	22.4	17.0	11.8
40	29.9	24.1	18.4	12.7
45	31.3	25.2	19.4	13.4
50	32.7	26.5	20.4	14.4
55	33.7	27.5	21.4	15.0
60	35.1	28.6	22.1	15.7

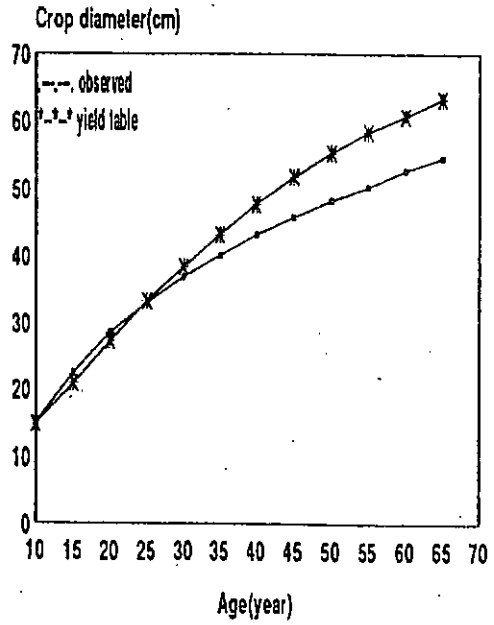

Figure 3a. Site Quality I

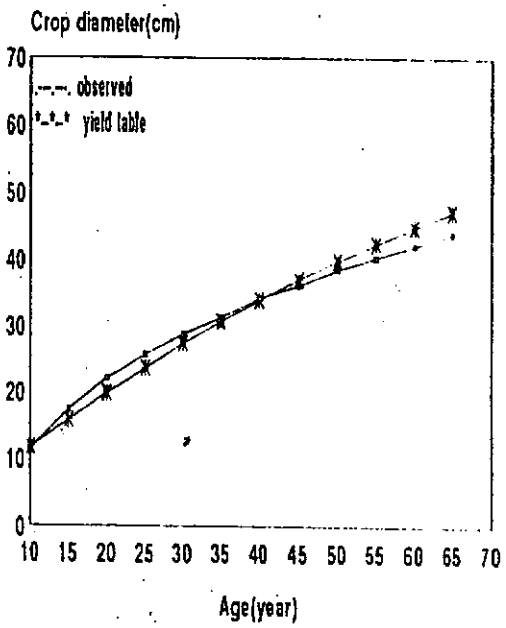

Figure 3b. Site Quality II

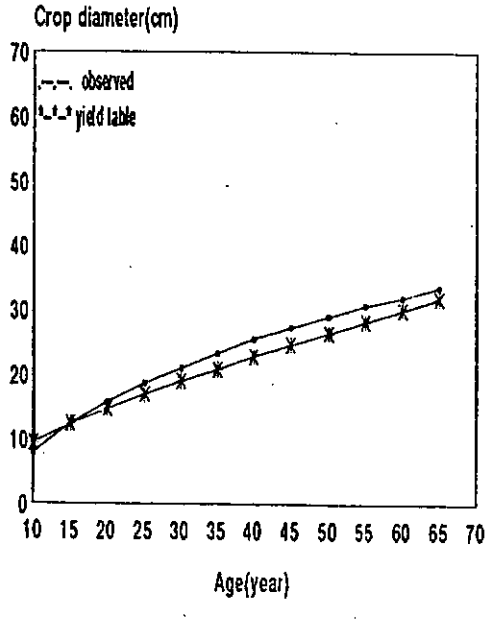

Figure 3c. Site Quality III

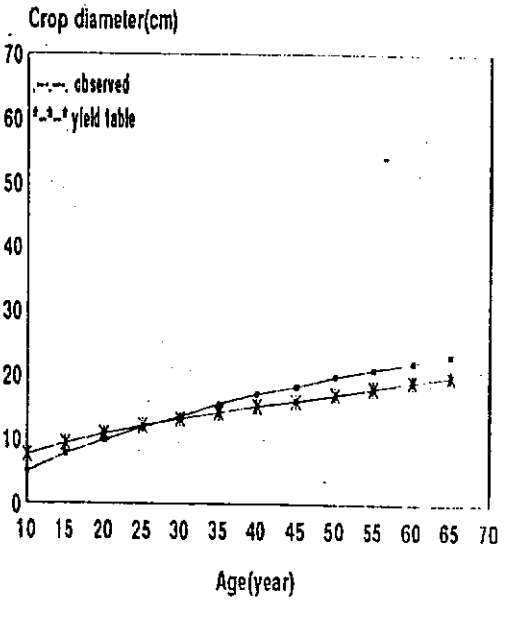

Figure 3d. Site Quality IV

Figure 3. Change in crop diameter of teak with age under different site quality classes

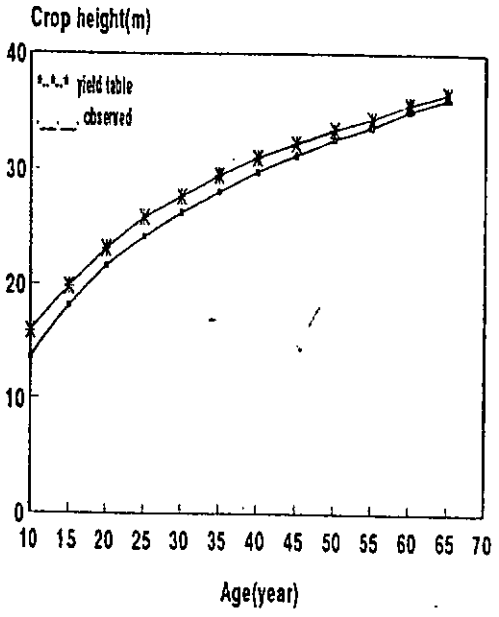

Figure 4a. Site Quality I

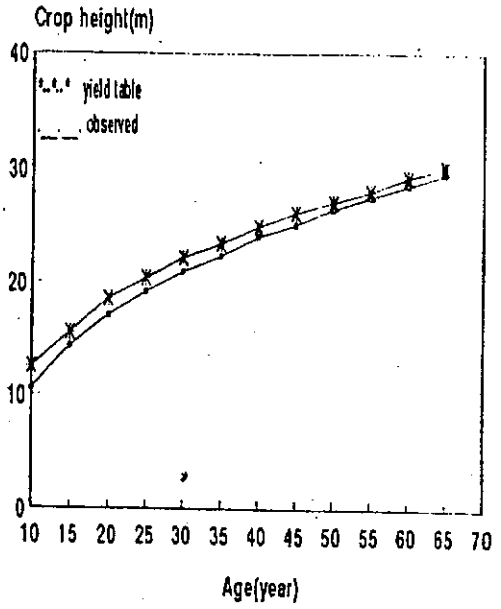

Figure 4b. Site Quality II

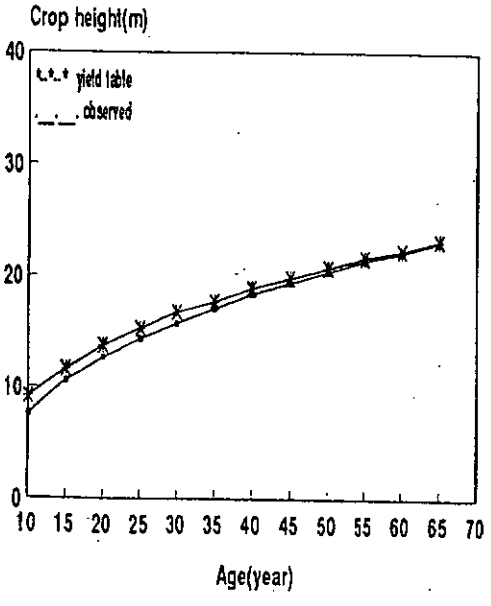

Figure 4c. Site Quality III

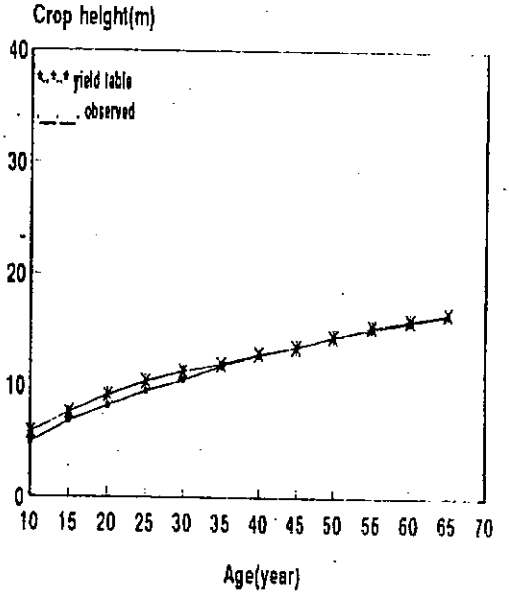

Figure 4d. Site Quality IV

Figure 4. Change in crop height of teak with age under different site quality classes

Table 17. Estimates of number of trees of teak at different age and site quality levels

Age (year)	Number of trees (no. ha^{-1})			
	SQ I	SQ II	SQ III	SQ IV
10	764	846	968	1156
15	421	463	524	625
20	308	339	384	457
25	255	280	316	373
30	224	246	276	325
35	204	223	250	290
40	189	206	230	267
45	178	194	216	251
50	169	184	205	236
55	163	177	196	226
60	157	171	189	218

3.4.2. Yield from thinning

The data obtained from past records on yield from thinning from the different Divisions were meagure and had to be pooled. *In toto*, there were 167 plantations from which the data were gathered, belonging to Kannur, Kozhikode, Chalakkudy, Malayattoor, Thrissur, Vazhachal, Konni, Ranni, Mannarkkad, Nemmara, North Nilambur, Palakkad, South Nilambur, Kothamangalam and Kottayam Divisions.

The average yield obtained from different thinning operations is indicated in Table 18. The actual yield levels observed are very low and there is considerable variation at every operation. The mean value for IV Silvicultural thinning is based on very few observations and therefore is not very reliable. The average values of age at which the different silvicultural operations are carried out in the State are also reported in Table 18. The MAI worked out for thinning yield came to 1.174 m^3 ha^{-1} of round wood.

Lack of proper records with the Forest Department was a series limitation in assessing the yield from thinning. The data on thinning yields are supposed to be recorded in the Plantation Journal or at least available in Felling Registers. Neither of these records were available in most cases. Information from other sources like official correspondence made by the Range Officers were inaccessible to us.

3.4.3. Total yield

The MAI of total yield at 60 years obtained for each Division is reported in Table 19.

