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LITTER DYNAMICS, MYCROBIAL ASSOCOATIONS AND SOIL STUDIES IN ACACIA AURICULIFORMIS PLANTATIONS IN KERALA

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ABSTRACT

Litterfall in 3- to &year-old acacia plantations was quantified using litter traps. Annual litter production in the plantations ranged between 9.3 and 12.0 t ha^{-1}. Monthly litterfall indicated a unimodal pattern with its peak during December-January. The dry months (October to March) accounted for 67.5 to 76.2% of the total litterfall. The leaf litter constituted 62 to 69% of the total fall; twigs, pods, inflorescence stalks, seeds, flowers and bark made up the rest of the collection. Litter production differed significantly between locations and months. Annual litter yield in acacia plantations was higher than those reported for other major forest plantation species in India and elsewhere.

Decay rate of acacia leaf litter was determined using the mesh bag technique. The dry weight loss of litter (laid on the surface of soil- LSS) at the end of 12 months was 64.4% at Chettikulam (C), 65.6% at Kothermanakkadu (K) and 86% at Kannamkuzhi (Ka) . The corresponding values for litter partially buried in the soil (LPB) were 94.5% at site C and 92.6% (after a period of six months) at site Ka. The rate of decomposition of LPB and LSS differed significantly between and within all sites. The decay rate was faster in the fertile site (Ka) compared to degraded areas (C and K). In general, the rate of decomposition of acacia leaf litter was lower than the decay rate of leaf litters of major plantation species reported from Kerala. The faster decomposition of LPB indicated that periodic raking of soils in acacia plantations would accelerate litter degradation.

Laboratory studies to quantify the addition of organic carbon (OC) to soil during litter decay indicated that significant amount of OC was added to soil during the decomposition of acacia leaf litter, compared to controls.

A survey was conducted in 26 plantations of acacia to assess the status of mycorrhizal associations. It revealed that acacia forms VA mycorrhizal association in Kerala soils. The extent of colonization by VAM fungi was very high (varied between 90 and 100%) in majority of the plantations, This indicated that acacia is mycorrhiza-dependent for its growth and establishment. The VAM colonization was correlated with silt content, clay content, porosity and bulk density of soil; it was not correlated with the soil nutrient status. *Glomus* spp. were found to be the dominant VAM fungi in acacia plantations. Among the *Glomus* spp. isolated, *G. radiatum* was the most frequent. *Gigaspora* was represented by a single species only.

Five VAM fungi were screened under glasshouse conditions for their efficacy in promoting the growth of acacia seedlings. Seedlings inoculated with *Glomus fasciculatum* had maximum increase in height, shoot and root dry mass, total P content and mycorrhizal colonization. Based on the present study, use of *G. fasciculatum* as an inoculant VAM fungus for acacia is found to be promising.

For assessing the status of root nodulation of acacia in Kerala, soil samples were collected from 26 plantations using soil core sampler. The average number of nodules per 100cm^3 of soil, based on sixty samples, was calculated for each plantation. The study indicated that nodule number varied depending upon the soil. Generally, degraded, less fertile soils showed more number of nodules. There was a significant inverse relationship between soil organic carbon and nodule number. Nursery experiments, inoculating acacia seeds with *Rhizobium* cultures isolated from the 26 plantations revealed significant difference between the isolates in their efficiency for nodule formation. There was significant positive correlation between number of nodules and seedling biomass.

The soil characters of acacia plantations were compared with those of adjacent fallow land to ascertain the effect of acacia growth on the soil properties. Representative pits were dug to a depth of 60 cm and soil samples collected (from 0-20, 20-40 and 40-60 cm layers) from 23 plantations and their respective adjacent fallows. Soil analysis revealed that there was no significant difference between acacia plantations and adjacent fallow land in physical and chemical properties of soil as well as soil nutrient contents except in the case of pH which was significantly lower in acacia plantations (pH 4.7). N, P, K, Ca and Mg contents of acacia leaf litter from the permanent plots were, on an average, 1.38, 0.085, 0.040, 0.035 and 0.0075 %, respectively.

GENERAL INTRODUCTION

Acacia auriculiformis A.Cunn. ex Benth. (acacia), a leguminous tree native to Australia, Indonesia and Papua New Guinea, has been introduced and grown in several parts of Asia for fuelwood, erosion control and ornamental purposes. It is known to be adaptable to a wide range of soils and environmental conditions (Pinyopusarerk, 1990). In India, the species has been used extensively in afforestation programmes. Acacia, under the Social Forestry Scheme, occupies an area of about 4,000 ha in Kerala in pure plantations. According to Jayaraman and Rajan (1991), the performance of acacia (in terms of yield) in the state has been exceptionally good when compared to many other parts of India or the continent.

The introduction of acacia in Kerala has been criticized by environmentalists alleging that it has deleterious impact on soil properties, biotic associations and water table. It is also argued that acacia litter does not decompose easily.

However, in the absence of appropriate research data on these aspects, none of the criticisms has any scientifc validity. It was against this background that the present study was envisaged. The broad objectives of the study were (i) to understand the litter dynamics in acacia plantations in Kerala, (ii) to assess the status of mycorrhizal and rhizobial associations, (iii) to determine the nutrient content of leaf litter, and (iv) to characterize the soils under acacia plantations.

It is hoped that the data generated would be helpful in making a proper assessment on the impact of planting acacia in Kerala.

1. LIITER DYNAMICS IN ACACIA PLANTATIONS

1.1. Introduction

Litterfall and its subsequent decomposition account for a substantial amount of the nutrient cycling that occurs during forest stand development (Fogel and Cromack, 1977). Slow rates of decomposition can result in the accumulation of large nutrient stocks in the surface horizons of soil limiting nutrients for primary producers (Adams *et al.*, 1970).

Litter production and its accumulation are known to be dependent on density, basal area and age structure of the stand (Stohlgren, 1988), altitude (Reiners and Lang, 1987) and latitude of the area (Bray and Gorham, 1964) and also the season (Luizao and Schubart, 1987). Studies on litter decay have indicated that the substrate quality

(principally nitrogen and lignin content), the soil organisms and the climatic variables (mainly rainfall and temperature) are the most important factors which control the rates of decomposition (Singh and Gupta, 1977; Fogel and Cromack, 1977; Meentemeyer, 1978). Investigations on litter dynamics in tropical forest ecosystems are limited in comparison to those of the temperate zones of the world (Anderson and Swift, 1983).

Since *Acacia auriculiformis* (subsequently referred to as acacia), an exotic species, is currently used in a large-scale €or afforestation programmes in the State, it is essential to understand the litter dynamics in plantations under this species. This information will be helpful in assessing the primary production and nutrient cycling in acacia plantations.

The main objectives of the study were (i) to quantify the annual production of litter in acacia plantations, (ii) to determine the rate of decomposition of the leaf litter and (iii) to quantify the addition of organic carbon to soil during the decomposition process.

1.2. Materials and Methods

1.2.1. Study Area

The study areas were located at Chettikulam (C) and Kannamkuzhi (Ka) under Trichur Social Forestry Division and Kothermanakkadu (K) under Palghat Social Forestry Division (lying between 10 and 11° N latitude and 76 and 77°F longitude) of Kerala State (Fig.1). All the three areas had warm-humid climate with a mean annual rainfall ranging from 2500 to 3000 mm.

The acacia plantations at site C (elevation 35 m) and K (elevation 40 m) formed part of a degraded moist deciduous forest previously. The former was used as storage yard of a timber depot for a few years, abandoned later on, and subsequently planted with acacia in 1984. Site K had isolated trees of cashew *(Anacardium occidentale* L,), interspersed with scrub vegetation, before planting with acacia in 1986. The plantation located at site Ka (elevation 150 m) was part of a moist deciduous to semi-evergreen forest earlier. Acacia was planted in this site during 1986. The extent of the plantations at sites C, K and Ka was 8, 50 and 55 ha, respectively. The soil types were sandy loam at site K, gravelly sandy loam at site C and loamy sand at site Ka. Acacia was raised at a spacing of 1.5 x 1.5 m in all the three plantations. The GBH of acacia trees ranged between 17.5 and 50 cm (mean 30.2 cm) at site C, 16 and 35.5 cm (mean 23.4 cm) at site K and 14 and 32 cm (mean 21.8 cm) at site Ka. The approximate height of the trees varied from 10 to 16 m, 6 to 12 m and 8 to 14 m at sites C, K and Ka respectively. Avoiding undulating terrain and disturbed patches, an area of 0.5 ha was selected in each of the three plantations for conducting studies on litter dynamics.

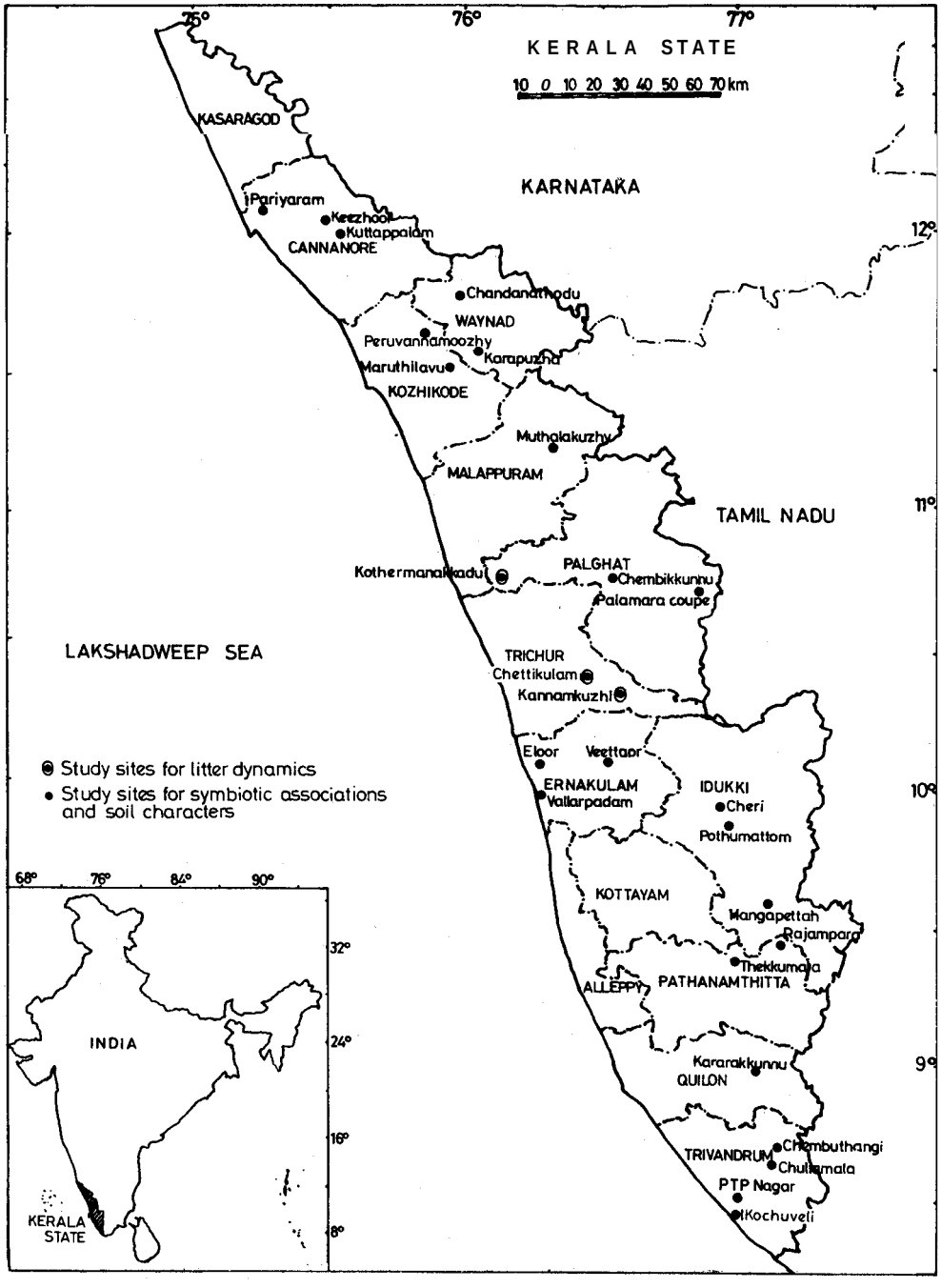


Fig. 1. Location map of experimental sites

Casual vegetation in the plantations included herbs, shrubs and seedlings of trees. The predominant plant species collected from the study plots at sites C and K are provided in Appendices I & II. Regeneration of acacia was approximately 17 seedlings/ 100 m^2 at site C and 45 seedlings/l00 m^2 at site K. Seedlings which had attained a height of 50 cm or more were only considered for this estimation. Data on casual vegetation and regeneration were not collected from site Ka.

All the three sites receive good rainfall between June and November through south-west monsoon (June to September) and north-east monsoon (October to November). The dry period is generally from January to May. The physico-chemical properties of soil in the study plots are provided in Table 1.

Table 1. Physicochemical properties of soils in Acacia plantations selected to study litter dynamics (Permanent plots)

Location	Soil depth (cm)	pH	Sand %	Silt t clay (%)	Organic carbon (%)	Exchange acidity (m.e.%)	Exchangeable bases (m.e.%)	Water holding capacity (%)
Chettikulam	0-20	4.5	78	22	0.92	7.1	2.4	18
Kannamkuzhi	0-20	5.1	83	17	2.10	10.6	12.2	35
Kother-manakkadu	0-20	5.0	79	21	0.80	6.3	6.1	21

1.2.2. Litterfall

Litterfall in acacia plantations was quantified by keeping litter traps in plantations at site C (Figs.2 & 4) and site K (Fig.3). Baskets (area 0.28 m^2) made of bamboo were used as litter traps (Fig.5). A total of 50 litter traps were placed (one litter trap each in the centre of 10 m x 10 m sub plots) in an area of 0.5 ha in each plantation during September 1989. The traps were fixed on 90 cm long stakes and kept at 20 cm above the soil surface. The plots were fenced using barbed wire to avoid human and livestock interference. The total number of living trees in the study plots at C and K were 1902 and 2198 respectively. Litter was collected at monthly intervals for a period of 2 years (October 1989 to September 1991). The collections were taken to the laboratory, dried at 70°C for 24 h, and separated into phyllodes, twigs and other components. The dry weight of each component was determined separately. The 1itterfall/ha was computed from this data.

