LEAF LITTER DYNAMICS IN ACACIA AND EUCALYPTUS PLANTATIONS

By

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THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT

FOR THE DEGREE

DOCTOR OF PHILOSOPHY

FACULTY OF AGRICULTURE

KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE

VELLAYANI

THIRUVANANTHAPURAM

1997

DECLARATION

I hereby declare that this thesis entitled "Leaf litter dynamics in Acacia and Eucalyptus plantations" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar little, of any other University or society.

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CERTIFICATE

Certified that this thesis, entitled, "**Leaf litter dynamics in Acacia and Eucalyptus plantations**" is a research work done independently by **Moossa, P.P.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to him.

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ACKNOWLEDGEMENT

I place on record my profound gratitude and indebtedness to Dr. V.K. Venugopal, Associate Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, for identification of the research project, for his sustained and inspiring guidance, critical suggestions and constant encouragement during the course of investigation and in the preparation of this manuscript.

I express my deep sense of gratitude to Dr. Thomas Varghese, Professor and Head, Department of Soil Science and Agricultural Chemistry, Dr. (Mrs.) Alice Abraham, Professor, Department of Soil Science and Agricultural Chemistry, Dr. G. Raghavan Pillai, Professor and Head, Department of Agronomy and Dr. Muraleedharan Nair, Professor, Department of Agronomy as the members of my advisory committee for their valuable guidance, expertise and constant encouragement through out the course of the study.

Heart felt thanks are also due to Dr.(Mrs.) P. Padmaja, Professor and Head (Rtd.) Department of Soil Science and Agricultural Chemistry for her constant encouragement and consideration shown to me during the course of investigation.

My sincere thanks are due to Dr. (Mrs.) P. Saraswathi, Professor and Head, Department of Agricultural Statistics for the valuable advice and Sri. C.E. Ajithkumar, Junior Programmer for the help rendered in the statistical analysis of the data.

I owe immense gratitude to Mr. Sasidharan Nair, I.F.S., Chief Conservator of Forest for alloting the experimental area for the study and Mr. Sainuddheen, forest guard for protecting the experimental material in forest area.

I am grateful to Dr. Nandakumar, Associate Professor, College of Veterinary and Animal Science, Dr. Karthikakutty Amma, Senior Scientist, Rubber Board, Kottayam, Dr. Rugmini, Senior Scientist, R.R.L., Pappanamcode, Dr. Kuruvilla Varghese, M.V.Sc. scholar and Dr. Rajesh, Research Associate, R.R.L., Pappanamcode for the co-operation and help rendered in carrying out the various analyses for the investigation.

I also express my heart felt thanks to Prof. Abdul Hameed, Professor, Department of Soil Science and Agricultural Chemistry, Dr. P. Rajendran, Associate Professor, Department of Soil Science and Agricultural Chemistry, Dr. T. Jiji, Department of Agricultural Entomology and all the staff members of the Department of Soil Science and Agricultural Chemistry for their constant encouragement and kind consideration showed on me through out the period of investigation.

It is my great privilege and pleasure to have the best help, co-operation and encouragement from my friends especially Sreekumar, E.T., Jacob John, Byju, G., Robert, C.P., Sindhu, J., Sreelatha, A.K., Chithra, V.G., Rajani, B., George T. Abraham, Jayakumar, Ramesh, P. and Prasanth, G.

I extend my special thanks to Sri. P.D. Krishnamony, J.D.A., Wayanad, Asha, A., Assistant Soil Chemist, Wayanad and all the members of the soil testing laboratory, Mananthavady for their kind consideration rendered to me during the writing stage of this manuscript.

Words cannot express my indebtedness and gratitude to my parents and family members for their patience and expectations which gave me courage and pushing power at various critical stages of my study.

I place on record my gratitude to Mr. K. Chandrakumar and members of ARDRA for their whole hearted co-operation in the documentation work of the thesis.

I extend my sincere thanks to Kerala Agricultural University for giving me K.A.U. Senior Fellowship for pursuing the studies.

Above all I gratefully bow before the "Allah" for the blessings showered up on me all throughout.

MOOSSA, P.P.

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INTRODUCTION

1. INTRODUCTION

The natural resources of the country are dwindling at an alarming rate. The shrinking land base is being strained too much to produce food and fodder required for our teeming millions. The large scale felling of trees has shattered the delicately balanced and dynamic ecosystem followed by a series of catastrophic events like erosion, flood and desertification.

In India at the current rate of deforestation of 1.2 lakh hectares per year, the present forest cover of 63.9 million hectares will become a sad memory for the future generation (Forest Survey of India 1991). WIth the twin problems of unsatisfied basic needs and ecological unstability, the regeneration of Indian forest has become a major issue in the recent past. It is in this back ground that a new paradigm to regenerate forest resources through social forestry was conceived in the eighties and finally culminated in the present social foresty programme being implemented in different parts of the country.

The national social forestry programme implemented on a massive scale has identified among other species two exotic fast growing trees namely *Acacia auriculiformis* and *Eucalyputs tereticornis*, considering their fast growing nature, ability to survive under a wide range of ecological conditions and hostile environment. These species are also not browsed and come up well in all soil types including degraded waste lands and problem soil areas. The wide adaptability of these species has paved the way for the birth of large scale plantations in different parts of the country covering degraded forests and waste lands, which could not support a natural forest.

In Kerala, the social forestry scenario is totally different. The majority of the existing Eucalyptus and Acacia plantations are located in the highly fragile ecosystem including the Western Ghat region. Many of the plantations have been raised after clear felling the existing natural forest fully overlooking the fact that manmade forests with monoculture species are no longer a substitute for the existing natural forests with wide species diversity.

Of the total of 10.81 lakh hectares of forest area in Kerala 1.59 lakh hectares (15%) are under the social forestry plantations (Resource Based Perspective plan 2020 AD, 1997). In spite of the fact that more than 20 tree species have been identified under the social forestry programme in Kerala, the two exotic fast growing tree species namely *Acacia auriculiformis*, *Eucalyptus tereticornis* constitute more than 30 per cent of the area under social forestry plantations (Kerala Forest Department 1997).

There have been many reports on the deleterious effects of monoculture plantations of Acacia and Eucalyptus on ground water, soil fertility, nutrient cycling and allelopathy. It has also invited criticism from ecologists and small farmers (Gupta 1986, Balagopalan and Jose 1986, Byju 1989, Shivanna *et al*. 1992). Arguments in favour of this wonder trees also had been put forward considering its thin crown and deep roots which practically do not interfere with the nutrition and photo-period enjoyed by agricultural crops. Thus Eucalyptus has been considered as a suitable companion crop in agriculture ecosystem (Alexander *et al*. 1981, Francis *et al*. 1986).

These conflicting reports have sparked off a raging controversy among the scientific community and the common man on the popularisation of these tree species in Kerala, leading to the initiation of a number of research programmes in Kerala on various aspects of monoculture plantations in relation to soil properties.

It is with this background that a comprehensive work on various aspects of monoculture plantations of Acacia and Eucalyptus in comparison with a moist deciduous forest was planned with emphasis on the following aspects.

1) Quantification of leaf litter production from Acacia, Eucalyptus and natural forests.

2) Estimation of chemical composition and biochemical constitutents of fresh as well as leaf litter from Eucalyptus and Acacia plantation and natural forest and determination of the allelopathic effect of leaf as well as soil extracts of these plantations on test crops - rice and cowpea.

3) Characterisation of leaf litter decomposition and nutrient release characteristics of various leaf litters.

4) Excavation and analyses of depth wise soil profile samples from various plantations.

5) Extraction and characterisation of organic matter separated from Eucalyptus, Acacia plantations and natural forest.

The results of the study would provide the necessary data base on the impact of monoculture plantations of Acacia and Eucalyptus on the soil ecosystem. The data generated, it is hoped will be of help in the reorientation of the social forestry programmes in the State so as to conserve the environment, the rich biodiversity of the State and maintain soil health with the ultimate goal of sustainable development.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The introduction of exotic species of Eucalyptus and Acacia for social forestry plantation has evoked considerable controversy on the deleterious effects of these species on the soil and environment. The enthusiasm and anxiety among the scientific community is clearly evident from the voluminous research data available covering various aspects. The research work relevant to the present study carried out so far is briefly reviewed in this chapter.

2.1 Litter production

Leaf litter on the forest floor plays a major role in the structure and function of a terestrial ecosystem. The litter on the forest floor acts as an input output system of nutrients, (Das and Ramakrishnan 1985). The rate at which forest litter falls and subsequently decay regulate energy flow, primary productivity and nutrient cycling in forest ecosystem (Waring and Schlesinger 1985).

2.1.1. Litter production in plantation ecosystem

Litter production from a 5 year old *Eucalyptus tereticornis* plantation in western Uttar Pradesh was reported to be 2.3 t ha^{-1} $year^{-1}$ (Singh 1975).

George (1982), based on a study on annual leaf litter production of a 5 year old *Eucalyptus tereticornis* plantation in Dehra Dune, Uttar Pradesh reported the annual leaf fall to be 3.4 t ha^{-1} $year^{-1}$. While Wiersum and Ramlan (1982) reported that in Java, Indonesia, annual litter production from a 3-4 year old *Acacia auriculiformis* plantation was 10.7 t ha^{-1} $year^{-1}$.

A comparison of annual litter production in *Acacia meerusii* and *Eucalyptus globulus* in Nilgris made by Venkataramanan *et al*. (1983) revealed that litter production was more in eucalyptus (1935 kg ha^{-1}) than in Acacia (900 kg ha^{-1}).

Gill *et al*. (1987) reported that annual litter production in 3-6 year old plantations of *Eucalyptus tereticornis* and *Acacia nilotica* were 1.0 - 1.1 and 2.5 - 5.7t ha^{-1} respectively.

Through a detailed investigation Premakumari (1987) compared the quantity of litter fall on Eucalyptus, Teak and Rubber plantations. The study revealed that the quantity of litter fall was maximum for Eucalyptus (14 t ha^{-1} $year^{-1}$) followed by Teak 8.17 t ha^{-1} $year^{-1}$) and Rubber (3.24 t ha^{-1} $year^{-1}$).

Sharma *et al*. (1988) have reported the total annual leaf litter in 24 year old *Dalbergia sisso* plantation of Bijnor Forest Division, Uttar Pradesh as 3715 kg ha^{-1}.

Swamy (1989) compared the litter production of 18-20 year old *Eucalyptus tereticornis*, 34-56 year old *Tectona grandis* and 9-11 year old *Acacia auriculiformis* in Karnataka, and showed that annual litter production was 8.6 t ha^{-1} for Eucalyptus, 11.4 t ha^{-1} in Tectorna and 17.5 t ha^{-1} in Acacia.

The annual leaf litter production estimated in *Acacia auriculiformis* was 7.8 t ha^{-1} (Assif 1990) and 12.9 t ha^{-1} (Kunhamu 1991).

George and Varghese (1991) reported that in Nilgris a 10 year old *Eucalyptus globulus* plantation returned 8.5 t ha^{-1} of leaf litter annually.

Comparative evaluation made by Pande and Sharma (1993) on the litter production among plantations of Sal, Teak, Eucalyptus and Pine showed that annual litter production was maximum for Sal (11.27 t ha^{-1} $year^{-1}$) followed by Pine (9.675 t ha^{-1} $year^{-1}$), Teak (6.95 t ha^{-1} $year^{-1}$) and Eucalyptus (1.07 t ha^{-1} $year^{-1}$).