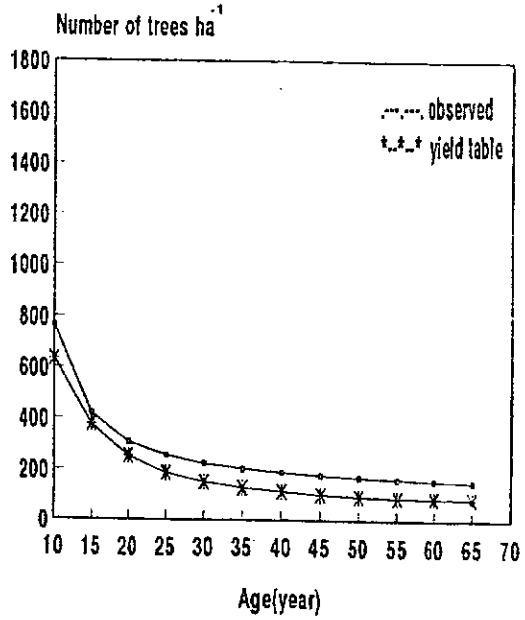

Figure 5a. Site Quality I

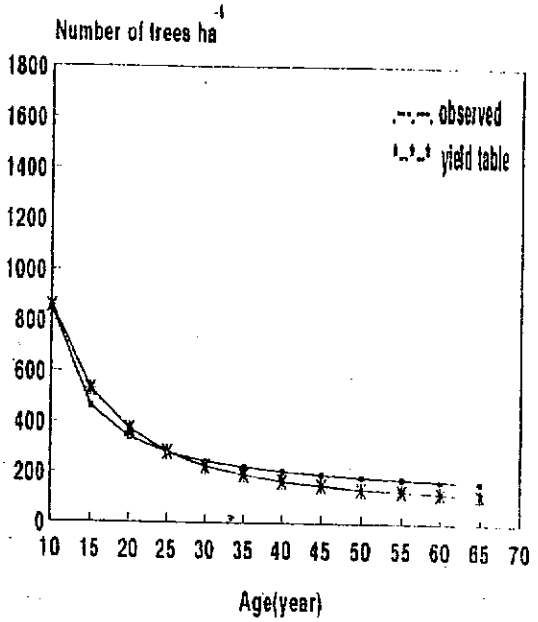

Figure 5b. Site Quality II

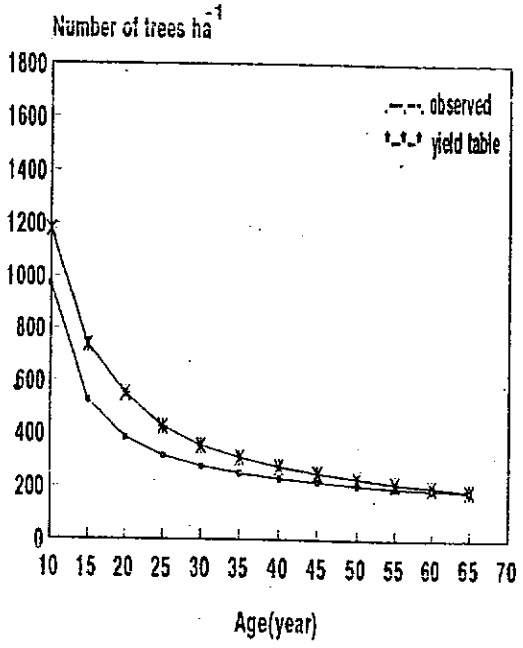

Figure 5c. Site Quality III

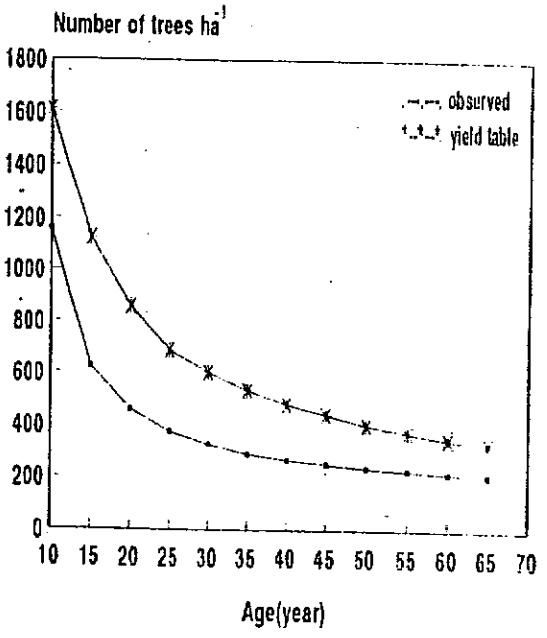

Figure 5d. Site Quality IV

Figure 5. Reduction in number of trees of teak with age under different site quality classes

Table 18. Yield of teak from thinning at different thinning operations in Kerala State

Type of thinning	Yield from thinning (m^3 ha^{-1})			Age at working (year)			Count
	Mean	Min	Max	Mean	Min	Max	(number)
I Mech	4.439	0.073	17.043	7	4	13	57
II Mech	6.029	0.783	16.001	10	5	17	34
I Silvi	4.095	0.292	16.584	16	10	24	56
II Silvi	5.660	0.100	28.557	24	12	33	47
III Silvi	12.706	2.319	30.108	31	19	43	24
IV Silvi	8.159	2.281	13.572	35	28	43	6

3.5. Factors affecting productivity

Traditionally, teak is grown in the State under rainfed conditions. Other than the planting and initial tending operations there are very little management inputs. In older plantations, cutting of loranthus and climbers is practiced in places where their incidence is high. Extensive studies on high input management for teak are yet to be conducted in the State. However, the survey conducted presently revealed a few facts. Results of compilation of observations on certain management and site features are furnished in Tables 20 to 23. All the estimates in these Tables were made in accordance with the sampling plan adopted for the survey.

The practice of maintaining Plantation Journals does not seem to be very much upheld in the Range Offices. The Plantation Journals were found available only in 51 per cent of the cases at the State level. Human interference was high in 17 per cent of the area and low in 57 per cent of the area. The signs of illicit felling were detected in 32 per cent of the area. Soil condition was good in 95 per cent of the area. Nearly 34 per cent of the land was externally devoid of rocks. The visual assessment of the overall condition of the plantations revealed that about 73 per cent of the plantation area is in good condition. Incidence of loranthus was high only in 3.8 per cent of the area. It was found to occur in low intensity in 45 per cent of the area. Climbers were found to occur in high amounts in 11 per cent of the area. The per cent incidence for low category in this case was 72 per cent. Borer attack was high in 3.6 per cent of the area. It occurred in low levels in 27 per cent of the area. Water blisters were serious in 0.7 per cent of the area but occurred in low intensity in 40.7 per cent of the area. Majority of the plantation area (68%) was found have slope between 3 to 15^0. About 28 per cent of the area in steep category having slope between 15 - 30^0.

Table 19. Estimates of MAI of teak at 60 years including yield from thinning for the different Divisions

Circle/Division	MAI ($m^3 ha^{-1}$)
Northern	
Kannur	2.511
Kozhikode	4.007
North Wayanad	2.600
South Wayanad	2.503
Central	
Chalakkudy	3.208
Malayattoor	3.049
Thrissur	2.815
Vazhachal	3.164
Southern	
Achencoil	3.825
Konni	3.428
Punalur	2.948
Ranni	3.159
Thenmala	2.976
Thiruvananthapuram	2.188
Olavakkode	
Mannarkkad	2.816
Nemmara	3.263
North Nilambur	3.342
Palakkad	2.773
South Nilambur	3.414
High Range	
Kothamangalam	2.878
Kottayam	2.161
Munnar	3.396
Overall	3.110

Table 20. Status of teak plantations with respect to certain management and site features

Feature	Condition (Percentage)			
Availability of Plantation Journals	Available (51.1)	Not available (48.9)		
Human interference	Nil (26.5)	Low (56.8)	High (16.7)	
Illicit felling	Nil (67.6)	Low (31.6)	High (0.8)	
Soil condition	Poor (3.5)	Good (95.1)	Very good (1.5)	
Rockiness	Nil (33.7)	Low (61.5)	High (4.8)	
Overall condition	Failed (4.6)	Poor (21.1)	Good (73.3)	Very good (1.0)

Table 21. Status of teak plantations with respect to presence of loranthus and climbers

Circle / Division	Loranthus			Climbers		
	Nil	Low	High	Nil	Low	High
Northern						
Kannur	25.6	74.4	0.0	2.7	69.3	28.0
Kozhikode	88.9	11.1	0.0	0.0	64.0	36.0
North Wayanad	37.4	62.6	0.0	22.5	77.5	0.0
South Wayanad	0.0	100.0	0.0	71.1	28.9	0.0
Central						
Chalakudy	100.0	0.0	0.0	0.0	100.0	0.0
Malayattoor	76.0	17.3	6.7	3.5	68.5	28.0
Vazhachal	52.0	48.0	0.0	8.7	74.5	16.8
Southern						
Achencoil	11.0	89.0	0.0	5.2	81.7	13.1
Konni	68.4	17.7	13.9	23.9	72.3	3.8
Punalur	83.5	16.5	0.0	0.0	100.0	0.0
Ranni	84.0	16.0	0.0	27.8	57.5	14.7
Thenmala	31.3	68.7	0.0	0.8	99.2	0.0
Thiruvananthapuram	60.2	39.8	0.0	43.8	30.8	25.4
Olavakkode						
Mannarkkad	65.4	34.6	0.0	71.8	28.2	0.0
Nemmara	31.8	68.2	0.0	28.1	71.9	0.0
North Nilambur	8.2	89.6	2.2	30.3	68.7	1.0
Palakkad	18.1	66.0	15.9	28.0	62.1	9.9
South Nilambur	21.4	57.3	21.3	9.2	73.7	17.1
High Range						
Kothamangalam	90.0	10.0	0.0	17.0	65.3	17.7
Kottayam	49.6	50.4	0.0	24.1	74.5	1.4
Munnar	45.2	54.8	0.0	34.8	57.0	8.2
Overall	51.4	44.8	3.8	17.4	71.9	10.6

Table 22. Status of teak plantations with respect to borer attack and presence of water blister

Circle / Division	Borer attack			Water blister		
	Nil	Low	High	Nil	Low	High
Northern						
Kannur	93.4	0.0	6.6	85.4	0.0	14.6
Kozhikode	100.0	0.0	0.0	65.0	35.0	0.0
North Wayanad	100.0	0.0	0.0	53.1	46.9	0.0
South Wayanad	74.0	26.0	0.0	0.7	99.3	0.0
Central						
Chalakudy	6.4	63.0	30.6	100.0	0.0	0.0
Malayattoor	12.1	82.2	5.7	52.3	45.9	1.8
Vazhachal	77.6	22.4	0.0	73.4	26.6	0.0
Southern						
Achencoil	75.3	24.7	0.0	49.3	50.7	0.0
Konni	87.9	12.1	0.0	46.8	53.2	0.0
Punalur	89.5	1.0	9.5	99.0	1.0	0.0
Ranni	94.5	5.5	0.0	63.0	37.0	0.0
Thenmala	100.0	0.0	0.0	54.5	45.5	0.0
Thiruvananthapuram	99.8	0.2	0.0	100.0	0.0	0.0
Olavakkode						
Mannarkkad	97.5	2.5	0.0	43.2	55.0	1.8
Nemmara	79.8	20.2	0.0	46.3	53.7	0.0
North Nilambur	82.7	17.3	0.0	71.0	29.0	0.0
Palakkad	100.0	0.0	0.0	75.1	21.8	3.1
South Nilambur	77.9	22.1	0.0	16.6	83.4	0.0
High Range						
Kothamangalam	78.1	21.9	0.0	67.2	32.8	0.0
Kottayam	39.2	60.8	0.0	57.2	42.8	0.0
Munnar	100.0	0.0	0.0	12.1	87.9	0.0
Overall	68.8	27.6	3.6	58.6	40.7	0.7

Table 23. Percentage of area in different slope classes in teak plantations in Kerala

Circle / Division	Flat (%)	Undulating (%)	Rolling (%)	Steep (%)	Very steep (%)
Northern					
Kannur	0	0	38	62	0
Kozhikode	0	0	77	17	6
North Wayanad	0	0	80	20	0
South Wayanad	0	0	89	11	0
Central					
Chalakkudy	3	0	51	46	0
Malayattoor	2	5	91	2	0
Thrissur	7	0	54	37	2
Vazhachal	5	7	47	39	2
Southern					
Achencoil	0	0	43	51	6
Konni	0	2	68	28	2
Punalur	0	0	83	17	0
Ranni	0	9	80	11	0
Thenmala	0	0	69	30	0
Thiruvananthapuram	0	22	72	6	0
Olavakkode					
Mannarkkad	0	0	68	30	2
Nemmara	0	0	66	34	0
North Nilambur	11	12	48	23	6
Palakkad	0	11	69	20	0
South Nilambur	11	0	55	34	0
High Range					
Kothamangalam	4	7	57	18	14
Kottayam	0	3	68	28	1
Munnar	7	18	41	30	5
Overall	3	4	63	28	2

Note : Flat(0 - 1^0), Undulating (1 - 3^0), Rolling (3 - 15^0), Steep (15 - 30^0), Very steep (>30^0) as defined in FAO (1979).

The results of analyses of variance are furnished in Table 24 and Table 25.

Table 24. Analysis of variance showing the effects of certain site and crop features on yield in logarithmic scale

Source	Degrees of freedom	Factor levels	Partial coefficient of determination	Significance at P=0.05
Age (reciprocal)	1	11 to 77 years	0.1734	*
Number of trees (logarithm)	1	32 to 2133 trees/ha	0.3559	*
Altitude	1	7 to 990 m	0.0016	ns
Slope	1	0 to 36 degrees	0.0008	ns
Distance to perennial water source	2	0m, <100m, >100m	0.0008	ns
Human interference	1	Absent, Present	0.0078	*
Climber	2	Nil, Low, High	0.0098	*
Loranthus	2	Nil, Low, High	0.0053	*
Borer	2	Nil, Low, High	0.0005	ns
Overall	817	--	0.4529	*

The partial coefficient of determination against each factor shows the effect unique due to that factor viz., the increase in the overall coefficient of determination by adding the particular variable in the model after having included all other variables in the model. In other words, the partial coefficient of determination indicates the degree by which a variable accounts for the variation in the dependent variable after eliminating the influence of all other independent variables in the model. Since the effect of each factor is adjusted for the effects of other variables, the sum of the corresponding values of partial coefficient of determination will not add up to the total coefficient of determination of the model with the unbalanced structure of the data.

In the present case, number of trees in the stand was found to have the largest influence on the stand basal area after eliminating the influence due to age and other site features. For a given basal area and a set of site features, variation due to age was less prominent. Since the volume of the standing crop is usually proportional to basal area, stand density comes out as a very strong variable associated with yield. The age alone could not account for a major portion of the variation because there were many plantations in the data set with very poor stocking due to plantation failure resulting in a situation where basal area was not determined by age alone to a great extent. As can be seen from Table 24, only the factors such as human interference, presence of climbers and loranthus were significantly associated with yield other than age and stocking.

