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MANAGEMENT OF SOILS OF TEAK PLANTATIONS FOR SUSTAINABLE PRODUCTIVITY

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MANAGEMENT OF SOILS OF TEAK PLANTATIONS FOR SUSTAINABLE PRODUCTIVITY

(Final report of the project KFRI 321/99 April 1999 – December 2001)

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PROJECT PROPOSAL

1. Code	:	KFRI 321/99
2. Title	:	Management of soils of teak plantations for sustainable productivity
3. Objectives	:	Study the physical and chemical properties of soils of teak plantations of different site quality classes in various age groups Evaluate the soil properties affecting the site quality classes
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6. Funding agency	:	Kerala Forest Department
7. Investigators		
Principal Investigator	:	M. Balagopalan
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ABSTRACT

In Kerala, teak (*Tectona grandis* Linn. f.) occupies an area of about 69,000 ha and constitute about 46.5 per cent of man made forests. There is wide variation in site quality classes in teak plantations. In order to study the physical and chemical properties of soils of teak plantations of different site quality classes in various age groups and also to evaluate the soil properties affecting site quality, this project was undertaken.

Teak plantations belonging to three age groups, 5-25 years, 25-45 years and above 45 years in the major teak growing Forest Divisions of Achencoil, Konni, Ranni, Thenmala, Nilambur (North & South) and Wynad (North & South) were selected. In each of the selected plantations, plots were marked along a randomly laid out transect running through the centre of the plantations. One plot was taken for every 10 ha with a maximum of 10 plots in any one plantation. Girth at breast height of all trees in the plots was taken. Trees having the largest height, smallest height and three trees in between the range were selected for measurement of height in each plot.

One soil pit was taken from each plot and samples collected from 0-20, 20-40 and 40-60 cm layers. Altogether 289 soil pits were taken. The samples were air dried, passed through 2 mm sieve and gravel content (particles >2 mm) was found out. Analyses were carried out for particle-size separates, bulk density (BD), particle density (PD), soil pH, organic carbon (OC), maximum water holding capacity (WHC), available N, P, K, Ca and Mg and $CaCO_3$. Discriminant analysis was done to identify the factors by which the soils under different site quality classes differred significantly under each age group.

It was found that in the age group 5-25 years, the soils were loamy and medium acidic in the different site quality classes I, II and III and there was no definite pattern for the soil properties. In the age group 25-45 years, the soils were sandy loam in site quality class I while in site quality classes II, III and IV, the soils were loamy. The soils were medium acidic in all the site quality classes. There was considerable difference in site quality classes I, II, III and IV with respect to some of the soil properties, viz.

water holding capacity, organic carbon, available N, Ca and Mg and $CaCO_3$. The available N, Ca and Mg and $CaCO_3$ were more in site quality I. Water holding capacity and organic carbon content were more in site quality class IV.

In the age group above 45 years, the soils were loamy in site quality classes I, II, III and IV and medium acidic in site quality classes I, II and III. In site quality class IV, the soils were slightly acidic. Organic carbon, available N, Ca and Mg showed considerable variation among the site quality classes. Organic carbon, available N, Ca and Mg were lowest in site quality class I while available N and Ca were highest in site quality class II. Organic carbon and available Mg were more in site quality classes IV and III, respectively.

It was observed that there was no general trend with respect to variation in soil properties in relation to different site quality classes. Particle density, bulk density, available P and Ca in the age group 5-25 years and $CaCO_3$, organic carbon, available K and silt in the age group 25-45 years discriminated the soils under different site quality classes. In the age group above 45 years, $CaCO_3$, available P, Ca and Mg and particle density discriminated the soils under different site quality classes. In other words, in the age group 5-25 years, soil physical properties and nutrients were the discriminating factors by which soils belonging to various site quality classes differed significantly. Soil texture, alkalinity, nutrient and fertility status were the discriminating factors by which the soils under the four site quality classes differed significantly in the age group 25- 45 years. In the age group above 45 years, soil alkalinity, nutrients and physical properties discriminated the soils belonging to various site quality classes.

On the basis of the study in teak plantations belonging to different site quality classes, it is recommended that steps should be taken to minimize soil compaction and also to enhance the nutrient status of the soil by retaining the litter and the thinning residues in the soil and also by controlling forest fire. In addition to the above, retaining calcium in the soil at optimum level is required for management of soils of teak plantations for sustainable productivity.

1. INTRODUCTION

Of all the tropical hardwood species, and perhaps all tree species, teak (*Tectona grandis* Linn. F.) exudes a particular fascination, somewhat like gold among precious metals. Teak planting in India started in 1840s and increased to significant levels from 1865 onwards within as well as outside its natural distributional range. During the past 20 years, most supplies of teak wood from natural forests have dwindled and increased interest has developed in the establishment of teak plantations (Pandey and Brown, 2000). Teak plantations constitute about 8 per cent of the total plantation area in countries with climates suitable for teak growing. In 1995, about 94 per cent of global teak plantations were in tropical Asia, with India accounting 44 per cent and Indonesia 31 per cent.

Teak grows well within an annual rainfall range of 1000-1500 mm and on a variety of geological formations notably lime stone, granite, gneiss, mica, schist, sand stone, quartzite, conglomerate, shale and clay. However, it can tolerate in extreme cases, a rainfall as low as 750 mm per annum with long dry season of 5-7 months and water vapour pressure below 30 per cent and also as high rainfall areas as 3750-5000 mm.

Teak thrives well on a variety of soils but it grows better in well drained soils with high oxygen content and neutral pH, and beyond 8.5 pH, the tree suffers growth. Griffith and Gupta (1948) showed the superiority of alluvial sites over other sites for teak in Nilambur.

The Kerala Forest Department now has about 75,000 ha under teak, out of which, approximately 64 per cent is in the first rotation and the remaining 36 per cent is in the second and third rotation stages (Balagopalan *et al*, 1998; Nagesh Prabhu, 2003). Teak plantations constitute about 46.5 per cent of man made forests (Tajuddin *et al*, 1996). Teak was worked on a 70 year rotation but the same is reduced to 50 years in certain parts.

Griffith and Gupta (1948) investigated laterization of teak soils and concluded that the molecular ratio of silica to sesqui oxides (oxides of Fe and Al) provides an indication of the suitability of soil for teak unless some factor such as a laterite under shallow soil, excessive boulders or high water table (3-4 feet in winter) intervenes. In Nilambur, Kadambi (1972) noted the following factors helpful for high quality of teak, viz. high SiO_2/R_2O_3 ratio in the soil, alluvial site, high content of bases, especially Ca and Mg in the soil, good moisture availability, sandy loam texture and good drainage.

Although comprehensive studies on soil properties in teak plantations are available (Alexander *et al*, 1980; Balagopalan and Alexander, 1984; Balagopalan and Jose, 1982; Jose and Koshy, 1972; Kolmert, 2001), very little information is available in India, on the physical and chemical properties of soils in relation to different site quality classes in various age groups (Akinsanmi and Akindele, 1994; Chongsuksantikan and Tantiraphan, 1991; Herrera and Alvarado, 1998; Lu- Junpei, 1994; Marquez *et al*, 1993; Singh *et al*, 1990). Alexander *et al* (1987) in a study in certain teak plantations found an increase in gravel content and exchange acidity values and decrease in sand, silt, pH and exchangeable bases in lower site quality. They also noted that soil variables accounted for 31 per cent variation in top height. As no detailed attempt has so far been made to study the physical and chemical properties of soils of teak plantations of different site quality classes in various age groups and to evaluate the soil properties affecting the site quality, this project was undertaken.

2. MATERIALS and METHODS

2.1. Study area

The study was restricted to teak plantations in the major teak growing Forest Divisions, viz. Wynad (North & South), Nilambur (North & South), Ranni, Konni, Thenmala and Achencoil.