Sankaran *et al*. (1993) reported that litter production from a 3-6 year old Acacia plantation was 10-12 t ha^{-1} $year^{-1}$ of which more than 70 per cent was contributed by leaf litter.

A comparison of annual leaf litter production made by Omkar Singh *et al*. (1994) indicated that leaf litter production was more for a 17 year old *Dalbergia sisso* (1892.6 kg ha^{-1} $year^{-1}$) than a 20 year old *Bombax ceiba* (1303.0 kg ha^{-1} $year^{-1}$).

Saravanan *et al.* (1995) compared the leaf litter production of Apple, Eucalyptus, Acacia and Pine for a period of 6 months. They reported that the leaf litter production was more in Pine (2124 kg ha^{-1}) followed by Eucalyptus, (1392 kg ha^{-1}) Acacia (720 kg ha^{-1}) and Apple (180 kg ha^{-1}).

Grewal *et al.* (1996) assessed the leaf litter production potential of 7 species of 16 year old Acacia namely *A. senegal*, *A. tortilis*, *A. modesta*, *A. suma*, *A. lenticularis*, *A. nilotica* and *A. catechu* and reported that the leaf litter production in t ha^{-1} $year^{-1}$ were 5.25, 4.05 5.01, 4.07, 5.21, 3.3 and 4.0 respectively.

2.1.2 Litter production in Natural forest

Srivastava (1981) reported that in India, annual litter production from deciduous forest was 4.3 t ha^{-1} $year^{-1}$.

According to Singh and Ramakrishnan (1982) mixed sub-tropical humid forests of Meghalaya annually produced 5.5 ton litter per hectare.

Annual litter production from a moist deciduous forest in Idukki, was 3 t ha^{-1} $year^{-1}$ (Singh 1985) and deciduous forest in Madhya Pradesh produced 6.28 t ha^{-1} leaf litter (Girolkar and Naik 1987).

Mohankumar and Deepu (1992) compared the litter production in 3 locations having wide variation in tree basal area, density and disturbance intensity coming under moist deciduous forests of Western Ghats. They have shown that litter fall varied from 12.17 to 14.43 t ha^{-1} $year^{-1}$ and there was no significant difference between the sites.

The annual leaf litter production was estimated to be 1.08 - 2.08 t ha^{-1} in deciduous forests of Orissa (Joshi, 1993) and 10.75 t ha^{-1} in moist deciduous forests of Coimbatore (Singh *et al*. 1993).

2.1.3 Seasonal/Climatic variation in litter production

In a study on the variation of litter fall in Sal, Eucalyptus, Teak and Pine, Pande and Sharma (1986) have observed a clear cut pattern with a maxima during the month of March-April. Eucalyptus recorded a bimodal pattern of leaf fall, one peak (22%) during October-November and other (18.8%) during April-May.

In plantations of ever green species such as *Acacia nilotica* and *Eucalyptus tereticornis*, the seasonal litter yield peak was during winter months (Gill *et al*. 1987)...

Premakumari (1987) quantified the annual litter production of Eucalyptus, Teak and Rubber at 4 months intervals commencing from October 1984. She observed that maximum litter fall was in January (37.6 to 73.1%) and minimum in May (13.3 to 30.9%).

Pascal (1988) working on the wet evergreen forests of Attappadi region of Western Ghats, indicated that the rhythm of leaf shed was characterised by heavy fall during the dry season.

Kunhamu (1991) studied the monthly leaf litter production in *Acacia auriculiformis* for a period of one year starting from November 1990 and reported that maximum litter production was in December (3.68 t ha^{-1}) and minimum for the month of May (0.27 t ha^{-1}).

Study conducted in the moist deciduous forests of Western Ghat by Mohankumar and Deepu (1992) indicated profound seasonal variation in litter fall. Leaf shedding was heavy during the dry period (November to April) for all dominant species.

Sankaran *et al*. (1993) showed that dry months accounted for higher fractions of annual litter production (67.5 - 76.2%) than wet months in Acacia plantations. Highest amount of litter fall occurred during December and January and lowest in May and June. Highest litter fall during summer months has been reported for Acacia (Sugur 1989) and for a host of other speices and forest types in India and elsewhere (O' Connell and Manage 1982, Das and Ramakrishnan 1985, Swamy 1989).

2.1.4 Nutritional and biochemical composition of leaf litter

Chemical composition is an intrinsic property of the litter which play a key role in the nutrient cycling and rate of turn over of organically bound nutrients. Just like the variations in the amount of litter fall from plantation to plantation the composition of forest floor and freshly fallen litter also showed large variation even within closely related species, reflecting the direct and indirect influence of age of plantation, soil and climatic factors.

2.1.4.1 Nutrient composition

Venketaramanan *et al.* (1983) studied the return of nutrients by the leaf litter in bluegum (*Eucalyptus globulus*) and observed that the litter of bluegum contained the highest amount of N (1.4 - 1.9%) followed by Ca (0.83 - 1.1%), K (0.14 - 0.32%) and Mg (0.07 - 0.19%).

Haridasan (1985), compared the N, P, K, Ca, Mg, Fe, Mn and Zn status of seven month old plantations of *Eucalyptus grandis* and *E. saligna* in a gallery forest soil and reported that N, P, K, Ca, Mg (in percentage), Fe, Mn and Zn (in ppm) status were 0.81 0.07, 0.84, 1.15, 0.44, 20, 1166 and 16 for *E. grandis* and 0.75, 0.23, 0.74, 1.06, 0.42, 23, 1649 and 13 for *E. saligna* respectively.

A comparative study on nutrient composition (in percentage) of dead Eucalyptus leaves of 4 species made by Adams and Attiwill (1986) revealed that N, P, K, Ca and Mg status were 0.702, 0.056, 0.183, 0.839 and 0.096 for *E. pauciflora*, 1.093, 0.039, 0.182, 0.604 and 0.113 for *E. siderocylon*, 1.286, 0.048, 0.186, 0.639 and 0.159 for *E. oblique* and 0.982, 0.042, 0.173, 0.588 and 0.149 for *E. regrans* respectively.

O'connell (1986) reported that the N, P, K, S, Ca, Mg, Na and Cl concentration (in percentage) of *Eucalyptus marginata* leaf litter were 0.33, 0.009, 0.25, 0.107, 1.15, 0.36, 0.22 and 0.29 respectively.

Byju (1989) studied the % N, P, K, Ca and Mg status of Eucalyptus and Acacia leaf and reported that respective values were 1.25, 0.08, 0.99, 0.59 and 0.48 per cent for *Eucalyptus tereticornis* and 1.82, 0.07, 0.66, 1.78 and 0.3 per cent for *Acacia auriculiformis*.

Assif (1990) observed that nutrient concentration in the leaf litter of *Acacia auriculiformis* ranged from 2.06-2.67% N, 0.05-0.08% P and 1.08-1.1% K.

George *et al*. (1990) stated that there was no significant difference in nutrient concentration between different age group as well as during different month of the year in *Tectona grandis* Linn. Nutrient values reported were 1.9% N, 0.12% P and 0.8% K.

Kunhamu (1991) showed that percentage nutrient status of *Acacia auriculiformis* was 1.3 N, 0.014 P and 0.242 K.

In an elaborate study on litter dynamics in moist deciduous forests of Western Ghats of Peninsular India, Mohankumar and Deepu (1992) compared the leaf litter nutrient status of different species. Foliar N content ranged from 0.66% in *Cleistanthus collinus* to 1.6% in Xylia and Grewia. The range value for P were 0.034% in *Schleichera oleosa* to 0.077% in *Bridelia retusa*. Potassium status varied from 0.25% in *Cleistanthus collinus* to 0.65% in *Grewia tiliaefolia*.

Singh *et al.* (1993) investigated the nutrient composition of moist deciduous forest dominated by *Grewia tiliaefolia*, *Pterocarpus marsupium*, *Dalbergia paniculata*, *D. latifolia*, *Anogeissus ratifolia*, *Litsea deccanensis* and *Olea diolica* and reported that the mean nutrient concentration were 1.8% N, 0.065% P and 0.714% K.

Foliar nutrient composition of six important tree species viz. Eucalyptus hybrid, *Acacia auriculiformis*, *Emblica officinalis*, *Tectona grandis*, *Dalbergia sisso* and *Hardiwickia binata* determined by Singh and Gupta (1993) showed that percentage P, K, Ca, Mg and N were 0.032, 0.199, 1.61, 0.45 and 0.03 for *T. grandis*, 0.044, 0.359, 1.81, 0.64 and 0.023 for *D. sisso*, 0.056, 0.145, 0.73, 0.24 and 0.03 for *E. officinalis*, 0.072, 0.197, 1.65, 0.5 and 0.023 for Eucalyptus hybrid, 0.044, 0.154, 1.17, 0.48 and 0.053 for *A. auriculiformis* and 0.088, 0.059, 1.45, 0.48 and 0.023 for *H. binata* respectively.

Jamaludheen (1994) studied the nutritional status of *Acacia auriculiformis* and reported that foliar nutrient concentration as 2.47% N, 0.077% P and 0.725% K.

Sreemannarayana *et al.* (1994) conducted a detailed study on the N, P, K as well as micronutrient status of important multi purpose trees widely grown in different soils. The reported values for N, P, K (in %) and Zn, Cu, Fe and Mn (in ppm) of leaf samples were 4.6, 0.25, 1.75, 84, 22, 120 and 148 for *Albizia lebbek*, 2.1, 0.62, 1.32, 65, 44, 550 and 150 for *Dalbergia sisso*, 2.43, 0.15, 1.52, 52, 15, 520 and 570 for *Acacia auriculiformis* and 2.6, 0.16, 2.32, 45, 21, 1340 and 139 for *Delonix regia* respectivelly.

Ilangovan and Kailash Paliwal (1996) found that the nutrient status of leaf litter of *Leuceana leaucocephala* were 2.5% N, 0.112% P, 0.298%.K, 0.116% Na, 0.638% Mg, 0.003% Mn, 0.0018% Cu and 0.208% Zn.

2.1.4.2 Biochemical composition

Leaf litter is composed of a variety of biochemical constituents like simple sugars, protein, Hemicellulose, cellulose and lignin. Since these compounds vary greatly in their rate of decomposition and subsequent nutrient release, they are important criteria in assessing the quality of a litter.

Gupta and Singh (1981) reported that Sesbania contains 22.3% water soluble compounds, 43.4% acid detergent cell wall components, 1.6% lignin and 54.6% cellulose.

According to Byju (1989) Eucalyptus leaf contains 21.9% fibre and 7.8% protein while Acacia has 25.5% fibre and 11.4% protein.

Mohankumar and Deepu (1992) compared the lignin content (percentage) of 6 dominant forest trees species and reported as 15.81% for *Pterocarpus marsupium*, 17.12% for *Tectona grandis*, 16.18% for *Xylia xylocarpa*, 17..18% for *Dillenia pengyne*, 17.07% for *Terminalia paniculata* and 15.17% *Grewia sp*.