Table 25. Parameters related to the different factors affecting the yield of teak in logarithmic scale

Variable/factor	Level	Parameter estimate
Age (reciprocal)	continuous	-17.61454
Number of trees (logarithm)	continuous	0.62373
Altitude	continuous	-0.00011
Slope	continuous	-0.00220
Distance	Near 0 m	-0.00677
	Less than 100 m	0.02159
	Greater than 100 m	-0.01482
Human interference	Absent	0.05951
	Present	-0.05951
Climber	Nil	0.11285
	Low	0.00761
	High	-0.12045
Loranthus	Nil	-0.05179
	Low	0.03177
	High	0.02001
Borer	Nil	0.03565
	Low	0.03057
	High	-0.06622

The values in Table 25 indicate that age had a positive effect on yield as the reciprocal of age had a negative coefficient. For a given age, the basal area was found to increase with increase in number of trees in the stand in a nonlinear fashion. Altitude and slope had very slight effects on yield individually, both having negative effects on yield with increase in their levels. Distance to perennial water source also had negligible effect although the yield levels were low for stands very near to water source and far away from water source as revealed by the corresponding parameter estimates in Table 25. Human interference when present was found to bring down the growth significantly. So was the case with climbers. Loranthus was found to occur more in better plantations. Only high incidence of borers could bring down the diameter based predictions of yield although not significantly. However, the damaging effect of borers on the wood cannot be neglected.

Referring back to Table 24, it can be seen that the model that included age, stocking and the extraneous factors mentioned above could explain only about 45 per cent of the variation in basal area growth leaving aside the predominant influence of soil on growth of trees which could not be incorporated in the present study. The present analysis had also excluded information on certain silvicultural and weather factors associated with the planting due to lack of proper data on the history of management of the plantations concerned. For instance a severe drought, intense fire, or damage from wild animals could bring down the plantation performance drastically both in younger and older stages. Thus any programme on enhancing the productivity of plantations has to give much attention on the soil and initial tending operations, other than proper stand density management practices.

3.6. Potential productivity

At the State level, the MAI of standing crop for teak was estimated as 2.423 m^3 ha^{-1}. The yield table (Anonymous, 1970) indicates an MAI of 4.968 m^3 ha^{-1} at 60 years for site quality class I under full stocking. The observed maximum volume in the presently conducted survey was 303 m^3 ha^{-1} at 58 years with an MAI of 5.2 m^3 ha^{-1} at 58 years. The above figures show that there is almost a doubling of yield possible under the conditions existing in Kerala.

The yield from thinning in the State as assessed from the records kept at the Range Offices was 1.174 m^3 ha^{-1} with the mean age of final thinning as 35 years. This could be an underestimate due to inadequate coverage of the felling sites of teak. In any case, there is indication that the thinning yields are very low compared to the value of 5.847 m^3 ha^{-1} at 35 years reported in the yield table for teak (Anonymous, 1970), corresponding to site quality I under full stocking.

The site quality distribution of area under teak indicated only 5 per cent of the area as belonging to site quality class I. Nearly 86 per cent of area was under site quality classes II and III which by appropriate measures is possible to be converted to site quality class I. Not much may not be possible with 9 per cent of the area falling under site quality class IV. Other than the changes in the site potential, one direct measure to improve the productivity would be to improve the stocking by number of trees in 63 per cent of the area detected as under-stocked.

PART II. PRODUCTIVITY OF EUCALYPT PLANTATIONS IN KERALA

1. INTRODUCTION

Eucalypts (*Eucalyptus spp.*) was introduced in Kerala as a fast growing species useful for pulpwood. Large scale planting of *E. grandis* in the State commenced in the late 1950's as part of the Grassland Afforestation Scheme implemented in the High Ranges situated between altitudes 900 m and 1500 m above msl. Later, the planting was extended to lower elevations mostly with *E. tereticornis*, by clear felling moist deciduous and even evergreen natural forests. Currently, eucalypts are worked under a rotation age of 8 years. Unlike in the case of teak, the Forest Department has contractual obligations to pulpwood industries in the State to supply raw materials of which eucalypts form a major component. Eucalypts are not usually grown in homesteads and hence production from plantations is of utmost importance.

2. MATERIALS AND METHODS

The list of eucalypt plantations raised by the Forest Department in each Forest Division as of the year 1995 was obtained from the concerned Divisions. A similar list was obtained for the plantations under the control of the Kerala Forest Development Corporation. Thus the target population was 30,641 ha of *E. tereticornis* and *E. grandis* plantations in the State. For lack of proper records, separate lists could not be prepared for the two species initially. The eucalypt plantations belonging to the Wildlife and Social Forestry Wing were excluded from the survey. The plantations belonging to the Wildlife Wing being inside the Wildlife Sanctuaries, do not fall under the regular management operations as in Territorial Circles. Eucalypt stands of the Social Forestry Wing which are mostly planted in nonforest environments have been assessed for productivity in a recent survey (Jayaraman *et al.*, 1992).The present survey on eucalypts was initiated in the month of June,1996. The plantations were stratified by Circles and by age groups within each Circle. The plantations belonging to the KFDC were merged with the nearest Territorial Circles. The age groups formed were 1-5, 6-10, 11-15 and so on up to 40 years with reference to the year 1996. Since the rotation age followed for eucalypts in the State has been around 10 years, plantations older than 10 years were mostly coppice crops. Roughly 7.4 per cent of the plantations were selected at random from each of the strata keeping a minimum of one plantation from a stratum. In each of the selected plantations, plots were marked along a randomly laid out transect running through the center of the plantation. The transects were mostly along the longer direction of the plantation. The number of plots varied proportionally with the size of the plantations. Roughly one plot was taken for every 10 ha with a maximum of 10 plots in any one plantation. The plots were circular with a radius of 10 m. The species grown was noted and measurements of girth at breast-height (gbh) of trees in the plots were taken. Observations were restricted to trees having a minimum gbh of 10 cm. Height (total height) was measured on a subset

of trees in the plot using multimeter. Trees having the largest height, the smallest height and three trees in between the range were selected for measurement of height in each plot. Several ancillary features of the site like slope, soil condition, incidence of fire, pests and diseases were also recorded from each plot. In terms of actual area measured, the overall sampling intensity worked out to 0.02 per cent.

A very serious limitations with the study on yield of eucalypt plantations was lack of proper records in respect of the species planted and the year of coppicing of individual plantations. This affected all estimates generated from the survey data. The Division-wise estimates of MAI were impossible to be developed with unknown year of coppicing. Even at the State level, the estimate of MAI had to be developed through trial and error with different possible values for rotation ages.

2.1. Spatial distribution and age structure

The area under eucalypts in different Divisions and also the age structure of the eucalypt plantations inclusive of both the species as of 1995 was generated from the above data base.

2.2. Species composition

In the absence of proper records regarding the particular species of eucalypts planted, the species composition of the plantation area had to be estimated. The species planted in the plantations selected for observations was noted and the proportions of area planted under each species in different Circles were estimated through the formulae corresponding to weighted estimator for proportions under stratified sampling (Appendix 2).The area planted under each species was then obtained by multiplying the proportions by the total area.

2.3. Growing stock

Estimate of growing stock in volume was developed for each Division through the formulae applicable to stratified sampling. For this purpose, estimate of commercial volume (volume of wood without bark greater than 5 cm diameter over bark) in each plot was obtained first by applying the following equations reported by Chaturvedi (1973b) and Chaturvedi and Pande (1973) for the respective species on each tree in the plots and added up to the plot level.

$$V_t = -0.0015 + 0.2401\ D^2h \quad (1)$$

$$V_g = -0.0030 + 0.2941\ D^2h \quad (2)$$

where V_t = Commercial volume of wood from the tree (m^3) for *E.tereticornis*

V_g = Commercial volume of wood from the tree (m^3) for *E.grandis*

D = Dbh of the tree (m)

h = Total height of the tree (m)

Since the height was not measured on all the trees in the plots for use in the above set of equations, it had to be predicted by using a height prediction model based on dbh fitted for each Circle for the two species.. The height-diameter relation fitted was of the following form.

$$\ln (h-1.37) = a + b \ln D \qquad (3)$$

where h = Total height of the tree (m)
D = Dbh of the tree (m)

The plot level estimates of volume thus obtained using equations (1), (2) and (3), formed the observations at the basic sampling unit for estimation of growing stock.

2.4. Productivity

2.4.1. Mean Annual Increment (MAI)

One of the measures of productivity in the case of forest plantations is the MAI in commercial volume. In a cross sectional survey like the present one, the MAI can be obtained only with respect to the existing volume in the field for a particular age. Since the selected plots need not fall in all the age-site quality-stocking combinations, a prediction function for MAI was to be developed. For this purpose, an estimate of commercial volume (wood greater than 5 cm diameter over bark) for each plot was obtained through equations (1), (2) and (3) applied on each tree.

A prediction equation of the following form was used for prediction of commercial volume at the stand level, after making a number of trials with the data.

$$\ln V = a + b A + c (A - A_0)_+^0 + d (A - A_0)_+^1 + e (A - A_1)_+^0 + f (A - A_1)_+^1 \qquad (4)$$

where V = Commercial volume ($m^3 ha^{-1}$)
A = Age (year)

$$(A - A_k)_+^i = (A - A_k)^i \text{ if } A > A_k$$

$$= 0 \text{ if } A \leq A_k, \quad i, k = 0, 1$$

Equation (4) belongs to the class of segmented polynomials and was specifically chosen to accommodate the changes in growth rate in successive crops on the same site. The value of k was chosen as that which maximized the fit after removing stray outliers. From the above equation, the MAI for any age was obtainable by dividing the corresponding predicted volume by age of the crop.

2.5. Potential productivity

Having worked out the current level of productivity at the State level, comparisons were to be made with certain standards possible. The values reported in yield table for the two species (Sharma (1978), Pande (1978)) were used to assess the potential productivity levels possible to be realized under the conditions prevailing in Kerala.

3. RESULTS AND DISCUSSION

3.1. Spatial distribution and age structure

The area of eucalypts in different Divisions in Kerala including that of KFDC is indicated in Table 1. The total area worked out to around 30,641 ha. The age structure of the plantations as of 1995 is indicated in Table 2 and Figure 1. Nearly 90 percent of the area carried stands older than 10 years which were mostly in their coppice phase. Neraly 56 per cent of the stands had crossed 20 years of existence.

3.2. Species composition

The estimates of area under the two species of eucalypts are given in Table 3. *E. tereticornis* dominated in all Circles except in the High Range where 75 per cent of the area was under *E. grandis*. The relative extent under the two species centered around 67:33 by percentage with *E. tereticornis* having the larger share.

3.3. Growing stock

The parameters of the height-diameter relation worked out for the two species in each Circle are given in Appendix 4. The values in Appendix 4 were utilized for obtaining the estimate of commercial volume in each plot.

The estimates of growing stock of commercial volume of eucalypts including both the species considered here are furnished in Table 4. The total growing stock in the State was estimated as 1.037 million m^3 of round wood in an area of 28,845 ha. Although the total extent under eucalypts as on 1996 was 33,054 ha, the growing stock could be estimated only for an area of 28,845 ha. Plantations in the remaining area of 4,209 ha could not be located in the field, although those plantations were present in the list of plantations updated to the year 1996.

Table 1. Area under eucalypt plantations in Kerala as on 1995

Circle/Division	Area under Eucalypt (ha)	Percentage of area
Northern		
Kannur	0.00	0.00
Kozhikode	711.45	2.32
North Wayanad	654.55	2.14
South Wayanad	2,549.31	8.32
Central		
Chalakkudy	53.80	0.18
Malayattoor	1,658.80	5.41
Thrissur	2,316.45	7.56
Vazhachal	466.32	1.52
Southern		
Achencoil	0.00	0.00
Konni	0.00	0.00
Punalur	1,321.72	4.31
Ranni	180.00	0.59
Thenmala	1,066.12	3.48
Thiruvananthapuram	2,709.66	8.84
Olavakkode		
Mannarkkad	241.10	0.77
Nemmara	95.56	0.31
North Nilambur	3,538.94	11.55
Palakkad	0.00	0.00
South Nilambur	201.22	0.66
High Range		
Kothamangalam	338.36	1.10
Kottayam	4,686.80	15.30
Munnar	1,792.86	5.85
KFDC		
Munnar	1,452.75	4.74
Punalur	1,968.21	6.42
Ernakulam	1,058.83	6.46
Thiruvananthapuram	1,578.05	5.15
Total	30,640.86	100.00

Table 2. Age structure of eucalypt plantations in Kerala as on 1995

Age group (years)	Area (ha)	Percentage of area	Cumulative percentage of area
0 - 4	1,516.53	4.9	4.9
5 - 9	482.39	1.6	6.5
10 - 14	2,622.01	8.6	15.1
15 - 19	8,907.72	29.1	44.2
20 - 24	4,184.91	13.7	57.9
25 - 29	7,043.80	23.0	80.9
30 - 34	5,246.02	17.1	98.0
35 - 39	637.50	2.0	100.0
Total	30,640.88	100.00	--

Table 3. Estimates of area under different species of eucalypts in Kerala as on 1995

Circle	Proportion of area		Area (ha)	
	E. tereticornis	*E. grandis*	*E. tereticornis*	*E. grandis*
Northern	0.871	0.129	3,410.2	505.1
Central	1.000	0.000	5,554.2	0.0
Southern	0.954	0.046	8,417.9	405.9
Olavakkode	1.000	0.000	4,076.8	0.0
High Range	0.248	0.752	2,051.2	6,219.6
Overall	0.673	0.327	20,621.3	10,019.6

