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GROWTH OF TEAK IN SUCCESSIVE ROTATIONS IN RELATION TO SOIL CONDITIONS

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ABSTRACT OF PROJECT PROPOSAL

1. Project No : KFRI 199/93

2. Title of the Project : Growth of teak in successive rotations in relation to soil

3. Objectives

   i. Study the soil properties in first, second and third rotation teak plantations

   ii. Evaluate the growth of teak in successive rotations

   iii. Correlative soil conditions with

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ABSTRACT

Teak (*Tectona grandis* Linn. f.) in forest plantations of Kerala occupies an area of about 69,000 ha of which about 64% are in first rotation and the remaining 36% are in second and third rotations. There is a general apprehension that the productivity of teak declines with successive rotations. Thus, a study was undertaken to examine the changes in soil conditions and evaluate the growth of teak in successive rotations.

Soil analyses revealed that the soils were sandy loam in the surface and loam in the deeper layers in the first rotation and sandy loam and loam in all layers in the second and third rotations, respectively. The soils were medium acid (pH 5.8-6.0) in all rotations, but a decrease in acidity was seen in successive rotations. Organic carbon contents were highest in the first (1.25%) while exchangeable bases remained almost same (11-12 me/100 g soil) in the three rotations. Total N (1119 ppm), available K (72 ppm), Ca (67 ppm) and Mg (69 ppm) were lowest in the second rotation.

Among the 11 soil properties studied, gravel and organic carbon contents varied significantly between rotations, while for soil texture, pH, total N, available K and Ca, there was no significant difference between rotations. The discriminant analysis revealed that there was significant decline in soil fertility with change in rotation.

Tree height differed significantly between rotations while dbh showed no significant difference. Only 14 percent of variation in tree height could be explained by the soil properties, as height growth, probably, is controlled by a host of factors other than soil properties. The differences in site index between rotations were found to be non-significant and could be due to the high variation in site index within each slope and rotation.

The study suggests the need for careful management of the soil to reduce soil deterioration. Site specific soil erosion control measures and proper management of slash, weed and litter are recommended.

1. INTRODUCTION

ESTablishment of plantations of teak (*Tectona grandis* Linn. f.) by the Kerala Forest Department started in 1846. The Department now has about 69,000 ha under teak (KFRI, 1997). Among them, approximately 64% are in the first rotation and the remaining 36% are in the second and third rotation stages. There is a general apprehension that productivity of teak would fall in successive rotations (Balagopalan *et al*, 1998).

Although comprehensive studies revealing changes in soil properties and growth of teak in successive rotations are not available, attempts have been made to understand changes in soil properties in plantations in Kerala. Alexander *et al* (1980) found that some of the soil properties showed a tendency to change in second rotation when compared with first. Balagopalan and Jose (1982) noted a decrease in soil organic carbon and total N contents in second rotation teak plantations in relation to the first one. Another observation was that there was a decline in soil organic carbon distribution in teak plantations in comparison to natural forest (Balagopalan and Alexander 1985). Alexander *et al* (1987) found that soil properties influenced site quality of teak plantations.

In a study of soils in first and second rotation teak plantations in Kerala, Jose and Koshy (1972) reported that soil compaction increased with age of plantations. They also observed that soil fertility declined in older plantations. Balagopalan and Jose (1982) also observed a decline in soil fertility in successive rotation teak plantations in Kerala. The fact that the growth of trees in successive rotations in relation to soil conditions has not been explored in detail led to the formulation of this study.

The objectives of the project are

i. to study the soil properties in the first, second and third rotation teak plantations

ii. to evaluate the growth of teak in successive rotations and

iii. to correlate soil conditions with growth of teak under successive rotations.

2. MATERIALS AND METHODS

2.1. STUDY AREA

The study was conducted in the teak plantations of Nilambur South and Nilambur North Forest Divisions of Kerala, India (Figs. 1, 2 and 3).

Teak plantations of comparable age groups were selected in the first, second and third rotations for the study. Twenty four such plantations of 8 to 17 years age, falling under the three rotations were selected randomly; six in the first, ten in the second and eight in the third rotations. Temporary sample plots of 20 m x 20 m were laid out in each plantation at the rate of one plot per 10 ha of plantation with a minimum of one and a maximum of eight. Details of teak plantations in the first, second and third rotations selected for the study are shown in Table 1. Total number of plots laid out in the plantations under first, second and third rotations were 26, 16 and 17, respectively. All the plantations located were at an elevation of 35 to 240 m asl and within a slope class of 0-10°.

2.2. SOIL SAMPLING AND ANALYSES

From each plot, one soil pit of 0.6 m x 0.6 m x 0.6 m size was dug and samples were collected from 0-20, 20-40 and 40-60 cm layers. The soils were analysed for particle-size separates, pH, organic carbon, exchangeable bases, total N, available K, Ca and Mg as per standard procedures in ASA (1965) and Jackson (1958). The mean values of soil properties in the three layers of different plantations under first, second and third rotations are given in Appendices I, II and III.

2.3. MEASUREMENT OF TREE GROWTH PARAMETERS

The girth at breast height (gbh) was measured at 1.37 m above ground level of all the trees within the selected plots and height was measured on a sub sample of trees within each selected plot. The girth at breast height (gbh) was converted to diameter at breast height (dbh).