From a detailed investigation on the biochemical composition of leaf litter, Dominique Gillon *et al*. (1994) compared the content of free sugar, hemicellulose, cellulose and lignin of leaf litter of coniferous trees, broad leaved trees and grasses. They showed that coniferous needle (*Pinus halepensis*) contained 0.0305% Sugar, 11.2% Hemicellulose, 18.7% Cellulose and 23.8% lignin. Corresponding values for grass (*Brachypodium retusum*) were 0.0685. 32.6, 32.2 and 8.8% respectively. Among broad leaved trees, 2 species were selected and *Fagus salvatica* contained 0.0082% sugar, 18.6% Hemicellulose, 28.1% Cellulose and 30.6% lignin and the respective values for *Quercus coccifera* were 0.0138, 16.1, 18.6 and 21.0 per cent.

Jamaludheen (1994) observed that *Acacia auriculiformis* leaf litter contained 16.5% lignin.

Robert and Ted (1995) reported that Pacific Silver fir and Western hemlock contained 17.5 and 11.7% lignin respectively.

2.2 Leaf litter decomposition

Leaf litter production and decomposition are the major components associated with the process of nutrient cycling in forest ecosystem. The build up of forest floor material depends upon the overall annual input of litter and the rate of decomposition of the forest floor by the decomposing community (soil organisms).

2.2.1 Rate of litter decomposition

Based on a study on leaf litter decomposition Bahuguna *et al.* (1990) reported that annual dry weight loss in *Eucalyptus camaldulensis* was 82%.

Mary and Sankaran (1991) compared the rate of decomposition of Teak, Eucalyptus and Albizia for a period of 18 months. They found that weight loss of Albizia litter under field condition was 93.9% with an annual decomposition rate constant (K) 1.67 and half life period of 5 months. Respective values for *E. tereticornis* were 63.7%, 0.74 and 11.2 month. *Tectona grandis* recorded a weight loss of 95.7%, with an annual decomposition rate constant of 2.00 and half life of 4.2 months.

Mohankumar and Deepu (1992) studied the leaf litter decomposition in a moist deciduous forest of the Western Ghats using litter bag technique and observed that all the six species investigated degraded completely within a period of 5 to 8 months.

The annual decomposition rate constant for the 6 species were 5.28, 3.84, 4.20, 3.96, 3.48 and 4.08 for Pterocarpus, Teotona, Xylia, Dillenia, Terminalia and Grewia sp respectively.

Pande and Sharma (1993) stated that the annual dry matter loss of leaf litter was 63% for Eucalyptus, 73% for Pine and 78% for Teak. Annual decomposition rate constant and half life of leaf litter (t 50) were 1.098 and 7.56 months for Eucalyptus, 1.319 and 6.3 months for Pine and 1.614 and 5.14 month for Teak respectively.

Sankaran *et al*. (1993) studied the leaf litter decomposition of *Acacia auriculiformis* and showed that annual dry weight loss through decomposition was 86% with decomposition rate constant of 1.4 and time taken for 50% decomposition 5-9 months.

Omkar Singh *et al*. (1994) compared the leaf litter decomposition of *Dalbergia sisso* and *Bombax ceiba* and observed that Delbergia recorded an annual weight loss of 73% with decomposition rate constant of 1.32 and half life period of 6.46 months. Corresponding figures for Bombax was 81%, 1.67 and 4.92 month.

Using litter bag technique Sushilkumar Joshi (1995) studied the leaf litter decomposition of composite samples in a tropical dry deciduous forest and reported that the annual weight loss was 83% with a decomposition rate of 2.14 and half life value of 3.9 months.

Ilangovan and Kailash Paliwal (1996) investigated the litter decomposition parameters of *Leucaena leucocephala* and *Cymbopogon citratus* and reported that decomposition parameters viz. annual weight loss, annual decomposition constant (K) and time taken for 50% decomposition were 70%, 1.191 and 6.98 month for Leucaena and 63%, 1.002 and 8.3 month for Cymbopogon respectively.

2.2.2 Factors effecting the leaf litter decomposition

Litter decomposition provides the main source of energy and nutrients for soil and litter organisms, and is a major pathway for the recycling of nutrients to the plant community. (Charley and Richards 1983). According to Swift *et al*. (1979) the rate and pathways of litter decomposition are determined by the quantitative and qualitative composition of the decomposer community, their physical environment and quality of the resources that animals and microorganisms are utilizing.

2.2.3 Environmental characteristics

Gupta and Singh (1981) characterised the decomposition of litter and roots of *Chenopodium album*, *Desmostachya bipinnata*, mixed grass samples, *Dichanthium annulatum* and *Sesbania bispinosa*. The mean relative decomposition rates were found to be highest in rainy season and lowest in winter months. Rainfall, particularly the frequency of rainfall was an important factor affecting the decomposition rates.

According to Donahue *et al*. (1990) a continuous warm temperature favours high plant production and faster decomposition, but the decay of the major plant constituents is depressed as the supply of oxygen diminishes.

Decay rates of litters in disturbed forests sites are slower than those in undisturbed sites due to nutrient status and altered micro/macro climatic factors consequent on site degradation (Mohankumar and Deepu 1992).

Maj-Britt Johansson *et al*. (1995), in a study on the decomposition of pine forest litters revealed that dominant rate regulating factor was climate (average annual temperature and actual evapotranspiration) especially in the initial stage.

Robert and Ted (1995) suggested that temperature was the dominant factor controlling decomposition rates in the litters of Western hemlock and Pacific silver fir.

2.2.4 Chemical composition of the litter

Plant litter with high initial nitrogen and low C-N ratio are known to decompose rapidly (Meentemeyer 1978).

Setiadi and Samingen (1978) reported that Allelopathic effect of Acacia leaves on the decomposer organisms may be a possible reason for its low degradability.

Low decomposibility of Acacia litter is attributed to the high content of crude fibre in the phyllodes and also the presence of a thick cuticle in the phyllode surface. (Widjaja 1980, Byju 1989). A negative correlation between the fibre content of litter and weight loss has been reported by Pandey and Singh (1982).

Initial lignin content of litter is recognized to be one of the most important factors controlling decay rates. (Meentemeyer 1978, Taylor *et al*. 1991). Further, the decomposition of lignin of the nitrogen rich litter is known to be significantly lower than those with poor nitrogen content (Berg *et al*. 1992). Others have suggested that lignin/N ratio is a better predictor (Melillo *et al*. 1982, Harmon *et al*. 1990, Robert and Ted 1995), although Taylor *et al*. (1991) found that lignin plus N concentration was better than lignin/N.

According to Mary and Sankaran (1991) the slow rate of decomposition of Eucalyptus litter was due to the presence of polyphenols and volatile terpenes. The presence of polyphenols in leaves is known to reduce decomposition rates of litter by inhibiting the microbial enzyme action. (Williams and Gray 1974).

Needles and leaf litter had an initial rapid phase of decomposition followed by a slower phase (Mary and Sankaran 1991, Reddy 1992, Mohankumar and Deepu 1992, Sankaran *et al*. 1993).

Harmon *et al.* (1990) reported that temperature strongly influenced decomposition rate during the initial rapid phase and substrate chemistry dominated in the later stages. The high leaching of soluble chemical components from the litter was attributed to the initial rapid phase of decomposition of Acacia leaf litter (Sankaran *et al.* 1993). Ilangovan (1993) reported that initial rapid loss is by physical leaching and microbial metabolism of water soluble material.

James and Carole (1995) stated that C:N ratio is not consistently an accurate predictor of organic matter decomposition as it does not take into account the carbon quality. They pointed out that cellulose : lignin : N ratio of decomposing material would take into account quality and quantity as well as nitrogen concentration and this may be an accurate and more widely adaptable predictor of organic matter decomposition.

2.2.3 Microbial association with litter decomposition

It is now well established that the decomposition of plant litter on the soil surface is brought about by a variety of micro organisms namely bacteria, fungi and actinomycetes (Swift *et al.* 1979). Among these microbes fungi recognised to be the chief colonizer and decomposer (Hayes 1979). The bacteria are known to act only as secondary decomposers and the role of actinomycetes is described to be limited (Good Fellow and Cross 1974).

Mary and Sankaran (1991) studied the microbial activity associated with litter decomposition of Albizia, Eucalyptus and Teak. The microbial activity (in terms of CO_2 evolution) was highest in Albizia (107-304.7 ug/l/h) and low in Eucalyptus (21-137.1 ug/g/h) especially in the initial stages of decomposition. The number of fungi/g of litter ranged between 1.46 - 88.2 x 10^5, 0.6 - 27.1 x 10^5 and 1.7 - 116.3 x 10^5 respectively in Albizia, Eucalyptus and Teak during different period of observation. The bacterial counts varied between 2.8 - 66.8 x 10^7 in Albizia, 0.6 - 12.8 x 10^7 in Eucalyptus and 3.6 - 93.2 x 10^7 in Teak. The number of actinomycetes /g litter ranged between 0.3 - 46 x 10^6, 0.2 - 6.9 x 10^6 and 0.4 - 73.2 x 10^6 in Albizia, Eucalyptus and Teak respectively.

Sajan Khan and Kapur (1992) investigated the microbial association with the decomposition of forest leaf litter. The total fungal population varied from 57.06 - 87.31 x 10^3 depending on the species. Bacterial population varied from 62.35 - 96.09 x 10^3 and maximum population for fungi as well as bacteria were observed at 5th month of decomposition.

Vijaya and Naidu (1995) studied the fungal population associated with decomposition of *Albizia amara* leaf litter, and observed that the number of fungi/g of litter ranged between 1.2 to 68.2 x 10^5. There was a rapid increase in the number of fungi in the litter during the first month of decay. The initial rapid rease in fungi and bacteria on decomposing litter was reported by several workers (Gray *et al*. 1974, Rai and Srivastava 1982).

In an experiment with microfloral association on decomposing leaf litters of Jack and Mango, Jannet Daniel (1996) observed that Jack leaf litter harbours more fungal population (35.67×10^5) than that of mango (16.67×10^5).

2.2.6 Nutrient mobility from decomposing litter

Litter decomposition and release of nutrient element present in the litter is inevitable in the nutrient cycling process in an ecosystem. Different nutrient elements are released or mobilised from the litter subsequent to the litter decomposition at different rate which determine the order of nutrient release pattern. Nutrient mobility series is characteristic of a leaf litter at a specific environment.

Das and Ramakrishnan (1985) reported that in the case of *Pinus kesiya* plantations in North Eastern India, the nutrient released in terms of percentage of the original nutrient within first 12 months were K (88%), Ca (63%) Mg (63%), P 53%) and N (35%) and after 2 year it was K (68%), Ca (98%), Mg (89%), P (87%) and N (72%).

Backheim and Leide (1986) showed that after one year of decomposition of *Pinus resinosa* litter; 77% of the original dry matter in litter bag remained. The release of macronutrient in decomposing leaf litter was K> Mg> P, S> N> Ca and that of micronutrient was Mn > Fe > Cu > Zn. Calculated half life (in years) for dry matter, N, P, K, Ca, Mg, S, B and Mn were 2.6, 7.3, 4.3, 0.5, 1.7, 1.6, 4.3, 2.4 and 2 respectively.

Bahuguna *et al.* (1990) studied the nutrient release in *Shoreia robusta* and *Eucalyptus camaldensis* leaf litter. Elemental mobility of the nutrient from decomposing litter was observed in the order of Mg > K > P > Ca > N for Sal and K > Mg > Ca > N for Eucalyptus.

From a 2 year decomposition study Stephen *et al.* (1992) observed that the relative mobility of nutrient elements in Ponderos pine needle litter was K > Mg = C = P > N > S > Ca.