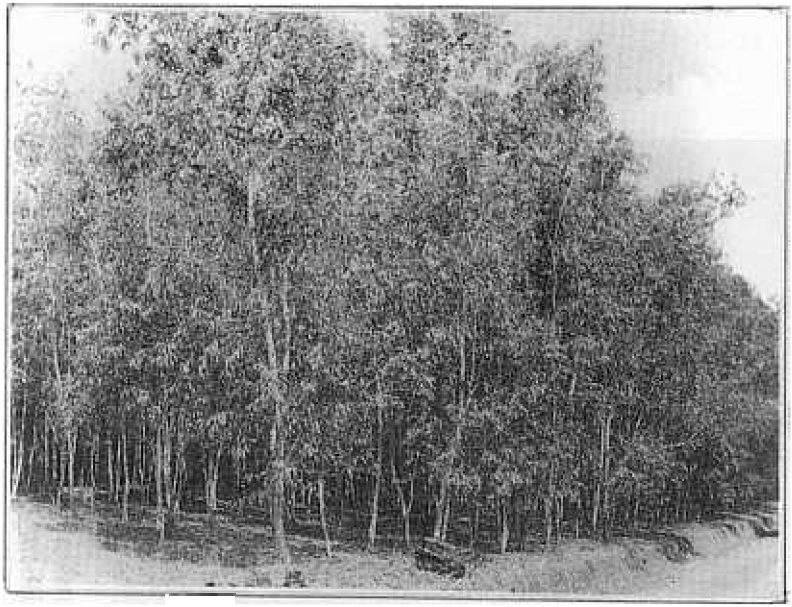


Fig. 2. Study plot at Chettikulam

Fig. 3. Study plot at Kothermanakkadu

Fig. 5. A view of the litter traps kept in the study plot at Chettikulam

Fig, 4. A view inside the plantation at Chettikulam showing accumulation of litter on the soil surface

1.2.3. Litter decomposition

Decay rate of acacia litter was determined in two ways - (1) by keeping the litter bags partially buried in the soil, and (2) by laying the litter bags on the surface of soil. The studies were conducted following the mesh bag technique (Bocock and Gilbert, 1957). The litter bags, made of nylon net (25 x 25 cm; mesh size 5 mm), contained 20g of air dried leaf litter. In September 1989, a total of 80 litter bags each, were laid partially buried in the study plots at C and Ka. An equal number of litter bags were spread on the surface of soil in these two plots in December 1989. During October 1990, another lot of 80 litter bags were laid on the surface of soil in the study plot at K. Samples were drawn from each plot at monthly intervals for a period of one year. Six litter bags were recovered at each sampling, cleaned free of extraneous materials, oven-dried at 70°C for 48 h and dry weight determined.

The lignin content of the leaf litter was determined following the Association of Official Analytical Chemists (1980) method.

1.2.4. Organic carbon content of soils

In December 1990, 25g of air dried leaf litter was transferred to 20 x 20 cm nylon mesh bags (mesh size 5mm) which were then closed by stitching. At otal of 24 litter bags were incubated separately over 1kg of soil (collected from the KFRI Campus, Peechi) taken in 25 x 15cm plastic bowls kept in the laboratory. Controls contained soil without any litter bag. The litter and soil in each bowl were watered periodically with 50 ml of de-ionised water to maintain moisture level at SO-70% water holding capacity. To determine the organic carbon content (OC), six replicate soil samples (5 g each) were drawn during March, June, September and December 1991 from the bowls with the litter bags and the controls. The OC content was estimated using the Walkley and Black method outlined by Jackson (1973).

The atmospheric temperature in the laboratory varied from a monthly maximum (mean) of 25.4°C in December to 28.9°C in May during 1991. The average relative humidity ranged between 60% in February and 95% in July.

1.2.5. Climatic data

The atmospheric temperature (minimum and maximum), relative humidity and soil temperature were recorded daily from the study plots. Rainfall data were collected from the Hydrology Division of the Kerala Public Works Department (Irrigation). Data are provided in

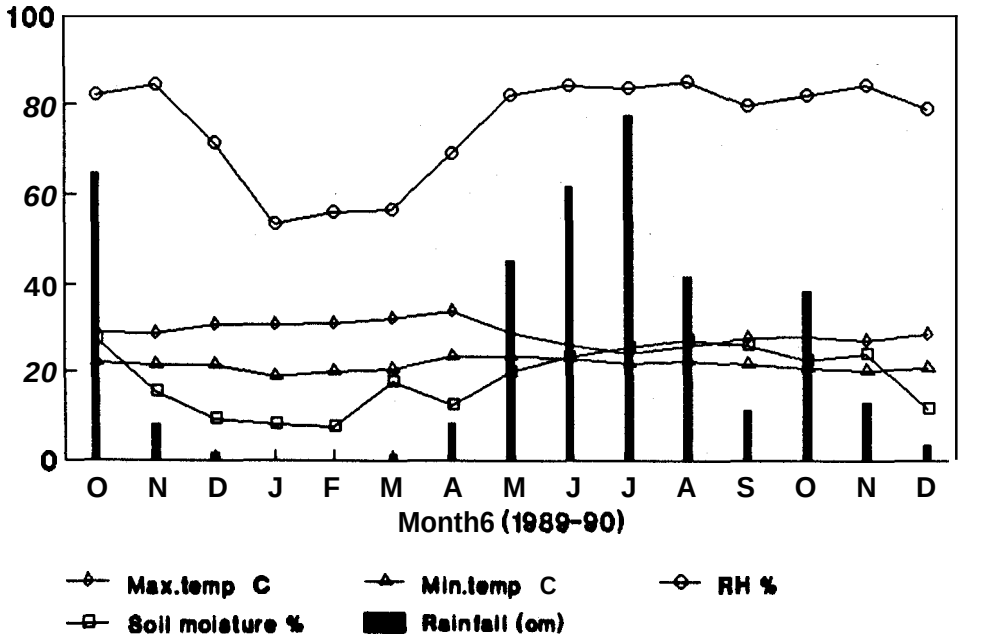


Fig. 6. Climatic data (atmospheric temperature, relative humidity, rainfall and soil moisture content) at Kannamkuzhi

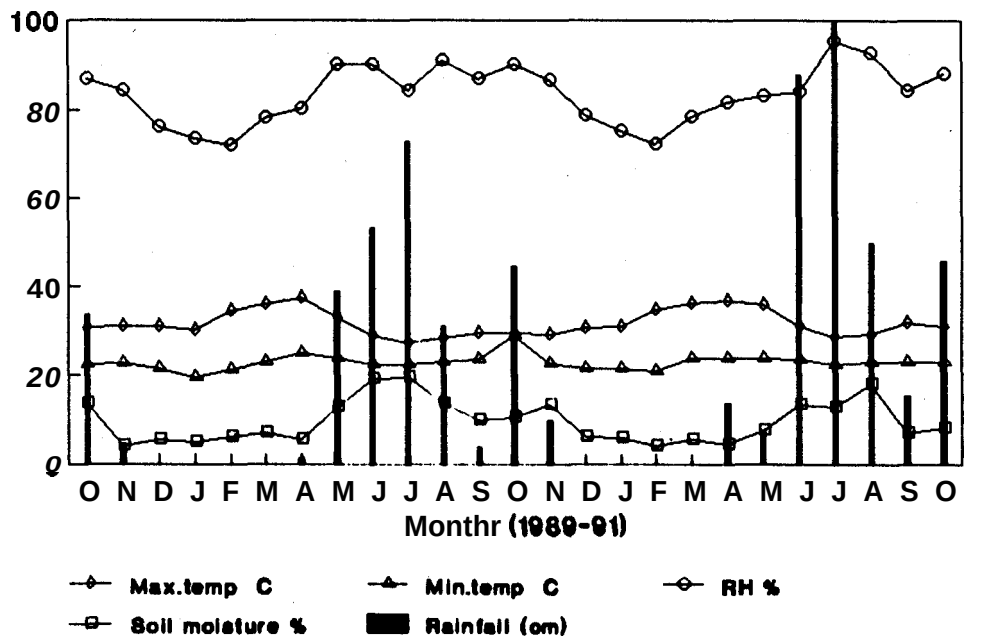


Fig. 7. Climatic data at Kothermanakkadu

1.2.6. Statistical analysis

The following exponential decay model (Olson, 1963) was used to estimate the annual decomposition rate of litter:

$$x/x^{o} = e^{-kt}$$

where, 'x' is the weight of litter remaining after time 't', 'x^{o}' is the initial weight of litter, 'e' is the base of natural logarithm and 'k' the decomposition rate constant. This exponential decay model was also used to calculate the half life of litters and the time required for 95% weight loss. The significance of differences between decay rates in different plantations and between the two methods of study was assessed by the 't' test by comparing regression coefficients.

Correlation analysis was carried out to analyse the relation between loss in weight of litter and the atmospheric/soil parameters. Two-way ANOVA was employed to assess the significance of differences in litterfall between months, sites and years of sampling. The significance of differences between OC content in soil under litter and control was also tested by two-way ANOVA.

1.3 Results

1.3.1. Litterfall

Data on monthly and annual litterfall in the two plantations of acacia are given in Tables 2 to 4 and Figs. 9 and 10. Annual litter production was 9.3 t ha^{-1} during 1989-'90 and 11 t ha-1 during 1990-'91 at site K. At site C, these values were 11.9 t ha^{-1} and 12.0 t ha^{-1} during 1989-'90 and 1990-'91, respectively. The average annual litterfall was 10.1 t ha^{-1} at site K and 12.0 t ha^{-1} at site C. The litterfall was spread throughout the year and its annual production increased with successive growth years. Phyllodes, twigs and pods constituted the major components of litter in acacia plantations. Total litterfall differed significantly between locations ($P < 0.01$ in 1989-'90 and $P < 0.05$ in 1990-'91) and months ($P < 0.01$). At site K, the litter yield differed significantly between years ($P < 0.01$); the increase being 18.5% (in 1990-'91) over the previous year. The litter yield did not differ significantly between years at site C.

Monthly litterfall in acacia plantations indicated a unimodal pattern with its peak during December-January (Figs. 9 & 10). The litterfall ranged between 370 and 2040 kg ha-1 at site C and 193 and 3117 kg ha^{-1} at site K during different months in 1989-1991. The litter yield increased gradually from June attaining a peak in January at site C. Thereafter it decreased in the succeeding months reaching a minimum in May. At site K, litterfall steadily increased from August to November, after which there was an abrupt increase in December followed by a sudden decline in January. This was followed by a gradual decrease till July. Highest litterfall was recorded in January at site C and in

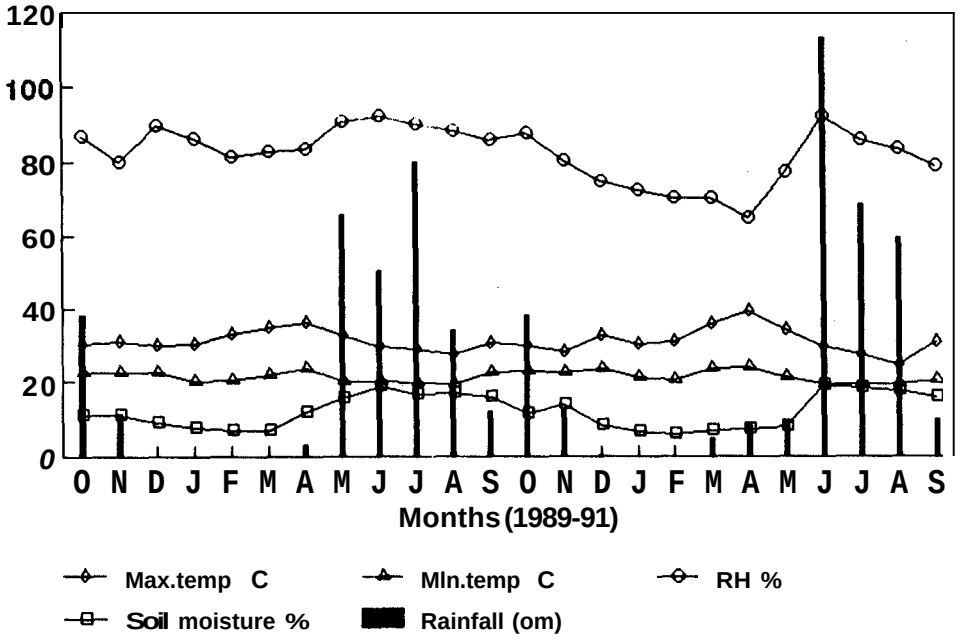
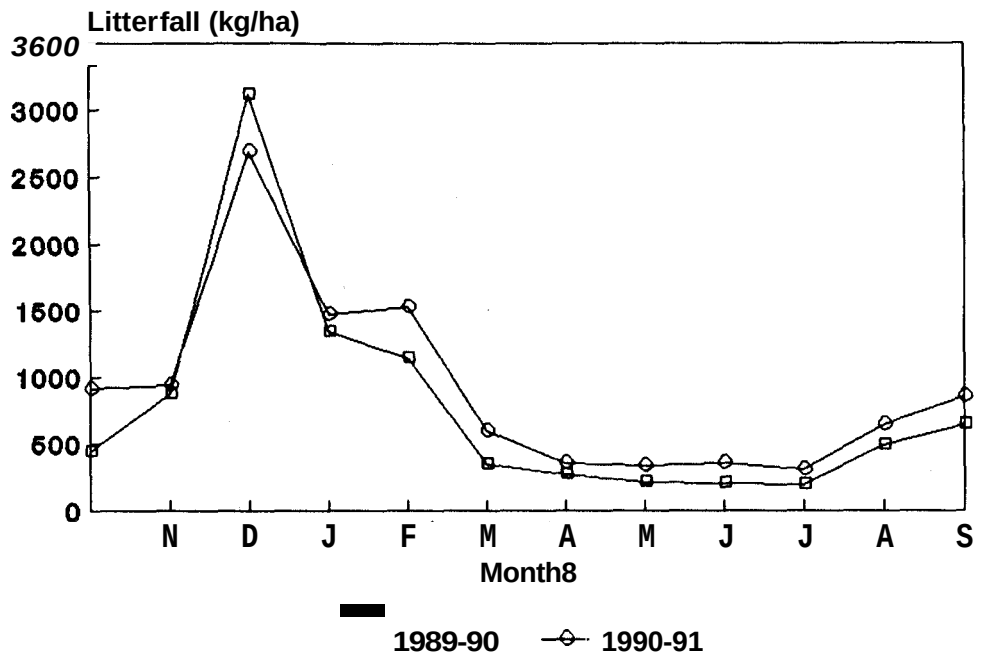


Fig. 8. Climatic data at Chettikulam



Fig, 9. Litterfall (kg/ha) recorded from Acacia plantations at Kothermanakkadu during different months (1989-91)

Table 2. Monthly litterfall (kg/ha) in Acacia plantations at Chettikulam (C) and Kothennanakkadu (K) during 1989-'90

Months	Phyllode		Pods		Twigs		Inflorescence stalk		Seeds		Flowers		Bark	Total	
	C	K	C	K	C	K	C	K	C	K	C	K	C	C	K
1989															
Oct	647.1	404.2	19.3	5.4	47.7	6.0	32.0	24.2	4.8	-	4.2	1.4	1.1	756.2	441.2
Nov	895.7	785.4	43.0	59.9	3.0	9.3	22.0	9.0	96.0	9.7	77.0	0.7	0.3	1137.0	874.0
Dec	939.0	2090.5	481.9	172.3	98.1	86.1	-	-	65.1	167.9	-	-	-	1584.2	3116.8
1990															
Jan	1007.8	860.3	680.8	295.3	186.6	117.3	-	-	55.3	68.4	-	-	-	1930.7	1341.2
Feb	1115.7	918.0	354.0	191.2	100.0	19.0	-		10.3	15.4	-	-	-	1580.2	1143.6
Mar	635.4	319.0	299.9	-	68.7	29.4	-	-	-	-	-	-	-	1004.0	348.5
Apr	470.3	189.9	335.2	62.2	157.8	18.2	-	-	-	-	-	-	-	963.3	270.0
May	220.6	170.0	108.6	12.9	119.4	28.5	-	-	-	-	-	-	-	448.5	211.4
June	188.7	128.7	86.0	32.4	197.8	43.2	.		-	-	-	-	-	472.5	204.3
July	349.0	152.1	29.2	13.3	311.6	27.6	-	-		-	-	-	-	689.9	193.0
Aug	417.5	303.2	7.2	9.1	97.5	85.4	43.3	76.3		-	12.4	18.3	-	577.9	492.3
Sept	561.8	125.2	2.2	1.2	130.2	90.4	87.7	415.0		-	25.0	7.7	-	806.8	639.5
Grand Total	7448.6	6446.5	2447.3	1455.2	1518.4	560.4	185.0	524.5	231.7	261.4	118.6	28.1	1.4	11951.2	9276.2

December at site K during both the years; the lowest yield being in May and July at C and K, respectively.