The teak plantations belonging to three age groups were selected. The age groups classified were 5-25 years, 25-45 years and above 45 years. The reason for selecting these three age groups was that the first and second mechanical as well as the first and second silvicultural thinnings would be over during the period 5-25 years after the establishment, third and fourth silvicultural thinnings would be over during the period 25-45 years, after which there will not be further operations in the plantations. This showed that in the age group 5-25 years, major operations were over while in the age group 25-45 years, the remaining operations completed. In the age group above 45 years, there will be no operation.

2.2. Sampling pattern

In each of the selected plantations, plots were marked along a randomly laid out transect running through the centre of the plantations. 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. Girth at breast height of all trees at 1.37 m above ground level, in the plots was taken. Height (total height) was measured on a subset of trees in the plots. Trees having the largest height, 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 conditions, incidence of fire, pests and diseases problems, etc. were also recorded. The site quality was worked out as per the procedure in KFRI (1997).

The details with respect to Divisions, Ranges. number of plantations and plots and age class are given in Table 1. Details with respect to Divisions, Ranges, name of plantations and number of plots, age and site quality are shown in Appendices I, II and III. One soil pit was taken from each plot and samples collected from 0-20, 20- 40 and 40-60 cm layers. Altogether 289 soil pits were taken. The samples were air dried, passed through 2 mm sieve and gravel content (particles > 2 mm) was found out. Analyses were carried out for particle-size separates, bulk density (BD), particle density (PD), soil pH, organic carbon (OC), maximum water holding capacity (WHC), available N, P, K, Ca and Mg and $CaCO_3$ as per standard procedures in ASA (1965) and Jackson (1958).

2.3. Statistical analyses

In order to compare the site quality classes, univariate analysis was carried out for each of the soil properties. As this analysis ignores the correlation among the several soil properties, discriminant analysis was done to identify the factors by which the soils under different site quality classes differ significantly (Jeffers, 1978).

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 sum of squares is maximised for the discriminant scores. This provides a convenient way of identifying the factors by which the groups differ most. Since the number of explanatory variables is more, step-wise discriminant analysis was carried out.

Table 1. Details of plantations selected for the study

Division	Range	No. of plantations	No. of plots	Age group* No.
Achencoil	Kallar	5	36	1,2
Konni	Konni,Mannarapara	19	56	1,2,3
Ranni	Vadaserikkara	2	8	1,2
Thenmala	Ariankavu,Thenmala	14	36	1,2,3
Nilambur(South)	Karulai,Kalikkavu	18	66	1,2,3
Nilambur (North)	Edavanna,Nilambur,Vazhikkadavu	17	29	1,2,3
Wayanad(South)	Chethaleth	7	16	1,2
Wayanad(North)	Begur	8	42	1,2,3

* 1, 2, and 3 refers to teak plantations belonging to 5-25 years, 25-45 years and above 45 years, respectively

In the step-wise discriminant analysis, the variables are added to the discriminant function one by one until it is found that adding more and more variables does not give significantly better discrimination. By this method, a reduced set of variables is identified, which is almost as good as and - sometimes better than - the complete set of variables and moreover the variables have got more discriminating power.

When there are two groups, one function is obtained. In general, for k groups, k-1 groups can be derived, each independent of the other. Since sand, silt and clay contents add up to unity, the clay content was not considered while performing step-wise discriminant analysis.

After the discriminant functions were developed through the step-wise estimation method, they were subjected to 'rotation' to redistribute the variance (Hair *et al*, 1998). Basically rotation preserves the original structure and reliability of the discriminant models while making them easier to interpret substantially. In the present study, the most widely used procedure, VARIMAX rotation was employed.

Discriminant loadings, referred to sometimes as structure correlation, are considered relatively more valid as a means of interpreting the discriminanting power of independent variables because of their correlational nature.

Step-wise discriminant analysis was carried out separately for the three age groups viz., 5-25, 25-45 and above 45 years, by considering the soils in 0-60 cm layer and independent variables as sand, silt, bulk density, particle density, maximum water holding capacity, soil pH, organic carbon, available N, P, K, Ca and Mg and $CaCO_{3.}$

3. RESULTS and DISCUSSION

3.1. Soil properties in the plantations belonging to different site quality classes in the age group 5-25 years

The mean values of different soil properties corresponding to the strata1 is given in Table 2. It was found that at Achencoil, there was not much difference between site quality classes I and II with respect to most of the soil properties except available K which was more site quality class I. Soils were sandy loam and slightly acidic in all site quality classes.

At Konni, there was not much difference between site quality classes I, II and III with respect to most of the soil properties except available N, K, Ca and Mg which were lowest in site quality class I. Soils were loamy in all site quality classes and medium acidic in site quality I while in site quality classes II and III, the soils were slightly acidic.

In the teak plantations at Ranni belonging to site quality class II, the soils were loamy and medium acidic.

There was not much variation among the site quality classes I, II and III with respect to most of the soil properties in the teak plantations at Thenmala, except available N and soil pH. Available N was more in site quality class III. Soils were loamy in all site quality classes and medium acidic in site quality classes I and II while in site quality class III, the soils were slightly acidic.

Soils in the teak plantations at Nilambur (North and South) Forest Divisions belonging to site quality classes I, II and III showed not much variation among the different site quality classes with respect to soil properties. Soils were loamy and medium acidic in all site quality classes. In the teak plantations at Wynad (North) Forest Division, the soils were loamy and medium acidic in the site quality class III. In the Wynad (South) Forest Division, the soils were loamy in site quality classes II and III and medium acidic in site quality II and slightly acidic in site quality class III. Available N, K, Ca and Mg were more in site quality class II.

When the overall mean values of soil properties in the 0-60 cm layer under different site quality classes were compared (Table 3 and Figs. 1-6), it was found that the soils were loamy and medium acidic in the different site quality classes I, II and III. There was no definite pattern for the soil properties.

Table 2. Mean values of soil properties in the 0-60 cm layer in teak plantations belonging to different site quality classes in various Divisions in the age group 5-25 years

Division	Site quality class	Sand (---	Silt %	Clay ---)	BD	PD	WHC %	pH	OC %	N (---	P ---	K ppm	Ca ---	Mg --)	$CaCO_3$ %	Number of plots
Achencoil	I	76	12	12	1.11	2.26	39.45	6.2	1.03	69	8	57	52	16	0.014	10
	II	76	12	12	1.10	2.25	38.70	6.2	1.08	67	8	48	54	18	0.013	11
Konni	I	71	17	11	1.07	2.20	40.82	6.3	0.85	69	9	28	31	17	0.010	6
	II	72	15	13	1.10	2.23	40.95	5.9	0.81	73	10	45	46	24	0.011	8
	III	74	13	12	1.07	2.13	40.50	6.1	0.85	77	10	44	43	23	0.014	4
Ranni	II	72	17	11	1.04	2.18	40.07	6.0	1.31	68	12	52	39	30	0.007	3
Thenmala	I	71	15	14	1.09	2.24	42.46	5.8	1.12	49	13	51	40	22	0.016	2
	II	74	13	13	1.07	2.21	41.07	6.0	1.06	51	10	55	40	27	0.013	8
	III	72	15	13	1.10	2.13	41.66	6.2	0.96	58	11	52	45	25	0.010	5
Nilambur (N)	I	73	14	13	1.12	2.25	38.44	5.9	0.76	45	8	53	38	22	0.008	1
	II	73	13	14	1.13	2.27	39.07	5.9	0.72	47	9	55	41	24	0.008	10
	III	74	14	12	1.16	2.30	38.33	5.9	0.74	42	9	53	38	22	0.008	3
Nilambur (S)	I	74	14	12	1.14	2.29	39.28	5.9	0.77	44	9	57	43	33	0.009	5
	II	74	12	14	1.13	2.31	39.56	6.0	0.78	46	10	57	44	34	0.009	13
	III	74	12	14	1.15	2.23	39.40	5.9	0.78	47	12	61	45	33	0.010	7
Wynad (N)	III	72	16	12	1.13	2.22	42.00	6.0	1.30	47	9	53	38	24	0.008	12
Wynad (S)	II	73	14	13	1.15	2.21	40.10	6.0	1.06	57	10	77	66	48	0.010	2
	III	75	13	12	1.07	2.17	42.13	6.1	1.09	50	12	56	47	32	0.012	2