Robert and Ted (1995) observed that relative mobility of N, P, K, Mg, Mn and Na in comparison to initial content in decomposing green needle of Western hemlock and Pacific silver fir was in the order K > Ca > Mn > Mg > P > Na > N for western hemlock and K > Na > Mn > Ca > Mg > P > N in Pacific silver fir.

2.3 Effect of monoculture plantation on soil physico-chemical and biological properties

The physico-chemical and biological properties of forest soils are known to differ in several respect with that of the adjacent forest plantations. These variations might have arisen out of the difference in nutrient recycling characteristics of the forest ecosystem compared to forest plantations which are more frequently subjected to disturbances and alterations by human intervention. Since all the vital properties of soils more or less influence the nature of the vegetation, both natural and man-made and vice versa, a thorough knowledge of the nature and properties of soils just as those in agriculture is essential for scientific forestry management (Kadeba and Advayi 1985).

2.3.1 Physical properties

Mithra Charly (1965) reported significant reduction in organic carbon and total nitrogen content in moist deciduous forest of Palode subsequent to deforestration.

Jose and Koshy (1972) have observed that the constitution of the clay is not altered to any marked extend by the removal of natural forest and by maintaining a pure teak plantation.

Alexander *et al.* (1981), based on a study of the properties of soils under teak noticed that the sand content decreased and silt and clay increased with depth indicating the downward movement of the latter due to leaching.

Balagopalan and Jose (1986) noticed that eventhough there was no significant difference in mechanical composition of surface soils of *Eucalyptus tereticornis* and an adjacent natural forest, deeper layers showed marked difference. At deeper layers Eucalyptus showed higher sand content, low silt and clay content indicating the loss of fine particles from soil through run off and erosion.

Premakumari (1987) stated that though there was no significant difference in mechanical composition by plantations of teak, Eucalyptus and rubber compared to a natural forest, significant increase in bulk density significant decrease in WHC, porosity and volume of expansion due to plantation.

Animon (1992) compared the physical properties of soils under Eucalyptus and Acacia compared to control (cashew). He observed no significant difference in mechanical composition among plantations. The sand content decreased with depth while silt and clay content showed an increase. But the moisture percentage of surface soils of Eucalyptus and Acacia were lower than that of control.

Parthiban and Vinaya Rai (1992) studied the physical properties of soils under different multipurpose tree species namely Casuarina, Eucalyptus and Tectona compared to cultivated land. Result showed that soils under different multipurpose tree species had high bulk density, particle density and porosity compared to the cultivated land. With respect to W.H.C., lowest value was recorded by Tectona (33.3%) followed by Eucalyptus (46.4%), cultivated land (46.8%) and Casuarina (48.5%).

From a detailed investigation on the physico chemical properties of soils under Teak, Bombax and Eucalyptus plantations of Trichur, Balagopalan*et al*. (1992) concluded that among the plantations, the variation in mechanical composition was negligible. In general sand content decreased and clay content increased with depth.

Balagopalan and Jose (1993a) compared the soil properties under evergreen forest, semi evergreen forest, moist deciduous forest, Teak, Eucalyptus and Rubber plantations. They observed that of the plantations studied, Eucalyptus reported the highest sand content, bulk density and particle density, lowest W.H.C., porosity and volume of expansion.

Bulk density and porosity of soils under *Eucalyptus tereticornis* and *Populus deltoides* were compared against cultivated soils by Ravikumar *et al*. (1993). Surface soils of cultivated land recorded the highest bulk density (1.44 mg m^{-1}) followed by Eucalyptus (1.36 mg m^{-1}) and Populus (1.3 mg m^{-1}). Populus showed the highest porosity value (50.9%) followed by Eucalyptus (48.9%) and cultivated land (45.6%).

Bargali *et al*. (1993) reported that replacing natural forest with *Eucalyptus tereticornis* resulted a decrease in WHC, prosity, water content and increase in bulk density.

Srivastava (1993) concluded from an experiment on Eucalyptus plantations, that planting of Eucalyptus will not cause any significant change in physico-chemical properties compared to an adjacent unplanted areas.

Jaiyeoba (1995) investigated the soil physical properties under different land use system and a natural savanna. He stated that there was significant decrease in the coarse fractions and bulk density under Eucalyptus plantations than natural vegetation.

2.3.2 Chemical properties

Jose (1968) reported that in general the organic matter and available nitrogen content of natural forest soil was significantly higher than that of Teak plantation of different ages.

Byju (1989) studied the impact of Eucalyptus and Acacia plantations on chemical characteristics of soils compared to forest and barren/cultivated soils. He showed that though plantation activity improved the soil chemical properties viz. pH, OC, CEC, Base saturation and available N P K, compared to cultivated/barren land, plantation soils showed deterioration in soil chemical properties compared to adjacent natural forest.

Sivadasan (1989) stated that DTPA extractable iron content were 218 ppm for deciduous forest, 456 ppm for Acacia and 132 ppm for Eucalyptus. Corresponding values for manganese content were 17, 15, 24 ppm respectively.

Balagopalan *et al*. (1992) showed that soils under the Teak and Bombax plantations had higher organic carbon, exchangeable bases and exchange acidity than those in the eucalypt (coppiced) plantations.

Bargali *et al*. (1993) observed that due to the replacement of natural forest with *Eucalyptus tereticornis*, organic carbon and total NPK decreased and this decrease become more pronounced as the age of the plantation increased.

Ravikumar *et al*. (1993) compared the soil chemical properties of *E. tereticornis*, *Populus deltoides*, and cultivated soils. pH was lowest in Eucalyptus but N, P_2O_5 and K_2O content in Eucalyptus was higher than cultivated soil and lower than that of Populus plantation.

Balagopalan and Jose (1995) observed that soil chemical characteristics like organic carbon, available nitrogen, total phosphorus and CEC were significantly lower in Eucalyptus plantations compared to the adjacent natural forest.

Rhoades and Blinkley (1996) observed that due to monoculture plantations of Eucalyptus and Albizia in Hawai, soil pH decreased from 5.9 to 5.0 in Eucalyptus and 5.9 to 4.6 in Albizia. They attributed this to the depletion of cations from the soil.

2.3.3 Biological properties

Lundgren (1982) observed that clear felling a scots pine stand resulted in a long lasting detrimental effect on the size of bacterial population.

Biological activity in terms of number of microflora per gram surface soils under Eucalyptus, Acacia cultivated and forest soils were compared by Byju (1989). The result showed the lowest biological activity was observed in Eucalyptus followed by Acacia compared to cultivated/forest soils.

Animon (1990) stated that microbial activity (Bacteria, fungi and Actinomycetes) under Eucalyptus plantations were lower than that of Acacia and Cashew (control).

Failho *et al*. (1991) studied the microbial activity of soil samples taken from 18 year old field plots under primary forest, pasture and Eucalyptus. They reported that lowest biological activity were found in Eucalyptus soil samples.

Effect of reafforestation by *Eucalyptus globulus* and Oak on edaphic collembola populations were studied by Gama *et al*. (1991). Analysis revealed differences in Collambola population between the two sites and species richness was greater in soils from Oak site.

Senapathi *et al*. (1993) conducted macrofaunal analysis in Tea Soil in comparison to forest soil. Total macrofaunal biomass (g. per sq. meter) accounted for 97.57 in forest soil and only 21.14 in Tea Soil. Average earth worm live biomass (g. per sq. meter) accounted for 88.5 in forest soil and 12.8 in Tea Soil.

2.4 Allelopathy

The concept that one plant influences the growth of another is well known in agriculture and forestry. Molisch (1937) coined the term allelopathy to refer to the biochemical interaction between all type of plants including microorganism. Rice (1974) has used the term allelopathy to refer to the deleterious effect that one plant has on another through the production of chemical retardents that escape into the environment.

2.4.1 Allelopathy to understory and crop plants

Lack of herbaceous growth under multi purpose monoculture plantations is very often attributed to competition for natural resources like light, water and nutrients. (Loomis and Whitman 1983). According to Muller (1969) Allelopathy - the direct or indirect deleterious effect of one plant upon another through production of chemical inhibitors are one of the environmental factors seldom recognized as one of the factors in analysing mechanisms of plant interactions, despite reports of such phytotoxic inhibition of understory or associated crops in several multipurpose trees including *Eucalyptus P. casuarina sp, Leucaena sp, Acacia sp, Populus sp* and *Pinus sp*.

De Candolle (1832) suggested that the soil sickness problem in agriculture might be due to the exudates of crop plants and that rotation of crops could help to alleviate the problem.

Chou (1982) reported that leaf extracts of *Leucaena leucocephala* prevent germination of lettuce and rye grass seeds. Inhibition of germination and radicle growth of several species by leaf extracts of *L. leucocephala* were also reported by Kuo *et al.* (1982).

Castal *et al.* (1985) reported that leachate of *Acacia dealbata* leaves, flowers and of soil collected from these plantations inhibited the germination and growth of plants below, especially grasses and legumes.

Baskar and Dasappa (1986) compared the herbaceous flora within young (2, 3, 4 and 7 years) plantations and coppice regrowth stands (1, 2, 4 and 5 year) of *E. tereticornis* to that within stands of *Grevillea robusta*, *Casuarina equisetifolia* and *Acacia auriculiformis*. The species richness in adjacent native vegetation was found to be 63 sp, in *Grevilea robusta* 54 sp, while the lowest value was attained in the 7 year Eucalyptus plantation, with only 14 sp. Suresh and Rai (1988) also recorded a species poor ground cover beneath *E. tereticornis* in relation to open area and beneath other tree species. But George *et al.* (1993) suggests that *E. tereticornis* overstory does not exert any inhibitory influence on understory vegetation development.

Sharma *et al.* (1987) reported that foliar leachate of *E. tereticornis* was found to be inhibitory to germination and seedling growth of maize, seedling growth of wheat, lentil and pea.

Suresh and Rai (1987) working at Mettupalayam in Tamilnadu, tested the allelopathic effect of multipurpose trees on crops. viz. sorghum, cowpea and sunflower by growing the crops on top soil or rhizosphere soil from 3 year old plantation or on field soil mulched with dry leaves or irrigated with aqueous leaf leachate. *E. tereticornis* significantly reduced both germination and seedling growth. Of the various media tested top soil proved to be most inhibitory.

Sunilpuri and Amarjeet Khora (1991) tested the allelopathic potentials of water extracts of leaves (green, brown and decayed stages) and bark of *E. tereticornis* on seed germination and primary root and shoot development of green gram. Though there was no significant difference in seed germination further development of seedling was effected by the treatment. Leachate from green and brown leaves were found to be most inhibitory. Inhibitory effect of leachate of leaf stem, and root extracts of *E. tereticornis* on germination and seedling growth of many crops were recorded viz. chickpea, cowpea, sorghum, wheat (Barsal 1988) wheat, pea, greengram, horsegram, maize (Bhaskar *et al.* 1992).

Jadhev and Gaynaer (1992) studied the allelopathic activity of top soil and rhizosphere soils of Acacia stands, field soil mulched with dry leaves of Acacia and field soil irrigated with cold extracts of fresh leaves of Acacia. The result showed that 15th day after sowing there was severe reduction in germination percentage in the case of leaf extract followed by top soil collected from Acacia stands. Among the growth characters only the root length reduced drastically in all the treatment. The inhibitory effect on germination and growth by leaf, stem litter and soil extracts of *A. tortilis* on pear millet, greengram, cluster bean (Sundramorthy *et al.* 1992) and *A. nilotica* on tomato, sorghum, wheat. pearmillet, okra, chilly (Swaminathan *et al.* 1989, Dadal *et al.* 1992) were also reported.