The leaf litter constituted 62-69% of the total fall; twigs, pods, inflorescence stalks, seeds, flowers and bark made up the rest of the collection. Phyllode and pod-fall showed a peak during December-February coinciding with the peak in total fall. Twig fall was highest during June-July at site C and during December-January at site K. Shedding of flowers was recorded during August-November, the peak flower fall being in September at both the sites in 1990-'91. Seeds could be collected during October-March; the highest seed fall was recorded during November-December. The dry months (October-March) accounted for 67.5% of the total litterfall at site C and 76.2% at site K.

1.3.2. Iitter decomposition

Weight loss (dry weight basis) data of leaf litter at different locations are summarised in Tables 5 to 8 and Figures 11 to 13. Partially buried litter (LPB) lost 94.5%

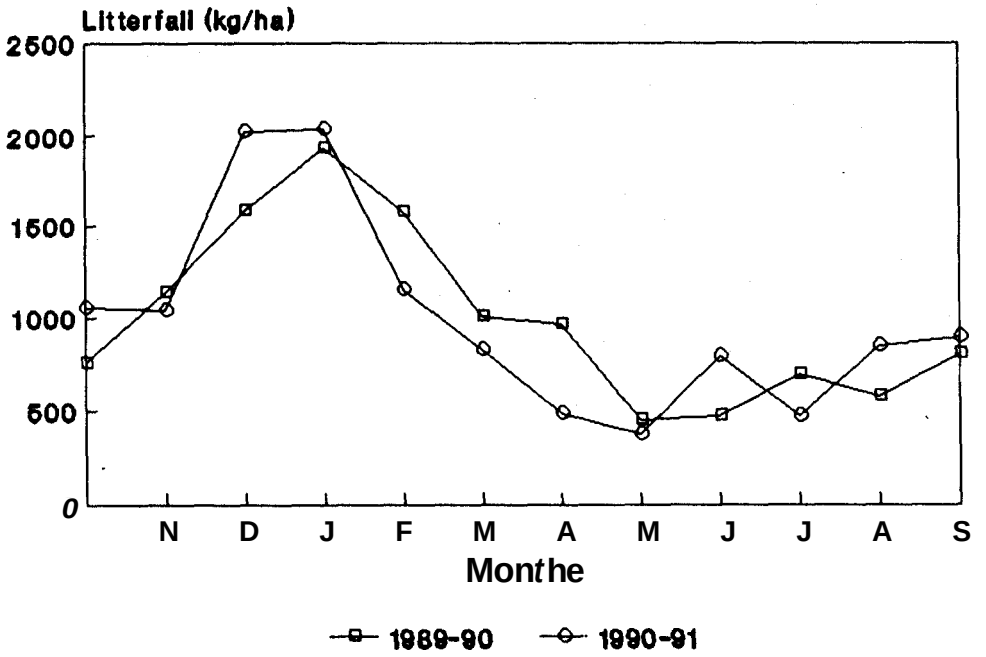


Fig. 10. Litterfall (kg/ha) recorded from Acacia plantations at Chettikulam during different months (1989-91)

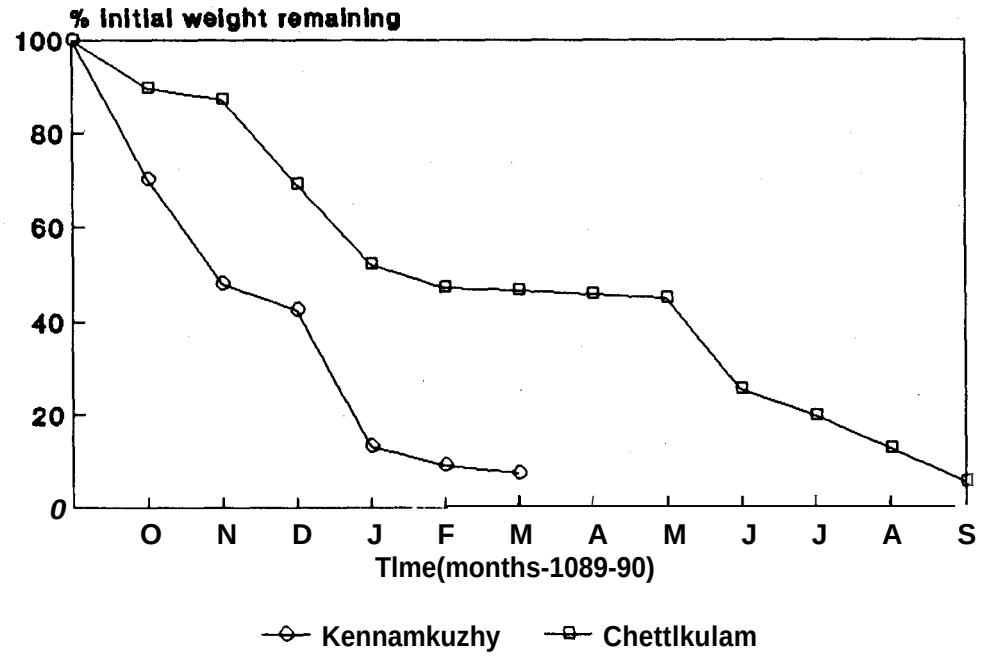


Fig. 11. Percentage of initial weight remaining of leaf litter (partially buried) after different periods of incubation at Chettikulam and Kannamkuzhi

Table 3. Monthly litterfall (kg/ha) in Acacia plantations at Chettikulam (C) and Kothemanakkadu (K) during 1990 - '91

Months	Phyllode		Pods		Twigs		Inflorescence stalk		Seeds		Flowers		Total	
	C	K	C	K	C	K	C	K	C	K	C	K	C	K
1990														
Oct	944.1	815.1	15.4	46.5	66.3	35.2	29.3	12.6	-			-	1055.0	909.4
Nov	832.8	191.3	65.0	102.2	82.0	40.5	1.6	-	60.3	-		.	1041.6	940.1
Dec	940.6	1077.9	181.8	1235.5	191.7	273.0	-	-	106.0	105.4	-	-	2020.1	2691.8
1991														
Jan	1115.8	1044.9	646.3	329.2	183.6	85.6	-	-	93.4	16.7	-	-	2039.1	1476.4
Feb	119.8	1210.6	286.1	227.9	113.8	95.2	-	-	32.0	0.3	-	-	1151.6	1533.9
Mar	643.2	500.7	131.4	42.0	46.0	53.0	-	-	3.7	0.2	-	-	824.4	595.9
Apr	324.9	315.8	110.0	24.7	48.5	17.9	-					-	483.5	358.4
May	200.0	271.9	136.7	15.7	33.2	43.2	-					-	369.5	336.8
June	242.4	211.5	181.3	39.8	370.2	106.8	.					-	194.0	358.2
July	279.2	219.1	29.6	13.7	160.7	10.9	-			-	10.4	9.3	469.5	304.3
Aug	516.6	521.6	15.4	2.8	293.5	97.6	10.9	9.4	-	.	70.6	82.5	846.8	640.1
Sept	671.6	600.2	5.8	1.8	51.0	60.2	94.4	105.7	-			-	893.4	850.4
Grand Total	7431.0	7593.2	2404.8	2081.8	1640.5	979.1	136.2	127.7	295.4	122.6	81.0	91.8	11988.9	10996.3

Table 4. Annual litterfall (kg/ha) in Acacia plantations of different age. Standard errors of the means are shown in parantheses.

Sample period	Plantation age(yrs)	Location	Phyllode	Pods	Twigs	Inflorescence stalk	Flowers, seeds etc.	Total
1989-'90	3	K	6446.5(308.8) 69.5*	1155.2(135.3) 15.7	560.4(3.3) 6.0	524.5(31.3) 5.7	289.6(109.5) 3.1	9216.2(391.2) 100
1990-'91	4	K	7593.2(68.2) 69.1	2081.8(144.0) 18.9	919.1(94.5) 8.8	127.7(1.2) 1.2	214.4(23.0) 2.0	10996.3 (305.7) 100
1989.'90	5	C	7448.6(15.1) 62.3	2447.3(28.7) 20.5	1518.5(125.8) 12.7	185.0(3.2) 1.6	351.8(29.0) 2.9	11951.2 (175.4) 100
1990-'91	6	C	1431.0(192.4) 62.0	2404.8(35.7) 20.1	1640.5(128.1) 13.1	136.2(18.9) 1.1	316.4(52.8) 3.1	11988.9 (396.6) 100

*Percent of total litterfall;1989-'90 and 1990-,91 refer to sampling periods Oct.1989-Sept. 1990 and Oct. 1990-Sept.1991.

of its initial weight alter a period of 12 months at site C. The corresponding value was 64.4% for litter laid on the surface of soil (LSS). At site Ka, the weight loss was 92.6% for LPB after 6 months, The weight loss of LSS was 86% and 65.6%, respectively for site Ka and site K after 12 months. The weight of litter decreased linearly with time for all the sites. The maximum weight loss was recorded during September-November (NE monsoon period) at all the sites except at Chettikulam where the highest weight loss occurred during June 1990 in the case of LPR. The minimum weight loss occurred during March-May in all cases.

The relation between the time and the extent of litter decomposition was brought out using regression analysis. The rates of decomposition of acacia leaf litter recorded during this study are a good fit to the exponential decay model proposed by Olson (1963) as the R^2 values were highly significant for all sites ($P < 0.01$), irrespective of method of study (Table 5). The decomposition parameters and the annual decomposition rate constant('k') are provided in Table 5. The 'k' value was the highest (5.4) for LPB at site Ka. The corresponding value for LPB at site C was 2.07. The decay rate for LSS was 0.72, 1.4 and 0.94 at sites C, Ka and K, respectively. The hall life (T^o50) and the time required for 95% weight loss (T^o95) were 4 months and 17.3 months, respectively lor partially buried litter at site C. At site Ka, these values were 1.5 months and 6.6 months, respectively. With regard to the litter laid on the surface of soil, the T^o50 and T^o95 values were 11.6 and 50.1 months for site C, 5.9 and 25.3 months for site Ka and 8.9 arid 38.5 months for site K.

Table 5. Dry weight loss and decomposition parameters of Acacia leaf litter

Sl No.	Plantation locality	Decomposition time (months)	Dry weight loss(%)		Annual decomposition rate constant(k)		Time required for decomposition (months)			
							50% (half life) (T^o50)		95% (T^o95)	
			LPB	LSS	LPB	LSS	LPB	ISS	LPB	LSS
1.	Chettikulam(C)	12	94.5	64.4	2.07* (R^2=0.89)	0.72* (R^2=0.89)	4	11.6	17.3	50.1
2.	Kannamkuzhi(Ka)	12	92.6 (by6 months)	86	5.4" (R^2=0.90)	1.4* (R^2=0.86)	1.5	5.9	6.6	25.3
3.	Kothermanakkadu(K)	12	NR	65.6		0.94* (R^2.0.96)	-	8.9	-	38.5

* $P < 0.01$; NR not recorded; LPB: litter partially buried in soil; LSS: litter on the surface of soil

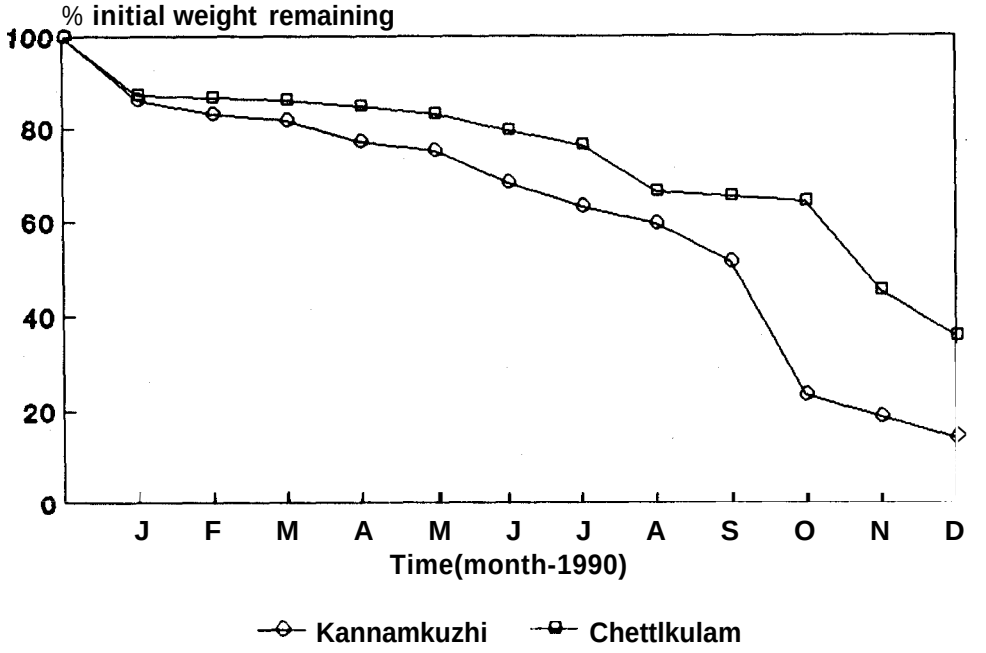


Fig. 12. Percentage of initial weight remaining of leal litter (laid on the surface of the soil) after different periods **of** incubation at Chettikulam and Kannamkuzhi

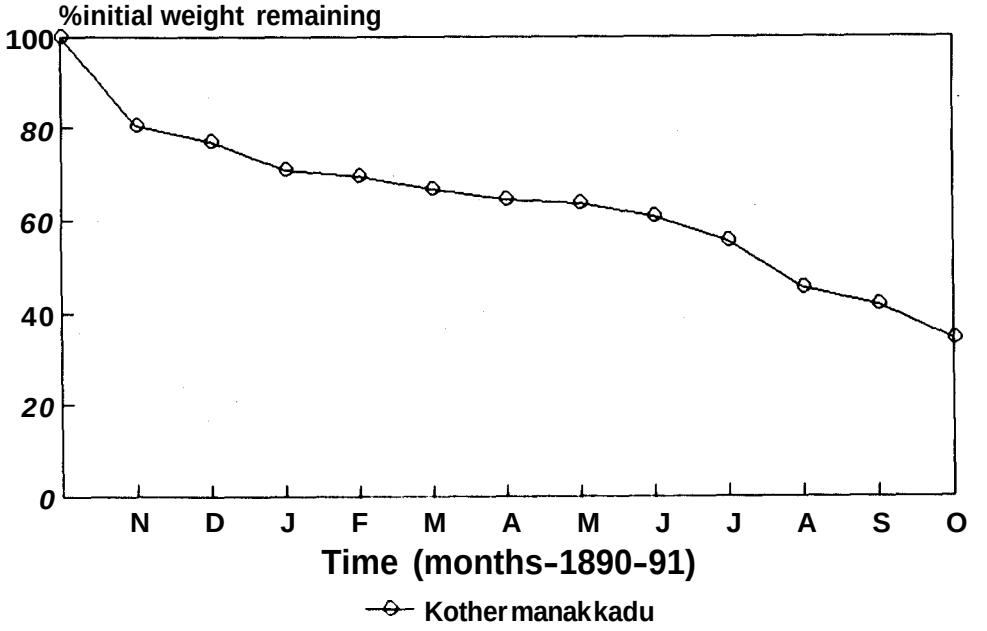


Fig. **13.** Percentage of initial weight remaining of leaf litter (laid on the surface of the soil) after different periods of incubation at Kothermanakkadu

Table 6. Loss in weight of Acacia leaf litter (%)- litter partially buried in soil (LPB)

Sl. No	Plantation locality	Oct 1989	Nov.	Dec.	Jan, 1990	Feb.	March	Apr	May	June	July	Aug.	Sept 1990
1.	Chettikulam	10.6	13.0	31.0	42.0	53.0	53.5	54.2	55.1	74.7	80.2	87.3	94.5
2.	Kannamkuzhi	30.6	52.1	57.5	87.0	91.0	92.6						

Table 7. Loss in weight of Acacia leaf litter (%)- litter laid on the surface of soil (LSS)

Sl. No	Plantation locality	Jan. 1990	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec. 1990
1.	Chettikulam	12.9	13.5	14.0	15.5	17.2	20.7	24.0	33.7	34.8	36.0	54.3	64.4
2.	Kannamkuzhi	14.2	17.0	18.4	23.3	25.0	31.9	37.0	40.6	48.8	76.8	81.5	86.0

Table 8. Loss in weight of Acacia leaf litter (%)- LLS

Sl. No	Plantation locality	Nov. 1990	Dec.	Jan. 1991	Feb.	March	April	May	June	July	Aug.	Sept.	Oct. 1991
1.	Kothermanakkadu	19.5	23.1	29.0	30.4	33.2	35.6	36.3	39.0	44.5	54.5	58.0	65.6

Table 9. t-values for differences between regression coefficients [sites (litter decomposition)/method]

Sites/method of study	t-values
Chettikulam LPB vs LSS	7.11**
Kannamkuzhi LPB vs LSS	7.16**
Kannamkuzhi vs Chettikulam (LPB)	5.52**
Kannamkuzhi vs Chettikulam (LSS)	4.50**
Chettikulam vs Kothermanakkadu (LSS)	2.83 **
Kannamkuzhi vs Kothermanakkadu (LSS)	3.27**

**P<0.0l; LPB : litter partially buried; LSS : litter laid on the surface of soil

The rate of decomposition of LPB and LSS differed significantly between and within all sites ($P < 0.01$) (“able 9). In general, the decay rate of the litter was the fastest at site Kairrespective of LPB or LSS compared to site C and K. The rate of decomposition was the slowest at site C; the value was intermediate for site K. The decomposition was characterized by an initial rapid phase followed by a slower phase. The weight loss was not correlated with soil moisture, atmospheric temperature, relative humidity or rainfall.