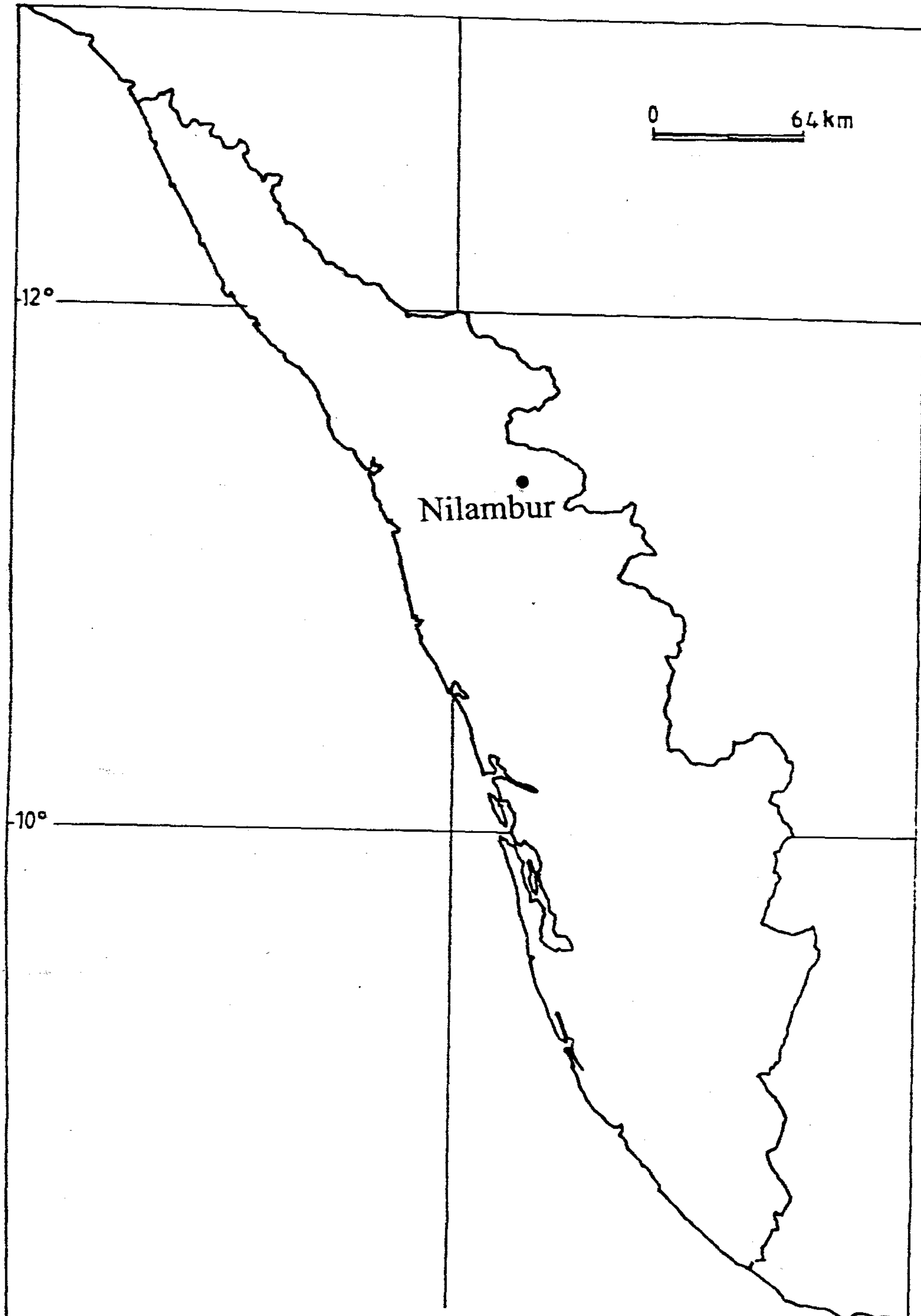

Fig. 1. Location of study area

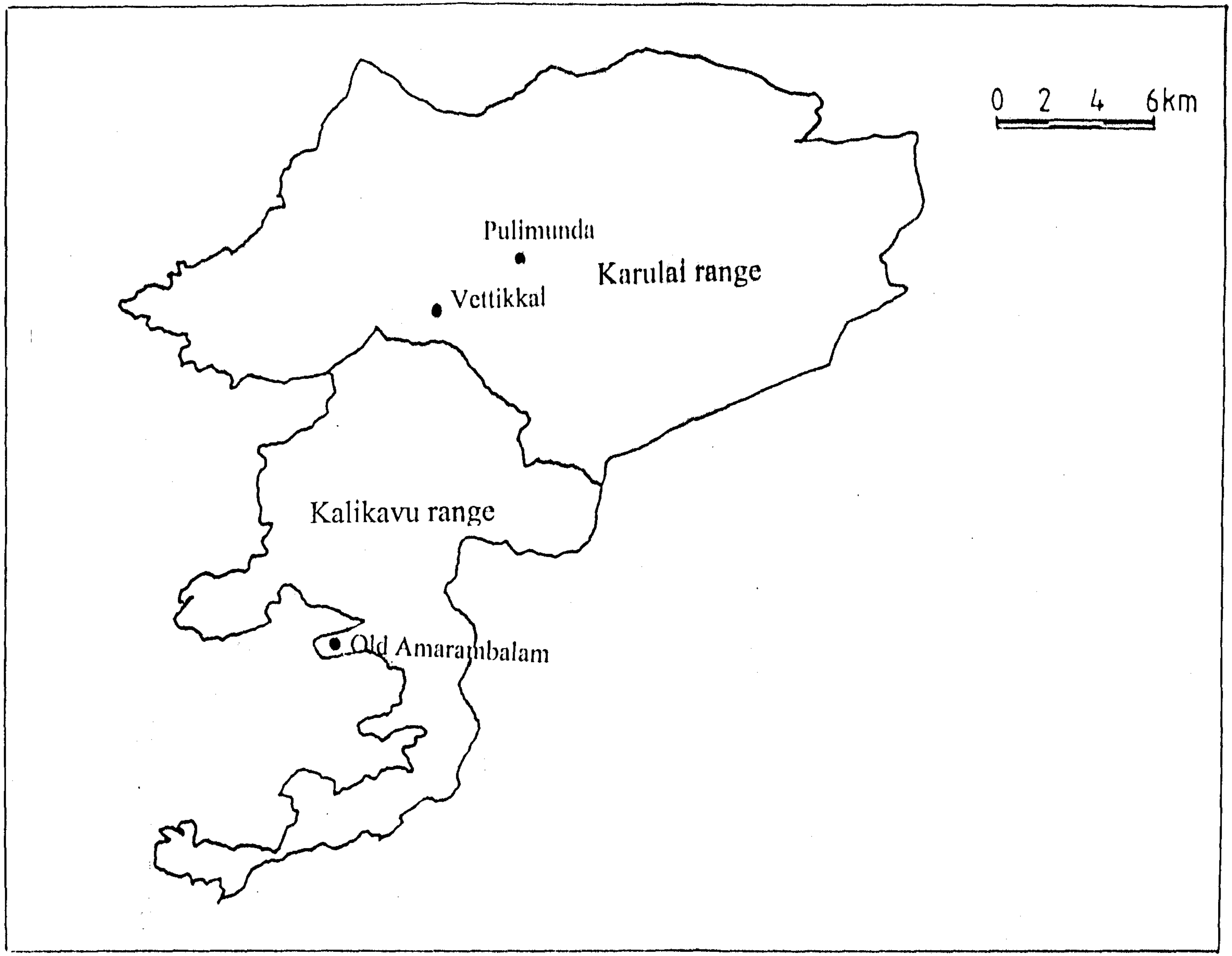

Fig. 2. Location of plantations selected for the study in Nilambur (South) Forest Division

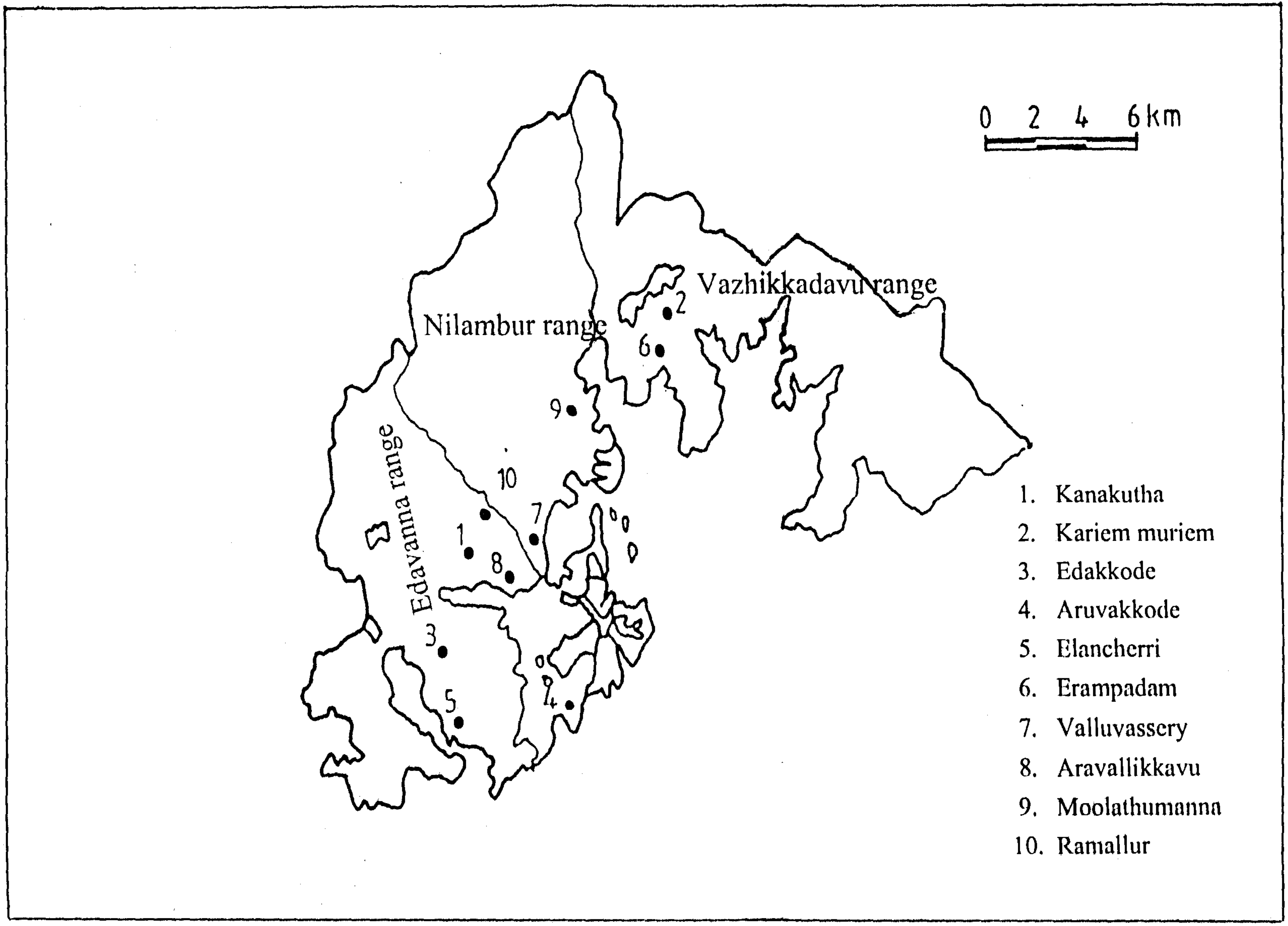

Fig. 3. Location of plantations selected for the study in Nilambur (North) Forest Division

Table 1. Details of teak plantations in first, second and third rotations selected for the study

Name of plantation	Range	Division Nilambur	Elevation (m asl)	Year of establishment	No. of plots	Slope	Area (ha)
First rotation							
Old Amaramblam	Kalikavu	South	110	1981	2	4°	7.118
"	"	"	120	1984	1	2°	1.370
Kanakutha	Nilambur	North	35	1978	8	Plain	82.050
"	"	"	45	1979	6	3°	108.230
Kariem muriem	Vazhikadavu	"	100	1980	8	4°	79.000
"	"	"	100	1982	1	3°	11.350
Second rotation							
Edakkode	Edavanna	"	110	1984	2	5°	20.760
"	"	"	110	1981	2	Plain	13.111
"	"	"	200	1979	1	12°	18.750
Aruvakkode	Nilambur	"	110	1978	1	Plain	10.060
Elancherri	Edavanna	"	60	1987	2	4°	3.630
Erampadam	Vazhikkadavu	"	75	1984	2	4°	22.060
Valluvasssery	Nilambur	"	110	1982	2	Plain	12.868
Pulimunda	Karulai	South	240	1981	1	Plain	27.275
Vettikkal	"	"	90	1981	2	Plain	8.375
"	"	"	90	1982	1	Plain	21.200
Third rotation							
Aravallikkavu	Nilambur	North	110	1987	2	7°	1.114
Moolathumanna	"	"	45	1981	2	Plain	16.099
"	"	"	50	1983	1	Plain	7.200
Edakkode	Edavanna	"	120	1983	3	3°	29.530
Ramallur	"	"	110	1981	2	Plain	1.680
"	"	"	100	1983	2	Plain	7.300
Elancherri	"	"	60	1983	2	Plain	15.800
Pulimunda	Karulai	South	200	1984	3	10°	49.720