Rao *et al.* (1994) observed that leaf extracts of agroforestry tree species viz. *Azadiracta indica, A. juss, Terminalia arjuna* Bedd, *Delbergia sisso* Roxb, *Albizzia labbeck* Benth. *Sesbania grandiflora* pers, *Acacia auriculiformis* wild and *Leucaena luecocephala* Benth severely inhibited the germination % of wheat, paddy and gram.

2.4.2 Chemical nature of Allelopathy

Allelochemicals are produced by any part of the plant viz. roots, leaves, pollen, seeds or fruits, although leaves and roots are the main source (Horsley 1977). These allelochemicals are mainly added to the environment from living plants (through washings or leachate of foliage, root exudates, volatilization from aerial parts) or dead or decay plant parts (Tukey 1969). The secondary metabolites in which most of the allelochemicals also fall, leach out of the plant in their water soluble form (Daizy 1990).

Moral *et al*. (1978) reported that foliar and litter leachate of *Eucalyptus baxteri* contained gentisic acid, allagic acid, gallic acid, synopic acid, caffeic acid and ellegic acid as allelochemicals.

Mashkoor *et al*. (1979) reported that the nematicidal property of oilcakes was due to the presence of phenolic acids.

Potential allelochemicals which are able to produce inhibitory effect on seed germination are identified as phenolic acid (Williams and Hoagland 1982).

Castal *et al*. (1985) observed that allelochemicals present in the leaves, flowers and soils collected from beneath the plants of *Acacia dealbata* were P-hydroxybenzoic acid, protocatechuic acid, vanillic acid, genistic acid, P-conmaric acid, coffeic acid, ferulic acid and synopic acid.

Different parts of Eucalyptus tree have been found to yield different amount of organic components (aglycones). Irrespective of the nature, the phytotoxicity of leachates from each part was correlated with the respective amount of aglycones (Kohli 1990).

Volatile terpenes present in Eucalyptus contribute maximum towards allelopathic potential of the tree. Not only the amount, the nature of terpene in each species has also been found to be highly variable (Kohli and Singh 1991).

Singh and Kohli (1992) reported that Eucalyptus rhizosphere was found rich in chemicals which were injurious to the vegetation growing nearby. The content varied with the distance from the tree as well as with depth of the soil. They also reported that the soil chemical content at 1 m distance from the tree were 504 mg/100g soil. The soil chemicals coming under the phenolic acid group were identified as gallic acid gentisic acid, syringic acid, vanillic acid coffeic acid, P-coumaric acid ferulic acid and cinnemic acid besides a few unidentified phenolics.

Kohli (1994) stated that eight phenolic acids occur in *Eucalyptic tereticornis* leaves as allelochemicals. In addition syringic acid and two unidentified compounds occur in the soil as inhibitant.

Bignel *et al*. (1996) characterised the volatile leaf oils of 15 Eucalyptus species by vaccum distillation and analysed by GC and GC-MS. Most species contained -pinene (5.1 - 47.2%) B - pinene (0.1 - 16.4%) 1, 8-Cineole (Eucalyptol) (2.7 - 48.6%) P - cymene (0.03 - 17.7%) aromadendrene (1.2 - 20.0%) and bicycloger macrene (0 - 28.5%) as principal leaf oil components.

Zygadlo *et al*. (1996) examined the volatile constituents from flowers of *Acacia praecox* using GC-MS. Thirty two components representing 95% of the oil were characterised. The major components were linalol (13.5%) undecane (13.3%) eugenol (10.5%) decane (10.5%) and Oct - len - 3 ol (9.1%).

2.4.3 Allelopathic effect on soil organisms

Allelopathic effect of higher plants on soil organisms and particularly in the field of inhibition of nitrogen fixation attracted the attention of various workers.

Mashkoor *et al*. (1979) reported that phenolic acid released during the decomposition of oil cake were toxic to plant parasitic nematodes namely *Hoplolaumus indicus*, *Helicotylenchus indicus*, *Rotylenchulus reniformis*, *Tylenchorhynchus brassicae* and *Tylenchus filiformis*.

Lodhi and Killing Beck (1980) studied the allelopathic inhibition of nitrification and nitrifying bacteria in a

Ponderosa pine community. He found that various phenolic inhibitors of nitrification were found in the extracts of pine needles, bark and A horizon soil and these were shown to be toxic to nitrosomonas.

Roy *et al*. (1993) observed that crude alcoholic extract of the funicles of *Acacia auriculiformis* killed 55% of *Meloidogyne incognita* at 4 mg/ml concentration.

2.5 Soil organic matter

Soil organic matter refers to the organic fraction of the soil, it include plant and animal residues at various stages of decomposition, living and dead cells and tissues of microbes and substances synthesised by soil population. Organic matter is of interest to soil scientists because it strongly effects various physico-chemical and biochemical properties of soils and subsequently their fertility.

Though addition of organic matter in any form helps in maintaining the organic matter and fertility level in soil, the type of organic materials added and the soils involved, influence considerably the rate of decomposition as well as the subsequent chemical changes brought in the soil.

2.5.1 Proximate constituents of soil organic matter

Gross chemical constituents of organic matter can indicate the stage of organic matter decomposition as influenced by various environmental factors and disclose the processes responsible for stabilisation of important constituants such as N and S in organic matter.

It has been reported that humus contains 0.5 - 4.7%. Fat, waxes and oils, 0.5-3% resins, 5-12% hemicellulose, 3-5% cellulose, 35-50% lignin and 30-50% protein (Waksman and Stevans 1930).

Tamhane *et al*. (1970) reported that lignin and protein contents of podzol and chestnut soils were 46%, 40% and 28%, 33% respectively and those of sierozem and chernozeme soils were 35%, 33% and 50%, 38% respectively.

Humus contains, sugars, starches, carbohydrates, cellulose, lignin tannin, fat, wax, oils, resins, proteins, pigments and minerals at various percentages (Tamhane *et al*. 1970, Beek and Frissel 1973).

According to Haider (1986) soil humus consists of polysaccharides and lignins as major components and of proteinaceous materials, free phenols and sugars and other components as minor ingredients.

From a detailed investigation on the influence of elevation on the proximate constituent of organic matter, Balagopalan (1995) observed that as the elevation increases the quantity of different fractions increases indicating the low decomposition at higher elevation. The percentage of different constituents were 0.18, 0.2, 0.17, 1.39, 0.41, 3.89 and 2.29 for fat, wax, resin, free sugars, hemicellulose, cellulose, lignin and protein respectively.

Sattar and Rahman (1995) reported that in the soils from Bangladesh, humus contains 0.34-2.54% fat, waxes and oils, 0.32 - 2.25% resin 0.42 - 2.62% water soluble polysaccharides, 6.89-12.95% hemicellulose, 2.83-5.35% cellulose, 32.25-41.33% lignin and 33.15-42.15% protein.

2.5.2 Fractionation of soil Humus

The rate at which the organic matter is accumulated or depleted is strictly controlled by the overall influence of climate and plant community, human interference and length of time (Jenny 1941 and Jones 1973).

Kononova (1961) recorded a general inverse relationship between fulvic acid and humic acid content. The ratio of HA to FA was found to vary between 0.3 - 2.5.

Schnitzer (1970) reported 31-56% fulvic acid in organic matter of Podzol soils while Felbeck (1971) observed that humic acid degraded to fulvic acid and Schnitzer and Khan (1972) stated that fulvic acid was the resultant product from humic acid.

Turski (1971) found that erosion resulted in decreased humus contents, decreased humic acid : fulvic acid ratios and lower degree of condensation and polymerisation of the humic acid fractions.

Budibal and Seshagiri Rao (1978) reported a humic acid content of 12.4% of organic matter for Karnataka soils. They also observed that neutral reactions and relatively higher base saturation favoured predominance of humic acids.

Humic acid was the first transformation product of soil organic matter whereas fulvic acid was formed by further transformation and destructive synthesis (Ram and Raman 1981).

Study conducted by Usha (1982) on organic matter fractions of major soil types of Kerala revealed that organic matter contains 8.3 - 47.55% Humic acid, 17.5-47.6% fulvic acid and the Humic acid : Fulvic acid ratio vary from 0.23 - 1.06.

Balagopalan and Jose (1993b) investigated the HA and FA fractions of organic matter in 6 vegetation types including 3 plantations viz. Teak, Eucalyptus and Rubber. They reported that all the vegetation types got a HA:FA ratio of >1 except Eucalyptus (HA : FA ratio 0.93) showing the predominance of FA over HA in Eucalyptus.

From a study on HA and FA content of forest soils of Kerala, Balagopalan and Jose (1994) stated that as the elevation increased the proportion of FA to HA increased resulting a low HA : FA ratio. They recorded a HA : FA ratio of 0.97 at 1450 m elevation.

Sahoo *et al*. (1995) conducted a study on the organic carbon status in the Sundarban mangrove soils and found that humus carbon fraction was very low ranging from 0.08 - 0.7% which was supposed to be due to less humification. The ratio of HA carbon : FA carbon was always less than one indicating less humification.

Sreedevi (1996) reported that the HA : FA ratio of Kari, Karappadam, Kayal and lateritic alluvial soil types of Kerala ranges from 0.94-1.15, 0.94 - 1.06, 0.81-0.98 and 0.54 - 1.13 respectively.

2.5.3 Characteristics of Humic acid and Fulvic acid

The tropical and subtropical soils have shown considerable variation in the amount of organic matter (Xu and Zhang 1989). Even within similar climatic conditions, different vegetation resulted in different amount of organic matter in soil (Balagopalan and Jose 1993a). This heterogenity is generally reflected in their molecular size distribution, functional group composition spectral and thermal characteristics.

2.5.4 Functional group analysis

The ability of humic and fulvic acid to combine with metal ions and a variety of organic agricultural chemicals is due to a large extent of their unusually high relative content of functional group.

Forsyth (1947) indicated the presence of carboxylic, phenolic, methoxyl, acetyl, quinone and probably carbonyl groups in humic acids.

Stevenson and Goh (1972) claimed that the humic acid separated from Brunizem soils of Illionis contains 540 me/100g total acidity, 390 me/100 g COOH and 150 me/100g acidic OH groups.

Schnitzer (1977) has shown that model humic acid contains 6.7 meq/g total acidity, 3.6 meq/g COOH and 3.9 meq/g phenolic OH group. Model fulvic acid contains 10.3 meq/g total acidity 8.2 meq/g COOH and 3 meq/g alcoholic OH group.

Chen *et al.* (1978) carried out the functional group analysis of humic acid and fulvic acid separated from two soils of Israel and four soils of southern Italy. Range of values for total acidity carboxyl and phenolic hydroxyl groups (meq/g) were 6.5-8, 3.1-4.2 and 2.4-4.4 for humic acid and 6.2-10.9, 2.4-5.9 and 3.2-8.1 for fulvic acid respectively.

Functional group characterisation of humic acid separated from Prince Edward Island, Canada and fulvic acid from central Alberta, Canada show that humic acid contains 6.6 meq/g total acidity, 4.5 meq/g COOH and 2.1 meq/g phenolic OH groups.

Fulvic acid had 12.4 meq/g total acidity, 9.1 meq/g COOH and 3.3 meq/g phenolic OH groups (Kunal Ghosh and Schnitzer 1979).