The lignin content of acacia leaf litter was estimated to be 18.3%.

1.3.3. Organic carbon content of soils

Organic carbon content of soil under decomposing acacia leaf litter during different periods of observation is given in Table 10. It ranged between 1.05 and 1.17% during the study period. The corresponding values for controls ranged between 0.45 and 1.04% Statistical analysis showed that the OC content of soil under acacia litter differed significantly from that of the control soil ($P < 0.01$). However, the OC level of soil under the litter remained almost static during the course of the study (over a period of one year).

Table 10. Organic carbon (%) in soil under Acacia leaf litter during different periods of observation (mean of 5 samples)

Months (1991)	Control	Soil under leaf litter
March	1.04	1.17
June	0.63	1.06
September	0.54	1.06
December	0.45	1.05

1.4. Discussion

1.4.1. Litterfall

Annual litterfall in tropical forests is estimated to range between 5.5 and 15.3 t ha^{-1} (Laudelot and Meyer, 1954; Williams and Gray, 1974). The annual litter yield in acacia plantations in Kerala (10 - 12 t ha^{-1}) recorded during the present study falls within this range. However, it is greater than the litterfall predicted from Bray and Gorham’s (1964) inverse relationship between total litter production per year and latitude of the region (9.8 t $ha^{1}yr^{-1}$ at 10^{o}N latitude). Also, it is more than the litterfall reported from acacia plantations in Karnataka State, India (Table 11). Litter production in an 8-yr-old acacia plantation at Sakleshpur (Karnataka), was reported to be 7.4 t ha^{-1} yr^{-1}

(Kushalapa, 1991). Sugur (1989) recorded a litterfall of 3.04 t $ha^{-1}yr^{-1}$ in a 10-yr-old acacia plantation at Shimoga. According to Tanpibal and Suhunalu (1981) total litter production in an 8-yr-old acacia plantation in South Thailand was 5.2 t ha^{-1}yrl. The results of the present study are comparable with a similar study conducted in Java, Indonesia (Wiersum and Ramlan, 1982) where the annual litter production in a 3-to 4-yr-old acacia plantation was reported to be 10.7 t ha^{-1}.

Annual litterfall in acacia plantations in Kerala is higher than those reported in plantations of *Acacia nilotica, Acacia mearnsii, Alnus nepalensis, Dalbergia sisso*, teak and eucalypt in India (Table 11). Swamy (1989) reported that litterfall in an acacia plantation at Chikmagalur, Karnataka is higher than that in wet evergreen, semi-evergreen and moist deciduous forests. According to Kumar and Deepu (1992), the annual litter production in moist deciduous forests of the Western Ghats (Kerala region) was 12.2 to 14.4 t ha^{-1}. This is only slightly higher than the litter production recorded from acacia plantations in Kerala.

The high rate of litter production in acacia plantations is evidently due to the fast vegetative growth exhibited by the species. The favourable climatic conditions (temperature, rainfall, etc.) prevailing in the study sites may have contributed to a higher primary productivity of the plantations leading to higher amount of litter production. According to Penfold and Willis (1961) more fast growing the species is, the more litter it would produce. The low rate of litter production in acacia plantations in Karnataka could possibly be due to the unfavourable climatic factors and the variation in site quality.

The percentage of phyllode (62-6%) and other individual components contributing to litter production as recorded during the present study is in agreement with reports of Bray and Gorham (1964), Wiersum and Ramlan (1982), Swamy (1989)) and Kumar and Deepu (1992).

A regular increase in the litter yield with successive growth years in acacia plantations shows continuous development of canopy which is characteristic of young plantations. Yearly litter yield is known to be a function of annual synthesis of fresh organic matter as foliage and other components in the plantations (Bray and Gorham, 1964). An increasing trend in the production of litter as stand ages has also been reported by other workers (O'Connell and Menage, 1982; Das and Ramakrishnan, 1985).

Data on monthly litterfall indicate that dry months account for higher fraction of annual litter production (67.5- 76.2%) than wet months in acacia plantations. An inverse relationship between litterfall and rainfall was evident. As acacia is an evergreen species, the observed maximum litterfall during dry months can be ascribed mainly to moisture stress for trees. According to Moore (1980), water stress triggers *de novo* synthesis of absicissic acid in the foliage of plants which in turn can stimulate senescence of leaves and other parts. Highest litterfall during summer months has been reported for acacia

Table 11. Annual litterfall in plantations of different species in India and else where

Species	Age (yr)	Locality	Litter production t ha^{-1} yr^{1}	Reference
Eucalyptus tereticornis	5	Western U.P.	2.3	Singh (1975)
	5	Dehra Dun, U.P.	3.4	George (1982)
	3-6	Karnal, Haryana	1.0- 1.1	Gill ***et al.*** (1987)
,,	18-20	Chikmagalur, Karnataka	8.6	Swamy (1989)
Tectona grandis	16-20	Coimbatore, Tamil Nadu	8.5-10.7	George ***et al.*** (1990)
,,	20	Jabalpur, M.P.	4.5	Soni (1985)
,,	54-56	Chikmagalur, Karnataka	11.4	Swamy (1989)
,,	4-45	Surguja, M.P.	8.5	Naik &Shrivastava (1985)
Eucalyptus sp.	20	Jabalpur, M.P.	7.6	Soni (1985)
E. globulus	10	Nilgiris,Tamil Nadu	8.5	George and Varghese (1991)
Dalbergia siso	24	Bijnor, U.P.	4.2	Sharma ***et al.*** (1988)
Alnus nepalensis	7-46	Kalimpong, E. Himalaya	3.2-5.8	Sharma and Ambasht (1987)
Acacia mearnsii	12	Nilgiris	0.9	Vekataramanan ***et al.*** (1983)
Acacia nilotica	3-6	Karnal, Haryana	2.5-5.7	Gill ***et al.*** (1987)
Acacia auriculiformis	8	Sakleshpur, Karnataka	7.4	Kushalapa (1991)
	10	Shimoga, Karnataka	3.0	Sugur (1989)
"	9-11	Chikmagalur, Karnataka	17.5	Swamy (1989)
,,	8	South Thailand	5.2	Tanpibal & Suhunalu (1981)
	3-4	Java, Indonesia	10.7	Wiersum & Ramlan (1982)
	3-6	Trichur, Palghat, Kerala	10-12	This study

(Tanpibal and Suhunalu, 1981; Sugur, 1989) and for a host of other species and forest types in India and elsewhere (Nye, 1961; O'Connell and Menage, 1982; Das and Ramakrishnan, 1985; Swamy, 1989).

The significant difference in litter yield between plantations can be related to the difference in age of the stands, Variations in the site quality and climatic conditions are other factors which can possibly influence litter production. The monthly litterfall was higher at site C throughout the sampling period, compared to site K, except in December when the peak in litter production was recorded at site K. This difference in litter yield may be attributed to the high wind speed (mean wind velocity 7.6 km h-1) recorded at site K during this period.

1.4.2. Litter decomposition

The data on litter decomposition showed that the weight loss of acacia leaf litter varied between 64.4 and 86% after a period of 12 months at different sites. The maximum weight loss (86%) was recorded from site Ka where the soil and climatic

conditions were very congenial for faster breakdown of litter. The 'k' value (LSS) ranged between 0.06 and 0.12. A comparison of the present data with the data reported in the literature (Table 12) indicated that the rate of decomposition of acacia leaf litter, in general, was lower than that of leaf litter of teak, *Albizia falcataria* (L.) Fosberg, *Xylia xylocarpa* Taub., *Terminalia paniculata* Roth, *Pterocarpus marsupium* Roxb., *Grewia tiliaefolia* Vahl and *Dillenia pentagyna* Roxb. reported from Kerala (Kumar and Deepu, 1992; Sankaran, 1993). The exception was the decay rate of partially buried litter at site Ka which lost 92.6% of its initial weight after a period of 6 months. Singh (1969), who determined the decay rate of leaf litter of 10 important tree species in the deciduous forests of Varanasi, India reported that a period of 3 - 15 months was required for almost complete decomposition of litters. According to Kumar and Deepu (1992) the time required for complete disappearance of leaf litter of six dominant tree species in moist deciduous forests of Kerala was 58 months. The decay rate of acacia litter at sites K and Ka, however, was faster than that of *Eucalyptus tereticornis* reported from Kerala (Sankaran, 1993) and Karnataka (Swamy, 1989).

According to Wiersum and Ramlan (1992) the loss in weight of acacia leaf litter was only 33% after 4 months in Indonesia, whereas the corresponding values were 56% and 76% respectively for *Albizia falcataria* and *Leucaena leucocephala*. The studies of Tanpibal and Suhunalu (1981) proved that the rate of disappearance of acacia litter in Thailand was 2 t ha-1 yr-1 (38.4% annually). A low rate of decomposition of acacia litter was also reported by Swamy (1989) and Byju (1989) in India.

Plant litters with high initial N content and low C-N ratios are known to decompose rapidly (Singh and Gupta, 1977; Meentemeyer, 1978). Though acacia leaves have a high initial N content and low C:N ratio (Swamy, 1989; Byju, 1989), interestingly, the decay rate was relatively low. The low decomposability of acacia litter can be attributed to the high content of crude fibres in the phyllodes and also the presence of a thick cuticle on the phyllode surface (Widjaja, 1980; Byju, 1989). Moreover, the lignin content of acacia leaf litter was estimated to be higher compared to that of teak, Xylia xylocarpa and a host of other tropical tree species (Kumar and Deepu, 1992). Swift *et al.* (1979) suggested that physical and chemical properties of litter might exert a strong influence on decomposition. A negative correlation between fibre content of litter and weight loss has been reported by Pandey and Singh (1992). The allelopathic effect of acacia leaves (Setiadi and Samingan, 1978) on the decomposer microorganisms may be another possible reason for its low degradability. Lignin content of litter is recognized to be one of the most important factors controlling decay rates (Meentemeyer, 1978). Further, the decomposition of lignin of the nitrogen rich litters is known to be significantly lower than those with poor nitrogen content (Berg *et al.*, 1992). Similar results were also reported for leaf litters of *Albizia falcataria* (Sankaran, 1993) and *Leucaena leucocephala* (Sandhu *et al.*, 1990).

Table 12. Decay rate of leaf litter of important tree species in Kerala

Locality	Species	rate of decomposition (monthly) 'k' value	Remarks	Source
Trichur Forest Division	***Tectona grandis***	0.32	Litter on the surface of soil	Kumar & Deepu, 1992
"	***Pterocarpus marsupium***	0.44	"	"
"	***Xylia xylocarpa***	0.35	"	"
"	***Dillenia pentagyna***	0.33	"	"
"	***Grewia tiliaefolia***	0.34	"	"
"	***Terminalia paniculata***	0.29	"	"
" (Peechi)	***Albizia falcataria***	0.14	ex-situ	Sankaran, 1993
	Eucalyptus tereticornis	0.06	ex-situ	"
(Chettikulam)	***Acacia auriculiformis***	0.17	litter partially buried	This study
(Kannamkuzhi)	"	0.45	"	"
(Chettikulam)	"	0.06	litter on the surface of soil	"
(Kannamkuzhi)	"	0.12	"	"
Palghat Forest Division (Kothermanakkadu)	"	0.08	"	"

The breakdown of litter was faster at site Ka compared to sites C and K irrespective of whether litter was partially buried or laid on the surface of soil. Acacia plantation at site Ka was adjacent to a natural moist deciduous to semi-evergreen forest and least exposed to human interference. The soil was comparatively more fertile and water holding capacity was higher than the other study sites (Table 1). The high rate of litter decay at site Ka may be ascribed to the congenial microclimatic conditions and soil factors which would have favoured high microbial activity. The presence of a diverse decomposer flora in these virgin soils may have also contributed to rapid breakdown of litter. The low nutrient status and altered micro/macro climatic factors due to site degradation may have been the possible factors for low rate of litter decomposition at C and K sites. Decay rates of litters in disturbed forest sites are reported to be slower than those in undisturbed sites (Kumar and Deepu, 1992).

Litter partially buried in soil decomposed much faster than that laid on the surface of soil. This is evidently due to the close contact of soil with all the layers of litter kept in the container which in turn would have helped retention of more moisture between litter layers. It may have also facilitated enhanced activity of soil microflora and fauna

on the litter. These results indicate that periodic raking of soil in plantations will enhance the rate of litter degradation, and through it, the nutrient cycling process.

The initial rapid phase of decomposition of litter at the three sites can be related to an initial high leaching of soluble chemical components from the litter. The study indicated that in general, North-East monsoon favours the fast rate of decomposition of acacia litter.

Earlier studies and comparison of litter decomposition at various latitudes have shown that the decay rates of plant litters are higher in tropical conditions than in temperate situations (Jenny *et al.,* 1949; Olson, 1963; Madge, 1965; Stohlgren, 1988). The decay rate of acacia leaf litter is also higher than that of several other plant species reported from temperate regions of the world (Anderson and Swift, 1983). The differences in temperature and moisture supply and the higher activity of decomposer flora can, to a great extent, explain such variations in litter decay rates between temperate and tropical regions (Williams and Gray, 1974).

1.4.3. Organic carbon content of soils

The OC content of soil under acacia litter recorded during this experiment, generally agrees with the OC values recorded from acacia plantations in the state (see under Soil Studies). The study revealed that significant amount of OC was added to soil during the decomposition of acacia litter. Though an increase in the OC level of soil under the litter was expected during the course of the study, the values remained almost static for a period of one year. The reasons for this are not clearly known, but it is possible that a good portion of the OC was liberated as CO_2 during the decomposition process and a substantial increase in OC levels may occur only after prolonged period of decay process. An initial increase in OC content of soils under acacia litter compared to other sampling periods may be due to the high rate of decomposition recorded during this period.