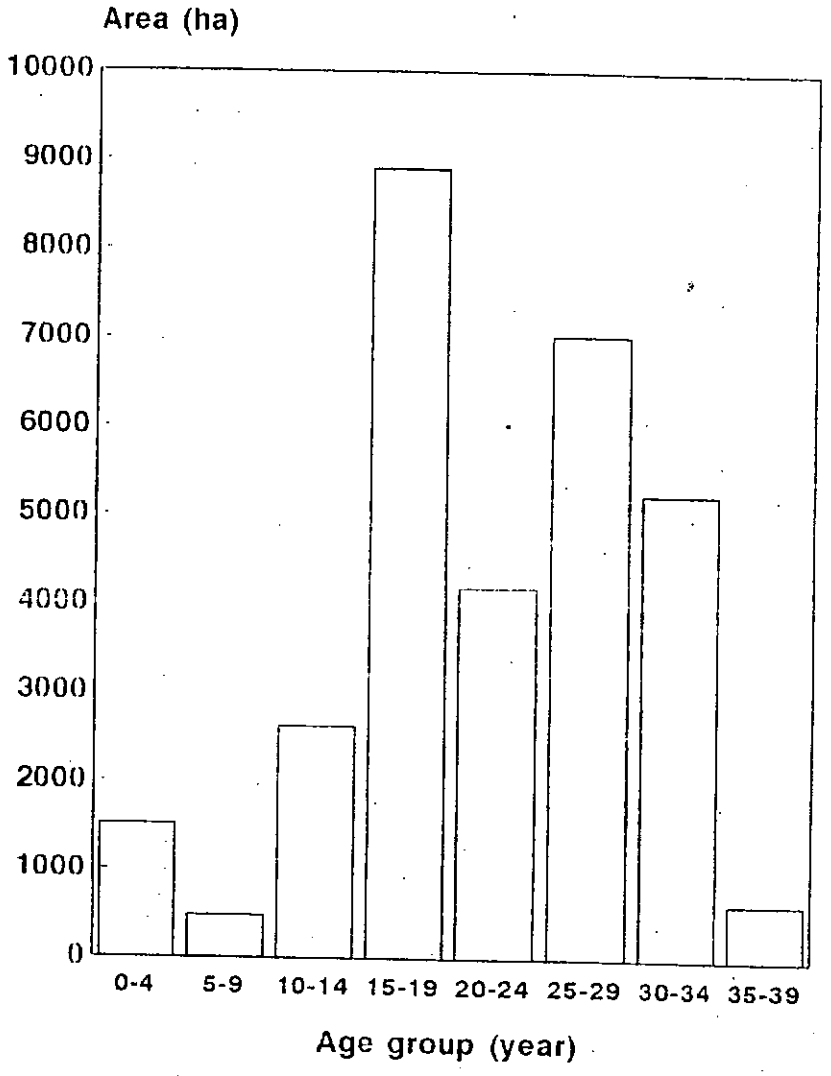

Figure 1. Age structure of eucalypt plantations belonging to Territorial Divisions and KFDC in Kerala as on 1995

Table 4. Estimates of growing stock of eucalypts in Kerala as on 1996

Circle	Area as on 1996 (ha)	Area encountered during enumeration (ha)	Growing stock (m^3)
Northern	3,141.9	2,723.7	286,548
Central	5,175.5	5,126.1	75,424
Southern	9,208.8	9,056.4	148,098
Olavakkode	4,236.1	728.1	1,130
High Range	11,291.7	11,211.1	526,025
Total	33,054.0	28,845.4	1,037,225

3.4. Productivity

3.4.1. Mean Annual Increment (MAI)

The estimated volume prediction equation for *E. tereticornis* at the stand level was the following.

$$\ln V = 2.1955 + 0.1261\ A - 2.1854\ (A - A_0)_+^0 - 0.0222\ (A - A_0)_+^1$$
$$- 5.8538\ (A - A_1)_+^0 + 0.8661\ (A - A_1)_+^1 \qquad (5)$$

$$\ln N = 7.4641 - 0.1438\ A + 0.4105\ (A - A_0)_+^0 + 0.1615\ (A - A_0)_+^1$$
$$+ 0.9598\ (A - A_1)_+^0 - 0.2554\ (A - A_1)_+^1 \qquad (6)$$

Where $A_0 = 10$, $A_1 = 24$, V and A as defined earlier.

A graphical representation of equations (5) and (6) is given in Figure 2. As can be seen from the Figure, there is considerable difference in yield between the seedling crop and the coppice crop. The values of volume expected as per equation (5) are furnished in Table 5. The MAI worked out based on the fitted equation came to 7.653 $m^3\ ha^{-1}$ at 8 years for the seedling crop and 2.545 $m^3\ ha^{-1}$ for the first coppice crop for the same age. The MAI value obtained for the second coppice phase was not reliable and is not reported. A similar study conducted in West Bengal (Anonymous, 1995) indicated an MAI of 6.5 $m^3\ ha^{-1}$ at 8 years for seedling crop of *E. tereticornis* in Southern Bengal.

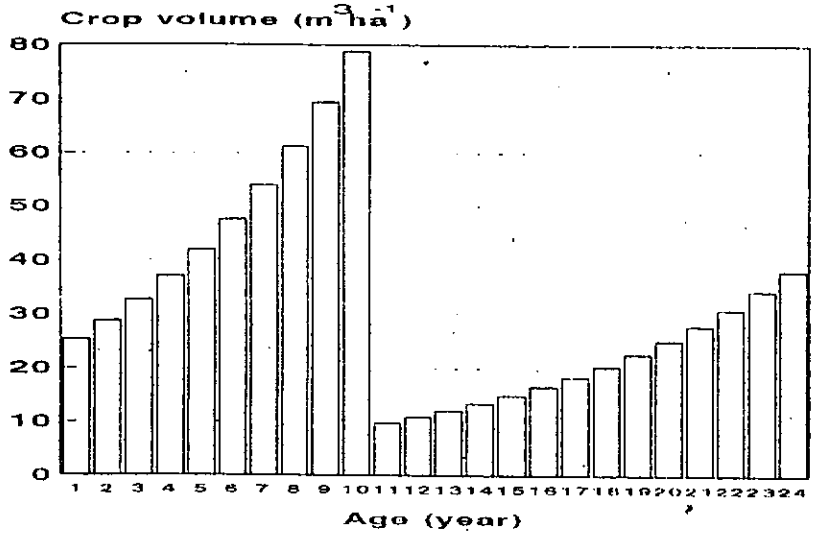

Figure 2a. Change in crop volume

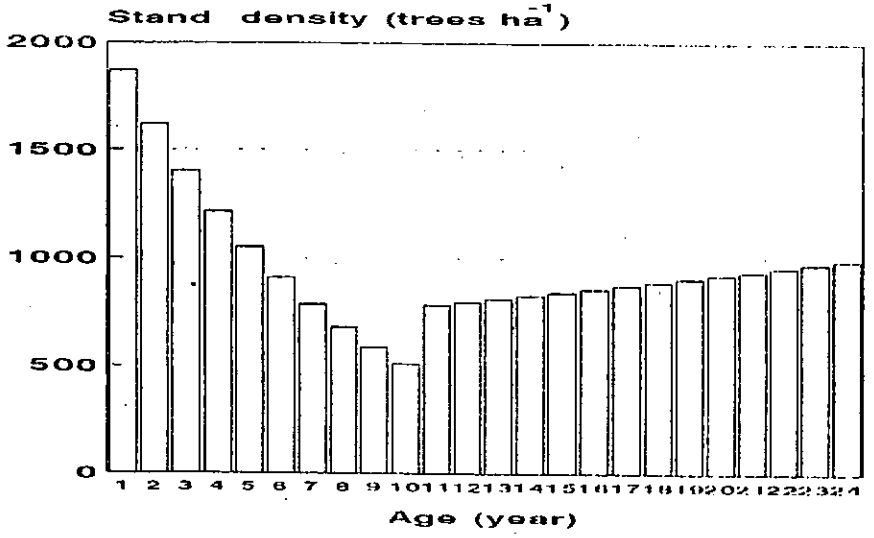

Figure 2b. Change in stand density

Figure 2. Changes in stand characteristics of *Eucalyptus tereticornis* with age

Table 5. Estimates of commercial volume and number of trees of *Eucalyptus tereticornis* at different age levels

Stand age (year)	Crop age (year)	Volume ($m^3 ha^{-1}$)	Number of stems ($no.ha^{-1}$)
1	1	25.321	1871
2	2	28.725	1621
3	3	32.587	1404
4	4	36.967	1216
5	5	41.937	1053
6	6	47.574	912
7	7	53.970	790
8	8	61.225	684
9	9	69.455	592
10	10	78.792	513
11	1	9.829	787
12	2	10.906	801
13	3	12.101	816
14	4	13.427	830
15	5	14.898	845
16	6	16.531	860
17	7	18.342	876
18	8	20.351	891
19	9	22.581	907
20	10	25.055	924
21	11	27.800	940
22	12	30.845	957
23	13	34.225	974
24	14	37.974	991

In the seedling crop, the number of trees was found to decrease from an initial value of 2500 plants ha^{-1} at the time of planting to around 500 plants ha^{-1} in 10 years. In the coppice phase the number of stems was found to increase slightly over time probably due to the increase in the number of coppice shoots .

The data were not sufficient to work out similar figures for *E. grandis*. The total number of plots selected for observations in the case of *E. grandis* was 51 which showed wide variation in their stand structure unexplainable by the models fitted. Past studies (Jayaraman and Krishnankutty, 1990) had revealed that the species yields an MAI of 9.770 $m^3 ha^{-1}$ at 10 years in the case of seedling crop.

3.5. Potential productivity

3.5.1. *E. tereticornis*

The present study revealed that *E. tereticornis* attains a MAI of about 7.653 m^3 ha^{-1} at 8 years. Sharma (1978) reports a maximum MAI of 18 m^3 ha^{-1} at 8 years under I quality site with 1600 trees ha^{-1}. This yield table was established from data collected from the States of Andhra Pradesh, Bihar, Goa, Hariyana, Kerala, Madhya Pradesh, Tamil Nadu, Karnataka, Utter Pradesh and West Bengal. By any standard, the current productivity level of the State is poor. At the end of 8 years, the average number of trees retained is just 500 ha^{-1}. Hence, poor stocking is possibly one of the reasons for poor yield.

The general expectation is that the coppice yields are as high or better than that of the seedling crop. The survey indicated a substantially poor MAI (2.545 m^3ha^{-1}) for *E. tereticornis* in the coppice phase. This might be an under estimate because the crop age had to be indirectly assessed from the data rather than through records. Even after leaving a large margin of error, the yield levels can be considered as substantially low. Multiple reasons like disease incidence, fire, illicit felling or plantation failures due to extreme weather conditions may be leading to the above situation. This aspect needs considerable further investigations.

3.5.2. *E. grandis*

No estimate of MAI could be developed out of the present survey with respect to *E. grandis* for want of adequate data. Although measurements were taken from several *E. grandis* plantations, estimates of MAI was not possible to be developed due to lack of information of crop age or year of coppicing. Jayaraman and Krishnankutty (1990) had estimated an MAI of 9.770 m^3 ha^{-1} for the species at 10 years based on felling records kept at Range Offices. The maximum MAI reported by Pande (1978) is around 36 m^3 ha^{-1} at 10 years with 1600 trees ha^{-1} under site quality class I. Data from Kerala and Tamil Nadu had been utilized for constructing the above yield table. The gap between actually realized yield and that of potential seems to be very wide indicating the need for devising appropriate measures to increase the productivity of the plantations.

PART III. STRATEGIES FOR ENHANCING THE PRODUCTIVITY OF TEAK AND EUCALYPT PLANTATIONS IN KERALA

As brought out in Part I and II, the productivity of teak and eucalypt plantations in Kerala is low as compared to the all-India figures. The reasons are poor stocking, poor site management and above all the inability of the Forest Department to carry out silvicultural operations in time due to financial constraints. Also, there is no mechanism by which the performance of the plantations can be evaluated. The measures for enhancing the productivity can be broadly grouped into technical and administrative measures. The technical measures are dealt with separately below for teak and eucalypt and the administrative measures are dealt with commonly for both the species.

1. TEAK

Teak plantations in Kerala are mostly on areas not easily accessible and this limits frequent inspections. As most of them lie uphill, disturbance to soil, and intensive application of fertilizers and chemicals can affect the downstream ecosystem adversely. Also, funds available for long-term investments in plantations is limited. Under these circumstances it is advisable to maintain the teak plantations at low input management. However, soil and moisture conservation, low level nutrient application in nutrient-deficient younger plantations, loranthus removal and removal of borer attacked trees are essential measures.

An analysis of the productivity of the plantations in relation to management, points to the need for ensuring the quality of planting stock and timely execution of silvicultural operations in order to ensure proper establishment and growth of the species which seldom recovers from the effects of 'ill-treatments'. The above considerations form the basis for suggestions for better management of the teak plantations, described below.

1.1. Management options for existing plantations

One of the major recommendations is on the management of existing plantations.