Kar *et al*. (1995) stated that humic acid separated from the soil under mulberry vegetation of Central Sericultural Research and Training Institute, Berhampore contained 1.63 meq/g COOH group and 4.14 meq/g phenolic OH group.

2.1.5 Spectral and thermal characteristics

Generally humic substances do not yield characteristic spectra in U.V. and visible region and optical density usually decreases as the wave length increases. The light absorption of humic substances appears to increase with increase in (1) the degree of condensation of the aromatic rings, these substances contain (Kononova 1966) (2) the ratio of carbon in aromatic nuclei to carbon in aliphatic side chain (3) total carbon content and (4) molecular weight.

Schnitzer and Gupta (1964) showed that IR spectra of humic substances showed bands at the following frequencies ~ 3400 cm^{-1} (H bond OH), 2900 cm^{-1} (alphalic C-H stretch) 172 cm^{-1} (C=O of COOH, C = O Stretch of Ketonic C=O) 1630 cm^{-1} (aromatic C= C, hydrogen bonded C=O of carbaryl or quinone COO^-), 1400 cm^{-1} (aliphatic C-H), 1200 cm^{-1} (C-O Stretch of OH determination of COOH) and 1050 cm^{-1} (SiO of silicate impurities).

T.G., D.T.G., D.T.A and Isothermal heating have been used for investigating the mechanism of thermal decomposition of humic materials.

Schnitzer and Hoffman (1964) stated the main reactions governing the thermal degradation (pyrolysis) of humic acid are (a) dehydrogenation (upto 200°C) (b) a combination of decarboxylation and dehydration (200-250°C) and (c) further dehydration. The main reaction governing the pyrolysis of fulvic acid is dehydration. They further stated that low temperature peaks result from the elimination of functional groups, whereas the high temperature maxima are due to the decomposition of the nuclei.

According to Kodama and Schnitzer (1970), the D.T.A. curve of fulvic acid from Canadian spodsol showed a shallow endotherm near 100°C, a shoulder like exotherm between 300-380°C and a prominant exotherm near 450°C.

The ratio of optical density of dilute aqueous humic acid and fulvic acid solutions at 465 and 665 nm usually referred to as E4/E6 has been reported to be independent of the concentration but to vary for humic materials extracted from different soil types (Schnitzer and Khan 1972).

According to Schnitzer and Kodema (1972) thermal stability depends on the cations involved in the formation of metal humic acid complexes. Monovalent cations yield thermally stable organic complexes and di-and trivalent cations causes severe strain in the molecular structure making it less stable against thermal decomposition.

Stevenson and Goh (1972) stated that IR spectra of fulvic acid had a strong absorption band at 3400 cm^{-1}, a weak band between 2980 and 2920 cm^{-1}, a medium strong band at 1720 cm^{-1} followed by a shoulder at 1650 cm^{-1} and a strong band at 1000 cm^{-1} attributed to vibrations of OH, aliphatic C-H, carbonyl (C=O) - carboxyl groups in COO^- form, ethyl or vinyl - $CH\text{-}CH_2$ or amine and SH group respectively. In contrast to fulvic acid, humic acid exhibited a strong absorption for C-H vibrations at 2980 to 2920 cm^{-1} and even stronger absorption for both carbonyl and carboxyl vibrations in COO form at 1730 and 1650 cm^{-1} respectively. Humic acid spectra does not have any absorption band at 1000 cm^{-1}.

Chen *et al*. (1978) studied the DTA and IR spectra of HA and FA of the Mediterranean region. The DTA curves of HA exhibited endotherm between 60°C and 70°C and 2 prominant exotherms between 305 - 325°C and 440 - 495°C. Some humic acid produced a third exotherm between 530-570°C. In general relative intensities of peaks at 440-495°C were higher than those in the 305-325°C region. The DTA curves of Fulvic acid produced exotherm near 290-325°C and 390-450°C. Some fulvic acid also exhibited some additional exotherm near 510-540°C. The difference between curves of fulvic acid is attributed to difference in ash content and composition.

Tan (1978) studied the DTA and IR spectra of humic acid extracted from Eustin loamy sand of Athens, and observed that DTA thermogram of humic acid exhibited only a very strong exothermic reaction at 415°C. This differed slightly from the reports by Dupuis (1971). The latter noticed that humic acid was characterised by a small and strong exothermic peak at 340°C and 430°C respectively. IR spectra of humic acid showed strong absorption at 2950 cm^{-1}, 2850 cm^{-1}, a weak shoulder at 1720 and a strong peak at 1625 cm^{-1}.

Kunal Ghosh and Schnitzer (1979) reported that visible and U.V. absorption spectra of humic acid and fulvic acid were featureless and E4/E6 ratio of humic acid varied from 3.3 to 3.65 at different concentration of NaCl and that of fulvic acid varied from 6.9-7.45.

Samirpal and Sengupta (1985) showed that humic acid separated from different sources got a E4/E6 ratio of 8-10.8.

Balagopalan and Jose (1993b) investigated the IR and UV spectra of humic acid and fulvic acid separated from different vegetation soils of red ferralitic soils. U.V. spectra of both humic acid and fulvic acid got a broad shoulder at 235 nm.

IR spectra of humic acid got broad absorption between 3800-3100 cm^{-1} in all vegetation types. A slight stronger band near 1610 cm^{-1} also observed in all vegetation. Absorption at 1710 cm^{-1} is strong in evergreen soils. With respect to fulvic acid absorption spectra of evergreen and moist deciduous types are stronger in 1640, 1460, 1380 and 720 cm^{-1} and such a variation is due to the difference in chemical composition.

From the characterisation of humic acid and fulvic acid separated from soils at different elevation, Balagopalan and Jose (1994) showed that UV spectra of both HA and FA in all the elevation had a broad shoulder at 235 mm. I.R. spectra of humic acid had a broad and strong band at 3400 cm^{-1}, weak peak at 2900 cm^{-1} and 1660-1600 cm^{-1} region in lower elevation. A strong broad absorption near 1200 cm^{-1} region was recorded in all the elevation. IR spectra of fulvic acid had strong absorption band at 1630, 1450, 1390 and 1100 cm^{-1} in all the elevations.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

Ever since the implementation of the Social Forestry programme aided by World Bank in Kerala, the area under *Eucalyptus tereticornis* and *Acacia auriculiformis* is increasing and at present there are 40000 hectares of Eucalyptus and 5000 hectares of Acacia plantations in the State. The present investigation envisages a multidimentional analysis of the impact of Acacia and Eucalyptus plantations on the ecosystem compared to a natural forest.

3.1 EXPERIMENTAL LOCATION

The study area was located at Mylamood coming under the Kulathupuzha range of Kerala Forest Department (8° 45'N latitude and 77° 02' E longitude). The area enjoys a warm humid climate with mean annual rainfall of 2085 mm. The average monthly maximum temperature ranged between 29.3 to 36.0°C, the minimum temperature ranged between 9.82 to 16.4°C and annual mean relative humidity was 75.1%. The meteorological data is given in Appendix. I. In the selected area, one hectare each of *Acacia auriculiformis*, *Eucalyptus tereticornis* and a moist deciduous forest lying adjacent to each other and having similar climatic condition were selected for conducting studies on litter dynamics. Acacia is a 8 year old plantation planted in 1986

Plate 1. General view of Acacia plantation

Plate 2. General view of Eucalyptus plantation

Plate 3. General view of a moist deciduous natural forest

after clearing moist deciduous forest (Plate 1). The Eucalyptus was also planted after clearing a moist deciduous forest in 1980 and clear felled during 1990. The resultant coppice growth of 4 year old plantation was selected for the study (Plate 2). The moist deciduous forest was dense with shrubs herbs and trees (Plate 3). The dominant tree species were Thanni (*Terminalia bellerica*), Pezhu (*Careya arboria*), Maruthu (*Lagerstromia reginae*), Thembav (*Terminalia crenulata*), Nelli (*Emblica officinalis*) etc. The biometric characters of the trees of selected plantations are given below.

Name of the plantation	Age (year)	Height (M)	GBH (cm)
Acacia	8	21.8	47.4
Eucalyptus (coppice)	4	14.6	41.2
Natural Forest	-	22.0	161.5

3.2 Litter production

Litter fall in each plantation was quantified using litter traps. Litter traps of 0.5 m^2 area were made by fitting polythene sheets to a circular ring of galvanised iron having 0.5 m^2 area, in the form of a cone of 50 cm depth (Plate 4). A total of nine litter traps were placed in an area of one hectare in each plantation during the last day of May 1995. The litter traps were fastened on three stakes of 1 m height in such a

Plate 4. Litter trap for leaf litter collection

Plate 5. Litter bag for decomposition of study

way that the base of the trap was approximately 50 cm above the ground surface. The litter was collected at monthly intervals for a period of 1 year starting from June 1995 to May 1996. The collections were taken to the laboratory and dried at 70°C for 24 hrs after removing larger twigs. The dry weight of the litter was determined and expressed as tons ha^{-1} $year^{-}$.

3.3 Litter decomposition

Freshly fallen leaves of *Acacia auriculaformis*, *Eucalyptus tereticornis* and composite leaf samples from all the species of natural forest were collected from the respective plantations of the experimental area during May 1995 and air dried.

The standard litter bag technique of Bocock and Gilbert (1957) was used for the decomposition studies. The litter bag made up of nylon net (25x20 cm, mesh size 4 mm) were filled with 50 g of air dried Acacia, Eucalyptus and natural forest leaf litter and closed firmly by stitching. These bags were placed on the surface of the soil after removing the litter layer on respective plots and anchored to small pointed stakes to facilitate easy detection (Plate 5). A total of 100 litter bags each of Acacia, Eucalyptus and natural forest were placed at respective plantations on 28th and 29th May 1995. At monthly intervals, five 5 litter bags from each plantations were collected, returned to the laboratory, cleared from extraneous

Plate 6. Soil profile - Acacia plantation

Plate 7. Soil profile - Eucalyptus plantation

Plate 8. Soil profile - Natural forest

material, oven dried at 70°C for 48 hrs and dry weight determined. The contents of each bag were kept for analysis of major and micro nutrients to study the nutrient release pattern.

Core as well as loose samples of soil to a depth of 5 cm below the litter bags were also collected and brought to the laboratory for physico-chemical and biological analysis.

3.4 Collection of soil profile samples

Three profile pits of 3x3' to a depth of 1 meter were excavated in each of the 3 selected plantations (Plate 6, 7 and 8). Bulk as well as core samples were collected at 0-20, 20-40, 40-60, 60-80 and 80-100 cm depth of the profile and brought to the laboratory for characterisation of physico-chemical properties, major and micro nutrients and organic matter characteristics.

3.5 Analytical methods

3.5.1 Biochemical analysis

The fresh and freshly fallen leaf litters from the Acacia, Eucalyptus and natural forests were collected and brought to the laboratory. These plant samples were first air dried and then dried at 70°C for 48 hrs in an oven, powdered and were analysed for the following biochemical constituents of polyphenolics, lignin, cellulose and water soluble conponents, adopting the standard procedures given in Table 1).

3.5.2 Chemicl analysis

Leaf samples (both fresh leaf and leaf litter) were subjected to the analysis of N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn adopting standard procedures given in Table 1.