2. MYCORRHIZAL ASSOCIATIONS

2.1. Introduction

The mycorrhizal association is considered crucial for the survival and growth of majority of plant species in natural ecosystems (Harley and Smith, 1983). The role of mycorrhizae in enhancing water and nutrient uptake, especially phosphorus, zinc and copper, is well known (Bowen, 1973). They also help protection of root against pathogens and environmental stresses (Trappe, 1977).

In many tropical soils, lack of phosphate is the most important constraint on plant growth (Vitousek, 1984). The mycorrhizal roots with a network of mycelia, explore large soil volume than non-mycorrhizal roots and enhance uptake of phosphorus into the plant. Two ways of ensuring the benefits from mycorrhizal associations are (i) by promoting the activity of effective indigenous mycorrhizal fungi by adequate cultural practices, and (ii) inoculating the plants with selected efficient fungi (Sieverding and Leihner, 1984). It has been demonstrated that the productivity of trees in plantations can be enhanced by inoculating seedlings in the nursery with selected mycorrhizal fungi (Marx, 1980). However, attempts to tap the potential of mycorrhizal fungi in improving the growth of trees, have been rare, especially in the tropics.

Jasper *et al.* (1989a) have reported that several Australian acacias are strongly dependent on VA mycorrhizal fungi€or phosphorus uptake. Though large-scale planting of *Acacia auriculiformis* was initiated in Kerala since 1980's, nothing was known on the mycorrhizal associations of this species in Kerala soils. This study was mainly intended to throw light on the status of mycorrhizal associations in acacia plantations in Kerala. The specific objectives of the study were (i) to understand the type of mycorrhizal associations in acacia plantations in Kerala, (ii) to assess the extent of root colonization by mycorrhizal fungi, (iii) to identify the fungi involved, and (iv) to select an efficient inoculant VA mycorrhizal fungus for acacia.

2.2. Materials and Methods

2.2.1. Survey

A total of 26 acacia plantations, with diverse site qualities, distributed throughout the State, were selected to assess the status of mycorrhizal associations. Of these, 17 plantations were situated on degraded sites, seven on fertile lands and two on sandy soils. Details on the location, age and characteristics of the plantations are provided in Fig.1 and Table 13. Initially, attempts were made to detect the type of mycorrhizal association by examining root sections and cleared root samples. To quantity the extent of

colonization by VA mycorrhizal fungi, root samples were collected from 12 trees, selected at random, from each plantation during January-April 1990. The samples were washed thoroughly and 1.0 cm long segments were cut (25 each from a single tree) from the fine roots. These samples were cleared and stained in trypan blue following the method of Phillips and Hayman (1970). A total of 300 root segments were examined from each plantation. The percentage colonization was determined based on the number of root segments colonized by VAM fungi. The interrelationship between the extent of colonizaton and physical and chemical characteristics of the soil was brought out by correlation analysis.

2.2.2. VAM fungi in soils under Acacia plantations

Six plantations (Table 14) were surveyed to identify VAM fungi associated with acacia roots. Soil samples were collected to a depth of 20 cm, near the root zone of 12 trees, selected at random, from each plantation. The samples from a single plot were pooled together and subjected to wet sieving and decanting (Gerdemann and Nicholson, 1963). The resultant extractions were examined under a stereomicroscope and spores of VAM fungi transferred to petri dishes. The species level identification was done following the keys of Trappe (1982) and Schenck and Perez (1987).

2.2.3. Glasshouse screening

Five VAM fungi viz., Acaulospora laevis Gerd. & Trappe, Glomus aggregatum Schenck & Smith, G. faciculatum (Thaxter sensu Gerd.) Gerd. & Trappe, G. leptotichum Schenck & Smith and G. mosseae (Nic. & Gerd.) Gerd. & Trappe were screened for their efficiency in promoting the growth of acacia seedlings. Black polythene bags (21 x 15 cm), filled with 1.5 kg of sterilized P-deficient (4.8 kg/ha) sandy loam soil of pH 5.4 amended with 150 g of farmyard manure, were used for raising the seedlings. Mycorrhizal inoculum (100-150 spores of individual fungus in 10 g soil) was placed 2 cm below the surface of soil in each container. Seeds of acacia, surface-sterilized in 2% NaOCl, were sown and four seedlings raised in each bag. Ten replicate seedlings for each fungus and uninoculated controls were maintained in a glasshouse (mean temp. 28±2°C; RH between 79-90%) and watered regularly. The seedlings were harvested 100 days after sowing and their height, dry weight of shoot and root and percentage mycorrhizal colonization of roots (Phillips and Hayman, 1970) recorded. Phosphorus content of seedlings was determined by vanadomolybdate phosphoric yellow colour method (Jackson, 1973). The data were analyzed by one-way ANOVA and the VAM fungi ranked for each character and compared using Duncan's multiple range test.

2.3 Results

2.3.1. Type of association and extent of colonization

The roots of acacia showed colonizaton by typical, thick-walled aseptate hyphae

Table 13. Level of colonization of Acacia roots by VA mycorrhizal fungi and phosphate content of soil in different plantations

SI. No.	Plantation locality	Year of planting	Social Forestry Division	Nature of site	% colonization (mean of 12 samples)	Extractable P (kg/ha)
1	Chembikkunnu	1984	Trichur	Degraded	98.0	nd*
2	Chettikulam	1984	Trichur	Degraded	98.0	5.11
3	Chembuthangi	1985	Trivandrum	Degraded	100.0	5.91
4	Eloor	1985	Ernakulam	Degraded	75.0	3.81
5	Kararakunnu	1985	Quilon	Degraded	98.0	3.36
6	Kuttappalam	1985	Cannanore	Adjacent to natural forest (fertile)	94.7	5.60
7	Pothumattom	1985	Idukki	Adjacent to natural forest (fertile)	79.0	28.22
8	Vallarpadam	1985	Ernakulam	Sandy soil (sea shore)	96.0	nd
9	Veettoor	1985	Ernakulam	Degraded	89.0	10.08
10	Chandanathodu	1986	Wynad	Degraded	99.7	10.30
11	Cheri	1986	Idukki	Degraded	97.0	7.84
12	Chuliyamala	1986	Trivandrum	Degraded	98.7	5.60
13	Kannamkuzhi	1986	Trichur	Adjacent to natural forest (fertile)	85.0	9.41
14	Karappuzha	1986	Wynad	Fertile	100.0	26.21
15	Keezhur	1986	Cannanore	Degraded	90.0	6.27
16	Kothermanakkadu	1986	Palghat	Degraded	96.0	6.65
17	Kochuveli	1986	Trivandrum	Sandy soil (degraded)	27.0	nd
18	Mangapetta	1986	Kottayam	Adjacent to natural forest (fertile)	75.0	22.62
19	Maruthilavu	1986	Wynad	Close to natural forest (fertile)	89.6	19.94
20	Muthalakuzhy	1986	Malappuram	Degraded	90.0	3.29
21	Palamaracoup	1986	Palghat	Degraded	94.0	7.62
22	Pariyaram	1986	Cannanore	Degraded	91.7	5.15
23	Peruvannamoozhy	1986	Calicut	Degraded	90.0	6.72
24	Rajampara	1986	Pathanamthitta	Adjacent to natural forest (fertile)	98.0	4.75
25	Thekkumala	1986	Pathananithitta	Degraded	83.0	8.06
26	PTPNagar	1987	Trivandrum	Degraded	81.0	3.00

*not determined

growing inter - and intra-cellularly through the cortex and penetrating to the inner cortex. Vesicles, mostly terminal and globose, subglobose or ellipsoidal in shape (Figs.14- 16) were very common inside the roots. Arbuscules were observed in the cells of the inner cortex. These observations indicate that A. auriculiformis is VA mycorrhiza1. There was no evidence of ectomycorrhizal association in acacia. Though Thelephora ramarioides Reid, a basidiomycete, could be collected on several occasions around acacia roots, its role in forming an ectomycorrhizal association is yet to be established.

The percentage colonization of acacia roots by VAM fungi in different plantations is given in Table 13. The data show that the extent of colonization by VAM fungi was very high in majority of the acacia plantations. It ranged between 90 and 100% in 17 out of 26 plantations surveyed, The level of infection varied between 75 and 89% in eight plantations. The lowest colonization (27%) was observed in sandy soils at Kochuveli. The colonization was, in general, higher in degraded sites compared to fertile areas. But, a few of the non-degraded sites also showed a high level of colonization. Though P level in soils (Table 13) was not correlated with colonization by VAM fungi, in 13 plantations where the extractable P was low (3.3 to 7.8 kg/ha), the percentage colonization was recorded to be high (90 to 100%) In two plantations, where the P level was very high (22.6 to 28.2 kg/ha), the VAM colonization was low (75 to 79%).

The extent of colonization was positively correlated with silt content ($P < 0.05$), clay content ($P<0.05$) and porosity ($P<0.05$) of the soil. It was negatively correlated with sand content ($P < 0.05$) and bulk density of soil ($P < 0.01$). VAM colonization was not correlated with soil pH (see Table 16) and N, K, Ca and Mg content of soil.

2.3.2. VAM fungi in soils under Acacia plantations

The percentage frequency of different VAM fungi isolated from the soil samples collected from various acacia plantations is given in Table 14. A total of 11 species of VAM fungi belonging to two genera were identified. Glomus was the most dominant genus. Gigaspora was represented by a single species only. Glomus radiatum was the most frequent fungus recorded from acacia plantations. The other most frequent fungi were G. fasciculatum and G. intraradices (frequency 67%). Glomus albidum and Gigaspora sp. could be collected from only one plantation each. Glomus claroideum, G. formosanum and Glomus sp. were less frequent compared to other fungi.

2.3.3. Selection of an efficient VAM fungus for Acacia

The results presented in Table 15 reveal that the seedlings inoculated with VAM fungi had significantly higher height, shoot and root dry mass and mycorrhizal root colonization as compared to uninoculated controls ($P<0.01$). The P content of seedlings also varied significantly between inoculated and control seedlings ($P < 0.01$) except for those inoculated with G. leptotichum, Seedlings inoculated with G. fasciculatum had

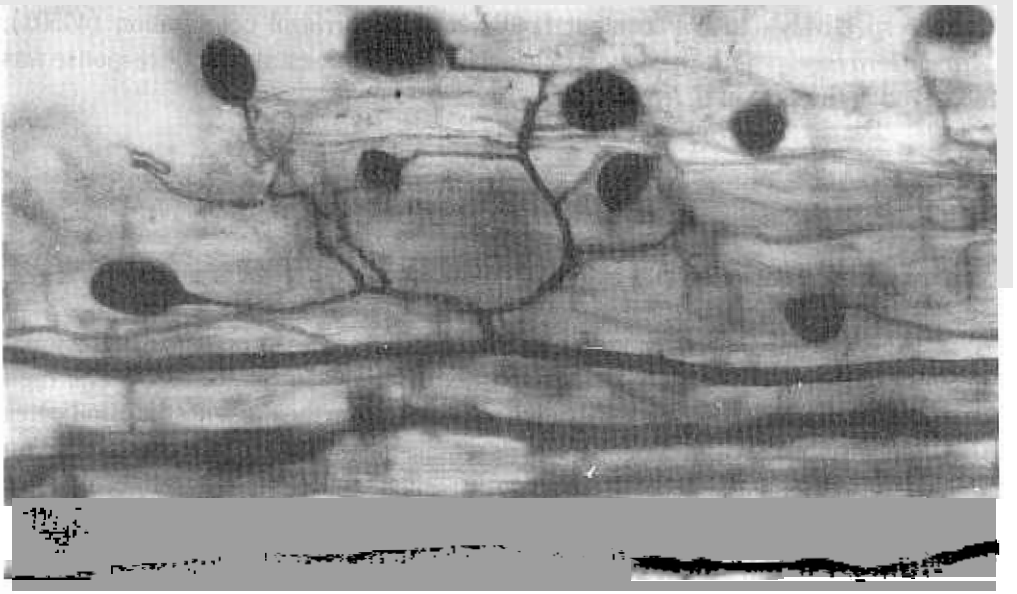


Fig. 14. Hyphae and vesicles of vesicular-arbuscular mycorrhizal fungi in roots of Acacia

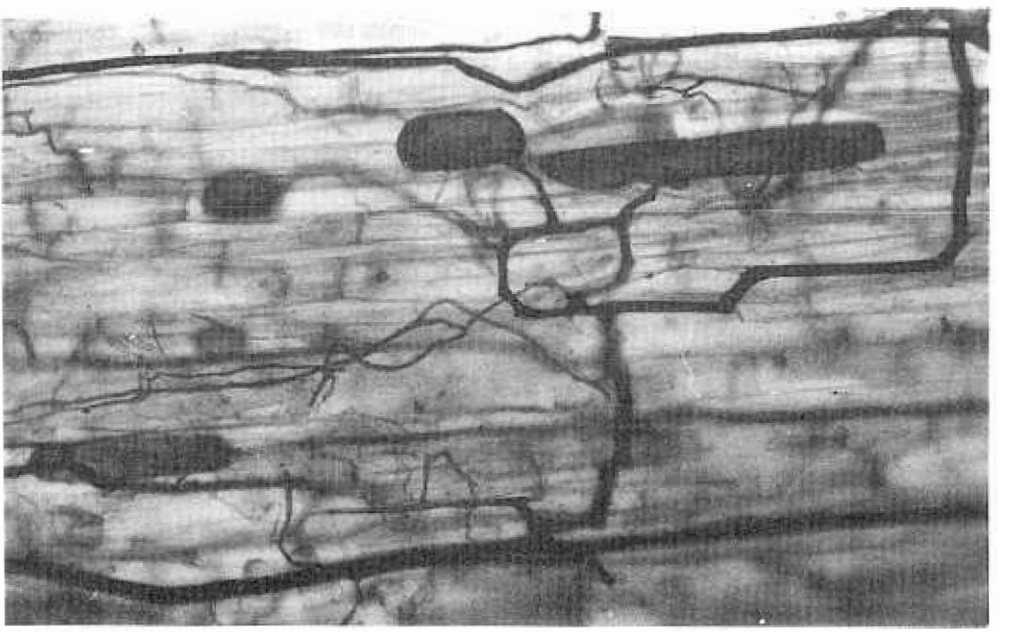


Fig. 15. Another view of hyphae and vesicles (note the variation in the shape of vesicles)

maximum increase in height (183%over control), shoot and root dry mass (278%and 267% respectively), total P content (140%) and mycorrhizal colonization (405036). Acaulospora luevis wasthe next most efficient fungus. The least symbiotic response was observed in the case of G. leptotichum.

2.4. Discussion

2.4.1. Type of association and extent of colonization

The widespread occurrence of VA mycorrhizae and their presence in the great majority of vascular plants are well established (Harley and Smith, 1983). The high colonization of acacia roots by VAM fungi, as evident from the present study, indicates that the plant is mycorrhiza-dependent for its establishment and growth. The association would be of substantial benefit to the plant to thrive better in degraded and unfertile soils. The occurrence of VA mycorrhizal association in A. auriculiformis has also been reported by Norani (1983) and Reddell and Warren (1986).