Based on the results of this study the teak plantations in Kerala can be classified into different categories depending on the slope of the planted area, stocking, extent of natural growth and site quality classes (Table 1). Management options based on the condition of the plantations are indicated for different categories. The management options are as follows. (1) The plantation in very steep slopes (above 30°) may be converted into natural forests, as continuation under plantations will lead to heavy soil erosion and eventual site degradation beyond recovery. About 1.38 per cent of the plantation area, amounting to about 1000 ha fall under this category (Table 2). (2) Majority of the plantations presently in SQ IV are not worthwhile retaining for timber production because of the very low productivity.

ıble 1. Scheme for management for different categories of existing teak plantation

(The proportion of area are indicated in bracket(s))

Condition of the crop			Management option for different site quality classes				
Stocking	Slope	Misc. growth	I	II	III	IV	Total
ıder-stocked	< 30°	Low	Timber (1.53)	Timber (8.10)	Timber (9.18)	Pole (2.00)	(20.81)
- do -	- do -	High	Timber (0.97)	Timber (6.96)	Timber (13.90)	Pole (2.93)	(24.76)
- do -	>= 30°	Low	--	Natural forest (0.06)	Natural forest (0.23)	Natural forest (0.01)	(0.30)
- do -	- do -	High	--	--	Natural forest (0.21)	--	(0.21)
ılly Stocked	< 30°	Low	Timber (1.45)	Timber (7.30)	Timber (7.37)	Pole (0.85)	(16.97)
do -	- do -	High	Timber (0.25)	Timber (3.02)	Timber (3.56)	Pole (0.97)	(7.80)
- do -	>= 30°	Low	--	Natural forest (0.23)	Natural forest (0.29)	--	(0.52)
- do -	- do -	High	--	--	Natural forest (0.11)	--	(0.11)
ver- stocked	< 30°	Low	Timber (0.94)	Timber (8.86)	Timber (9.50)	Pole (2.16)	(21.46)
- do -	- do -	High	Timber (0.09)	Timber (2.34)	-Timber (3.44)	Pole (0.95)	(6.82)
- do -	>= 30°	Low	--	Natural forest (0.18)	Natural forest (0.06)	--	(0.24)
- do -	- do -	High	--	--	--	--	--
Percentage of area			5.23	37.05	47.85	9.87	100.00

ote : Timber = Timber and pole production (pole production is through thinning)

Pole = Exclusive pole production on shorter rotation of 20-25 years under simple coppice system of management

Natural forest = Conversion to natural forest

Miscellaneous growth is regarded as low if the percentage of miscellaneous trees in the plantation is less than 25 per cent of the total; otherwise it is treated as high.

The reasons for their very low productivity require scientific investigation. In the meantime, it is recommended that they may be managed for pole production under simple coppice system of management. Nearly 10 per cent of the plantation area amounting to about 7500 ha fall under this category. (3) The remaining area may be managed for timber production. The details may be seen in Table 1 and 2. Within this category, there are a few plantations with very low stocking either due to damage by carpenter worms or due to illicit felling and heavy lopping. They are not worth retaining and therefore they may be felled and replanted.

Table 2. Site quality-wise summary of management options for teak plantations of Kerala

Management options	Site Quality				
	I	II	III	IV	Total
Timber	5.23	36.58	46.95	--	88.76
Poles	--	--	--	9.86	9.86
Natural forest	--	0.47	0.90	0.01	1.38
Total	5.23	37.05	47.85	9.87	100.00

In addition to these recommendations, suggestions on various other technical matters are provided in the ensuing sub sections.

1.2. Technical measures in existing and new plantations

1.2.1. Site selection

The site set apart for plantation may be examined in detail and a treatment map prepared. Rocky and water-logged areas, gulleys, tree growth to be retained, etc., may be demarcated in the treatment map. A site with less than 30° slope, 60-80 cm soil depth, low rockiness, low erosion, moderate waterholding capacity and good drainage is regarded as suitable for teak planting. Water logged patches in plantations, as in some areas in Nilambur (eg. Valluvasserry, Kariem Muriem), may be patch-planted with *Bambusa bambos* (Chandrasekhara, 1996).

1.2.2. Silvicultural aspects

Site preparation

If felling is planned before December, most of the small branches and leaves may get degraded by termite activity by the time of planting, and the practice of slash-burning, which is preferred mostly for improving accessibility, can be avoided on ecological considerations. Studies at KFRI have shown that slash burning has no long-term effect on

growth of teak. On the other hand if slash burning is not carried out, firewood down to 10 cm girth, which is burnt for slash disposal, could be salvaged and sold. (Chacko *et al.*, 1991).

Method of planting

The method of stump planting may continue till the technology of planting root-trainer seedlings or such other improved methods are field tested in Kerala and accepted.

The present method of planting of stumps in crow bar holes is advisable in areas where the soil is loose. In hard soil, especially in the second and third rotations, where soil has become hard either due to laterization or due to trampling by animals and human beings, stumps may be pit-planted. In such cases, pits may be of 15 cm x 15 cm x 20 cm size. The bottom of the pit may be loosened before refilling for planting. In practice, a spade with a blade width of 10 cm and a length of 30 cm can be used for this purpose. While filling the pit, care should be taken to see that slightly excess soil remains at the top to allow for settling of the soil.

Preliminary field trials in Maharashtra have shown good performance of root trainer-raised seedlings (Khedhar, 1997). Therefore, as an experimental measure, it is suggestible that each Forest Division may plant 5 per cent of their planting target with root-trainer seedlings in the first two years. The planting rate can be enhanced later depending upon the performance.

Quality of planting stock

Seeds: Seeds continue to be the basic propagule for raising plantations. The seeds may be used from plantations of known identity and with above-average performance. A total of 2500 ha of plantation of 25 to 50 years of age may be earmarked for the purpose as Seed Production Areas (SPA). SPAs shall be well weeded by the month of December to facilitate seed collection in January-February.

The 'seeds' (technically fruits) after collection and calyx removal may be sieved through a 9 mm sieve. Only 9 mm retained 'seeds' may be used for sowing to ensure better germination (Indira *et al.*, 1996).

At present, there are 4 teak clonal seed orchards with a total area of 35 ha in the State. The number of clones used in these orchards is around 25. This is a narrow genetic base. Therefore, efforts may be taken to establish two clone banks each of 2 ha incorporating about 100 plus trees from Kerala and similar agroclimatic zones in Karnataka and Tamil Nadu. This will serve as source for bud wood material for establishing clonal seed orchards (CSO).

Nursery: A survey in teak nurseries of Kerala (Indira *et. al.*, 1996) has indicated that production of plantable stumps per standard nursery bed of 12 m x 12 m is usually very low; maximum was 808. The mean number of plantable stumps for Territorial Divisions was 409 whereas the overall mean was as low as 262. Use of seeds with poor germinability, hard nursery soil condition, delayed nursery operations, over-crowding in beds, etc., are some of the reasons for the poor output of quality seedlings (Chacko, 1995). It is reasonable to expect 520 plantable stumps (as against the present expected number of 1000) per standard nursery bed for which 4 kg fruits (with mesocarp) may be sown after weathering treatment for 14 days. The fruits should be accepted as good for sowing only if cutting test provides around 80 per cent good fruits. However, in emergency cases, a lower percentage, up to 60 per cent, may be accepted, in which case the seed rate should be increased accordingly. The fruits shall be sown in nursery along with first rains in March-April. Most of the fruits germinate 45 days after sowing. Culling of weaker seedlings may be done during August-September to avoid congestion in beds. Previous years' nursery may be abandoned after using stumps for casualty replacement in May-June. (Calculation of plantable stumps:-4kg fruits x 1900 fruits/kg x 40% germination x 70% post-germination survival x70% retained after culling x 35%plantable stumps =520).

Effort should also be made to standardize seedling production in root-trainers using compost as a major component of the potting medium. Since this will need building up of infrastructure, centralized nurseries are advised.

Species mixing

Experience with mixtures in teak plantations in Kerala is not encouraging (FAO, 1985). Underplanting or interplanting in teak plantations may not be taken up without clear evidence of its success. Past experience does not favour planting of species such as *Evodia lunu-ankenda*, *Bombax malabaricus*, *Swietenia macrophylla* and *Bambusa arundinacea*. Plantations underplanted with bamboos are not available for planting teak in the ensuing rotation as bamboos occupy the space very aggressively following final felling of teak (as seen in Puthoor, Thrissur Division). Instead, patches unsuitable for teak in plantations may be planted up with bamboo as indicated earlier.

1.2.3. Soil management

Soil conservation measures

Staggered trenches in plantations can slow down the process of soil erosion and conserve moisture. Gulleys and ravines in plantations also need to be plugged/stabilized using brush wood and locally available stones. There cannot be a common prescription for this as the work will vary with the nature of land. Therefore, such measures may be decided in consultation with experts in soil and moisture conservation.

Nutrient application

Since the soils under teak vary in nutrients and pH, a uniform optimum recommendation for all plantations cannot be made. Soil should be tested for pH, Organic carbon, Nitrogen, Phosphorus, Potassium, Calcium and Magnesium before recommendations are made. However, in degraded second and third rotation sites, 10 g active ingredients each N, P and K may be applied in the month of July in the first year, double the above dose in the second year with the onset of South West Monsoon. Average composition of common fertilizers and manures are provided in Appendix 14.

1.2.4. Pest and disease management

Although there are a number of pests associated with teak, white grubs in nurseries and defoliators in plantations cause the major damage. White grubs attack teak seedlings in nursery. The root portion of the seedlings are eaten up and the seedlings wilt. If the problems are noticed, remedial insecticidal treatment may be undertaken as recommended by KFRI (Varma, 1992).

Defoliation of teak trees by the teak defoliator (*Hyblaea puera*) is common in teak plantations of Kerala. Repeated defoliation causes up to 40 per cent loss of potential increments in young plantations (Nair, *et al.*, 1985). Although control is effective with chemical insecticides, it is not advised because of environmental damage; a baculovirus (NPV) is being standardized by KFRI which may be adopted in future.

No major disease has been noticed in teak in Kerala, except leaf spot and bacterial wilt in nurseries. Recommendations are available from KFRI for control of these diseases, if they are noticed.

1.2.5. Loranthus control

The problem of loranthus should be viewed as serious as it can reduce volume increment and even kill the trees. In plantations of Nilambur, incidence up to 85 per cent is reported by KFRI. About one-fourth of the death, and loss in potential increment up to 44 per cent is observed in pole crops up to 12 years. Loranthus infestation mostly starts on plantations of 9 years, the infestation becomes crucial at 20 years. In addition to causing death, loranthus also causes deterioration in strength properties of wood (Ghosh *et al.*, 1984). Physical removal by engaging tree climbers is the only practical way of solving it at present. Loranthus removal may be carried out at least once in two years as removal of well established clumps from the trees is difficult and often amounts to removal of major branches, and at times the leader itself amounting to formation of forks (e.g. Punnamattom teak plantation in Chalakkudy Division). As loranthus removal is a risky job, the tree climbers may be provided with insurance coverage during the period of work.

1.2.6. Research

An analysis of 626 publications on teak during the 10 years of 1985-94 shows that the share of Silvicultural Research is only 13.7 per cent. On Genetics the contribution is 4.5 per cent. In silvicultural research itself, nearly half of the work is on seed and nursery. Studies on growth and yield, mixtures, thinning, spacing and rotation put together contributes only 25 per cent (Chacko, 1995). There is a need for long term continuous research efforts on less attended areas.

2. EUCALYPTS

The present study has brought out the low productivity status of eucalypt plantations, especially under coppice management, in Kerala. Nevertheless, there is scope for enhancement of productivity through effective management.

As in the case of teak, most of the eucalypt plantations, are on areas not easily accessible. About 28 per cent of them lie on steep slopes and 2 per cent on very steep slopes. Therefore, disturbance to soil, and elaborate application of fertilizers and chemicals can affect the downstream ecosystem adversely. Large scale pest and disease control measures using chemicals are also not feasible and hence to be limited to nurseries. Moreover, the availability of funds that can be diverted for long-term investments in plantations is also limited. Under these circumstances, it is advisable to maintain the eucalypt plantations at medium input level with stress on tree improvement. Soil and moisture conservation, and nutrient application in nutrient-deficient younger plantations are some of the specific inputs needed to maintain the sustainability of the plantations. The above aspects form the basis for suggestions for better management of the eucalypt plantations.

2.1. Management options for existing plantations

Eucalypts in Kerala continue to be planted at 2 m x 2 m spacing although studies in Karnataka suggest that a wider square spacing would be beneficial for the growth of the 'crown shy' species (Adlard *et al.*, 1992). However, this aspect needs to be examined before a decision on change in spacing is made. In order to classify a plantation either as satisfactory or failed for the purpose of prescribing management prescriptions, some standards will have to be followed. Survival rate for plantations up to 3 years and basal area (per hectare) for plantations of 4 years and above are suggested as parameters of performance. Since there is no definite basis for suggesting standards for correct survival rates, the standards for survival were fixed as 90, 80 and 70 per cent for plantations of 1, 2 and 3 years respectively in areas with favorable site conditions based on experience. A lower rate may be considered for hostile sites such as those sites which are highly wind prone, frost prone, etc.