Top height for each plot was computed as specified by Chaturvedi and Khanna (1982) which is the height corresponding to the quadratic mean diameter of the largest 250 diameter/ha (Dq) as read from the height-diameter curve. The height-diameter relation for the purpose was worked out by fitting an equation of the following form with the corresponding data

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

Where

h = Total height of the tree (m)

D = Diameter of the tree at breast height (cm)

a and b are coefficients.

When D = Dq, the predicted total height corresponds to top height (H).

In order to study the effect of rotation on site quality (SQ), which is the composite of physiological make-up of a tree and environmental variables, site index was estimated. Site index is the projected top height to a base age. The base age is the age at which the height growth culminates. Base age for teak is taken as 50 years.

The site index was calculated using the following equation (Jayaraman, 1998)

$$\ln S = \ln H + 7.6959 (A^{-1} - A_0^{-1}) \qquad (2)$$

(Adj. $R^2 = 0.57$)

Where

S = Site index (m)

H = Top height (m)

A = Age of the plantation (years)

A_0= 50 years

Mean square error (MSE) = 0.04596

A correction factor MSE/2 has been added to the predicted value before transforming to the original units.

2.4. STATISTICAL ANALYSES

2.4.1. Soil properties

2.4.1.1. Analysis of covariance on soil properties

The differences in soil properties over rotations were studied through analysis of variance (Snedecor and Cochran, 1965). Since the plantations differed with respect to age, the data were subjected to analysis of covariance (ANACOV) with age of the plantation as the ancillary variable and the mean comparison was done, wherever needed, through Duncan's multiple range text (DMRT). In ANACOV, slope category was also used as a factor with two levels such as plain (slope = 0°) and hilly terrain (slope > 0°). The ANACOV was carried out using 'MANOVA Univariate' procedure of SPSS described in Norusis (1988). All the analyses were done after transforming the original data as mentioned in Rugmini and Jayaraman (1998).

Through ANACOV, the effect of rotation, slope and their interaction on the status of each soil property could be studied separately. This may be inadequate in the presence of inter- correlation among the soil properties. In order to get a better picture of the influence of rotation on the soil properties combinedly, discriminant analysis was done (Jeffers, 1978).

2.4.1.2. Discriminant analysis on soil variables

Discriminant function deals with the problem of how best to discriminate two or more predefined groups, each individual of which has been measured in respect of several variables. The model provides a linear function of the measurements on each variable such that the ratio of between group sum of squares to that of within group sum of squares is maximized for the discrimant scores. This provides a best way of identifying the variables by which the groups differ most.

When there are three groups, two functions are obtained. For K groups, k-1 function can be derived each independent of the other. In the present study the discriminant analysis was carried out to identify the factors by which the soils under different rotation differ.

Since sand, silt and clay contents add up to unity, the clay content was not considered while performing discriminant analysis. As the preliminary analysis indicated the nonsignificant effect of slopes on soil properties, slope category was also excluded from the discriminant analysis.

2.4.2. Growth parameters

2.4.2.1. *Analysis of covariance on growth parameters*

In order to study the effect of rotation on height, dbh and site index, ANOVA was carried out. Since the plantations differed with respect to age, the data on height and dbh were subjected to ANACOV, with age of the plantations as the covariate variable and mean comparison test was done using DMRT, wherever needed. In ANACOV, slope category was also used as a factor with two levels such as plain (slope = 0°) and hilly terrain (slope = > 0°).

3. RESULTS AND DISCUSSION

The results of ANACOV on different soil properties in each layer of the plantations are given in Table 2. Adjusted mean values of soil properties in each layer under different rotations are shown in Table 3.

Table 2. Analysis of covariance on different soil properties in each layer of teak plantations under different rotations

Sources	df	F values/Layers (cm)			
		0-20	20-40	40-60	0-60
Gravel					
Age	1	0.10ns	1.12ns	1.14ns	1.18ns
Rotation	2	0.27ns	0.04ns	3.46*	4.27*
Slope	1	2.24ns	4.44*	0.16ns	0.18ns
Rotation x slope	2	0.12ns	0.22ns	1.26ns	1.28ns
Sand					
Age	1	1.17ns	1.94ns	0.01ns	0.03ns
Rotation	2	2.11ns	0.71ns	0.19ns	0.18ns
Slope	1	1.22ns	1.08ns	0.89ns	2.45ns
Rotation x slope	2	0.49ns	0.09ns	0.65ns	0.26ns
Silt					
Age	1	1.48ns	2.49ns	0.51ns	1.84ns
Rotation	2	2.83ns	1.74ns	1.38ns	1.57ns
Slope	1	0.28ns	0.64ns	0.05ns	2.01ns
Rotation x slope	2	0.37ns	0.27ns	0.13ns	0.15ns
Clay					
Age	1	0.58ns	1.11ns	0.08ns	1.90ns
Rotation	2	1.68ns	0.08ns	2.03ns	3.05ns
Slope	1	1.97ns	1.08ns	0.25ns	1.05ns
Rotation x slope	2	0.65ns	0.10ns	0.02ns	0.45ns

Table 2 contd...