Table 1 Chemical analyses of plant and litter bag samples

Plant parameter	Method of estimation	Reference
Biochemical analysis		
Polyphenols	Folin-Denis method	King and Heath (1967) and Allen *et al*. (1974).
Lignin	Acid Detergent fibre method	Van Soest and Wine (1968)
Cellulose	Acid Detergent fibre method	Van Soest and Wine (1968)
Water soluble component	Hot water extract-ion method	Harper and Lynche (1981)
Chemical analysis		
Nitrogen	Modified kjeldahl method	Jackson (1973)
Phosphorus	Vanedomolybdate yellow colour method of diacid extract	Jackson (1973)
Potassium	Flame photometer method of diacid extract	Jackson (1973)
Sulphur	Turbidimetric method	Jackson (1973)
Calcium, magnesium, iron, manganese, copper and zinc	Atomic absorption spectro photo metric method of diacid extract	Lindsay and Norval (1978)

3.5.3 Physico chemical and biological analysis of litter decomposition

To study the leaf litter decomposition, nutrient release characteristics, micro organism and soil fauna associated with litter decomposition, the following analyses were conducted.

3.5.4 Chemical analysis of litter bags

Litter bags collected at monthly intervals were brought to the laboratory and extraneous materials like soil particles and fresh plant roots were removed. Then oven dried at 70-80°C for 48 hrs, powdered and subjected to N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn determination as per the methodology given in Table 1.

Soil lying immediately below the litter bag kept for decomposition study were also subjected to detailed analysis. Before taking samples, soil temperature of 20 cm depth was measured using a soil thermometer. Core samples as well as loose soil samples lying immediately below the litter bags were taken. Subsequently soil of 1 m^2 to a depth of 1 m covering the litter bag laid area were excavated and earth worm counts were recorded and expressed as no/sq. meter. The soil samples taken from below the litter bags were brought to the laboratory. About 150 g of fresh soil were kept aside for microbial and nematode determination and the remaining soil subjected to physico chemical analysis such as bulk density, porosity, WHC, pH, organic carbon, available N, P, K, exchangeable Ca, Mg, S, Fe, Mn, Cu and Zn, adopting the standard procedures given in table 2.

3.6 Isolation of microorganism

The microorganisms viz. fungi, bacteria and actinomycetes were isolated from the soil below the litter bag of each plantation at monthly intervals starting from May 1995 to April 1996. The first isolation was made from the fresh soils of each plantation. Subsequent sampling were made from among the soil below the litter bag incubated at field condition. The dilution plate technique (Parkison *et al*. 1971) was employed for the isolation of micro organism. Ten g of soil was suspended separately in 100 ml sterile water in 250 ml conical flasks. Dilution of 10^{-4}, 10^{-6} and 10^{-8} were used to isolate fungi, actinomycetes and bacteria respectively. One ml of the suspension was transferred separately to 3 respective petridishes and 20 ml of the respective media for isolation were poured in each. Martin's Rose Bengal agar were used to isolate fungi, Thornton's agar for bacteria and starch casein agar for actinomycetes. The fungal, bacterial and actinomycetes colonies were counted after incubation at room temperature (28 - 32°C) for 5, 7 and 10 days respectively. From this data the average number of microorganism g^{-1} of oven dry weight of soil was computed.

3.7 Isolation of nematodes

100 ml soil collected from the individual plantations were processed for extracting nematodes by the modified method of Cobb's decanting and sieving technique. Each soil samples weighing about 100 g was transferred to a plastic basin and mixed thoroughly with 300 ml water, coarse particles and foreign materials were allowed to settle. The supernatant liquid was then passed through a sixty mesh sieve. The materials collected in the sieve and the sediments in the basin were discarded. The filtrate was allowed to stand for a few minutes and then passed through 350 mesh sieve. The fine silt and nematodes collected in these sieve were washed down and collected in a beacar with minimum quantity of water. The nematodes were extracted from the filtrate by the petridish method. The suspension was poured over a tissue paper placed over a wire gauge kept on a petridish containing sterile water in such a way that the suspension was just in contact with water. This was kept undisturbed and at the end of complete recovery, the suspension in the petridish was collected and examined under binocular microscope and the population was estimated.

3.8 Analysis of profile samples

Soil samples collected at definite depth of the soil profile in each plantations were brought into the laboratory. Inorganic nitrogen viz. NH_4^+-N and NO^-_3-N were determined on fresh soil samples. Ammoniacal nitrogen determined by the distillation method as per the procedure outlined by Jackson (1973) and nitrate nitrogen determined colorimetrically adopting the procedure described by Jackson (1973). Appropriate corrections were made on the inorganic nitrogen depending on the moisture content of the soil on oven dry basis. The remaining soil was air dried, powdered and analysed for various physico chemical characteristics viz. mechanical composition, single value constant, field capacity, wilting coefficient, available water, pH, EC, organic carbon, Exchangeable Ca, Mg and K, exchangeable H and Al, CEC and ECEC, total NPK, NO_3--N, NH_4^+-N, available P and S and available Cu, Zn, Fe and Mn. adopting standard analytical procedures as given in Table 2.

Table 2 Details of methods followed in soil analyses

Physical properties:-

Soil characteristics	Method of estimation	Reference
Mechanical composition	International pipette method	Jackson (1973)
Single value constant	Soil core method	Gupta and Dakshinamoorthi (1980)
Field capacity	Pressure plate apparatus	Gupta and Dakshinamoorthi (1980)

Wilting coefficient	Pressure plate apparatus	Gupta and Dakshinamoorthi (1980)
Available water	Pressure plate apparatus	Gupta and Dakshinamoorthi (1980)
Chemical properties		
pH	Using Perkin and Elmer pH meter	Jackson (1973)
Organic carbon	Walkley and Black rapid titration method	Jackson (1973)
Exchangeable K	N-Ammonium acetate extract read in Flame photometer	Jackson (1973)
Exchangeable Ca	N - Ammonium acetate extract read in AAS	Jackson (1973)
Exchangeable Mg	N - Ammonium acetate extract read in AAS	Jackson (1973)
Exchangeable H&Al	Tritration method of 1 M KCl extract	Black (1965)
CEC	N - Ammonium acetate saturation and distillation method	Jackson (1973)
ECEC	Addition of total bases and exchangeable acidity	Van Reeuwijk (1993)

Total N	Modified microkjeldahl method	Jackson (1973)
Total P	Vanadomolybdate yellow colour method of diacid extract	Jackson (1973)
Total K	Flame photometer method of Diacid extract	Jackson (1973)
Available N	Alkaline permanganate distillation and Titration method	Subbiah and Asiji (1956)
Available P	Molybdenum blue colour method read in Klett Summerson Photoelectric Colorimeter	Jackson (1973)
Available K	N - Ammonium acetate extract read in flame photometer	Jackson (1973)
Available S	Turbidimetric method read in Klett Summerson Photo electric colorimeter	Chesnin and Yien (1951)
Available Fe	DTPA extract read in AAS	Lindsay and Norvel (1978)
Available Cu	,,	,,
Avaialble Mn	,,	,,
Available Zn	,,	,,

3.9 Characterisation of soil organic matter

Upper most layer of the profile samples collected from different plantations were used for gross characterisation of organic matter adopting the procedure outlined by Stevenson (1965). The proximate constituents estimated were fats and waxes, resins, water soluble polysaccharides, hemicellulose, cellulose, protein and lignin + humus, using seperate extracts for each fractions as given below.

Fractions	Treatments/method
Fat, waxes and oils	Ether extraction
Resin	Alcohol extraction
Water soluble polysacchrides	Hot water extraction
Hemicellulose	Hydrolysis with 2% HCl
Cellulose	Hydrolysis with 80% H_2SO_4
Protein plus lignin-humus	Analysis of the final residue for carbon and nitrogen

Humus extracted from the soil fractionated into humic acid and fulvic acid following the procedure of Stevenson (1965).

3.10 Characterisation of Humic and Fulvic acid:-

3.10.1 Functional group analysis:-

Total acidity and functional groups like phenolic - OH groups and carboxyl groups were determined adopting the procedure detailed by Schnitzer and Gupta (1965). Total acidity were determined by barium hydroxide titration method and the carboxyl groups were determined by reacting humic acid with 1 N calcium acetate and determining unreacted calcium acetate by back titration with 0.1 N NaOH. The difference betwen the total acidity and carboxyl groups was taken as the number of phenolic hydroxyl groups.

3.10.2 Spectral and thermal analysis

The UV spectra of HA and FA was recorded using Shimadzu U.V. 21000 Spectrophotometer. For this 0.5 g of the material was dissolved in 0.5 N NaOH and the UV spectra recorded. In the case of IR spectra, 0.5 g of the material was ground with K Br and made into a thin pellet and the spectra was taken using Perkin Elmer (Model 882) IR spectrometer. Thermal analysis of Humic and Fulvic acid were recorded on Seiko instruments 320 (Japan) DTA apparatus. Here 10 mg of the material was subjected to constant rate of heating of 10°C/min from 30-700°C and the DTA and TG curves were recorded.

3.11 Allelopathic studies

Aqueous extracts of fresh as well as leaf litter of Acacia, Eucalyptus and natural forest at 1:2, 1:5 and 1;10 leaf:water ratio were used to assess the allelopathic effects on the germination and growth of rice and cowpea. The methodology adopted was similar to that described by Rai and Tripathi, (1986). Distilled water served as control. Observations on percentage germination and length of plumule and radicle were recorded seven days after sowing.

To study the allelopathic effects of compounds present in the soil, 100 g of surface soils of each plantation was thawed, placed in an extraction thimble and extracted with redistilled isopropyl alcohol in a Soxhlet extractor for 48 hr. The allelopathic effects of this extract on germination and growth of rice and cowpea were studied.

3.12 Statistical analysis

Data pertaining to the various characteristics were analysed statistically by applying the technique of analysis of variance (Panse and Sukathme 1967) and decomposition parameters of leaf litter and different nutrients were worked out from the exponential decay formula.

$X : Xoe^{-kt}$ (Olsen, 1963)

Where X : Weight remaining at the end of the period of measurement

Xo : Initial weight

K : Decomposition constant

T : Time in months

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

Inorder to conserve the existing natural forest from over exploitation and at the same time to meet the basic need for forest resources of the local people, social forestry programmes were implemented. In this programme massive plantings were undertaken in degraded, unproductive land as well as poor natural forest with fast growing tree species incorporating the participation of local people.

In India especially in Kerala, the exotic species like Eucalyptus and Acacia dominated the social forestry programme to the extend that these plantations became a synonym for social forestry. Social forestry programme using these exotic species are subjected to strong criticism from environmentalist saying that these plantations will adversely affect the soil fertility, flora, fauna, hydrological cycle and ecological balance in the fragile forest ecosystem.

A detailed investigation was therefore carried out to probe into the impact of *Acacia auriculiformis* and *Eucalyptus tereticornics* monoculture plantations on nutrient cycling, soil fertility, soil physico-chemical properties and allelopathic effects on soil flora and fauna compared to an adjacent moist deciduous natural forest. Salient findings of the investigation are presented and discussed in this chapter.