For plantations of 4 years and above, basal area per ha may be measured. For computing basal area per ha, the following procedure may be followed. Sample plots of 20 m x 20 m may be laid out at random in the plantations and each stem (one coppice stool may have more than one stem) may be measured for girth at breast height in cm. The corresponding basal area may be computed using the formula :

$$\text{basal area of a stem} = \text{girth}^2/4\pi$$

Basal area of all the stems in a plot may be added up and multiplied by 0.0025 to get the basal area per ha in m^2. Mean of such values over different sample plots in a plantation may be computed. Tables indicating expected minimum basal area for *E. grandis* and *E. tereticornis* are presented in Tables 3 and 4.

Table 3. Minimum acceptable values for stand parameters for *E. tereticornis* plantations

Age (year)	Number of stems ha^{-1}	Basal area (m^2 ha^{-1})
4	1031	7.754
5	994	9.321
6	957	10.570
7	922	11.528
8	889	12.221
9	856	12.661
10	825	12.898

Table 4. Minimum acceptable values for stand parameters for *E. grandis* plantations

Age (year)	Number of stems ha^{-1}	Basal area (m^2 ha^{-1})
4	1031	8.295
5	994	11.890
6	957	14.809
7	922	17.418
8	889	19.573
9	856	21.237
10	825	22.392

Table 5 indicates that 7 per cent of the eucalypt plantations in High Range Circle and 2 per cent of the eucalypt plantations in Southern Circle are on very steep slopes. The corresponding figure for the State works out to 2.79 per cent. These areas may be managed under simple coppice system as long as the plantations show vigorous growth from coppice. Once the coppice vigour is lost, they may be converted to natural forests. No replanting should be done in such areas.

Table 5. Percentage of area in different slope classes in eucalypt plantations in Kerala

Circle	Flat (%)	Undulating (%)	Rolling (%)	Steep (%)	Very steep (%)
Northern	---	---	85.00	15.00	---
Central	1.00	---	79.00	20.00	---
Southern	---	4.00	58.00	36.00	2.00
Olavakkode	---	---	71.00	29.00	---
High Range	---	1.00	62.00	30.00	7.00
Overall	0.21	1.62	67.47	27.91	2.79

Note : Flat(0 - 1^0), Undulating (1 - 3^0), Rolling (3 - 15^0), Steep (15 - 30^0), Very steep (>30^0) as defined in FAO (1979).

2.2. Silvicultural aspects

2.2.1. Method of planting

The method planting polypotted seedling shall continue till the technology of planting clonal root-trainer plants is standardized. Plants may be planted in pits of 30 cm x 30 cm x 30 cm.

Every Forest Division shall make an attempt to plant 5 per cent of their planting target with clonal root-trainer plants every year. The planting rate can be enhanced later depending upon the performance; however the clonal plantation shall be limited to 30 per cent of the total planting area. The number of clones used should be large enough to guard against the disadvantages of a narrow genetic base.

2.2.2. Quality of planting stock

Experience elsewhere gives clear indication of productivity increase when clonal plants were used for planting. However, at present, the Department is not well equipped with

enough clones for multiplication. Therefore, steps should be taken to select sufficient plus trees of *E. grandis* and *E. tereticornis* and establish clonal multiplication garden at different localities and simultaneously lay out trials to evaluate the performance of the clones. The clones of *E. tereticornis* and *E. camaldulesis* available in the KFRI may be utilized in the mean time (KFRI has 80 clones, of which 10 are of proven superiority, which can supply 25,000 plants per year). Seeds, however, will continue to be the main propagule for plantations. Seeds used for raising plantations should be from known and superior plantations or proven provenances. For outplanting, four months old polypot seedlings or 2.5 to 3 months old root-trainer seedlings could be used for planting. It may be borne in mind that when seeds are used for propagation, not more than 15 per cent of the total germinated become are plantable (Chacko *et al.*, 1990).

2.3. Soil management

2.3.1. Soil conservation measures

Soil and moisture conservation measures such as gully plugging and trenching may be needed in some plantations. The specific treatment will depend on the site features and as such there cannot be a common prescription. Site specific treatment plan may be prepared and implemented in consultation with a Soil Conservation Specialist.

2.3.2. Nutrient application

Any nutrient application should be based on soil analysis. Soil may be tested for soil pH, Organic carbon, Nitrogen, Phosphorus, Potassium, Calcium and Magnesium.

However, in degraded soil the following *adhoc* doses are recommended for both *E. tereticornis* and *E. grandis*.

Nutrient dose at planting (per plant):

Element	Dose (g)
Nitrogen	15
Phosphorus	15
Potassium	10

The above dose of nutrients may be mixed with soil while refilling the pits for planting.

Nutrient dose in the second year (per plant):

Element	Quantity (g)
Nitrogen	30
Phosphorus	30
Potassium	15

Proportion of nutrients in different commercial fertilizers and manures are provided in Appendix 14.

2.4. Pest and disease management

Termite attack of younger plantations contribute to poor stocking. Among all forest plantation crops, eucalypts are the most vulnerable to attack by termites. Prophylactic treatment of containerized seedlings with chlorpyrifos, as recommended by KFRI (Varma and Nair, 1995) should be carried out in the nursery to ensure satisfactory survival.

Eucalypts grown in Kerala are very susceptible to fungal diseases. A number of fungal diseases are reported from Kerala. Some of them are devastating (Sharma *et al.*, 1985). In nurseries, pre and post emergence damping off, web blight, seedling blight, seedling wilt, root rot, stem infection and leaf spot are the serious ones. Prophylactic fungicidal treatments suggested in KFRI information bulletin 6 (KFRI, 1984) should be followed.

2.5. Alternative species for pulpwood

There has been a preference for *Acacia auriculiformis* by the main pulpwood mill (HNL, Mavelloor) due to ease in establishment, better productivity and satisfactory pulp yield and quality (M.R. Arvindakshan, pers. comm.). However, the question of alternative species for eucalypts needs a separate study.

3. COMMON MEASURES FOR TEAK AND EUCALYPTS

This section is organized into two subsections: (i) general plantation management and (ii) funds administration.

3.1. General plantation management

3.1.1. Plantation identity

At present, the plantations are identified by the year of planting, species and the name of the locality and extent. This is quite all right. However, in order to facilitate computerized management of data at State level, allotment of numbers for each plantation is necessary.

3.1.1.1. Method of allotment of plantation number

Each plantation shall be known by a number with four digits. The number may start from 0001 and continue up to 9999. A species code for teak in three digits (101) may be prefixed (other plantation species may be given numbers 102, 103, etc., in the order of importance). Thus the first teak plantation may take the seven digit number 1010001, the

second plantation 1010002, the third plantation 1010003, etc. *E. tereticornis* plantation may have numbers 1020001, 1020002, 1020003, etc. ; *E. grandis* plantation will have 103001, 1030002, 1030003, etc.

As soon as a plantation is established, the matter shall be reported (Appendix 5) to the Chief Conservator of Forests (D), who may allot a number in chronological order irrespective of locality. If a plantation is replaced by another plantation, either because of failure or as a result of final felling, the replaced plantation shall bear a new number. A new plantation number will be allotted as soon as the first activity for a plantation starts viz., site preparation.

3.1.1.2. Method of ensuring allotment of plantation number

The expenditure for different activities shall be admitted only if plantations bear plantation number.

3.1.2. Demarcation of plantations

The boundaries of most of the plantations are unclear in the field as they are not clearly demarcated on ground.

3.1.2.1. Procedure for demarcation of plantation boundaries

The boundaries may be clearly demarcated using stone posts of 10 cm x 10 cm x 45 cm which are buried to a depth of 30 cm at all survey stations along the boundary, and the above-ground portion of the post painted with yellow paint. All the stones may be serially numbered on opposite sides, in the direction of the survey line, using white paint.

3.1.2.2. Survey and preparation of plantation sketch

The plantations may be surveyed (using prismatic compass and chain) and a sketch prepared on a 1:4000 scale in triplicate; one copy for the plantation journal maintained at the Range Office, one copy for the Divisional Forest Office, and the third copy at the Section Forester's Office. It will be advisable to record the latitude and longitude of the survey stations using a GPS (Geographic Positioning System) so that the position of the plantation could be easily incorporated in the GIS (Geographic Information System) for the Kerala Forests.

3.1.2.3. Verification of species and area in existing plantations

Along with field survey, physical verification of the present plantations may be carried out to ascertain the species and the area under each species. In some of the plantations, the originally planted species is either replanted partially or fully with another species or the area is invaded naturally by some colonizers such as bamboo.

Therefore, this procedure will help to update the position.

The display board may be 60 cm x 45 cm made of 18 gauge tin sheet. It may be painted using metal primer and green paint. Over this, the letters may be written using white paint.

The board may be displayed close to the easily accessible boundary by tying to a tree in the plantation at 2.5 m above ground, using a plaited GI wire of appropriate thickness. This board shall be properly maintained with all relevant information. A certificate (Appendix 6) to the effect of maintenance of plantation display board may be furnished by the Section Forester annually in the month of May.

3.1.2.4. Plantation display board:

A board containing the following details shall be displayed in a plantation.

Details	Method of display
Division	A two digit number allotted by the PCCF (e.g. 01, 02 ... 23, 24, etc.)
Range	A one digit number suggested by the DFO and allotted by the PCCF (e.g. 1, 2, 3, 4)
Species	Local name (e.g. Teak) Scientific (Latin) name (e.g. 101 *Tectona grandis*)
Year of clearing the previous plantation	(e.g. 1951 F)
Year of planting	(e.g. 1952 P)
Rotation	R1 for 1st rotation R2 for 2nd rotation R3 for 3rd rotation
Coppice	C1 for 1st coppice (e.g. 1966 C1) C2 for 2nd coppice (e.g.1976 C2) C3 for 3rd coppice (e.g. 1996 C3)
Thinning	T1 for 1st thinning (e.g. 1956 T1) T2 for 2nd thinning (e.g.1960 T2) T3 for 3rd thinning (e.g. 1968 T3) T4 for 4th thinning (e.g. 1986 T4) T5 for 5th thinning (e.g. 1997 T5) and so on

A specimen board for teak and eucalyptus are given as under :

13 - 2 - 1010013	Division code - Range code - Plantation code
Kanjirakadavu	Locality
Teak (*Tectona grandis*)	Species
R2	Rotation
1978 F	Felling of previous plantation
1979 P	Planting year
1983 T1	First thinning
1987 T2	Second thinning
1994 T3	Third thinning

13 - 2 - 1040013	Division code - Range code - Plantation code
Peermade	Locality
Blue gum(*E. globulus*)	Species
R1	Rotation
1978 F	Felling of previous plantation
1979 P	Planting year
1988 C1	First coppicing
1997 C2	Second coppicing

3.1.3. Record keeping

Plantation Journals should be maintained at every Range Office by the Range Officer. By linking record maintenance with payments, timely entries in the plantation records can be ensured. Therefore, the payment vouchers for various operations shall bear the following certificate:

> Certified that all entries regarding operations done and amount spent under this voucher/bill have been entered in the Plantation Journal. All the work under this voucher have been carried out as per technical guidelines.
>
> Range Officer

The officer admitting the bills/vouchers (Divisional Forest Officers) shall ensure the above certificate duly signed by Range Officer concerned. This procedure will ensure timely entry of all operations in Plantation Journals and other plantation records.

Plantation records, especially the Plantation Journals, Felling Registers, Yield Registers, etc., are valuable documents providing the history of plantations, yield realised, etc., and as such, they need to be kept under safe custody of the Range Officer, under lock

and key. An Issue Register (Appendix 7) may be maintained to keep track of the Plantation Journals and other records taken from its designated place. Since most of the Range Offices lack the facility for safe custody of these records necessary facilities may be provided for this purpose.

3.1.4. Plantation programme

3.1.4.1. Responsibility and authority

The Divisional Forest Officer should be given the responsibility and authority to ensure success of the plantation. To effect this, the present system may be re-examined. A system of acknowledging/rewarding the good work of the staff may also be considered.

3.1.5. Calendar of operations

A calendar of operations for two years (a format for teak is given in Appendix 8) may be prepared for each plantation and got approved by the competent authority at least six months in advance of the first proposed operation. An estimate of work submitted for approval shall contain a copy of the approved calendar of operations. All formalities in connection with approval of estimate shall be complete at least one month in advance of the proposed date of commencement of work to facilitate timely execution of work. If the Divisional Forest Officer is not confident of enough supply of quality planting material, or timely completion of formalities and field operations necessary for planting, latest by the first week of April, the plantation work may be deferred to the next year rather than doing a sub-standard work in a hurry.

During the course of the present field survey it has been observed that in several plantations, there has been considerable delay in carrying out thinnings. It is well recognized that delay in carrying out thinning will affect increment adversely. Therefore, greater importance must be given to this aspect.

3.1.5.1. Protection

Protection to plantations from cattle, human beings and fire has to be ensured for establishment and growth.