Table 2 contd...

pH					
Age	1	0.82ns	0.22ns	1.22ns	1.57ns
Rotation	2	0.06ns	0.61ns	0.14ns	0.58ns
Slope	1	0.04ns	0.30ns	0.45ns	2.48ns
Rotation x slope	2	4.64*	1.63ns	0.31ns	0.19ns
Organic carbon					
Age	1	1.32ns	1.24ns	1.02ns	1.40ns
Rotation	2	3.47*	0.13ns	1.47ns	4.33*
Slope	1	0.32ns	4.16*	0.80ns	0.39ns
Rotation x slope	2	1.36ns	0.20ns	1.11ns	1.41ns
Exch. bases					
Age	1	0.02ns	1.96ns	0.05ns	0.08ns
Rotation	2	1.85ns	0.72ns	0.48ns	0.52ns
Slope	1	6.10*	1.13ns	0.45ns	2.85ns
Rotation x slope	2	2.12ns	0.07ns	0.23ns	0.30ns
Total N					
Age	1	0.80ns	2.49ns	0.51ns	1.84ns
Rotation	2	1.71ns	1.74ns	1.38ns	1.57ns
Slope	1	10.51**	0.64ns	0.05ns	2.01ns
Rotation x slope	2	1.68ns	0.27ns	0.13ns	0.15ns
Available K					
Age	1	0.10ns	1.19ns	0.07ns	1.80ns
Rotation	2	0.27ns	0.07ns	1.97ns	3.00ns
Slope	1	2.42ns	1.21ns	0.28ns	1.04ns
Rotation x slope	2	0.12ns	0.05ns	0.05ns	0.36ns
Available Ca					
Age	1	1.26ns	0.22ns	1.15ns	1.65ns
Rotation	2	2.07ns	0.61ns	0.13ns	0.60ns
Slope	1	1.32ns	0.31ns	0.46ns	2.69ns
Rotation x slope	2	0.49ns	1.65ns	0.44ns	0.10ns
Available Mg					
Age	1	1.48ns	0.02ns	0.30ns	0.01ns
Rotation	2	2.52ns	5.24**	0.45ns	0.91ns
Slope	1	0.39ns	2.10ns	0.00ns	0.18ns
Rotation x slope	2	0.42ns	5.05**	2.61ns	2.74ns

ns = non-significant; *= significant at $p = 0.05$.

Table 3. Adjusted mean values of soil properties in each layer of teak plantations under dfferent rotations

Soil properties	Rotation	Depth (cm)			
		0-20	20-40	40-60	0-60
Gravel %	I	31	34	40[a]	34[a]
	II	28	30	31[b]	28[b]
	III	32	30	33[b]	32[b]
Sand %	I	76	75	74	75
	II	79	76	77	77
	III	74	73	73	73
Silt %	I	12	13	14	13
	II	10	11	11	11
	III	13	14	14	14
Clay %	I	12	12	12	12
	II	11	13	12	12
	III	13	13	13	13
PH	I	5.9	5.8	5.8	5.8
	II	5.8	5.9	5.9	5.9
	III	5.9	5.9	6.0	6.0
Org. carbon %	I	1.47[a]	1.20	0.99	1.25[a]
	II	1.09[b]	0.93	0.83	0.92[b]
	III	1.02[b]	1.03	0.94	0.99[b]
Exch. Bases me/100g	I	13	14	11	12
	II	12	10	11	11
	III	11	11	13	12
Total N ppm	I	1484	1153	1046	1226
	II	1288	1158	978	1119
	III	1269	1214	1153	1253
Av.K ppm	I	62	62	139	82
	II	82	75	89	72
	III	133	115	66	107
Av. Ca ppm	I	81	74	70	76
	II	65	70	66	67
	III	87	87	86	90
Av. Mg. Ppm	I	89	90[a]	109	90
	II	60	62[b]	44	69
	III	104	118[b]	95	105

*Values superscribed by the same letter do not differ significantly.
I - First rotation; II – Second rotation and III – Third rotation.

3.1. SOIL PROPERTIES IN DIFFERENT LAYERS UNDER DIFFERENT ROTATIONS

3.1.1. Gravel

Analysis of covariance showed that the gravel contents differed significantly between rotations in the 40-60 and 0-60 cm layers. They showed significant difference between slopes in the 20-40 cm layer. The interaction between rotation and slope was found to be non-significant with respect to gravel contents in all layers (Table 2).

Pair-wise comparison between the rotations after eliminating the influence of age with regard to gravel contents indicated that in the 40-60 and 0-60 cm layers, the mean values corresponding to rotation I were significantly different from those in rotations II and III while the difference in mean values between rotations II and III were found to be non-significant (Table 3).

The adjusted mean values of gravel contents increased with depth in the first and second rotations whereas there was no trend for third rotation. In the 0-60 cm layer, gravel content was highest in rotation I followed by that in rotation III (Table 3).

3.1.2. Particle-size separates and texture

There were no significant differences between rotations, with respect to sand, silt and clay contents in all the layers viz., 0-20, 20-40, 40-60 and 0-60 cm. With respect to slope, the same pattern was followed. The interaction between rotation and slope with respect to sand, silt and clay was also found to be not significant in all the layers (Table 2).

The soils were sandy loam in the surface and subsurface and loam in the 40-60 cm layer in the first rotation while the soils were sandy loam and loam in all layers in the second and third rotations, respectively. They were loam in the first and third rotations and in the second, they were sandy loam in the 0-60cm layer (Table 3).

3.1.3. Soil pH

In the case of soil pH, analysis of covariance showed that there was no significant difference between rotations in all the layers. Same pattern was followed with respect to slope. The interaction between rotation and slope was found to be not significant with respect to soil pH in all the layers except in the 0-20 cm layer (Table 2). The soils were medium acid in all layers in the three rotations (Table 3).

3.1.4. Organic carbon

The differences in organic carbon contents between rotations were found to be significant in the 0-20 and 0-60 cm layers. There was also significant influence of slope on organic carbon contents in the 20-40 cm layer. The interaction between rotation and slope was found to be non-significant (Table 2).

Pair wise comparison between rotations with regard to organic carbon contents after eliminating the influence of age between rotations in the 0-20 cm and 0-60 cm layers showed that mean values in rotation I differed significantly from those in rotations II and III while those in rotations II and III showed no significant difference (Table 3).