Table 3. Overall mean values of soil properties in the 0-60 cm layer in different site quality classes corresponding to the age group 5-25 years

Site quality class	Sand (---	Silt %	Clay ---)	BD	PD	WHC %	pH	OC %	N (--	P ---	K ppm	Ca ---	Mg ---)	$CaCO_3$ %	Number of plots
I	74	13	13	1.11	2.26	39.60	6.0	0.87	54	9	53	43	24	0.011	24
II	74	13	13	1.10	2.25	39.93	6.0	0.95	57	9	52	45	26	0.011	55
III	73	14	13	1.12	2.20	40.47	6.0	0.96	55	10	53	43	26	0.010	33

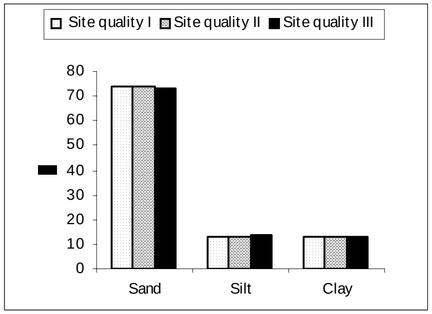

Fig. 1. Mean values of sand, silt and clay in different site quality classes

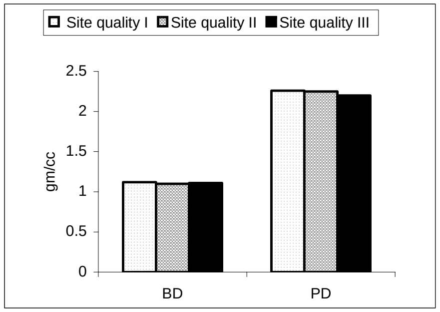

Fig. 2. Mean values of bulk density and particle density in different site quality classes

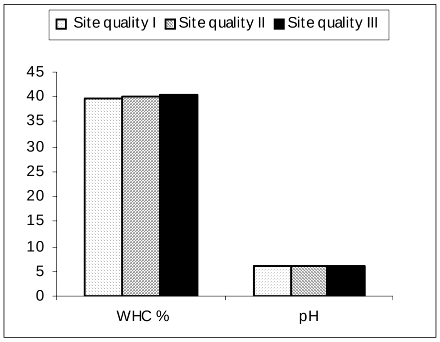

Fig. 3. Mean values of water holding capacity and pH in different site quality classes

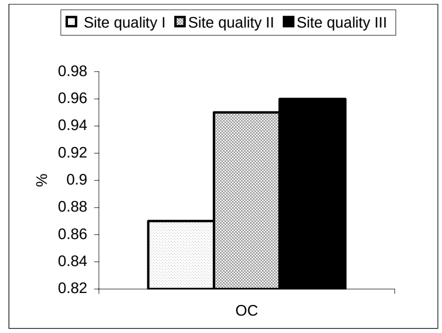

Fig. 4. Mean values of organic carbon in different site quality classes

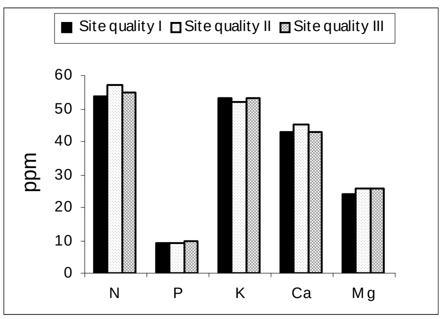

Fig. 5. Mean values of N, P, K, Ca and Mg in different site quality classes

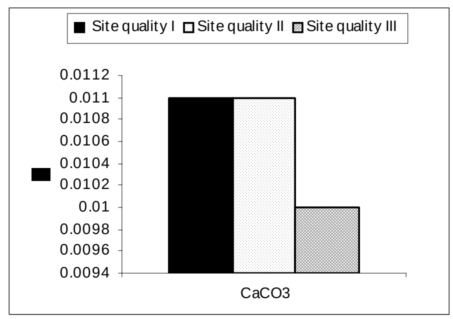

Fig. 6. Mean values of Calcium carbonate in different site quality classes

The univariate analysis of variance on each of the soil properties indicated that two of the 13 variables, viz. particle density and available P, showed significant difference between the three site quality classes (Table 4). Since there were three groups, two discriminant functions could be derived and they explained 93.3 per cent and 6.7 per cent of the total variance, respectively.

The step-wise discriminant analysis revealed that the four independent variables, viz. particle density, bulk density, available P and Ca, could discriminate between the three site quality classes (I, II and III) significantly. The coefficients of the discriminant functions are reported in Table 4.

In order to find the contribution of the variables to each function, the correlation coefficients (rotated discriminant function loadings) between the variables and the functions were examined (Table 4) and also the group centroids (mean discriminant score).

Table 4. Summary of interpretative measures in respect of soil variables obtained from three different site quality classes (I, II and III) in the age group 5-25 years

Soil variables	Rotated Discriminant function loadings		Univariate F ratio	Standardized discriminant function coefficients	
	Function 1	Function 2		Function 1	Function 2
BD	-.528	-.372	0.851	-.572	-.685
PD	.197	-.750	4.439**	.934	-.028
WHC	-.042	.186	1.659	NI	NI
CaCO3	.289	.198	.304	NI	NI
N	.227	.212	0.592	NI	NI
P	-.138	.663	3.148*	-.355	.563
K	.016	.109	0.011	NI	NI
Ca	.542	.247	1.206	.485	.599
Mg	.017	.120	0.482	NI	NI
Sand	.280	-.087	0.366	NI	NI
Silt	-.140	.067	0.759	NI	NI
OC	.087	.086	0.784	NI	NI
pH	.282	-.092	0.123	NI	NI

NI : Not included in the stepwise solution ** : Significant at P = 0.01
* : Significant at P = 0.05

The first discriminant function was found to be highly negatively correlated with bulk density and positively with available Ca (absolute correlation value >0.5), implying that change in site quality brings about changes largely in the status of the above two soil variables, viz. bulk density and available Ca. The mean discriminant score was high in site quality class II (0.259) followed by site quality classes I (-0.134) and III (-0.591). This shows that bulk density was high in site quality class III while available Ca was more in site quality class II.

The second discriminant function was positively correlated with available P and negatively with particle density. The mean discriminant score was high in site quality class III (0.472) followed by site quality classes II (-0.125) and I (-0.427) and hence available P was high in site quality class III and low in site quality I whereas particle density was high in site quality class I and low in site quality class III.

The four soil properties viz. bulk density, particle density and available P and Ca, correlated with the discriminant functions, together represent a major portion of the important soil physical properties and fertility status. Discriminant analysis identified soil variables, viz. bulk density, particle density and available P and Ca, by which the soils of teak plantations belonging to the age group 5-25 years under the three site quality classes, viz. I, II and III, differed significantly.

3.2. Soil properties in the plantations belonging to different site quality classes in the age group 25-45 years

Under this age group, the plantations belonged to four site quality classes viz. I, II, III and IV. The mean values of different soil properties is given in Table 5. There was not much difference between site quality classes I and III with respect to soil properties at Achencoil except available N which was more in site quality class I. The soils were sandy loam and medium acidic.