3.1.5.2. Fencing

In areas of high anthropogenic interference, the younger plantations need to be fenced using barbed wire or chain links. The watch and ward of younger plantations should be ensured round the year during the initial years till the seedlings become established. This is not effectively done at present.

3.1.5.3. Fire control measures

Although quantified data is not available on the extent of financial damage caused by forest fires, it is well recognised that recurring forest fires do adversely affect teak plantations; the extent of damage may vary depending upon the intensity of fire and age of plantations. Therefore, measures to prevent forest fires may be taken by effective implementation of the prescribed practice of fire tracing before December and supervision by fire watchers. One fire watcher for 10 ha should suffice. A report of the fire control measures (Appendix 9) carried out may be submitted by the first week of January every year by the Section Forester. A fortnightly report of fire incidence (including nil report) (Appendix 10) shall be filed by the Forester/Forest Guard at the Range Office every first and third week of every month during January-May. Every attempt shall be taken by the staff to contain a plantation fire whenever detected.

3.1.6. Model plantation

Every circle shall raise one model plantation every year treating it as a prestigious task. This will help to demonstrate various plantation activities. These plantations shall not suffer set back under any circumstance.

3.1.7. Plantation monitoring and evaluation

Periodic monitoring of plantation performance is necessary for planning on a sustained yield basis. At present there is no mechanism to ensure systematic and regular plantation monitoring by which the productivity are measured and reported (Chacko, 1995). Performance of the plantations may be recorded every year in the month of April/May to assess stocking and growth. For this purpose, permanent sample plots shall be laid out in the plantations. The number of sample plots shall be decided at the rate of one per hectare for a plantation, with a minimum of two and a maximum 10 per plantation. The form for data collection is indicated in Appendix 11.

A Plantation Evaluation Cell (PEC) may be created under CCF(D). The PEC shall be competent to evaluate the plantation performance based on data furnished, and also through field inspections, if necessary. The PEC shall advise on matters of plantation management whenever necessary.

3.1.8. Plantation productivity workshops (PPW)

Plantation Productivity Workshops (PPWs) may be organised at the Forest Circle level for Divisional Forest Officers, Assistant Conservators and Range Officers, twice a year, during the first weeks of January and June to discuss implementation of various plantation activities, to update the technical knowledge and also to take stock of the activities carried out during the preceding six months. The Conservator of Forests, if necessary, may invite specialists in different aspects of plantation technology for this

workshop. A short report of the workshop (Appendix 12) together with decisions may be submitted to the Chief Conservator of Forests (D). The Range Officers also may organise a half day workshop for Deputy Range Officers, Foresters and Forest Guards within one week after the Circle level workshop and provide a report of the same (Appendix 13).

3.2. Funds administration

Under the present system, release of funds for various expenditure in the Forest Department is mainly in three ways.

Funds for most of the forestry operations are released from the Government Treasury through Letter of Credit (LC) issued by the Government once in every quarter based on annual allotment and the quarterly requirements furnished by the Drawing and Disbursing Officer. However, in the event of financial stringency faced by the State Government issue of LC may get upset which inturn affect the programme of work, and this has happened in the past.

However, in the case of salary payments, a different system is adopted. Amounts for salary are drawn against Bank Cheques for which LC is not applicable. This ensures salary payments in time.

In certain special category of works, specially those funded by the Government of India as centrally assisted schemes such as RLEGP, MPCA and WEP, the amount is transferred to the Treasury Public (TP) Account. The allotment is made by the CCF/CF and the amounts are transferred by the State Government to the TP Accounts maintained at different treasuries by the Drawing and Disbursing Officers. This is similar to a Current Account operated in Banks. The amount once transferred to the TP Account is not resumed by the Government and therefore is available for use in time.

Non release of funds in time is a serious constraint in plantation establishment and management. The TP Account system will help in making funds available in time and therefore, it is recommended for funds related to plantation activities.

CONCLUSIONS

Plantations of teak and teak mixed with other species in Territorial Forest Divisions in Kerala were found to occupy about 68,797 ha as on 1995. A study on the status of teak plantations in the State revealed that a substantial portion of the area (86%) fell in medium site quality classes and the extremes were rare. There was considerable variation in site quality distribution over the different Divisions. Achencoil, Konni and Kozhikode Divisions recorded major share of area under better site quality classes (SQ I and SQ II) whereas Thiruvananthapuram, Kottayam, Wayanad, and Kannur Divisions had larger area under poor site quality classes. This in turn reflected in the MAI of commercial volume attained in these Divisions. Kozhikode and Achencoil Divisions recorded the highest MAI in the State, exceeding 3 m^3 ha^{-1} of commercial volume including timber and smallwood at 60 years. Kottayam and Thiruvananthapuram had the lowest values of MAI, which were less than 2 m^3 ha^{-1}. For the State as a whole, the value of MAI of standing crop was 2.423 m^3 ha^{-1} at 60 years. A study on past records of yield from thinning indicated an average MAI of 1.174 m^3 ha^{-1} for the State with 35 years as mean age of final thinning. The MAI of total yield for teak at 60 years in the State worked out to 3.110 m^3 ha^{-1}. A comparison with the range of values in the All India yield table for teak indicated that the mean yield for teak is far below that of potential. Almost a doubling in MAI is possible by improving the site conditions and stocking in many plantations.

Nearly 48 per cent of the plantations were under-stocked in the State. This was found mainly due to the reduced number of trees. The estimate of growing stock of teak in plantations older than 10 years in the State as on 1996 worked out to 3.248 million m^3 of timber and 1.590 million m^3 of smallwood.

A trend to keep better quality plantations over-stocked was detected. This was found to affect the diameter growth of trees substantially in later years. Plantations of lower site quality classes were found to be heavily under-stocked resulting in reduced overall volume. However, such variations were not found to affect the height growth of trees.

Investigations on the influence of certain factors affecting crop growth revealed significant effects of external human interference, loranthus and climbers other than that due to age and stocking. The analysis also showed indirectly the predominant influence of soil and the need for proper silvicultural operations in the successful establishment of plantations.

As on 1995, eucalypts were reported to be grown in 30, 641 ha belonging to the Territorial Divisions of the Kerala Forest Department and KFDC. Nearly 90 per cent of this area carried stands older than 10 years. Around 20 per cent of the stands have crossed 20 years of existence. *E. tereticornis* was estimated to occupy around 67 per cent of the area under eucalypts and *E. grandis* was found in the remaining area. The combined growing stock for the two species was estimated as 1.037 million m^3 in 28,645 ha.

Based on a survey, the MAI of the seedling crop of *E. tereticornis* was estimated as 7.653 m^3 ha^{-1} at 8 years. For the first coppice crop of the same species, the MAI worked out to 2.545 m^3 ha^{-1} at 8 years. A comparison with the range of values in the existing yield table indicated that the currently realized yield levels are far below the potential.

Based on the information gathered on the status of the plantations in the State, suggestions on means of improving the productivity of teak and eucalypt plantations are made. For both species, it is recommended that plantation areas above 30° slope be converted to natural forests to avoid erosion and eventual permanent site deterioration. Both technical and administrative measures for proper management of the plantations in the remaining areas are suggested.

For teak, the technical measures include (1) management of very low productivity areas under SQ IV for pole production under simple coppice system on a short rotation of 20-25 years and (2) management of the remaining areas for timber production under low input but efficient management system which include appropriate silvicultural, and site, nutrient and pest management.

For eucalypts, technical measures include retention of only those plantations which satisfy minimum standards in terms of stocking and basal area and managing them with appropriate silvicultural site, nutrient and pest/disease management, for which guidelines are given. Use of improved clonal planting material in a phased manner is suggested for raising future plantations.

Administrative measures suggested for efficient management of both teak and eucalypt plantations include systematic maintenance of plantation records, organization of Plantation Productivity Workshops (PPWs) at Circle and Range levels, monitoring and evaluation procedures. To facilitate timely availability of funds for various plantation activities, a Treasury Public (TP) system of cash transaction is suggested.

REFERENCES

Adlard, P.G., Kariyappa, G.S. and Srinivasalu, N.V., 1992. Spacing at planting of short-rotation *Eucalyptus* in Karnataka. In : Calder, IR3, Hall RC and Adlard, P.G. (eds.) Growth and water use of Forest Plantations. John Willey & Sons. Chichester (UK).

Anonymous. 1970. Growth and Yield Statistics of Common Indian Timber Species Forest Research Institute and Colleges. Dehra Dun. 328 p.

Anonymous. 1995. Annual Report - 1994-95. Department of Forest, Government of West Bengal, Silviculture South Division. Midnapur. 83 p.

Chacko, K.C. Pandalai, R.C. and Nandakumar, U.N. 1990. Estimation of quantity of eucalypt seeds for sowing in nurseries. KFRI Research Report 76. Kerala Forest Research Institute, Peechi.

Chacko, K.C., Sankar, S. Pandalai, R.C., and Nandakumar, U.N. 1991. Effects of slash-burning on soil properties, weed growth, taungya yield and growth of teak. Indian Forester, 117:237-248 (KFRI Scientific Paper No. 271).

Chacko, K.C., 1995. Silvicultural problems in management of teak plantations. (Paper presented at the Second Regional Seminar on Teak, 29 May-3 June 1995, Yangon, Myanmar.

Chandrasekhara, U.M., 1996. Geological studies on *Bambusa arendinacea* (Retz.) wild growing in teak plantations of Kerala, India, KFRI Research Report 107. Kerala Forest Research Institute, Peechi : 33 p.

Chandrasekharan, C., 1973. Forest resources of Kerala : A quantitative assessment. Kerala Forest Department. Thiruvananthapuram. 245 p.

Chaturvedi, A.N. 1973a. General standard volume table and height-diameter relationship for teak (*Tectona grandis*) . Indian Forest Records (New Series), Siviculture, Vol. 12, No. 8. Forest Research Institute and Colleges, Dehra Dun.

Chaturvedi, A.N. 1973b. General standard volume table for *Eucalyptus* hybrid. Indian Forest Records (NS)- Silviculture, Vol.12 (14). FRI and Colleges, Dehra Dun. 9 p.

Chaturvedi, A.N. and Pande, G.C. 1973. General volume table for *Eucalyptus grandis*. Indian Forest Records (NS)- Silviculture, Vol.12 (17). FRI and Colleges, Dehra Dun. 8 p.

FAO, 1979. Watershed development with special reference to soil and water conservations. FAO Soils Bulletin 44, FAO, Rome, 29 p.

FAO, 1985. Intensive multiple-use forest management in the tropics. FAO Forestry Paper 55, FAO, Rome.

Ghosh, S.K., Balasundaran, M. and Mohamed Ali, M.I., 1984. Studies on the host-parasite relationship of phanerogamic parasites on teak and their possible control. KFRI Research Report 21. Kerala Forest Research Institute, Peechi 39 p.

Indira, E.P., Chacko, K.C. and Krishnankutty, C.N. 1996. Growth performance of teak nursery stock from genetically better sources for developing improved plantation technology. KFRI Research Report No. 102.

Jayaraman, K. and Krishnankutty, C.N. 1990. A data bank for forestry sector in Kerala. KFRI Research Report 66. Kerala Forest Research Institute, Peechi. 27 p.

Jayaraman, K., Muraleedharan, P.K. and Gnanaharan, R. 1992. Evaluation of Social Forestry Plantations raised under the World Bank Scheme in Kerala. KFRI Research Report 85. Kerala Forest Research Institute, Peechi. 146 p.

Jayaraman, K. and Rugmini, P. 1993. Variation in the productivity of teak plantations in Kerala. *In* : Ravikumar, R. (Ed.). Proceedings of the Fifth Kerala Science Congress. State Committee on Science, Technology and Environment, Government of Kerala. pp 156-157.

KAU, 1993. Package of practices recommendations. 'Crops' 1993. Kerala Agricultural University, Directorate of Extension, Mannuthy, Kerala, India.

KFRI, 1979. Yield from teak plantations in Kerala, KFRI Research Report No.6. Kerala Forest Research Institute, Peechi. 11 p.

KFRI, 1984. Nursery diseases of eucalypts in Kerala and their control. KFRI Information Bulletin, No. 6., Kerala Forest Research Institute, Peechi. 16 p.

Khedhar, M.H., 1997. Root trainer nursery technology. Indian Forester, 123(2) : 183-184.

Nair, K.S.S., Sudheendrakumar, V.V., Varma, R.V. and Chacko, K.C., 1985. Studies on the seasonal incidence of defoliators and the effect of defoliation on volume increment of teak. KFRI. Research Report 30. Kerala Forest Research Institute, Peechi : 78 p.

Pande. G.C., 1978. Yield table for *Eucalyptus grandis*. Indian Forest Record (N.S.) Forest Management and Mensuration 2(1). Forest Research Institute & Colleges. Dehra Dun. 11 p.

Sharma, R.P. 1978. Yield table for *Eucalyptus* hybrid (plantation) for various levels of stocking. Indian Forester, 104 (6) : 387 - 397.

Sharma J.K., Mohan, C. and Florence EJM. 1985. Disease-survey in nurseries and plantations of forest tree species grown in Kerala. KFRI Research Report 36. Kerala Forest Research Institute, Peechi. 268 p.