The adjusted mean values of organic carbon contents decreased with depth in the first rotation while in the second and third, no trend was followed. They were found to be highest in the first rotation in the surface and subsurface layers while in the 40 –60 cm layer, it was in the second rotation. In the 0-60 cm layer, the organic carbon content was highest in rotation I followed by rotation III (Table 3).

3.1.5. Exchangeable bases

There was no significant effect of rotation on exchangeable bases contents in all the layers, but there was significant influence of slope on exchangeable bases content in the 0-20 cm layer. The interaction between rotation and slope was also found to be non-significant. (Table 2).

There was not much difference in the adjusted mean values of exchangeable bases contents in different layers under different rotations (Table 3).

3.1.6. Total N

ANACOV indicated that there was no significant difference between rotations in different layers with respect to Total N. There was significant difference between slopes in the 0-20 cm layer only. The interaction between rotation and slope was also found to be non-significant (Table 2).

Total N contents decreased with depth in all the rotations. The adjusted mean values were relatively higher in the surface in the first rotation while in deeper layers, relatively higher values were recorded in third rotation. In the 0-60 cm layer, the first rotation recorded relatively higher values (Table 3).

3.1.7. Available K

Analysis of covariance showed non-significant effect of rotation, slope and interaction between slope and rotation on available K contents in all the layers (Table 2).

Adjusted mean values of available K were found to be lowest in the surface and subsurface layers in the first rotation while it was highest in the 40-60 cm layer when compared with those in the second and third rotations (Table 3).

The available K contents decreased with depth in the third rotation while no trend was followed in the second rotation. In the first rotation, the available K remained same in the surface and subsurface layers and increased in the 40-60 cm layer. Available K content in the 0-60 cm layer was highest in the third rotation.

3.1.8. Available Ca and Mg

Analysis of covariance with respect to available Ca showed non-significant effects due to rotations and slopes in all the layers. The interaction between rotation and slope was also found to be non- significant with respect to available Ca in all the layers.

In the case of available Mg content, ANACOV showed that there was significant influence of rotation in the 20-40 cm layer while in other layers, the influence was found to be non-significant. There was no significant effect on available Mg contents due to slope in all layers. The interaction between rotation and slope with respect to available Mg contents showed significant difference in the 20-40 cm layer only while in all the other layers, no significant difference was observed (Table 2).

Adjusted mean values of available Ca decreased with depth in the first rotation whereas in the second rotation, no trend was followed. In the third rotation, available Ca remained same in the surface and subsurface layers while in the 40-60 cm layer, the value slightly decreased.

Pair-wise comparison between rotations with regard to available Mg contents after eliminating the influence of age in the 20-40 cm layer, showed that mean value in the first rotation differed significantly from those in second and third rotations while those between second and third rotations showed no significant difference (Table 3).

In the case of available Mg, the mean values increased with depth in the first rotation while in the second and third rotations, no pattern was found (Table 3).

Available Ca and Mg showed that they were highest in soils under third rotation in all layers. Lowest values were observed in all layers in the second rotation (Table 3).

3.2. DISCRIMINANT ANALYSIS ON SOIL PROPERTIES

Since there were three rotations, two discriminant functions were generated and they explained 71% and 29% of the total variance, respectively. The corresponding X^2 values were also highly significant, which indicated that the function identified had significant discriminating ability. The coefficients of the discriminant functions are reported in Table 4.

Table 4. Standardized canonical discriminant function coefficients

Properties	Function 1	Function 2
Sand	0.81568	1.70827
Silt	1.10449	2.33321
pH	.49384	.36814
Organic carbon	-.96121	.19741
Exchangeable bases	-.43847	-.76213
Gravel	-.14398	.09682
Total N	.50963	-.11698
Available K	.11899	.25176
Available Ca	-.42009	.48813
Available Mg	.00948	.38403

In order to find the contribution of the variables to each function, the correlation coefficients between the variables and the functions were examined (Table 5). The first discriminant function was found to be highly negatively correlated with organic carbon, total N and available Ca. The result indicated that the changes in rotation brought about changes largely in the status of these soil properties. The three soil properties together represent a major portion of soil fertility. The negative sign indicated that the values of function 1 would be high for the least values of organic carbon, total N and available Ca or as the function value increased, the soil fertility decreased (Table 5).

Table 5. Pooled within groups correlations between discriminating variables and canonical discriminant functions

Property	Function 1	Function 2
Organic carbon	-.85686	.37250
Total N	-.64522	.32639
Available Ca	-.46275	.33366
Available Mg	.36769	-.06295
Exchangable bases	-.36588	.22548
pH	.24978	.20160
Available K	-.20504	.15629
Silt	-.23170	.66369
Sand	.24952	-.48013
Gravel	-.21087	.21439

In the case of function 2, it was highly correlated with silt (positively) and sand (negatively). This indicated that the changes in rotation affected the changes in these soil properties. These properties together represent the soil texture. The value of the function 2 would be large for high silt and low sand contents (Table 5).

It can be seen quite clearly from Table 6 that the mean values of function 1 were lowest in rotation I and highest in rotation III. This revealed that the soil fertility decreased from rotation I through III. There was no specific trend for the mean values for the second discriminant function viz. soil texture among rotations. Thus the results clearly indicated that soil fertility decreased in successive rotations.

Table 6. Canonical discriminant functions evaluated at rotation means

Rotations	Function 1	Function 2
I	-0.86692	0.12411
II	0.41357	-0.74333
III	0.87545	0.50979

3.3. GROWTH PARAMETERS

The results of ANACOV on height and dbh of trees are given in Table 7. The adjusted mean values of height and dbh and unadjusted mean values of site index in the three rotations are reported in Table 8. The results of analysis of variance on site index are shown in Table 9.