In teak plantations at Konni belonging to site quality classes II and III, there was not much difference between site quality classes with respect to soil properties. The soils were loamy and medium acidic.

In the teak plantations at Ranni, the soils were loamy and medium acidic in the site quality class III.

The variation in site quality classes II, III and IV at Thenmala with respect to soil properties was not much, except available N and Ca. Available N was more in site quality class II where as Ca was more in site quality class III. The soils were loamy in site quality classes II, III and IV and medium acidic in site quality classes II and IV and slightly acidic in site quality class III.

In the teak plantations at Nilambur (North and South) Forest Divisions belonging to site quality classes III and IV (North) and II and III (South), there was not much difference in site quality classes with respect to soil properties. The soils were loamy and medium acidic in all site quality classes.

In the Wynad South Forest Division, the variation in the site quality classes III and IV with respect to soil properties was not much. The soils were loamy and medium acidic. In the Wynad (North) Forest Division, the soils were also loamy and medium acidic.

When the overall mean values of soil properties in the 0-60 cm layer were compared (Table 6 and Figs.7-12), it was observed that the soils were sandy loam in the site quality class I while in the other three site quality classes, the soils were loamy. The soils were medium acidic in all the site quality classes. There was considerable difference in site quality classes I, II, III and IV with respect to soil properties viz. water holding capacity, available N, Ca and Mg and $CaCO_3$. The available N and Ca and $CaCO_3$ were more in site quality class I while Mg was more in site quality classes III and IV. Water holding capacity and organic carbon content was more in site quality class IV.

The four soil properties, viz. $CaCO_3$, available K and organic carbon and silt together, represent a major portion of the soil alkalinity, fertility and texture, respectively. The discriminant analysis identified these four soil variables, viz. $CaCO_3$, available K and organic carbon and silt by which the soils of teak plantations belonging to the age group 25-45 years, under the four site quality classes, viz. I, II, III and IV differred significantly.

Table 5. Mean values of soil properties in the 0-60 cm layer in teak plantations belonging to different site quality classes in various Divisions belonging to age group 25-45 years

Division	Site quality class	Sand %	Silt %	Clay %	BD	PD	WHC %	pH	OC %	N ppm	P ppm	K ppm	Ca ppm	Mg ppm	$CaCO_3$ %	Number of plots
Achencoil	I	76	12	12	1.09	2.19	37.22	6.0	1.00	79	9	57	54	19	0.028	10
	III	76	12	12	1.10	2.14	36.90	6.0	0.91	72	9	56	57	16	0.014	5
Konni	II	73	15	12	1.08	2.19	39.53	6.0	0.89	65	9	45	54	30	0.010	18
	III	73	15	12	1.06	2.16	39.21	6.0	0.95	69	8	46	55	28	0.012	8
Ranni	III	71	15	14	1.06	2.19	39.89	6.0	1.30	55	12	55	41	36	0.009	5
Thenmala	II	73	12	15	1.06	2.27	41.28	5.9	0.97	51	10.	51	36	23	0.012	2
	III	74	12	14	1.09	2.20	40.64	6.1	0.96	44	10	55	46	27	0.013	8
	IV	71	12	17	1.07	2.17	40.33	5.9	1.06	46	11	49	40	26	0.010	3
Nilambur (N)	III	74	14	12	1.16	2.30	38.37	5.9	0.76	47	9	56	40	23	0.008	5
	IV	73	14	13	1.09	2.22	38.03	5.7	0.79	47	8	52	39	24	0.009	2
Nilambur (S)	II	73	14	13	1.15	2.30	39.22	5.9	0.80	48	11	54	41	32	0.010	7
	III	73	14	13	1.15	4.65	38.82	5.9	0.79	51	11	59	44	33	0.012	20
Wynad (N)	III	72	14	14	1.11	2.19	40.98	6.0	1.28	51	8	57	42	31	0.009	28
Wynad (S)	III	73	15	12	1.11	2.22	40.87	5.9	1.22	57	8	62	52	34	0.011	8
	IV	73	13	14	1.13	2.18	41.28	5.9	OC	61	9	66	54	38	0.010	4

Table 6. Overall mean values of soil properties in the 0-60 cm layer in different site quality classes corresponding to the age group 25 - 45 years

Site quality class	Sand (---	Silt %	Clay ---)	BD	PD	WHC %	pH	OC %	N (---	P ---	K ppm	Ca ---	Mg ---)	$CaCO_3$ %	Number of plots
I	76	12	12	1.09	2.19	37.22	6.0	1.00	79	9	57	54	19	0.028	10
II	73	14	13	1.11	2.22	39.59	6.0	0.91	58	10	51	50	28	0.011	27
III	73	14	13	1.11	2.23	39.88	6.0	1.05	55	9	56	47	30	0.011	87
IV	73	13	14	1.12	2.20	40.33	5.9	1.16	52	9	57	43	30	0.009	9

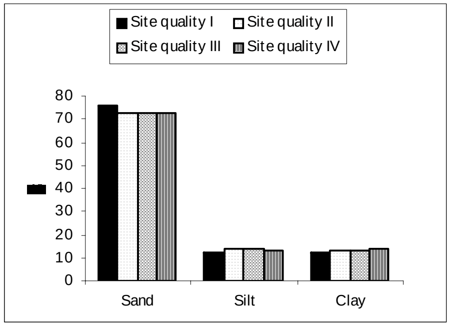

Fig. 7. Mean values of sand, silt and clay in different site quality classes

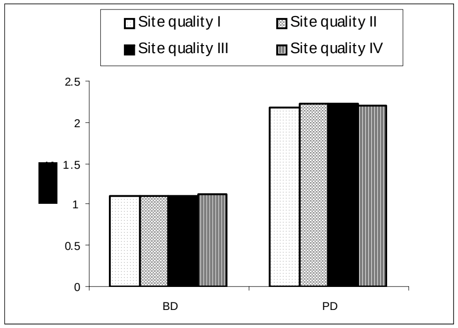

Fig. 8. Mean values of bulk density and particle density in different site quality classes

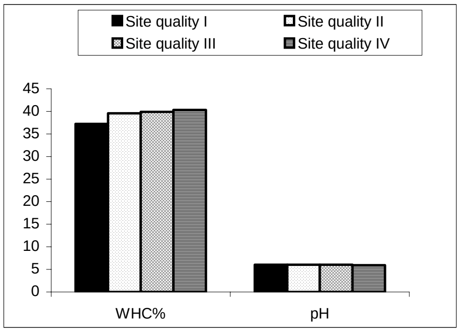

Fig. 9. Mean values of water holding capacity and pH in different site quality classes

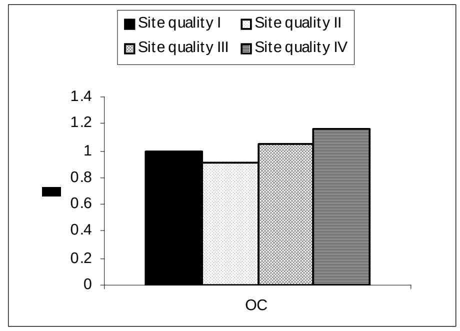

Fig. 10. Mean values of organic carbon in different site quality classes

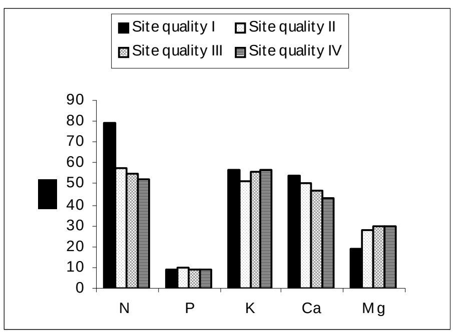

Fig. 11. Mean values of N, P, K, Ca and Mg in different site quality classes

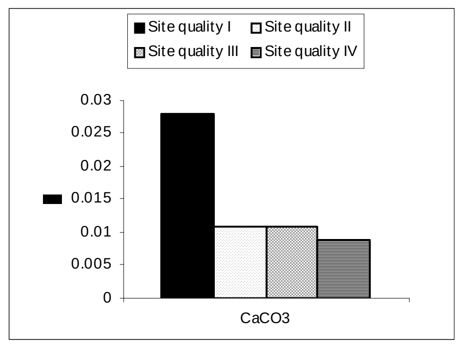

Fig. 12. Mean values of $CaCO_3$ in different site quality classes

The univariate analysis of variance on each of the soil properties indicated that seven of the 13 variables, viz. $CaCO_3$, water holding capacity, available N, K, Ca and Mg, sand and organic carbon, showed significant differences between the four site quality classes (Table 7). Since there were four groups, three discriminant functions could be derived.