Varma, R. V., 1992. Control of white grubs in teak nurseries. Evergreen, 28:3.

Varma, R.V. and Nair, K.S.S., 1995. Termite control in eucalypt plantations. Evergreen. 34:3.

Appendix 1

Formulae for ratio estimator under stratified sampling

Let $\bar{Y}_t$ represent the mean of individuals in the t th stratum. The ratio estimator for ...

$$\hat{\bar{Y}}_t = (\bar{y}_t / \bar{x}_t)(X_t / N_t)$$

Estimate of the variance of $\hat{\bar{Y}}_t$ is given by

$$\hat{V}(\hat{\bar{Y}}_t) = \frac{(1/n_t) - (1/N_t)}{n_t - 1}\left[\sum_{i=1}^{n} y_{ti}^2 - 2\hat{R}_t \sum_{i=1}^{n} y_{ti} x_{ti} + \hat{R}_t^2 \sum_{i=1}^{n} x_{ti}^2\right]$$

where $\hat{R}_t = \bar{y}_t / \bar{x}_t$

$$\bar{y}_t = (1/n_t)\sum_{i=1}^{n_t} y_{ti}$$

$$\bar{x}_t = (1/n_t)\sum_{i=1}^{n_t} x_{ti}$$

N_t = Number of sampling units in t th stratum
n_t = Number of sampling units in the sample selected from t the stratum
y_{ti} = Value of character y on i th unit in the t th stratum
x_{ti} = Value of auxiliary character x on the i th unit in the t th stratum
X_t = Total of x in the t th stratum

The estimates from the different strata are combined using the following formulae.

$$\hat{\bar{Y}} = \sum_{t=1}^{k} (N_t / N)\,\hat{\bar{Y}}_t$$

$$\hat{V}(\hat{\bar{Y}}) = \sum_{t=1}^{k} (N_t / N)^2 \hat{V}(\hat{\bar{Y}}_t)$$

where $\hat{\bar{Y}}$ = Estimate of the population mean
N = Number of sampling units in the population

Note : Although the overall sampling scheme was stratified two-stage, the second stage information had to be condensed first to the level of the first stage units before applying the above formulae, because of the nonrandom (in the strict sense) nature of the samples within each first stage unit.

Formulae for weighted proportion estimator under stratified sampling

Let P_t represent the proportion of a particular category for the t th stratum. The weighted proportion estimator for P_t is

$$\hat{P} = \frac{\sum_{i=1}^{n_t} \alpha_{ti} x_{ti}}{\sum_{i=1}^{n_t} x_{ti}}$$

Where $\alpha_{ti} = 1$ for the category of interest
$= 0$ otherwise
x_{ti} = Value for the i th units in the t th stratum

$$V(\hat{P}_t) = \frac{s_t^2 \left(X_t - \sum_{i=1}^{n_t} x_{ti} \right)}{\sum_{i=1}^{n_t} x_{ti}} \quad X_t$$

$$s_t^2 = \sum_{i=1}^{n_t} \frac{\left(\alpha_{ti} x_{ti} - \Sigma \alpha_{ti} x_{ti} / n_t \right)^2}{n_t - 1}$$

$$X_t = \sum_{i=1}^{N_t} x_{ti}$$

N_t = Number of sampling units in t th stratum
n_t = Number of sampling units in the sample selected from t th stratum

The estimate for the different strata are combined using the following formulae

$$\hat{P} = \sum_{t=1}^{k} (X_t / X) \hat{P}_t$$

$$V(\hat{P}) = \sum_{t=1}^{k} (X_t / X)^2 \hat{V}(\hat{P}_t)$$

$\hat{P}$ = Estimate of the population proportion

$$X = \sum_{t=1}^{k} X_t$$

Appendix 3. Parameters of the height-diameter relation for teak in different Divisions

Circle / Division	a	SE(a)	b	SE(b)	Adj. R
Northern					
Kannur	3.8473	0.0687	0.7023	0.0455	0.6853
Kozhikode	4.6877	0.2440	1.1040	0.1147	0.6045
North Wayanad	3.8005	0.0519	0.8118	0.0343	0.7559
South Wayanad	3.6445	0.0497	0.6616	0.0300	0.7210
Central					
Chalakkudy	3.8542	0.0289	0.6328	0.0199	0.7086
Malayattoor	3.9524	0.0488	0.7595	0.0303	0.7800
Thrissur	4.3056	0.0118	1.1031	0.0183	0.9349
Vazhachal	3.8552	0.0323	0.7205	0.0202	0.7625
Southern					
Achencoil	3.8096	0.0189	0.6947	0.0289	0.8423
Konni	3.8282	0.0312	0.6720	0.0209	0.7929
Punalur	3.7813	0.0972	0.6217	0.0602	0.4807
Ranni	4.2215	0.0314	1.0203	0.0167	0.9017
Thenmala	3.7223	0.0500	0.6673	0.0338	0.7083
Thiruvananthapuram	4.1942	0.1518	1.0810	0.0923	0.6603
Olavakkode					
Mannarkkad	4.0283	0.0491	0.9236	0.0307	0.8375
Nemmara	3.7983	0.0418	0.6505	0.0287	0.6450
North Nilambur	4.0157	0.0470	0.7908	0.0265	0.7923
Palakkad	4.0926	0.0378	0.9622	0.0161	0.9066
South Nilambur	3.8124	0.0356	0.6399	0.0235	0.7647
High Range					
Kothamangalam	3.8398	0.0314	0.7473	0.0203	0.8180
Kottayam	3.7980	0.0579	0.8003	0.0351	0.6938
Munnar	3.8389	0.0350	0.6861	0.0227	0.8043

Note : SE(t) indicates standard error of t.
a, b refers to the parameters of the equation (1)

Appendix 4. Parameters of the height-diameter relation for eucalypts in different Circles in Kerala

Circle	a	SE(a)	b	SE(b)	Adj. R^2
Eucalyptus tereticornis					
Northern	3.8067	0.0714	0.5671	0.0318	0.7586
Central	4.3934	0.1110	0.9467	0.0436	0.7942
Southern	4.6424	0.0554	0.9976	0.0196	0.8861
Olavakkode	5.0144	0.2208	1.1161	0.0754	0.8290
Highrange	4.3689	0.3081	0.9126	0.1358	0.7104
Eucalyptus grandis					
Northern	3.6074	0.1228	0.3079	0.0601	0.5576
Southern	4.3843	0.2777	0.7957	0.1317	0.7978
Highrange	4.7372	0.1038	1.0321	0.0471	0.6696

Appendix V

Report of commencement of plantation activities (in quadruplicate)

i) Division :
ii) Range :
iii) Section :
iv) Suggested name of plantation (local place name) :
v) Species to be planted :
vi) Total area (ha) :
vii) Date of commencement of site preparation :
viii) Remarks (if any) :

Range Officer
_____ Range
Place name with Pin Code

Forwarded to the CCF (Development) for allotment of plantation number

i) Whether the plantation activity has been carried out or not :
ii) Is the plantation raised as per the approved plan/scheme :
iii) Remarks (if any) :

Divisional Forest Officer
_____ Division

Plantation No. allotted : Division | | Range | | Plantation number | | | | | | | | |

Chief Conservator of Forests (Development)

(one copy to be returned to the Divisional Forest Officer)

Orientation training on Integrated Solid Waste Management System

Target group: Elected representatives and Officials of 53 Municipalities
Purpose: Evolving policy decision and project concept on integrated solid waste management
Training Date: 2004 April 30; June 21 and June 24

No. of training conducted: Three
Number of Municipalities participated: 48
No. of elected representatives attended: 59
No. of officials attended: 131

Topics covered

1. Municipal Solid Waste Management (Management & Handling) Rules, 2000
2. State Planning Board- Plan Guidelines
3. Components of solid waste management system
   a. Segregated collection at source
   b. Street cleaning
   c. Primary collection
   d. Transportation
   e. Processing of biodegradable waste
   f. Reuse/recycling of non-biodegradables
   g. Sanitary land filling of rejects/refuse
4. Waste processing technologies
   a. Technology options
   b. Windrow Composting
   c. Vermi Composting
   d. Biogas generation
5. Awareness and IEC campaign
6. Project implementation & monitoring

Resource persons
Sri. V.N. Jithendran, Director, Kerala Total Sanitation & Health Mission
Sri. C.O. Kurian, Former Director, Kerala Total Sanitation & Health Mission
Sri. M. Dileepkumar, Asst. Env. Engineer, State Pollution Control Board
Sri. R.C Sasidharn Nair, TDASAT Co-operative Society Ltd.
Sri. G. Jayachandra, Regional Technology & Training Centre
Dr. K. Krishnakumar, Programme Officer (UPA), Kudumbashree
Dr. R. Ajaykumar Varma, Director, Clean Kerala Mission

Appendix

Register of temporary issue of Plantation Journal/other Plantation Records

Date	Name of the record/ register	Issued to whom	Reason for issue	Signature of the officer to whom the Register is issued	Date of return	Initial of the Range Officer /authorised person

Appendix 8

Calendar of operation for proposed plantation

Plantation number

(To be prepared in triplicate)

Species	Planting year	Rotation	Division	Range	Locality

Year	Month	Operation suggested	Remark

Submitted

Name :
Designation :

Approved

Name :
Designation :

Appendix 9

Report of fire control measures

Plantation number

Certified that

(i) Fire line work has been done/has not been done
(indicate reason if not done) *

(ii) Fire watchers have been employed/have not been employed
(indicate reason if not done)

Remarks of Range Officer

Date :

Range Officer

To

The Divisional Forest Officer
_____ Division
_____

Appendix 10

Fortnightly report of fire incidence

(To be submitted on 16th and 1st of every month)

Plantation number : | | | | | | | | |

Period	Whether there was any fire during the above period/ (If yes, indicate nature of damage)
1 Jan - 15 Jan	
16 Jan - 31 Jan	
1 Feb - 15 Feb	
16 Feb - 28/29 Feb	
1 Mar - 15 Mar	
16 Mar - 31 Mar	
1 Apr - 15 Apr	
16 Apr - 31 Apr	
1 May - 15 May	
16 May - 31 May	

Date :

Section Forester

Remarks

Range Officer

Appendix 11

Plantation Evaluation Form

Forest Division :
Name of plantation:

Forest Range :
Year of planting:

...ies name
Local :
Scientific :

Plantation and plot numbers:

Divn. Code	Range Code	Plantation number	Plot No. (For each pln. Start from 01)

...REE MEASUREMENT IN PLOT (Total number of trees in this plot =)

Tree No.	Species	Gbh(cm)	Height(m)	Remarks

(Continued ...)

Remarks : C = Coppice, S = Seedlings (< 10cm gbh), T = Top broken, D = Dry,
I = Insect damage, B = Buttressed at base.

* Height refers to total height of trees to be measured on five trees of differing sizes

General remarks :

Date of observation :

Name and signature of recorder :

Date of inspection :

Signature, name and address : of the Inspection Officer

Reinforcement training on Integrated Solid Waste Management System

Target group: Elected representatives and Officials of all Municipalities
Purpose: Capability building to prepare Integrated SWM Projects
Training Date: 2004 May 28, 29, 31; July 19, 21, 23.

No. of training conducted:	Six
Number of Municipalities participated:	41
No. of elected representatives attended:	17
No. of officials attended:	69

Topics covered

1. Why an integrated SWM system for a Municipality
2. Components of solid waste management system
   a. Segregated collection at source
   b. Street cleaning
   c. Primary collection
   d. Transportation
   e. Processing of biodegradable waste
   f. Reuse/recycling of non-biodegradables
   g. Sanitary land filling of rejects/refuse
3. Waste processing technologies
   h. Technology options
   i. Windrow Composting
   j. Vermi Composting
   k. Biogas generation
4. Project budget

Resource persons
Sri. M. Dileepkumar, Asst. Env. Engineer, State Pollution Control Board
Dr. R. Ajaykumar Varma, Director, Clean Kerala Mission

Appendix 13

Report of Plantation Productivity Workshop at Range level

Date of PPW :

Venue :

No. of persons attended

Dy. Range Officers :
Foresters :
Forest Guards :
Watchers :
Others (specify) :

Brief report of the workshop

Date :

Signature of Range Officer
..... Range

Appendix 14

Average Composition of fertilisers and manures

Material	Percentage of Nutrients		
	N	P	K
Ammonium sulphate	20.50	--	
Ammonium nitrate	33.50	--	
Ammonium phosphate	16.00	20.00	
Calcium ammonium nitrate	20.50	--	
Nitrate of soda	16.50	--	
Urea	46.00	--	
Super phosphate - single	--	18.00	
Super phosphate - double	--	35.00	
Super phosphate - triple	--	45.00	
Muriate of Potash	--	--	50.00 or 60.00
Musssoriephos	--	20.00 - 24.00	
Rock phosphate	--	28.40	
Bone meal	3.50	21.40	
Poultry manure	1.20 - 1.50	--	
Sheep manure	0.80 - 1.60	--	
Farm yard manure	0.40	0.30	0.20
Compost	0.50	0.25	0.50

Source : KAU (1993)