Table 7. Analysis of covariance on tree height and dbh

Sources	df	Mean square	F value
Height			
Age	1	0.44251	1.35 ns
Rotation	2	1.05409	3.21*
Slope	1	0.15986	0.49 ns
Rotation x slope	2	0.45125	1.37 ns
Dbh			
Age	1	0.00096	0.00 ns
Rotation	2	0.78427	1.94 ns
Slope	1	2.83692	7.01**
Rotation x slope	2	0.93341	2.31 ns

Ns = non-significant; *, ** = significant at $p = 0.05$ and 0.01 respectively.

Table 8. Adjusted mean values of height and dbh of trees and unadjusted mean values of site index under three rotations

Growth parameters	Rotations		
	I	II	III
Height (m)	16.58[b]	12.45[a]	13.70[ab]
Dbh (cm)	18.09	14.35	14.58
Site index (m)	24.71	21.91	24.21

Figures superscribed by the same letter in the first row indicate non-significant.

Table 9. Analysis of variance on site index

Source	df	Mean square	F values
Rotation	2	60.653	1.440 ns
Slope	1	126.122	2.995 ns
Rotation x slope	2	27.352	0.650 ns
Residual	53	42.106	
Total	58		

The differences in height between rotations were found to be significant (Table 7). In the case of dbh. the differences were found to be non-significant between rotations, while there was significant influence of slope on dbh. There was no interaction between rotation and slope with respect of height as well as dbh. Age did not have significant effect on height and dbh since there were considerable variation in the characters within any particular age level.

Pair-wise comparison between the rotations after eliminating the influence of age with regard to height is reported in Table 8. The adjusted mean values for height and dbh were maximum in rotation I and minimum in rotation II. There was slight increase in height and dbh in rotation III as compared to rotation II.

The significant difference in height between rotations could be due to, among several factors. the significant change in soil fertility and variation in soil texture. The effect of soil properties on height was studied through multiple linear regression analysis and it was found that soil properties accounted for 14% of the variation in height, after eliminating the age affect.

Analysis of variance on site index between rotations as well as slopes revealed that the differences were non-significant. The interaction between rotations and slope was also found to be nonsignificant with regard to site index (Table 9). It was also noticed that there was considerable variation in site index within each slope category and rotation (Table 10). This shows that the effect of rotation is very much dependent on site. Mean value for site index was maximum in rotation I and minimum in rotation II. There was slight increase in site index in rotation III as compared to rotation II (Table 8).

Table 10. Coefficient of variation of site index within rotation and slope

Rotation	Slope	Coefficient of variation
I	1	12.88
I	2	38.77
II	1	17.83
II	2	38.34
III	1	11.51
III	2	18.46

*1 = indicates plain
2 = indicates hilly terrain

Before conversion to teak plantations. the areas were under natural forest. In the natural forest ecosystem. most of the nutrients were present in living and dead biomass and tight cycles existed. There would be a shift in equilibrium when the natural forests are clearfelled and the plantations established. The soils in rotations I. II and III were under teak for 8-17. 63-72 and 118-127 years. respectively after clearfelling the natural forest. taking into account. the rotation age of teak as 55 years. Moreover. the soils in first. second and third rotations have undergone complete exposure to environmental factors. once in the case of first rotation while the plantations in the second and third rotations were exposed to twice and thrice, respectively. They were after clear felling the natural forest in the case of rotation I and with respect to rotation II. in addition to this. another one which was after final felling the first rotation teak when it was 55 years old. With regard to rotation III. in addition to the above two. the third exposure was after final felling the second rotation teak.

This showed that these disturbances followed by establishment of plantations have affected the soils in successive rotations. This is clearly manifested in gravel. sand and silt as well as organic carbon. total N and available Ca contents. Usually it will take thousands of years for the particle-size separates to change. Here there was significant change in gravel and particle-size separates between rotations which have taken place in a period of around 8-127 years. This revealed that the plantation activities have significantly affected the gravel and particle-size separates; this could be most probably the disturbance caused by accelerated soil erosion due to exposure of soil surface. With respect to organic carbon. total N and available Ca. removal of slash from the sites. weed problem as well as poor litter accumulation. the latter two due to exposure could be some of the pertinent factors which have affected the soil fertility.

The decline in soil fertility in successive rotations was found to affect the tree growth significantly. It was also noted that the soil properties accounted for 14% variation in tree height. The effect of soil properties on dbh of trees was not very much. This could be due to the fact that as the plantations selected were in the age group of 8-17 years old. only the first and second mechanical thinnings have taken place. During the period prior to these operations. the emphasis was more on height of the trees rather than dbh and the former was found to be significantly affected. It may be worthwhile investigating these factors little more extensively to further examine the effect of various soil parameters for which evidence for explanation was lacking.

4. CONCLUSIONS

The study of soils and growth of trees in first, second and third rotation teak plantations at Nilambur showed that:

1. The soil fertility, in terms of organic carbon, total N and available Ca, declined from first rotation to second and third rotations.

2. Decline in soil fertility was reflected on tree height rather than diameter at breast height.

3. Soil properties accounted for 14% variation in tree height.

4. The differences in site index between rotations were found to be non-significant due to the high variation in site index within each slope and rotation.

5. There is an urgent need for careful management of the soil to reduce soil deterioration. Site specific soil erosion control measures and proper management of slash, weed and litter are recommended.

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Appendix I

Mean values of soil properties (unadjusted) in three layers of different plantations under first rotation

Name of plantation	Year	Layer (cm)	Gravel %	Sand %	Silt %	Clay	pH	OC %	EB me/ 100 g	Total N ppm	Available K	Available Ca	Available Mg
											(-----ppm-----)		
Old Amarambalam	1981	0-20	40	83	9	8	5.8	1.17	8	1288	53	58	126
		20-40	40	83	9	8	5.7	1.13	8	1120	40	45	204
		40-60	52	80	10	10	5.6	0.93	8	1036	34	53	114
	1984	0-20	41	71	15	14	6.1	1.35	14	1680	148	114	44
		20-40	27	68	15	17	5.6	1.02	20	1200	50	70	312
		40-60	43	66	18	16	5.7	0.72	14	1008	42	70	408
Kanakutha	1978	0-20	26	76	13	11	5.6	1.64	13	1554	82	74	66
		20-40	33	73	14	13	5.6	1.41	13	1176	79	90	47
		40-60	36	73	14	13	5.6	1.15	11	1274	123	84	28
	1979	0-20	34	68	16	16	5.6	1.07	18	1904	135	143	32
		20-40	39	67	18	15	5.6	1.36	14	1465	80	145	10
		40-60	41	68	16	16	5.6	1.28	15	1325	96	118	23
Kariem muriem	1980	0-20	42	73	13	14	6.4	1.40	19	1387	97	115	64
		20-40	40	75	12	13	6.2	1.06	18	1596	104	99	37
		40-60	44	73	12	15	6.3	1.02	16	1092	106	95	33
	1982	0-20	16	80	9	11	6.0	1.51	9	1064	37	64	96
		20-40	15	83	8	9	6.1	1.49	7	1120	53	54	16
		40-60	19	83	9	8	6.0	1.23	6	1008	305	44	48