Table 7. Summary of interpretative measures in respect of soil variables obtained from three different site quality classes (I, II and III) in the age group 25-45 years

Soil variables	Rotated Discriminant function loadings			Univariate F-ratio	Standardized discriminant function coefficients		
	Function 1	Function 2	Function 3		Function 1	Function 2	Function 3
BD	-.193	-.046	.457	0.657	-.356	-.076	.808
PD	-.041	-.055	-.041	0.230	NI	NI	NI
WHC	-.321	.433	-.096	3.472*	-.470	.137	-.127
$CaCO_3$	.845	-.116	.034	10.851**	.820	-.306	-.116
N	.304	-.349	-.022	5.689**	NI	NI	NI
P	.105	-.027	-.006	0.718	NI	NI	NI
K	.112	.538	-.076	3.402*	.353	.436	-.683
Ca	.199	-.453	-.138	3.124*	-.241	-.500	.291
Mg	-.156	.269	-.309	2.813*	NI	NI	NI
Sand	.268	-.286	.224	3.812*	NI	NI	NI
Silt	-.168	.058	**-.573**	1.674	-.265	-.032	-.650
OC	-.069	.677	.360	6.986**	.475	.522	.531
pH	.018	-.072	.062	0.297	NI	NI	NI

NI : Not included in the stepwise solution; ** : Significant at P = 0.01;
* : Significant at P = 0.05

The step-wise discriminant analysis revealed that the seven independent variables, viz. bulk density, water holding capacity, $CaCO_3$, available K and Ca, silt and organic carbon, could discriminate between the four site quality classes (I, II, III and IV) significantly. The coefficients of the discriminant functions are reported in Table 7. In order to find the contribution of the variables to each function, the correlation coefficients (rotated discriminant function loadings) between the variables and the functions were examined (Table 7) and also the group centroids (mean discriminant score).

The first discriminant function was found to be highly positively correlated with $CaCO_3$ (Table 7) alone (absolute correlation value >0.5), implying that change in site quality brings about changes largely in the status of the soil variable $CaCO_3$.

The mean discriminant score was highest in site quality class I (3.708) followed by site quality classes III (0.029), II (0.211) and IV (-0.399). This showed that $CaCO_3$ was higher in site quality class I and lowest in site quality class IV.

The second discriminant function was positively correlated with available K and organic carbon (Table 7), indicating that change in site quality brings about changes largely in the status of available K and organic carbon. The mean discriminant score was highest in site quality class IV (0.695) followed by site quality classes III (0.292), I (-0.133) and II (-0.743). This indicated that available K and organic carbon were highest in site quality class IV and lowest in site quality class II.

The third discriminant function was negatively correlated with silt (Table 7), revealing that change in site quality brings about changes largely in the status of silt. The mean discriminant score was highest in site quality class I (0.837) followed by site quality classes IV (0.670), II (-0.147) and III (-0.059). The status of silt was highest in site quality class III followed by site quality classes II, IV and I.

The four soil properties, viz. $CaCO_3$, available K and organic carbon and silt together, represent a major portion of the soil alkalinity, fertility and texture, respectively. The discriminant analysis identified these four soil variables, viz., $CaCO_3$, available K, organic carbon and silt by which the soils of teak plantations belonging to the age group 25-45 years, under the four site quality classes, viz. I, II, III and IV differed significantly.

3. 3. Soil properties in the plantations belonging to belonging to different site quality classes in the age group above 45 years

The plantations belonged to four site quality classes, viz. I, II, III and IV in this age group. The mean values of different soil properties corresponding to age group above 45 years is given in Table 8.

There was not much difference between site quality classes II and III of teak plantations at Konni Forest Division with respect to soil properties. The soils were loamy in all the site quality classes II and III and medium acidic in site quality II and slightly acidic in site quality class III.

In the teak plantations at Thenmala belonging to site quality classes II, III and IV, there was considerable difference in site quality with respect to available N, K, Ca and Mg. Available N was more in site quality class III while available K, and Ca and Mg were more in site quality classes IV and II, respectively. The soils were loamy in all the site quality classes and medium acidic in site quality classes II and III and slightly acidic in site quality class IV.

In the Nilambur (North and South) Forest Divisions, the teak plantations belonging to site quality classes I, II and III and II and III, respectively, site quality variation with respect to soil properties was not much except available Ca which was more in site quality class III in Nilambur North Forest Division. The soils were loamy and medium acidic in all the site quality classes.

The teak plantations in Wynad (North) Forest Division belonged to site quality class III. The soils were loamy and medium acidic.

On a comparison of mean soil properties in the 0-60 cm layer in different site quality classes, it was seen that the soils were loamy in all the site quality classes while the soils were medium acid in site quality classes I, II and III. In the site quality class IV, the soils were slightly acidic. Organic carbon, available N, Ca and Mg showed considerable variation between the site quality classes. Organic carbon, available N, Ca and Mg were lowest in site quality class I while available N and Ca were highest in site quality class II whereas available Mg and organic carbon were more in site quality classes III and IV, respectively (Table 9).

Table 8. Mean values of soil properties in the 0-60 cm layer in teak plantations belonging to different site quality classes in various Divisions in the age group above 45 years

Division	Site quality class	Sand (---	Silt %	Clay ---)	B.D	P.D	W.H.C %	pH	OC %	N (---	P ---	K ppm	Ca ---	Mg ---)	$CaCO_3$ %	Number of plots
Konni	II	74	13	13	1.09	2.28	39.37	6.0	0.94	69	9	51	54	26	0.014	6
	III	75	14	11	1.06	2.20	41.55	6.1	0.94	67	11	50	50	29	0.015	6
Thenmala	II	75	14	11	1.08	2.21	41.64	5.9	1.06	51	11	56	43	27	0.011	2
	III	73	13	14	1.08	2.15	42.18	6.0	1.03	57	10	45	33	21	0.010	2
	IV	72	14	14	1.07	2.12	41.45	6.1	1.03	50	12	59	41	24	0.009	4
Nilambur(N)	I	74	14	12	1.11	2.28	39.27	5.9	0.75	42	9	52	35	21	0.009	3
	II	74	13	13	1.11	2.22	38.90	6.0	0.84	45	8	55	40	22	0.008	4
	III	74	13	13	1.13	2.27	40.04	6.0	0.73	43	8	56	42	24	0.008	1
Nilambur(S)	II	74	14	12	1.12	2.31	39.63	6.0	0.96	50	10	59	45	33	0.008	3
	III	74	13	13	1.15	2.30	38.97	5.9	0.79	49	11	56	43	32	0.010	11
Wynad(N)	III	72	14	14	1.15	2.20	41.36	5.9	1.24	44	8	55	39	27	0.008	2

Table 9. Overall mean values of soil properties in the 0-60 cm layer in different site quality classes in the age group above 45 years