Table 14. VAM fungi identifed from various Acacia plantations in Kerala

	Fungi	Sampling sites						Frequency
		1	2	3	4	5	6	(%)
1.	Gigaspora sp.	+		-	-	-	-	17
2.	Glomus albidum Walker & Rhodes		+			-	-	17
3.	G. laroideum Schenck & Smith			+	+			33
4.	G. formosanum Wu & Chen					+	+	33
5.	G. fasciculatum (Thaxter Sensu Gerd.) Gerd. & Trappe	+	+		+	+		67
6.	G. heterosporum Smith & Schenck		+	+		+		50
7.	G. intraradices Schenck & Smith	+	+	+		+		67
8.	G. macrocarpum Tul. & Tul.			+		+	+	50
9.	G. radiatum (Thaxter) Trappe & Gerd.	+	+	+	+		+	83
10.	Glomus sp.1				+		+	33
11.	Glomus sp.2	+		+				33

t =present; - = absent

Sampling sites: (1) Chettikulam, (2) Kannamkuzhi, (3) Kothermanakkadu, (4) Kuttappalam, (5) Keezhur, (6) Veettoor

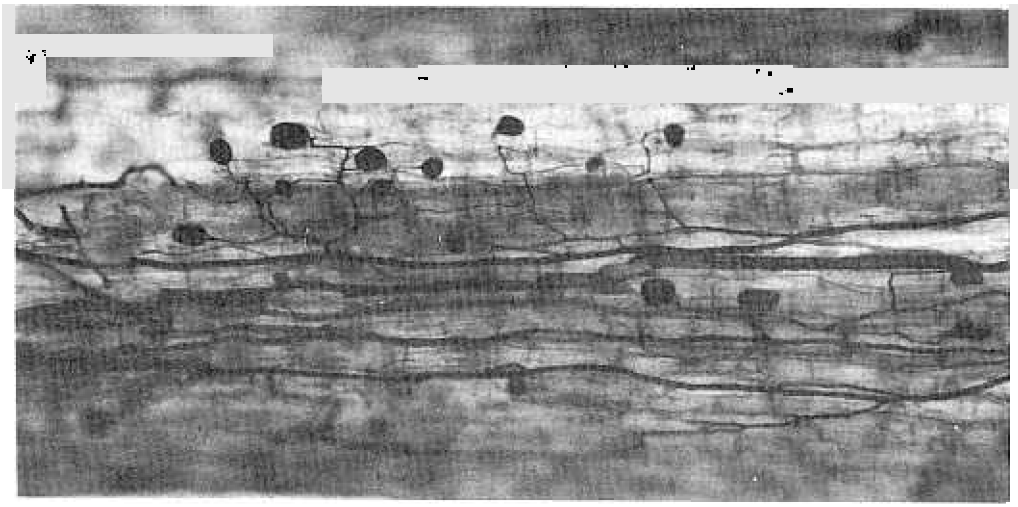


Fig. 16. Note hyphal colonization (of VAM fungi) in roots of acacia - vesicles are also seen

Fig. 17. Root system of acacia showing nodulations (arrows)

The relationship between levels of mycorrhizal colonization and soil physical and chemical properties is reported to be markedly variable (Sparling and Tinker, 1978; Jeffries *et al*,, 1988). High level infection has been observed over a wide range of soil pH (Read *et al.*, 1976) and soil phosphate levels (Jueffries *et a1*., 1988). The lack of correlation between extractable phosphate levels and soil pH and extent of colonization by VAM fungi has been reported by several workers (Sparling and Tinker, 1978; Hayman, 1978). The results of the present study are in agreement with these reports. As the climatic factors, soil microflora and fauna and a host of other variables are known to play a role in mycorrhizal colonization, the chance of these factors nullifying the influence of one or the other would be high in any ecosystem. This may be the reason why no torrelation could be detected between soil nutrient status and VAM colonization.

A positive correlation between silt content, clay content and porosity of soil and level of VAM infection can be ascribed to the positive influence of these factors on soil moisture and nutrient relationships facilitating enhanced root proliferation. The bulk density of soil was negatively correlated with extent of colonization. This may be due to the effect of bulk density on soil compaction. Mulligan *et al.* (1985) have reported that an increase in soil compaction and resultant decrease in root growth would decrease level of infection by VAM fungi.

Table 15. Response of Acacia to inoculation with different VAM fungi

VAM fungi**	Plant height (cm)	Shoot dry wt. (mg)	Root dry wt. (mg)	Total P (%)	Mycorrhizal colonization (%)
Glomusfasciculatum	24.2[a]*	540[a]	80[a]	0.42[a]	81"
Acaulospora laevis	21.5[b]	361[b]	60[b]	0.39[ab]	47b
Glomus mosseae	21.3[bc]	383[b]	62[b]	0.34[bc]	54c
G. aggregatum	20.7[c]	330[bc]	51[b]	0.34[bc]	30d
G. leptotichum	18.0[d]	292[c]	55[b]	0.30[c]	30d
Uninoculated	13.2[c]	194[d]	30[c]	0.30[c]	

* Values with similar superscript(s) in each column do not differ significantly at 1%.

** Cultures of **G.** fasciculatum, G. mosseae and G. aggregatum were obtained from BAIF Development Research Foundation, Pune, India, and G. leptotichum and A. laevis from Dr. D.J. Bagyaraj, University of Agricultural Sciences, Bangalore, India.

The low level of colonization by VAM in sandy soils at Kochuveli may be associated with low organic carbon content (0.15%) and high disturbance of the soil due to human interference. Disturbance to soil is known to decrease mycorrhizal infection either through a change in physical, chemical and biological environment of the soil or

through an unfavourable effect on plant growth (Evans and Miller, 1988; Jasper *et al.*, 1989b). A reduction in the extent of infection in certain degraded sites like Eloor and Thekkumala can also be related to disturbance of soil. At Vallarpadam (the other study site with sandy soil) the soil was less disturbed and OC content was high (0.54%) compared to that of Kochuveli. A relationship between OC content of sand dunes and VAM infection was reported by Nicolson (1960).

2.4.2. VAM fungi in Acacia plantations

Species of the genus *Glomus* were the dominant VAM fungi in acacia plantations in Kerala. According to Schenck and Perez (1987) *Glomus* spp. are very common in cultivated soils and widespread in native grasslands and forests. The dominance of *Glomus* spp. in Indian soils has been reported by several workers (Rani and Mukherji, 1988; Ganesan *et al.*, 1990; Baby and Manibhushan Rao, 1992). The occurrence of *Glomus fasciculatum, G. claroideum, G. formosanum, G. macrocarpum* and *G. intraradices* in Kerala soils has also been recorded by Baby and Manibhushan Rao (1992). *Glomus albidum, G. claroideum, G. intraradices, G. heterosporum* and *G. fasciculatum* recorded during this study were reported from soils in Tamil Nadu also (Ganesan *et al.*, 1990). Baby and Manibhushan Rao (1992) found *G. fasciculatum* as the most dominant species in the rice fields in Kerala. In the present study, *G. fasciculatum* was recorded as the second dominant fungus. It is felt that further intensive collections from diverse areas would be essential for getting a more conclusive picture on the VAM flora of acacia plantations in Kerala.

2.4.3. Selection of an efficient VAM fungus for Acacia

The increase in growth and shoot and root dry mass of inoculated plants may be due to the enhanced nutrient uptake, especially phosphorus, through the mycorrhizal association. This positive response to mycorrhizal inoculation is typical of many mycorrhiza-dependent plants grown on P deficient soils (Punjand Gupta, 1988; Bagyaraj *et al.*, 1989).

The increase in biomass of acacia seedlings due to inoculation with VAM fungi was reported by Aggangan *et al.* (1987) and Cruz *et al.* (1988) from Philippines, Chang *et al.* (1986) from China and Mohammed and Singh (1988) from India. Chang *et al.* (1986) and Mohammed and Singh (1988) reported *G. fasciculatum* as the most efficient inoculant for acacia. Aggangan *et al.* (1987) described *G. etunicatum* and *G. macrocarpum* as more effective than *G. fasciculatum*. Cruz *et al.* (1988) found *Gigaspora persica*, along with *Rhizobium* as the most suitable inoculant for enhancing growth of acacia. However, a comparison of these results with the present observations is not worthwhile, as the ability for stimulating plant growth is known to vary widely among and within different species (Abbott and Robson, 1978).

Based on the present study, use of *G. fasciculatum* as an inoculant VAM fungus for *Acacia auriculiformis* is found to be promising.

3. ROOT NODULATION

3.1. Introduction

The ability of *A. auriculiformis* to form root nodules and fix atmospheric nitrogen is reported by several authors from different countries (Dreyfus and Dommergues, 1981; Ding *et al.*, 1986; Roughley, 1987; Xiangquan and Sufeng, 1987; Siddiqui, 1989; Sufeng and Xiangquan, 1991). However, no systematic study had been carried out on the nodulation of *Acacia auriculiformis* in Kerala, even though several hectares of degraded forests and wastelands have been planted with this species. Hence the present study is conducted with the objective of assessing the status of root nodulation of acacia trees growing in plantations raised in wastelands and degraded soils of diverse topography and nutrient status. The effect of seed inoculation with *Rhizobium* on the growth and biomass of seedlings has also been assessed.

3.2. Materials and Methods

3.2.1. Selection of plantations to assess the nodulation status

In order to assess the status of root nodulation in Kerala, 26 pure stands of acacia (Table 16), each having more than 5 ha area were identified. The locations of the selected plantations were such that they represented the topography of the degraded forests and wastelands of Kerala State.

3.2.2. Method of sampling

Soil was collected using soil core sampler, 15 cm long and approximately 3.5 cm diam. An initial trial was carried out in order to fix the depth of soil to be sampled and also the distance from the base of a tree. Soil samples were collected from a depth of 5, 10, 15 and 20 cm at a distance of 10, 20, 30, 40, 50 and 60 cm from the basal region of a tree. Five samples were collected from the base of each tree from five locations around the tree and there were six replicates (trees), This trial was carried out in a 4-year-old plantation near Nilambur where the soil was gravelly sandy. Each soil sample was sieved in a 2 mm mesh sieve over water and the number of nodules enumerated. Analysis of the results showed that the number of nodules was greater between 20 and 30 cm away from the base and 90 % of the nodules were from 0 - 10 cm depth. Hence, soil samples were taken from a distance of 25 cm from the base and up to a depth of 0 - 10 cm for assessment of root nodulation.

3.2.3. Assessment of nodulation

In each of the 26 plantations, a representative site was located after

tion. Soil samples were collected from the base of 12 trees from each plantation as mentioned earlier and there were 60 samples from one plantation. Soil samples were sieved using 2 mm mesh sieve keeping the sieve over water, so as to minimise the disturbance to the nodules attached to the fine roots. The nodules were enumerated and their size and shape noted. GBH of 50 trees at the sampling site was measured and recorded.

3.2.4. Isolation of *Rhizobium*

Large and healthy nodules were collected from the samples and taken to the laboratory for isolation of Rhizobium. The nodules were thoroughly washed and surface-sterilized with 0.01% mercuric chloride solution. Rhizobium was isolated by a method suggested by Vincent (1970). The cultures were preserved on Yeast Mannitol Agar slants,

3.2.5. Effect of *Rhizobium* inoculation on root nodulation and seedling biomass

The efficiency of *Rhizobium* isolates in producing root nodulations was tested in greenhouse experiment. Surface-sterilized, scarified seeds were soaked in sterilized water for 24 h. The seeds were pelleted with adequate quantity of pelleting mixture containing *Rhizobium* culture in yeast mannitol broth, sterilised peat soil, calcium carbonate and carboxy methyl cellulose as sticking agent (Vincent, 1970). Pelleted seeds were sown in poly bags containing thoroughly washed river sand. The poly bags were watered with required quantity of nutrient solution (Vincent, 1970). All the 26 isolates were used for the test and suitable controls were maintained by pelletisation of seeds excluding *Rhizobium* culture. Twenty five poly bags were maintained for each treatment. After three months of growth, the seedlings were removed and number of nodules counted. The seedlings were oven-dried and the biomass recorded. The isolates were ranked based on the biomass and number of nodules.

3.3. Results and Discussion

3.3.1. Size and pattern of nodulation

The size of nodules ranged from 2 to 10 mm. The shape varied from round to finger-shaped (Fig.17) and corallpid to astragalloid. Small nodules were usually found in sandy to sandy loam soil. Some of such nodules were too small and lacked the typical pink pigmentation of leghaemoglobin. Apparently such nodules were non-functional. Most of the nodules were found attached to fine roots generally within 0 - 5 cm layer of soil. Nodules were also found under decaying litter, interspersed with a network of fine roots. Coralloid nodules were seen at Chettikulam, Kothermanakkadu and Vallarpadam, and astragalloid nodules at Kochuveli.

3.3.2.Number of nodules

Table 16 provides the number of nodules per 100 cm^3 of soil from all the 26 localities. Acacia planted in all the 26 localities nodulated. The average number of nodules/100 cm^3 soil ranged between 1.42 arid 33.85. The presence of several nodules in such a small quantity of soil indicated that acacia nodulated well in Kerala soils, though the number of nodules varied from place to place. The highest number of nodules (33.85/100 cm^3 of soil) was obtained Irom a 6-year- old plantation at Chettikulam. This was followed by a 4-year-old plantation with sandy soil at Kochuveli (27.12/100 cm^3 of soil) and degraded soils of Periivannamoozhy (24.00/100 cm^3 of soil), Table 17 gives correlation coefficients between the number of nodules and some of the important physical and chemical characters of soil from 0 - 20 cm layer (see Chapter 4). When data from 25 locations were considered (excluding Chembikunnu), a significant negative correlation ($P < 0.05$) was obtained between the number of nodules and the amount of organic carbon (OC). From the table it can also be seen that generally there is a negative correlation between the number of nodules and pH, exchange acidity, exchange bases, silt, porosity, maximum water holding capacity (MWHC), etc. Soil samples from 23 localities (for details see Chapter 4) were analysed for soil nutrients. Correlation coefficients between root nodules and soil nutrients were computed for those localities only (Table I8), From Tables 17 and 18 it can be seen that correlation coefficients are negative for most of the nutrients viz., nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg) and organic carbon (OC) and also for C/N ratio. The same trend is shown by all the values when the data from 4-year-old plantations are considered separately (Table 19).

The consistent negative correlation between number of nodules and soil nutrients and other characters indicated that root nodulation in acacia responded positively to stress conditions of the soil. Stress conditions are generally an inherent feature of degraded soils consequent to soil erosion, leaching and laterisation. The present data gives an indication that there is an inverse relationship between soil fertility and nodulation. Hence, the plant's ability to fix atmospheric nitrogen will be more evident when planted in degraded soils. This is in accordance with the general belief that acacia is more suitable for degraded soils. The significant negative correlation between organic carbon (OC) and number of nodules (Table 17) is important. Probably this might be the reason why the number of nodules was lower at localities like Kannamkuzhi, Kuttappalam, Mangapetta, Rajampara, etc. which are adjacent to natural forests and are with medium fertile soil (Table 16).

Though a negative correlation coefficient was obtained between soil pH and number of nodules, the values were not significant indicating that even though pH values of more than 90% of plantations were below 5.5, the soil acidity did not affect the root nodulation potential significantly. This positive aspect is a highly desirable character of acacia for planting in degraded soils of Kerala where the soil pH is usually less than 5.5.

Tablel6. Number of nodules/100 cm^3 of soil contained in the soil samples collected from the various Acacia plantations of Kerala.