Appendix II

Mean values of soil properties (unadjusted) in three layers of different plantations under second rotation

Name of plantation	Year	Layer (cm)	Gravel %	Sand %	Silt %	Clay %	pH	OC %	EB me/ 100 g	Total N ppm	Available K	Available Ca	Available Mg
											(-----ppm-----)		
Edakkode	1984	0-20	44	72	13	15	5.9	1.14	13	1596	79	58	22
		20-40	47	71	13	16	6.0	1.02	12	1204	66	63	19
		40-60	51	74	12	14	6.1	0.69	13	1008	95	70	18
	1981	0-20	25	80	10	10	5.8	1.26	10	1568	57	46	22
		20-40	38	72	14	14	5.8	1.01	10	1260	50	63	9
		40-60	35	74	12	14	5.8	0.89	11	1176	133	52	16
	1979	0-20	11	80	9	11	6.1	1.05	14	1176	216	78	11
		20-40	17	76	14	10	6.0	1.14	13	1401	100	86	96
		40-60	8	78	10	12	5.6	1.65	11	1176	68	82	72
Aruvakkode	1978	0-20	56	74	11	13	6.5	0.85	15	1011	55	102	180
		20-40	36	70	14	16	6.0	0.54	10	1232	48	86	216
		40-60	27	70	14	16	6.4	0.48	12	784	34	108	144
Elancherri	1987	0-20	22	83	8	9	6.1	1.03	16	1232	84	62	128
		20-40	29	78	10	12	5.8	0.81	14	980	61	38	55
		40-60	23	80	10	10	5.8	0.78	13	812	127	43	48
Erampadam	1984	0-20	37	84	8	8	5.3	1.34	2	1120	30	24	9
		20-40	38	81	9	10	5.8	1.08	3	1148	102	36	36
		40-60	51	81	9	10	5.8	0.89	5	840	28	30	120
Valluvassery	1982	0-20	28	72	13	15	6.1	0.90	17	1251	63	79	126
		20-40	40	72	14	14	6.2	0.71	17	1091	48	79	174
		40-60	39	70	15	15	6.2	0.63	13	639	46	106	153
Pullimunda	1981	0-20	13	85	8	7	6.4	0.71	19	1223	27	78	56
		20-40	5	84	7	9	6.2	1.02	17	825	192	112	38
		40-60	10	87	6	7	6.3	1.25	18	1170	193	14	22
Vettikkal	1981	0-20	8	86	8	6	5.9	1.03	7	1064	60	69	91
		20-40	7	85	8	7	5.9	0.76	5	958	24	58	62
		40-60	26	78	14	14	5.9	0.74	9	1011	23	51	24
	1982	0-20	22	88	7	5	5.7	0.87	5	904	53	36	96
		20-40	14	86	8	6	5.4	0.60	3	745	25	46	204
		40-60	8	86	8	6	5.7	0.45	5	532	29	48	84

Appendix III

Mean values of soil properties (unadjusted) in three layers of different plantations under third rotation

Name of plantation	Year	Layer (cm)	Gravel %	Sand %	Silt %	Clay %	pH	OC %	EB Me/ 100g	Total N ppm	Available K	Available Ca	Available Mg
											(----ppm----)		
Aravallikavu	1987	0-20	28	75	11	14	5.9	0.62	7	1036	87	69	180
		20-40	36	68	17	15	6.0	0.69	7	896	53	55	246
		40-60	27	70	15	15	6.0	0.50	6	526	53	51	288
Moolathumanu	1981	0-20	23	72	14	14	5.6	0.72	10	1038	31	43	12
		20-40	21	71	15	14	5.5	0.72	8	931	30	45	12
		40-60	24	69	15	16	5.5	0.93	11	798	23	54	7
	1983	0-20	22	71	12	17	6.1	0.83	11	745	65	64	216
		20-40	18	72	14	14	5.7	0.92	12	904	96	66	168
		40-60	20	75	12	13	5.9	0.77	11	692	70	58	228
Edakkode	1983	0-20	49	69	14	17	5.7	1.15	8	1531	127	71	232
		20-40	51	70	15	15	5.8	1.14	10	1287	141	60	284
		40-60	48	69	16	15	5.8	0.90	14	1419	78	73	156
Ramallur	1981	0-20	13	80	11	9	6.0	0.69	12	1036	193	71	158
		20-40	15	77	11	13	6.0	0.57	12	980	134	69	234
		40-60	21	79	12	9	6.3	0.42	9	644	123	69	168
		0-20	22	80	10	10	6.1	0.84	11	1204	113	63	210
		20-40	30	77	12	11	5.9	0.48	10	1064	154	57	228
		40-60	34	79	12	9	6.2	0.62	11	1232	69	65	252
Elancheri	1983	0-20	58	69	16	15	6.3	1.49	14	1456	36	80	10
		20-40	32	75	15	10	6.4	1.19	18	1238	42	58	20
		40-60	60	66	19	16	6.3	1.12	16	1260	92	89	54
Pullmunda	1984	0-20	23	84	9	7	6.1	1.17	13	1206	178	130	22
		20-40	20	81	10	9	6.1	1.59	15	1330	157	129	13
		40-60	24	82	10	8	6.2	1.29	14	1277	127	108	20