Site quality class	Sand (---	Silt %	Clay ---)	BD	PD	WHC %	pH	OC %	N (…	P ….	K ppm	Ca ….	Mg …)	$CaCO_3$ %	Number of plots
I	74	14	12	1.11	2.28	39.27	5.9	0.75	42	9	52	35	21	0.009	3
II	74	13	13	1.09	2.26	39.85	6.0	0.95	57	10	55	47	27	0.011	15
III	74	13	13	1.12	2.25	40.29	6.0	0.89	53	10	53	43	28	0.011	22
IV	72	14	14	1.07	2.12	41.46	6.1	1.03	50	12	59	41	24	0.009	4

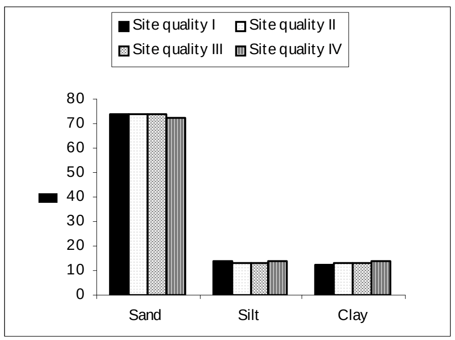

Fig. 13. Mean values of sand, silt and clay in different site quality classes

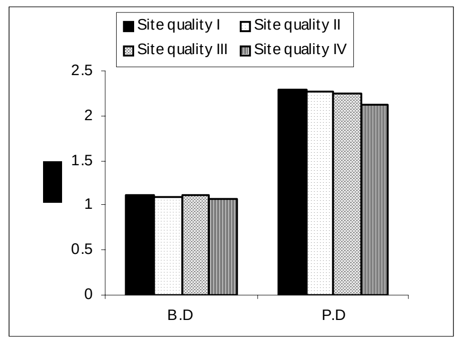

Fig. 14. Mean values of bulk density and particle density in different site quality classes

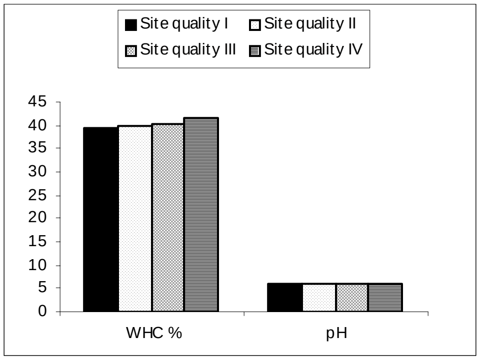

Fig.15. Mean values of water holding capacity and pH in different site quality classes

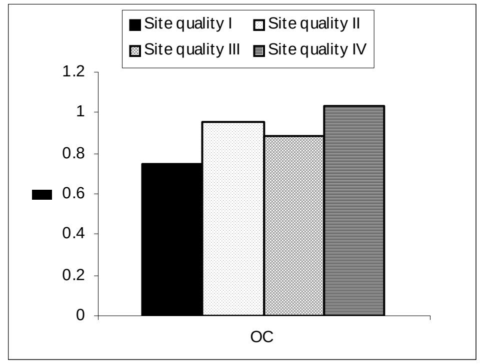

Fig. 16. Mean values of organic carbon in different site quality classes

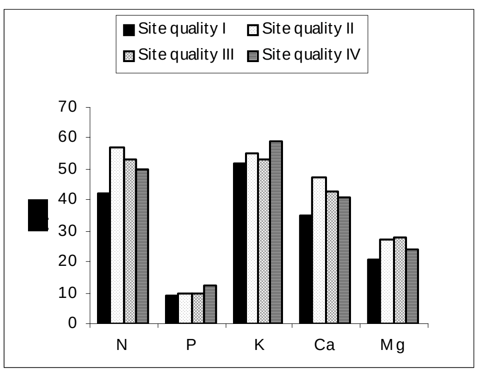

Fig. 17. Mean values of N, P, K, Ca and Mg in different site quality classes

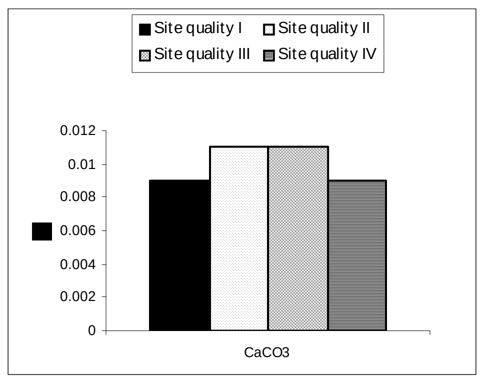

Fig. 18. Mean values of $CaCO_3$ in different site quality classes

The univariate analysis of variance on each of the soil properties indicated that there was no significant difference between the four site classes with respect to any one of the soil properties (Table 10). Since there were four groups, three discriminant functions could be derived and they explained 56.7 per cent, 30.3 per cent and 13.0 per cent of the total variance, respectively.

The step-wise discriminant analysis could identify the soil variables, viz. available Ca and Mg and particle density that could discrimianate between the four site quality classes (I, II, III and IV) significantly. The coefficients of the discriminant functions are reported in Table 10.

The first discriminant function was found to be highly positively correlated with $CaCO_3$, available Ca (Table 10) (absolute correlation value >0.5), implying that change in site quality brings about changes largely in the status of these soil variables. The mean discriminant score was highest in site quality II (0.489) followed by III (-0.283), IV (-0.428) and I (-0.931). The $CaCO_3$ and available Ca were highest in site quality class II followed by III, IV and I.

Table 10. Summary of interpretative measures in respect of soil variables obtained from different site quality classes (I, II , III and IV) in the stratum III

Soil variables	Rotated Discriminant function loadings			Univariate F ratio	Standardized discriminant function coefficients		
	Function 1	Function 2	Function 3		Function 1	Function 2	Function 3
BD	-.236	.308	.260	1.014	NI	NI	NI
PD	-.021	.947	.322	1.286	0.796	-0.485	0.662
WHC	-.001	-.409	-.137	0.481	NI	NI	NI
$CaCO_3$	.645	-.090	-.142	0.688	NI	NI	NI
N	.488	-.308	-.206	1.033	NI	NI	NI
P	.064	-.176	.587	1.096	NI	NI	NI
K	-.044	.275	.469	0.477	NI	NI	NI
Ca	.940	-.020	.341	2.265	0.964	0.690	-0.209
Mg	.212	.146	.966	1.449	-1.017	0.451	0.572
Sand	.244	-.241	.095	0.822	NI	NI	NI
Silt	-.035	-.033	.022	0.316	NI	NI	NI
OC	-.073	-.398	-.016	1.367	NI	NI	NI
pH	.249	-.007	-.139	0.838	NI	NI	NI

NI : Not included in the stepwise solution ; ** : Significant at P = 0.01; : Significant at P = 0.05

The second discriminant function was positively correlated with particle density (Table 10) indicating that change in site quality brings about changes largely in the status of particle density. The mean discriminant score was highest in site quality class I (0.822) followed by site quality classes II (0.211), III (-0.160) and IV (-1.768). This revealed that particle density was highest in site quality class I followed by site quality classes II, III and IV.

The third discriminant function was highly positively correlated with available P and Mg (Table 10), implying that change in site quality brings about changes largely in the status of available P and Mg. The mean discriminant score is high in site quality class IV (0.288) followed by site quality classes II (-0.218), III (-0.366) and I (-1.161) and since available P and Mg are positively correlated with the discriminant function, the status of available P and Mg would be high in site quality class IV followed by II, III and I.

The soil properties, viz. $CaCO_{3,}$ available Ca, Mg, P and particle density together represent the soil attributes alkalinity ($CaCO_3$), nutrient status (available Ca, Mg and P) physical properties (particle density). The discriminant analysis identified soil variables viz. $CaCO_{3,}$ available Ca, Mg, P and particle density by which the soils under the four site quality classes, viz. I, II, III and IV, differed significantly.