SI. No.	Name of plantation	Year of planting	Social Forestry Division	GBH of trees* (cm)	No. of nodules/ 100 cm^3 of soil**	Soil PH
1	Chcttikulam	1984	Trichu	30.2	33.85	4.5
2	Kochuveli	1986	Trivandruni	27.2	27.12	5.0
3	Peruvannamoozhy	1986	Calicut	19.9	24.00	4.6
4	Karapuzha	1986	Wayanad	22.9	22.30	4.5
5	Kothermanakkadu	1986	Palghat	23.2	17.41	5.0
6	Muthalakuzhy	1986	Malappuram	20.6	16.33	4.9
7	Veettur	1985	Ernakulam	21.9	10.80	4.7
8	Chandanathodc	1986	Wayanad	17.9	8.83	4.8
9	Pothumattom	1985	Idukki	18.5	8.75	5.1
10	Chcnihikkunnu	1984	Trichur	28.4	8.10	4.6
11	Chuliyamala	1986	Trivandrum	27.8	7.73	4.3
12	Vallarpadam	1985	Ernakulam	33.7	7.33	7.2
13	Cheri	1986	Idukki	15.2	7.20	4.8
14	Chembuthangi	1985	Trivandrum	20.1	6.92	4.7
15	Eloor	1985	Ernakulam	23.9	6.86	4.7
16	PTP Nagar	1987	Trivandrum	11.8	6.58	4.9
17	Kararakunnu	1985	Qtuilon	24.4	6.37	4.8
18	Kannamkuzhi	1986	Trichur	22.5	5.94	5.1
19	Rajampara	1986	Pathanamthitta	23.0	5.23	4.9
20	Thekkumala	1986	Pathanamthitta	20.2	5.22	4.5
21	Palamara coup	1986	Palghat	16.5	4.12	6.0
22	Kuttappalam	1985	Cannanore	20.2	3.58	5.0
23	Maruthilavu	1986	Calicut	23.3	3.40	5.0
24	Mangapctta	1986	Kottyam	20.9	2.48	4.8
25	Par iyaram	1986	Cannanore	19.3	1.58	4.7
26	Keezhoor	1986	Cannanore	22.9	1.42	4.7

*Average of 50 trees; **Average of 60 values

Table 17. Correlation coefficient between the number of nodules and GBH, and physical and chemical properties of soil (data from 25 locations)

Corrcla-lions	pH	Exchange acidity	Exchange bases	OC	Gravel	Sand	Sill	Clay	BD	PD	Poro-sity	MWHC	No. of nodules
No.of nodules	-.1888	-2209	-3380	-.4436*	.0388	-.0001	-2348	-.0012	.3283	,3893	-.1079	-.1150	1.000
GBH	,2607	-.1456	-.2769	-.1504	-.2294	3115	-.2856	-.1890	3166	.1187	-.2568	-.3520	.3527

*Significant at 5% level

Table 18. Correlation coefficient (r*)between the number of nodules and GBH, and soil nutrients irrespective of age of plantation (data from 23 locations)

Correlations	N	P	K	Ca	Mg	C/N
No. of nodules	-.1764	,0210	-.0138	-.1584	-.1449	-.3001
GBH	-.0059	-.0323	-.0102	-.0255	-.1725	.1953

*r = 0.413 with 21 d.f at P< 0.05

Table 19. Correlation coefficient (r*)between the number of nodules and GBH, and soil nutrients for 4year-old plantations (data from 14 locations)

Correlations	N	P	K	Ca	Mg	C/N
No. of nodules	-.1460	.0902	-.1730	-.3061	-.1350	-.1759
GBH	-4413	,1178	-.0221	-.0626	-.3973	.2776

*r = 0.532 with 12 d.f. at P < 0.05

This is in contrast to the undesirable attribute of *Leucaena leucocephala,* which has poor root nodulation potential below pH 5.5 (Balasundaran and Mohamed Ali, 1987).

3.3.3. Tree girth and nodule number

Girth of trees measured at breast height (GBH) showed a positive correlation with number of nodules, but the values were not statistically significant. Positive correlations were also found between GBH and pH, and GBH and percentage of sand (Table 17).

According to the data available from the study, there is an inverse relationship between soil nutrients (ie. soil fertility) and number of root nodules. Hence, in a medium fertile soil where the number of root nodules are less, the contribution of N from root nodulation and nitrogen fixation is expected to be minimum. In such soils where soil nitrogen is freely available, the plant will utilize it without going for root nodulation and nitrogen fixation. Consequently, there will be a depletion of soil nitrogen if the tree is cut and the entire biomass removed. Hence, in order to exploit the desirable attribute of atmospheric nitrogen fixation, acacia has to be planted in localities with degraded

unfertile soils. This is well evident from Table 16 also, where it can be found that higher number of nodules are reported mostly from degraded areas and sandy localities.

3.3.4. *Rhizobium* inoculation, root nodulation and seedling biomass

The number of nodules observed on roots of seedlings raised from the seeds inoculated with the different isolates were significantly different ($P < 0.05$) from each other (Table 20).

Table 20. Effect of *Rhizobium* inoculation on root nodulation and seedling biomass (mean of 25 values)

sl. No.	Locality	Nodules/plant	Biomas/plant (g)
1.	Peruvannamoozhy	6.12 a*	0.144 a
2.	Chettikulam	4.14 b	0.115 b
3.	Chembikkunnu	4.05 bc	0.104 bcdef
4.	Cheri	3.80 bcd	0.114 bc
5.	PTP Nagar	3.75 bcde	0.116 b
6.	Mangapetta	3.69 bcde	0.113 bcd
7.	Pariyaram	3.55 bcde	0.099 bcdefg
8.	Keezhoor	3.42 bcde	0.099 bcdefg
9.	Eloor	3.33 bcde	0.084 efghi
10.	Chandanathodu	3.20 bcde	0.107 bcde
11.	Veettur	3.17 bcdef	0.085 efghij
12.	Rajampara	3.13 bcdef	0.082 fghij
13.	Muthalakuzhi	3.07 bcdefg	0.083 fghij
14.	Chuliyamala	2.96 bcdefg	0.090 defghi
15.	Vallarpadam	2.88 bcdefgh	0.069 ijk
16.	Kararakunnu	2.87 bcdefgh	0.097 bcdefg
17.	Maruthilavu	2.82 cdefgh	0.106 bcde
18.	Kochuveli	2.76 defgh	0.086 efghij
19.	Palamara coup	2.73 defgh	0.062 jk
20.	Chembuthangi	2.69 defgh	0.091 cdefgh
21.	Kannamkuzhi	2.58 efgh	0.096 bcdefg
22.	Kuttappalam	2.51 efgh	0.074 hij
23.	Thekkumala	2.33 efgh	0.087 efghij
24.	Karapuzha	2.29 efgh	0.090 defgh
25.	Kothermanakkadu	2.18 fgh	0.060 jk
26.	Pothumattom	2.14 gh	0.079 ghi
27.	Control	2.00 h	0.054 k

*Any two means having a common letter are not significantly different at 5% level of significance (Duncan's multiple range test)

Thoughcontrol seedlingsalso produced nodules they were the lowest in number. The nodules formed on the roots of control seedlings might be due to native *Rhizobium* present in the sand, or the nodules might be non-functional. Among the inoculated *Rhizobium* isolates, those from Peruvannamoozhy produced the largest number of nodules per plant and isolates from Pothumattom the lowest.

Generally, the biomass of seedlings raised from *Rhizobium* inoculated seeds was significantly higher than that of the non-inoculated (control) seeds. Seedlings raised from seeds inoculated with *Rhizobium* isolated from Peruvannamoozhy showed the highest biomass also. The improvement in seedling biomass varied significantly indicating that the efficiency of *Rhizobium* in improving the seedling biomass also varied. The significant positive correlation between the number of nodules and seedling biomass ($r = 0.8169 > P = 0.01$ with d.f 25) indicates that the number of nodules have a beneficial effect on increasing the seedling biomass. Thus the results confirm that there will be significant improvement in the root nodulation and seedling biomass if acacia seeds are pelleted with efficient *Rhizobium* culture.

4. SOIL STUDIES

4.1. Introduction

Acacia auriculiformis is reported to occur and grow well in a wide range of soils. It has been found to thrive on acid soils as well as saline and alkaline soils (Banerjee, 1973; Hu *etal.*, 1983; Tomar and Gupta, 1985; Khandiya, 1987) though contrary observations were also reported (Gupta *et al.*, 1986 Totey *et al.*, 1987). Acacia is known to perform well even in very poor soils (Banerjee, 1973; I'rasad and Chadhar, 1987; Yang *et al.*, 1991) and is drought resistant (Glover and Heuveldop, 1985; Babu *et al.*, 1987). It has also been reported to improve soil (Swamy, 1989; Yap, 1987; Chakraborty and Chakraborty, 1989; Zheng *et al.*, 1989; Ohta, 1990) but Byju (1989) from his studies in Kerala arrived at the conclusion that acacia monoculture has very deleterious impact on soil. The present investigation was taken up with the intention of characterising the soils in acacia plantations of Kerala and comparing them with adjacent fallow land to ascertain the effect of this species on soils.

4.2. Study Area and Methodology

Soil samples were collected from 23 plantations of acacia distributed throughout the State. Table 13 gives details on location and age of the trees in the plantations. Soils collected from Vallarpadam and Kochuveli could not be included due to lack of comparability between acacia and adjacent fallow land and no sample was collected from Chembikkunnu. The climate of Kerala in general is warm, humid with a dry cool spell from December to February and hot summer from March to May. The State enjoys both south-west and north-east monsoons receiving an average annual rainfall of 2000-3500 mm. Day temperatures vary from 18 to 4O°C The hills belong to the crystalline rocks of Archaean age comprising chiefly of granitic gneisses and charnockites though biotite gneisses are also not uncommon (GSI, 1976). The soils in general are well drained reddish-yellowish oxisols.

Representative soil pits were dug to a depth of 60 cm and soil samples collected from 0-20, 20-40 and 40-60 cm 1ayers. Three soil pits each were taken in acacia plantations and adjacent fallow respectively. Core samples were collected separately for bulk density and big clods for aggregate stability estimation. Soil samples were air dried, passed through 2 mm sieve and subjected to analyses following procedures given in ASA Monograph (1965) and Jackson (1973). Sand, silt and clay (.02-2, ,002-.02 and < .002mm) were determined by hydrometer and particle density (I'D) by using standard flask. Bulk density (BD) and maximum water holding capacity (MWHC) were estimated gravimetrically. Water stable aggregates were quantified using a Yoder type wet sieving apparatus; pH in 20:40 soil-water suspension and organic carbon (OC) by potassium

dichromate-sulphuric acid wet digestion. Exchange acidity (EA) was determined by 0.5 N barium acetate and exchangeable bases by 0.1 N hydrochloric acid. Available nitrogen (N) was estimated by alkaline permanganate; extractable phosphorus (P) by vanado molybdo phosphoric acid blue colour; exchangeable potassium (K) by colorimeter and exchangeable calcium (Ca) and magnesium (Mg) by EDTA titrimetry. Mean weight diameter (MWD) was calculated using the formula MWD = $\varepsilon x_i w_i$ where x_i is the mean diameter of a particular size class and w_i is the weight in that range as a fraction of the total sample weight. Nitrogen content of leaf litter was determined by microkjeldahl method while phosphorus, potassium, calcium and magnesium were extracted by tri acid method and assayed following methods given earlier.

4.3. Results and Discussion

4.3.1. Soil physical properties in Acacia plantations

Soil physical properties such as texture (gravel, sand, silt and clay contents), BD, PD, porosity and MWHC are depicted in Table 21. Most of the sites were gravelly sandy loam in texture. The gravel content increased while that of sand decreased with depth. The finer soil separates, namely silt and clay, increased first and then decreased with depth. BD was lowest in the surface and it increased consistently down the soil pit while PD did not show any definite trend, Porosity followed the trend of BD but MWHC was higher in the subsurface soil.

Greater amounts of sand and lesser amounts of finer soil separates in the surface soil can be due to either or both of the following reasons. Finer separates might have been lost from the surface soil during plantation establishment through surface run-off or they might have migrated down the soil profile resulting in their accumulation, especially clay, in the lower horizons. Higher OC coupled with the activity of roots and other organisms might explain the porosity which is seen to be more in the surface layers. However, MWHC is less in the surface soil in spite of higher levels of OC and porosity, This may be due to the greater amounts of finer soil separates in the lower horizons which will contribute to the formation of more micropores which will hold more water by capillary force. In addition, the fact that ferralsols contain large amounts of iron and aluminium, the hydroxides of which are capable of holding water, may further explain the matter.

4.3.2. Soil chemical properties in Acacia plantations

Chemical properties of soil, viz., pH, OC, EA, EB, available N and extractable P, K, Ca and Mg are given in Table 22. The reaction of the soil was acidic; the surface soil being slightly more acidic than the subsurface. OC and EA decreased with depth while EB showed an increasing trend and this seems to be reflected in the pH value. N, P and

K were more in the surface and their contents diminished down the soilpit. The content of Ca increased with depth while that of Mg increased first and then decreased.

The higher levels of N, P and K in the surface soil may be due to higher organic activity and nutrient mineralization. Ca and Mg contents, on the contrary, are more in the subsurface indicating leaching on the one hand and lower rates of cycling of these nutrients on the other.

Table 21. Soil physical properties in Acacia plantations

Soil depth (cm)	Gravel	Sand	Silt	Clay	Silt t Clay	BD	PD	Pore sity	MWHC
		g/kg				g/cm^3		%	
00-20	260 (160)*	578 (145)	72 (30)	90 (32)	162 (55)	1.35 (0.07)	2.42 (0.08)	44.3 (3.6)	22.3 (5.7)
20-40	338 (200)	490 (164)	72 (29)	100 (39)	172 (58)	1.43 (0.08)	2.45 (0.11).	41.4 (3.9)	25.7 (6.9)
4060	390 (200)	446 (161)	68 (31)	96 (43)	164 (56)	1.52 (0.08)	2.42 (0.07)	36.9 (3.8)	24.7 (8.3)

n = 23

*Figures in parentheses indicate standaddeviation

Table 22. Soil chemical properties in Acacia plantations

Soil depth (cm)	pH	OC g/kg	EA	EB	N	P	K	Ca	Mg
			me/kg				mg/kg		
00-20	4.7 (0.20)''	11.9 (5.8)	64.9 (23.3)	36.1 (25.5)	133.6 (59.8)	4.25 (3.44)	128 **(66)**	297 (183)	216 (166)
2040	4.8 (0.24)	7.8 4.6	53.8 (22.5)	50.6 (35.9	103.3 (59.7)	1.88 (0.9)	92.8 (70.2)	325 (198)	265 (208)
40.60	4.8 (0.20)	5.2 (3.1)	40.9 (19.7)	37.4 (28.4)	67.6 (35)	1.77 (1.24)	86.8 (58.7)	338 (206)	212 (206)

n = 23

*Figures in parentheses indicate standard deviation

4.3.3. Comparison of soil physical properties of Acacia plantations with adjacent fallow land

Soil physical properties such as texture (gravel, sand, silt and clay), BD, PD, porosity and MWHC in acacia plantations and comparable adjacent fallow land have been determined and subjected to a statistical comparison (Table 23). None of the physical properties did show any significant difference though a few trends are worthy of mention, Among the coarser soil separates, gravel was more in acacia plantation while sand in fallow land. This pattern remained unchanged with depth. The finer soil separates, namely, silt & clay was less in the surface soil of acacia as compared to fallow though reverse was the case in the succeeding depths. BD was slightly less in plantation soil, both in the 0 - 20 and 20 - 40 cm layers. Though not significant, this points to the loosening of soil which may be due to the activity of roots. PD did not follow any definite pattern. Porosity remained almost the same in both cases while MWHC was slightly higher in the lower depths of acacia plantations. Higher levels of finer separates in the subsurface horizons could probably have contributed to this difference.

4.3.4. Comparison of soil chemical properties of Acacia plantations with adjacent fallow land

Soil chemical properties like pH, OC, EA, EB, available N and extractable P, K, Ca and Mg have been determined in acacia plantations and adjacent fallow and a comparison attempted (Table 24). None of the chemical properties were significantly different, except pH which was significantly lower in acacia soil. This was true in all the three depths also. OC was more in fallow than acacia, especially in the surface layers: it decreased with depth in both cases. EA did not follow any definite pattern while higher values of EB were obtained in fallow. EA decreased with depth but EB increased in the 20 - 40 and then decreased in the 40 - 60 cm layer irrespective of the vegetation. N was slightly more in the fallow surface soil. The pattern got reversed in the 20 - 40 cm layer and then followed the pattern of surface soil in the 40- 60 cm layer. P, on the other hand, was more in acacia soil as compared to fallow, especially in the surface soil. K was similar to P in its distribution. It was more in the upper layers (0-20 and 20 - 40 cm) of acacia soil. The content of Ca was more in the fallow surface while in the lower layers it was more in acacia soil. Fallow soil had higher levels of Mg in all the three soil layers and in both acacia and fallow land its content decreased with depth.

The flux in nutrients between soil and the plant may not be one favouring equilibrium or it may take more years than the age of the plants (4 years) considered in the present study. Similar view was expressed by Adams and Attiwill (1984) in their statement "large amounts of N, Ca, Mg and K are immobilized in acacia biomass, much of which is returned to the soil after canopy closure". The lower levels of exchangeable bases in acacia soils lend support to the lower pH values. *Acacia holosericea* has been found to accumulate calcium (Langkamp and Dalling, 1983), while Gill *et al.* (1987)

Table 23. Comparison between Acacia plantations and adjacent fallow - soil physical properties

Soil depth (cm)	Gravel		Sand		Silt		Clay		Silt+Clay		BD		PD		Porosity		MWHC	
	g/kg										g/cm^3				%			
	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F
00-20	268	257	578	588	65	74	88	82	153	156	1.34	1.37	2.41	2.44	44	44	23	23
	(168)''	(186)	(150)	(145)	(18)	(21)	(24)	(41)	(34)	(59)	(0.07)	(0.09)	(0.07)	(0.14)	(3.3)	(4.2)	(5)	(6)
2040	356	349	481	496	68	69	94	84	162	153	1.42	1.45	2.47	2.44	42	40	28	23
	(230)	(236)	(197)	(191)	(29)	(28)	(31)	(40)	(45)	(63)	(0.09)	(0.08)	(0.12)	(0.16)	(3.6)	(5.2)	(6)	(5)
40-60	388	384	454	470	68	59	89	85	157	144	1.50	1.50	2.42	2.47	37	38	26	24
	(236)	(182)	(193)	(155)	(33)	(26)	(39)	(44)	(53)	(66)	(0.09)	(0.08)	(0.08)	(0.15)	(4.1)	(3.9)	(8)	(6)

n = 12; A= Acacia; F = Fallow

*Figures in parentheses indicate standard deviation

Table 24. Comparison between Acacia plantations and adjacent fallow - soil chemical properties

Soil depth (cm)	pH		OC		EA		EB		N		P		K		Ca		Mg	
			g/kg		me/kg		me/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg	
	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F
0020	4.7	5.0''	10.6	12.9	61.3	61.0	41.0	49.3	126	132	3.9	2.8	153	131	305	431	265	311
	(0.2)'	(0.3)	(6.4)	(7.4)	(22)	(17)	(32)	(61)	(55)	(79)	(3)	(1)	(59)	(69)	(179)	(243)	(208	(269)
2040	4.7	4.9*	7.0	7.0	51.7	47.8	44.0	56.5	108	104	1.7	1.8	115	106	305	304	257	271
	(0.2)	(0.2)	(5.7)	(4.3)	(26)	(21)	(31)	(44)	(72)	(51)	(0.8)	(1.2)	(79)	(62)	(189)	(161)	(254)	(274)
40-60	4.8	4.9*	4.6	5.0	40.5	43.0	32.0	42.0	74	84	2.0	1.6	106	113	354	337	192	273
	(0.1)	(0.2)	(3.6)	(3.0)	(24)	(19)	(35)	(30)	(43)	(49)	(1.4)	(0.8)	(64)	(54)	(210)	(195)	(239)	(304)

n = 12; ''Figures in parentheses denote standard deviation

*P< 0.05; A = Acacia; F = Fallow

observed more N, P, S and K and less Ca, Mg and Na in leaf litter of Acacia nilotica when compared with Eucalyptus tereticornis. The slightly higher levels of OC, N, Ca and Mg in fallow can be due to the comparatively greater nutrient drain by fast growing acacia coupled with slow litter decomposition (refer Chapter 1). Swamy (1989) also reported lower litter decomposition rates of this species. The fact that N is less in acacia in spite

of good nodulation (refer Chapter 3) lends further credence to the aboveview. But it can also be true that fallow lands with more diversity of flora and fauna might be cycling nutrients more efficiently. The content of P was higher in acacia soil. Mycorrhizal association of acacia roots might have contributed towards this since their activity has been observed in all the localities studied (refer Chapter 2). The reason for slightly higher K in acacia soil is not known.

4.3.5. Comparison of water stable soil aggregates in Acacia plantation with adjacent fallow land

Water stable aggregates in the size class 4.76-6.00 mm was slightly more in acacia soils in the 0 - 20 and 40 - 60 cm layer but in the middle layer fallow land contained more (Table 25). Slightly smaller aggregates (2.00-4.76 mm) were more in the two upper soil 1ayers of acacia. Aggregates of size 1.00-2.00mm showed still another trend-it was more in fallow only in the surface layer. The smallest clods were more in the upper soil layers of acacia as compared with fallow. Large aggregates were seen more in the surface and smaller aggregates increased proportionately with increasing depth. Mean weight diameter (MWD), an index of aggregate stability, was found to be slightly more in acacia as compared to fallow. These results indicate that there is some improvement in soil structure in acacia plantations.

Table 25. Aggregate stability of soil — comparison between Acacia plantations and fallow land

Soil depth (cm)	Size class (mm)	Weight of aggregates in different size classes (g)		Mean weight diameter	
		Acacia	Fallow	Acacia	Fallow
	4.76 - 6.00	30.1	26.4		
	2.00 - 4.76	24.9	24.4	2.67	2.45
00-20					
	1.00 - 2.00	12.1	13.2		
	0.21 - 1.00	3.9	2.1		
	4.76 - 6.00	13.4	14.1		
	2.00 - 4.76	27.1	26.0		
20-40					
	1.00 - 2.00	15.8	14.9	1.90	1.88
	0.21 - 1.00	4.3	3.6		
	4.76 - 6.00	5.6	5.4		
	2.00 - 4.76	20.4	21.6	1.38	1.40
40-60					
	1.00 - 2.00	24.5	23.2		
	0.21 - 1.00	3.4	5.6		

4.3.6 Nutrient content in Acacia leaf litter

Acacia leaf litter from the permanent plots of Chettikulam and Kothermanakkadu was analysed for nutrient contents, the result of Which is given in Table 26. It can be seen that freshly fallen leaf litter of acacia on an average contains 1.38% nitrogen, 0.085% phosphorus, 0.04% potassium, 0.035% calcium and 0.0075% magnesium. Similar values were recorded for N and P (Table 27) by other workers (Kushalapa, 1991; Pande *et al.*, 1987; Sugur, 1989; Swamy, 1989) though the content of bases, namely, K, Ca and Mg obtained in this study was much lower,

Table 26. Nutrient content of Acacia leaf litter from permanent plots

Site	N	P	K	Ca	Mg
			%		
Chettikulam	1.37 (0.20)*	0.09 (0.007)	0.06 (0.005)	0.03 (0.005)	0.006 (0.0006)
Kolharmanakkadu	1.39 (0.20)	0.08 (0.005)	0.02 (0.001)	0.04 (0.005)	0.009 (0.0007)
Mean	1.38	0.085	0.04	0.035	0.0075

n = 10; *Figures in parentheses denote standard deviation

Table 27. Nutrient content of Acacia leaf litter reported in other studies

Location	N	P	K	Ca	Mg	Reference
			%			
Karnataka	1.221	0.061	0.296	2.440	0.669	Kushalapa, 1991
Karnataka	1.230	0.109	0.740	1.070	1.090	Sugur, 1989
Bihar	2.030	0.030	0.560	0.500	0.120	Pande dab, 1987
Karnataka	1.846	0.089	0.339	2.651	0.522	Swamy, 1989

Considering the very high litterfall of acacia it may be presumed that it returns large amounts of nutrients to the soil. But the results of soil analyses do not support this view. Reasons for this anomaly, though not clear, can be attributed to the slow rate of decomposition of leaf litter on the one hand (refer Chapter 1) and the expected high levels of nutrient drain from the soil considering the very fast rate of biomass production. Among the nutrients in the surface soil, N, Ca and Mg were found to be lesser in acacia plantations as compared to adjacent fallow, while P and K contents were found to be higher in acacia soil, but the differences were not significant. In spite of the heavy litterfall of acacia (refer Chapter l), the OC content of surface soil remained less than that in the adjacent fallow.

5. SUMMARY AND CONCLUSIONS

Litterfall in acacia plantations in Kerala was quantified (for a period of 2 years) using litter traps in plantations at Kothermanakkadu (K) (3- to 4-year-old) in Palghat District and Chettikulam (C) (5 to &year-old) in Trichur District. Annual litter production in the plantations ranged between 9.3 and 12.0 t ha^{-1}. The average annual litterfall was 10.1 t ha^{-1} at site K and 12.0 t ha^{-1} at site C. The litterfall indicated a unimodal pattern with its peak during December-January each year. The dry months (October to March) accounted for higher fraction (67.5 - 76.2%) of litter yield. Total litterfall differed significantly between locations and months. The litter production recorded from acacia plantations was higher than that reported for major forest plantation species like teak, eucalypt, etc. in India and elsewhere.

The rate of decomposition of acacia leaf litter was determined in plantations at Kannamkuzhi and Chettikulam (Trichur District), and Kothermanakkadu (Palghat District) following the mesh bag technique. Decay rate was quantified in two ways - 1) by keeping the litter bags partially buried in the soil (LPB) and 2) by laying them on the surface of soil (LSS) . The dry weight loss of leaf litter (LSS) varied between 64.4 and 86% after a period of 12 months at different sites. The corresponding values for LPB were 94.5% at Chettikulam and 92.6% (after six months) at Kannamkuzhi. Decay rate of acacia litter was faster in fertile sites compared to degraded areas.

In general, the rate of decomposition of acacia leaf litter was slower compared to that of teak, *Xylia xylocarpa, Albizia falcataria, Terminalia paniculata* etc. recorded from Kerala. The observation that the litter partially buried in soil decomposed much faster than litter laid on the surface of soil indicates that periodic raking of soil in acacia plantations would accelerate litter decay. The two major reasons for litter accumulation in acacia plantations are the high litter production and apparent low rate of litter degradation.

Laboratory studies to quantify the addition of organic carbon (OC) to soil during litter decay indicated that significant amount of OC was added to soil during the decomposition of acacia leaf litter.

A survey was conducted in 26 plantations of acacia (distributed throughout the State) to assess the status of mycorrhizal colonization. The results revealed that acacia forms VA mycorrhizal association in Kerala soils. The high level of colonization of acacia roots by VAM fungi showed that the plant is dependent on mycorrhiza for its establishment and growth. The extent of colonization by VAM was correlated with silt content, clay content, porosity and bulk density of soil; it was not correlated with soil nutrient status. *Glomus* spp. were the dominant VAM fungi recorded from acacia plantations. Among the different species of *Glomus, G. rudiatum* was the most frequent.

Five VAM fungi were screened under glasshouse conditions for their efficacy in promoting the growth of acacia seedlings. Of these, *Glomus fasciculatum* was proved to be the most efficient inoculant for acacia.

For assessing the status of root nodulation of acacia in Kerala, soil and root samples were collected from 26 selected plantations. The study clarified that acacia, which is known to fix atmospheric nitrogen, forms root nodules in Kerala soils also. There was an inverse relationship between the number of nodules and soil fertility attributes. Nursery experiments using *Rhizobium* inoculated seedlings indicated signif-cant variation in etficiency of various *Rhizobium* isolates (collected from various plantations) in forming root nodules. There was a direct correlation between number of nodules and seedling biomass in nursery experiment. It can be concluded that the desirable attribute of acacia to fix at mospheric nitrogen can be realised only if it is planted in degraded, unfertile soils. Studies indicated that inoculation of seeds with efficient *Rhizobium* isolates will improve plant growth and biomass.

The physico-chemical characters of soil in acacia plantations were compared with those of adjacent fallows to ascertain the effect of acacia growth on soil properties. Twenty three acacia plantations and their respective adjacent fallows were surveyed for this purpose. Soil analysis revealed that there was no significant difference between acacia plantations and adjacent fallow land in physical and chemical properties of soil as well as soil nutrient contents except in the case of soil pH which was significantly lower in acacia plantations (average pH in acacia plantations, 4.7; fallow lands, 5.0). N, P, K, Ca and Mg contents of acacia leaf litter from the permanent plots were, on an average, 1.38, 0.085, 0.040, 0.035 and 0.0075 %, respectively.

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Appendix- I

List of Casual Plants Collected from Acacia Plantation at Kothermanakkadu

1. *Artocarpus integrifolia* L.
2. *Bombax ceiba* L.
3. *Bridelia retusa* (L,) Spreng.
4. *Calycopteris floribunda* Lam.
5. *Caryota urens* L.
6. *Curculigo orchioides* Gaertn.
7. *Desmodium triflorum* (L.) DC.
8. *Eupatorium odoratum* L.
9. *Evolvulus alsinoides* L.
10. *Grewia microcos* L.
11. *Ichnocarpus frutescens* (L.) Ait. & Ait.f.
12. *Justicia simplex* D. Don
13. *Lantana aculeata* L.
14. *Macaranga peltata* (Roxb.) Muell. Arg.
15. *Naregamia alata* Wight & Am.
16. *Olea dioica* Roxb.
17. *Oplismenus compositus* (L.) Beauv.
18. *Sauropus quadrangularis* (Willd.) Muell. Arg.
19. *Sebastiana chamaelea* (L.) Muell. Arg.
20. *Tabernaemontana divaricata* (L.) R. Br.
21. *Triumfetta rhomboidea* Jacq.
22. *Wattakaka volubilis* (L.f.) Stapf
23. *Zanthoxylum rhetsa* (Roxb.) DC.
24. *Ziziphus oenoplia* (L.) Mill.

List of Casual Plants Collected from Acacia Plantation at Chettikulam

1. *Alstonia scholaris* (L.) R. Br.
2. *Annona squamosa* L.
3. *Aristolochia indica* L.
4. *Artocarpus integrifolia* L.
5. *Asparagus racemosus* Willd.
6. *Bombax ceiba* L.
7. *Cayratia pedata* (Lam.) Juss. ex Gagnep.
8. *Clerodendrum viscosum* Vent.
9. *Costus speciosus* (Koenig) Smith
10. *Desmodium triflorum* (L.) DC.
11. *Elephantopus scaber* L.
12. *Eupatorium odoratum* L.
13. *Ficus hispida* L.f.
14. *Helicteres isora* L.
15. *Hemidesmus indicus* (L.) R. Br.
16. *Hymenodictyon excelsum* Wall.
17. *Hyptis suaveolens* (L.) Poit.
18. *Ichnocarpus frutescens* (L.) Ait. & Ait. f.
19. *Justicia procumbens L.*
20. *Lagerstroemia microcarpa* Wight
21. *Leucas aspera* (Willd.) Spreng.
22. *Naregamia alata* Wight & Arn.
23. *Phaulopsis dorsiflora* (Retz.) Sant.
24. *Rungia parviflora* Nees
25. *Sida rhombifolia* L.
26. *Strychnos nux-vomica* L.
27. *Wattakaka volubilis* (L.f.) Stapf
28. *Wrightia tinctoria* R. Br.
29. *Vitex altissima* L.f.
30. *Ziziphus oenoplia* (L.) Mill.