3.4. Soil variables and factors by which the soils under different site quality classes differed

It was found that in the 0-60 cm layer, the soil properties viz. particle density, bulk density, available P and Ca, in the 5-25 year age group and $CaCO_3$, organic carbon, available K and silt in the 25-45 year age group, discriminated the soils under different site quality classes. In the age group above 45 years, $CaCO_3$, available P, Ca and Mg and particle density discriminated the soils under different site quality classes (Table 11).

The pattern of changes associated with different site quality classes under one age group is different from other two age groups (Tables 3, 6 and 9). This showed that there was no general trend with respect to the variation in soil properties in relation to different site quality classes. In the age group 5-25 years, soil physical properties and nutrients were the discriminating factors by which the soils belonging to site quality classes I, II and III differed significantly. Soil texture, alkalinity, nutrient and fertility were the discriminating factors that discriminated the soils under the four site quality classes (I, II, III and IV) in the age group 25-45 years. In the age group above 45 years, soil alkalinity, nutrients and physical properties discriminated the soils belonging to site quality classes I, II, III and IV.

Table 11. Soil variables and factors by which the soils under different site quality classes differed significantly in three age classes (considering soils in the 0-60 cm layer)

	Age groups (years)		
	5-25	25-45	>45
Soil variables	Particle density Bulk density Available P, Ca	$CaCO_3$, Organic carbon Available K Silt	$CaCO_3$ Available P, Ca, Mg Particle density
Site quality classes	I, II and III	I, II, III and IV	I, II, III and IV
Soil factors	Soil physical properties and nutrients	Soil texture, alkalinity, nutrients and fertility	Soil alkalinity, nutrients and physical properties

It was also noticed that available Ca was the common discriminating soil variable in the age groups 5-25 years and above 45 years. Similarly in the age groups 25-45 years and above 45 years, $CaCO_3$ was the common discriminating soil variable. In other words, Ca was the soil property which discriminated the site quality.

It has been reported by Dreschel and Zech (1994) that Ca is one of the soil nutrients which controlled teak yield in West Africa. Similar results were also obtained by Marcelino *et al* (2001) and Tanaka *et al* (1998) for teak in South and South East Asia and Murugesh *et al* (1999) in India. Observations on similar lines were also made by Chongsuksantikan and Tantiraphan (1991), Marquez *et al* (1993), and Singh *et al* (1990). Hence, the site quality in all age groups was affected by calcium content in the soil, as revealed in the present study also.

It is a common phenomenon in teak plantations that the litter is either removed from the site by local people for green manure or burnt annually in man made fire. This might have caused the soils to be more and more compact by exposing the surface layer to environmental factors. In addition to this, there is poor incorporation of nutrients into the soil due to the very low litter decomposition. Another reason for the compaction and poor nutrient status is the complete removal of thinning residues from the site. On the basis of the study in teak plantations belonging to different site quality classes, it is recommended that steps should be taken to minimize soil compaction and also to enhance the nutrient status of the soil by retaining the litter and thinning residues in the soil and also by controlling forest fire. In addition to the above, retaining calcium content in the soil at optimum level by application of lime is required for management of soils of teak plantations for sustainable productivity.

4. CONCLUSIONS

The study on soil physical and chemical properties in major teak growing areas in different site quality classes in major teak growing areas in Kerala showed that

1. there was no general pattern with respect to variation in soil properties in relation to different site quality classes in various age groups.

2. the pattern of changes associated with various site quality classes differed among the three age groups .
3. in the age group 5-25 years, soil physical properties and nutrients were the discriminating factors between different site quality classes.
4. soil texture, alkalinity, nutrient and fertility status were the discriminating factors between different site quality classes in the age group 25-45 years.
5. in the age group above 45 years, soil alkalinity, nutrient status and physical properties discriminated between different site quality classes.
6. calcium content in the soils being the discriminating factor between site quality classes, it is recommended that calcium in the soil should be retained at optimum level for management of soils of teak plantations for sustainable productivity.

5. RECOMMENDATIONS

On the basis of the study in different site quality classes in teak plantations, it is recommended that steps should be taken to minimize soil compaction and also to enhance the general nutrient status of the soil. This can be done by retaining the litter and thinning residues in the soil and also by controlling forest fire. In addition to the above, retaining calcium content in the soil at optimum level by application of lime is required for management of soils of teak plantations for sustainable productivity.

6. REFERENCES

Alexander, T.G., Balagopalan, M., Thomas P. Thomas and Mary, M. V. 1980. Properties of soils under teak. KFRI Research Report 7. Kerala Forest Research Institute, Peechi.13 p.

Alexander, T.G., Sankar, S., Balagopalan, M. and Thomas P. Thomas. 1987. Soils in teak plantations of different site quality. KFRI Research Report 45. KFRI, Peechi.17 p.

ASA. 1965. Methods of Soil Analysis. Parts 1 & 2. C.A. Black et al. American Society of Agronomy, Madison, Wisconsin, USA. 1572 p.

Akinsanmi, F. A. and Akindele, S. O. 1994. Teak productivity in relation to soil conditions: A re-assessment of teak plantations in the dry high forest area of southwestern Nigeria. *Nigerian J. For.,* 24/25: 7-10.

Balagopalan, M. and Alexander, T.G. 1984. Soil organic carbon distribution along a transect through teak, eucalypt and albizia plantations in Kerala. *J. Trop. For.,* 12: 33-37.

Balagopalan, M. and Jose, A.I. 1982. Dynamics of organic carbon and different forms of nitrogen under first and second rotation teak plantations of Kerala. *Agric. Res. J. Kerala,* 20: 92-97.

Balagopalan, M.; Rugmini, P. and Chand Basha, S. 1998. Soil nutrient management for teak plantations of Kerala. KFRI Res. Report No. 138. Kerala Forest Research Institute, Peechi. 40 p.

Chongsuksantikun, P. and Tantiraphan, W. 1991. Study on relationship between some soil properties and growth of *Tectona grandis*. *Vanasarn* 49: 38-41.

Drechsel, P. and Zech, W. 1994. DRIS evaluvation of teak (*Tectone grandis* L. F.) mineral nutrition and effects of nutrition and site quality on teak growth in West Africa. *Forest Ecol. Manage.,* 70: 121-133.

Gangopadhyay, S. K., Nath, S. and Banerjee, S. K. 1987. Nature and properties of some introduced teak (*Tectona grandis*) growing soils of North –West Bengal. *Ind.For.,* 113: 65-72.

Griffith, A. L. and Gupta, R. S. 1948. Soils in relation to teak with special reference to laterisation. Ind. Forest Bullettin, 141. 58 p.

Hair, J. F.,Jr., Anderson. R. E., Tatham, R. L. and Black, W. C. 1998. Multivariate Data Analysis. Pearson Education, Inc. India. 730p

Herrera, B. and Alvarado, A. 1998. Site quality and environmental factors in Central American forests. *Agronomia Costarricense* 22 : 99-117.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice Hall Inc. USA 428 p.

Jeffers, J. N. R. 1978. An Introduction to Systems Analysis: with Ecological Applications. Edward Arnold, London. 198 p.

Jose, A. I. and Koshy, M. M. 1972. A study of the morphological, physical and chemical charcteristcs of soil as influenced by teak vegetation. *Ind. For.,* 98: 338-348.

Kadambi, K. 1972. *Silviculture and Management of Teak.* Chapter 4. 18-20.

KFRI, 1997. Productivity of teak and ecualypt plantations in Kerala. KFRI Consultancy Report. 68 p.

Kolmert, A. 2001. Teak in Northern Laos. Minor Field Studies, International Office, Swedish University of Agricultural Sciences 175. Swedish University of Agricultural Sciences, International Office, Uppsala, Sweden. 40p.

Lu-Junpei. 1994. Site classification and evaluvation of teak forests in Hainan, China. *Forest Research,* 7: 677-684.

Marcelino Montero, M., Ugalde Arias, L. A. and Kanninen, M. 2001. The relationship between site index and site factors known to influence the growth of *Tectona grandis* L. F. and *Bombacopsis quinata* (Jacq.) Dugand, in Costa Rica. (Spanish*). Revista Forestal Centroamericana* 35:13-18.

Marquez, O., Hernandez, R., Torres, A. and Franco, W. 1993. Changes in the physicochemical properties of soils in a chromosequence space of *Tectona grandis. Turrialba* 43: 37-41.

Murugesh, M., Sreenivasan, V. M. Rai, R. S. V. and Parthiban, K. T. 1999. Teak (*Tectona grandis* L. f.) on farm land and its effect on soil fertility. *Adv. Hort. For.,* 6: 153-161.

Nagesh Prabhu. 2003. Teak in Kerala- past, present and future. Paper presented in the International Conference on Quality Timber Products of Teak from Sustainable Management, 2-5 December, 2003. Kerala Forest Research Institute, Peechi.

Norusis, M.J. 1988. SPSS/PC+ Advanced Statistics Version 2.0 for the IBM PC/XT/AT and PS/2. SPSS Inc. Chicago.

Pandey, D. and Brown, C. 2000. Teak: A global overview of global teak resources and issues affecting their future outlook. *Unasylva,* 51, 4-7.

Singh, P., Das, P. K., Nath, S. and Banerjee, S. K. 1990. Characteristics of teak (*Tectona grandis*) growing soils in the tarai in region of West Bengal. *Van Vigyan* 28: 6-15.

Tajuddin, E. Anoop, E..V. and Santhosh Jacob. 1996. *Teak.* Kerala Agricultural University, Vellanikkara. 5p.

Tanaka, N., Hamazaki, T. and Bacharangkura, T. 1998. Distribution, growth and site requirements of teak. JARQ, *Japan Agricultural Research Quarterly* 32 : 65/77.

Appendix 1

Details of plantations selected in the age group 5-25 years

Division	Range	Name of plantation	No.of plots	Age (as on Jan 1997)	Year of plantation	Site quality class
Achencoil	Kallar	Panathoopu	10	15	1981	1
		Chittar North	2	17	1979	2
		Chittar North	9	24	1972	2
Konni	Konni	Kummanoor	2	16	1984	2
		Kummanoor	4	17	1983	3
	Mannarappara	Chembala	2	16	1980	2
		Chembanaruvi	4	17	1979	2
		Chembala	6	21	1975	1
Ranni	Vadaserikkara	Adukuzhy	3	13	1983	2
Thenmala	Arankavu	Palaruvi	2	6	1990	1
		Edapalayam	2	13	1983	3
		Thalappara	2	14	1982	2
		Ariankavu	3	16	1980	2
		Thalapara	3	21	1975	3
	Thenmala	Choodal	3	19	1977	2
Nilambur(South)	Karulai	Pulimunda	2	10	1986	2
		Nedumkayam	2	11	1985	1
		Nedumkayam	4	19	1977	3
		Ezhuthukkal	5	15	1981	2
		Ezhuthukkal	6	23	1973	2
		Ingar	3	17	1979	1
		Ingar	2	21	1975	3
		Ingar	1	24	1972	3
Nilambur(North)	Nilambur	Aravallikkavu	2	9	1987	2
	Edavanna	Kanakkuthu Elanjeri	2 1	20 9	1976 1987	2 1
		Moolathumanna	2	13	1983	2
		Ramallur	1	15	1981	2
		Ex Manjerikov	1	19	1977	3
		Ex Manjerikov	2	20	1976	3
	Vazhikkadavu	Kariyanmuriyu	3	23	1973	2
Wayanad(South)	Chethaleth	Palakolly	2	16	1980	2
		Madaparamaba	2	18	1978	3
Wayanad(North)	Begur	Alathur	9	6	1990	3
		Begur	3	19	1977	3

Appendix I1

Details of plantations selected in the age group 25-45 years

Division	Range	Name of plantation	No.of plots	Age (as on Jan 1997)	Year of plantation	Site quality class
Achencoil	Kallar	Chittar North	5	26	1970	3
		Chittar North	10	28	1968	1
Konni	Mannarappara	Chembala	4	25	1971	2
		Karikunnam	5	32	1964	2
	Konni	Avolikuzhy	4	26	1970	2
		Mundomuzhy	2	30	1966	3
		Njaloor	3	32	1964	2
		Njaloor	2	36	1964	3
		Udumpanoor	4	39	1957	3
		Kanjirapara	2	43	1953	2
Ranni	Vadaserikkara	Adukuzhy	5	43	1953	3
Thenmala	Ariankavu	Palaruvi	2	28	1968	2
		Rajacoup	4	36	1960	3
	Thenmala	Rock Wood	3	29	1967	4
		Shalikkara	2	32	1964	3
		Shaliakara	2	34	1962	3
Nilambur(South)	KarulaiI	Vattikkal	4	30	1966	2
		Kanhirakkadav	3	30	1966	2
		Ezhuthukal	4	32	1964	3
		Mundakkadavu	4	33	1963	3
		Pulimunda	6	40	1956	3
		Poolakkapara	6	42	1954	3
Nilambur(North)	Edavanna	Edakkode	2	28	1968	3
		Edakkode	1	35	1961	3
		Edakkode	2	37	1959	4
	Nilambur	Panayangode	2	44	1952	3
Wayanad(South)	Chedalath	Vilangady	2	25	1971	3
		Pakkom	2	27	1969	4
		Chiyambam	3	32	1964	3
		Pambra Teak p	2	33	1963	4
		Chiyambram	3	41	1955	3
Wayanad(North)	Begur	Thirunelly	5	25	1971	3
		Thirunelly	8	28	1968	3
		Shanamangalam	4	32	1964	3
		Oliot	7	33	1963	3
		Ontayangadi	4	38	1958	3

Appendix II1

Details of plantations selected in the age group above 45 years

Division	Range	Name of plantation	No.of plots	Age (as on Jan 1997)	Year of plantation	Site quality class
Konni	Konni	Vattapara	2	50	1950	3
		Kummanoor	2	51	1949	2
		Kanjirapara	2	53	1953	2
		Inchapara	2	55	1945	3
		Adichanpara	2	58	1938	3
	Mannarappara	Thora	2	51	1945	2
Thenmala	Ariankavu	Edapalayam	4	55	1941	4
		Edapalayam	2	61	1935	3
		Edapalayam	2	78	1918	2
Nilambur(South)	Kalikkavu	Old Amarambalam	5	46	1950	3
	Karulai	Kalkulam	6	51	1945	3
		Kanhirakkadavu	2	57	1939	2
		Nedumkayam	1	77	1919	2
Nilambur (North)	Nilambur	Chathanparai	1	50	1946	3
		Aravallikkavu	2	62	1934	2
		Mundapadam	1	129	1867	1
	Vazhikad	Nellikkuthu	2	52	1944	1
		Nellikkuthu	2	59	1937	2
Wayanad(North)	Begur	Shanamangalam	2	53	1943	3

No. ID/KFRI 321/99/06

The Research Coordinator
KFRI, Peechi 30 May 2006

Sir,

Sub: KFRI Research Project 321/99- Submission after incorporation of comments –reg.
Ref: Your letter No. RME 321/06 dt. 15-03-2006

I am submitting herewith one soft copy of the report of the project KFRI 321/99 after incorporation of your comments. I request you to kindly assign Research Report Number.

Thanking you

Yours faithfully,

Dr. M. Balagopalan
Programme Coordinator
Instrumentation Division

Encl: as above