4.1 Leaf litter production

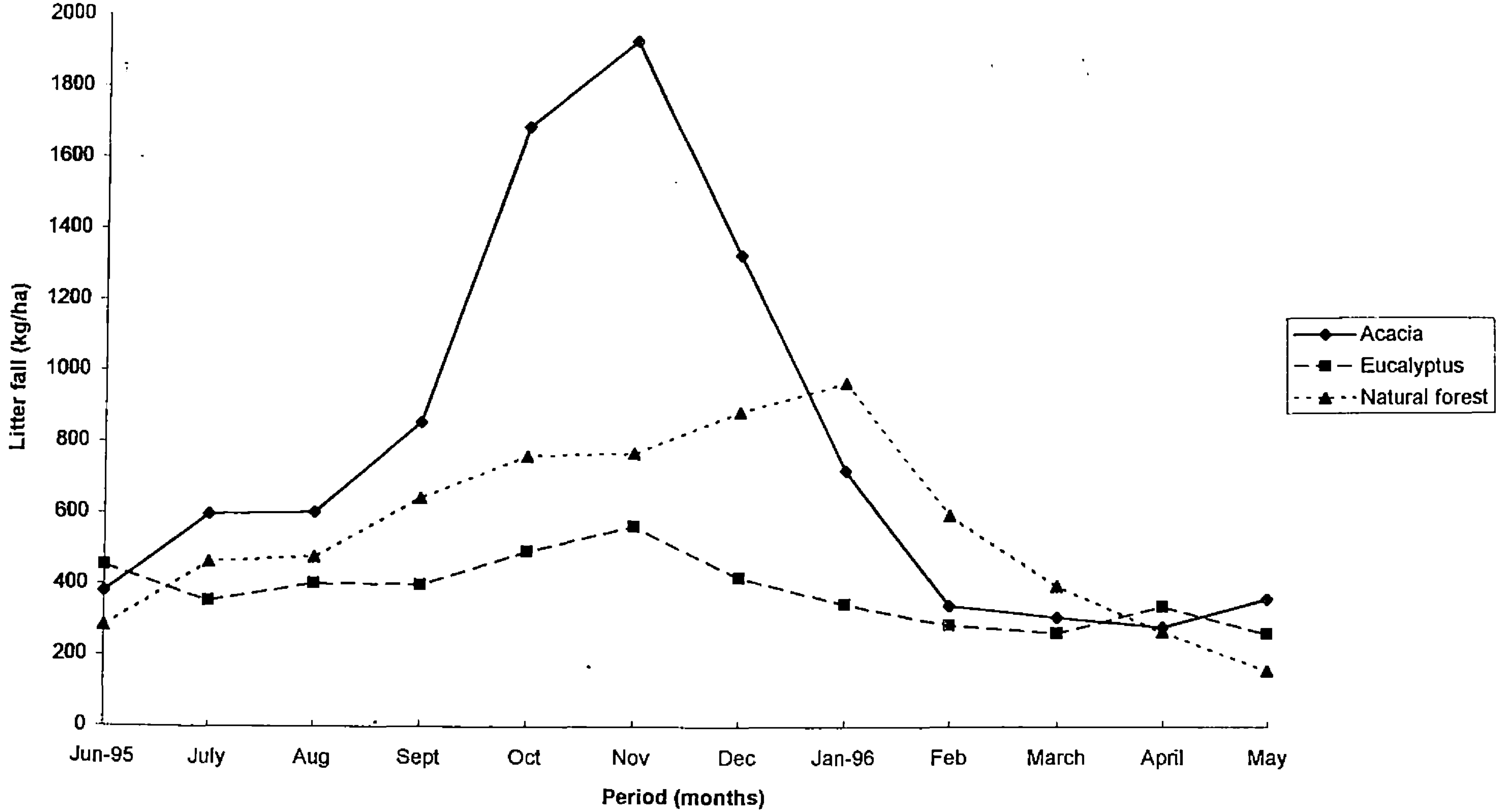
Data on monthly and annual litter fall in the plantations of Acacia, Eucalyptus and natural forest are given in Table 3. Annual litter production was 9404.5 kg ha^{-1} for Acacia, 4682.2 kg ha^{-1} for Eucalyptus and 6676.5 kg ha^{-1} for natural forest. Though litter fall was spread throughout the year, it differed significantly between months. Mean monthly litter fall ranged from 294.1 to 1088 kg ha^{-1}. Maximum litter production was noticed in November (1088 kg ha^{-1}) followed by October (981.5 kg ha^{-1}) and minimum production noticed in May (294.13) followed by April (296.03 kg/ha). Monthly litter fall in Acacia plantation indicated a unimodal pattern with its peak during October-November (Fig. No. 1). The litter fall ranged between 280.92 to 1929.53 kg ha^{-1} during different months. The litter yield increased gradually from June and attained the peak in November. Thereafter it decreased in the succeeding months recording a minimum in April. In the case of Eucalyptus monthly litter fall indicated a bimodal pattern with highest peak in October-November followed by June. The monthly litter fall ranged between 263.76-564.04 kg ha^{-1}. The litter yield showed an uneven decrease from June till September and then increased and attained its maximum in November followed by a gradual decrease up to March (Fig.1). Litter fall in natural forest was unimodal with its peak during December-January. The monthly litter fall ranged between 158.85 to 968.46 kg ha^{-1}. The pattern of litter production indicated a

Table 3 Monthly leaf litter production (kg ha^{-1})

Months	Acacia	Eucalyptus	Natural forest	Mean
June 1995	380.00	452.23	283.94	372.05
July	599.08	354.26	463.98	472.44
August	604.66	403.78	478.58	495.67
September	858.60	398.84	644.52	633.98
October	1689.18	493.76	761.58	981.50
November	1929.53	564.04	770.68	1088.08
December	1329.38	419.48	886.14	878.33
January 1996	722.06	345.70	968.46	678.74
February	341.14	286.66	595.02	407.60
March	308.94	263.76	396.80	323.16
April	280.92	339.22	267.96	296.03
May	361.04	362.48	158.85	294.13
Total	9404.50	4682.20	6676.54	
Mean	783.71	390.35	556.37	

CD (0.05) Bet. Pln. 47.54 Bet.int.95.08 Within pln. 164.68

Fig No1
Monthly leaf litter production from plantations



gradual increase from June till January and subsequently decreased to the lowest value of 158.85 kg ha^{-1} during May.

Annual litter production in Acacia plantation obtained in the present investigation was comparable with the reported values of Sankaran *et al.*, (1993) (10.12 t/ha/ha^{-1}), Assif (1990) (7.8 t/ha) and Wiersum and Ramlan (1982) (10.7 t/ha). Eucalyptus litter fall observed in the present study also confirms to the reports of Singh (1975) and George (1982). Though litter production in deciduous natural forest in different locations are highly variable due to species diversity and differential stand, the result obtained in the present study are supported by the findings of Singh (1985) and Mohankumar and Deepu (1992). The high rate of litter production in Acacia plantation is evidently due to the fast vegetative growth exhibited by the species. According to Penfold and Willis (1961) more the fast growing the species is, the more litter it would produce. Eventhough *Eucalyptus tereticornis* is also a fast growing species, growth retardation due to coppicing might be the reason for its lowest litter production in contrast to the report of Premakumari (1987) and Swamy (1989).

Data on monthly litter fall indicated that dry months account for higher fractions of litter production than wet months in all the plantations. As Acacia and Eucalyptus are evergreen species, the observed maximum litter fall during dry months can be ascribed mainly to moisture stress. According to Moor (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 litter fall during summer months has been reported for Acacia, Eucalyptus and forest types in India and elsewhere (Pascal 1988, Pande and Sharma 1986, Kunchamu 1991, Sankaran *et al*., 1993, Swamy 1989 and Mohankumar and Deepu 1992). Unimodel pattern of litter fall in Acacia and Natural forest and Bimodel pattern in Eucalyptus observed in the present study is in conformity with that of Pande and Sharma (1986), Mohankumar and Deepu (1992) and Sankaran *et al*. (1993).

4.2 Chemical and Biochemical composition of leaf litter

Nutrient status as well as biochemical constituents of fresh leaf and leaf litter of various plantations determined are given in Table 4.

Perusal of the data revealed that nutrient status of fresh and leaf litter differed significantly. Highest nitrogen content in fresh and leaf litter was recorded in Acacia (1.59 and 1.32 per cent respectively) and lowest in the case of natural forest. Nitrogen content in the leaf decreased as the leaf age increased irrespective of the plantations. Eucalyptus recorded the highest P content of 0.091 and 0.086 per cent for fresh and leaf litter respectively, and lowest in the case of natural forest. Fresh leaf contains the highest amount of P than that of leaf litter in all the plantations. Natural forest recorded the highest amount of K in fresh as well as leaf litter (0.852 and 0.76 per cent respectively) and Acacia recorded the lowest K content of 0.61 in fresh leaf and 0.51 per cent in leaf litter. Potassium content also recorded an inverse relationship with the age of the leaf. In fresh leaf and leaf litter, Eucalyptus recorded the highest content of calcium (1.178 and 0.97% respectively) and lowest values observed in fresh leaf of Acacia (0.738%) and leaf litter of natural forest (0.924%). Calcium content increased with aging except in Eucalyptus where it showed an inverse relationship. With respect to Mg, Acacia and natural forest recorded the same content of magnesium in fresh leaf (0.38%) and leaf litter (0.32%). Magnesium content of Eucalyptus leaf and leaf litter were 0.136 and 0.168% respectively. Eventhough magnesium content in Acacia and natural forest showed a decreasing trend with aging, Eucalyptus recorded an increasing trend. Fresh as well as leaf litter of Acacia recorded the highest content of S (0.48 and 0.97% respectively) and lowest values was recorded by Eucalyptus (0.122 and 0.12% respectively). Aging of the leaf does not have any influence on the S content of the leaf. Fresh and leaf litter of Acacia recorded the highest content of Fe (474 and 520 ppm respectively) and Zn (37.8 and 39.2 ppm respectively). While the lowest values of Fe (232 and 274 ppm respectively) and Zn (20.2 and 22.0 ppm respectively) were noticed in Eucalyptus. As the age of the leaves increased,

Table No.4 Chemical and Bio chemical composition of leaf samples of various plantations

Constitution	Fresh leaf				Leaf litter			
	Acacia	Eucalyptus	Natural forest	CD (0.05)	Acacia	Eucalyptus	Natural forest	CD (0.05)
Nitrogen (%)	1.590	1.338	1.196	0.056	1.320	0.910	0.868	0.033
Phosphorus (%)	0.079	0.091	0.065	0.003	0.076	0.086	0.059	0.003
Potassium (%)	0.610	0.782	0.852	0.051	0.510	0.680	0.760	0.067
Calcium (%)	0.738	1.178	0.834	0.048	0.794	0.970	0.924	0.089
Magnesium (%)	0.380	0.136	0.380	0.031	0.320	0.168	0.320	0.052
Sulphur(%)	0.480	0.122	0.314	0.033	0.470	0.120	0.310	0.039
Iron (ppm)	474.000	232.000	332.400	39.330	520.000	274.000	380.000	44.700
Manganese (ppm)	104.800	146.800	116.800	9.630	117.000	160.000	133.000	3.370
Copper (ppm)	27.200	18.000	12.400	2.920	30.000	18.000	14.000	3.020
Zinc (ppm)	37.800	20.200	27.400	3.300	39.200	22.000	30.000	3.530
Water soluble component (%)	40.740	33.040	46.260	3.160	34.060	31.340	38.440	2.210
Polyphenol (%)	1.352	2.802	1.054	0.114	2.296	4.094	1.854	0.222
Lignin (%)	16.810	20.370	13.500	1.490	24.080	25.950	22.110	1.430
Cellulose (%)	31.180	26.930	23.520	1.790	40.970	33.330	31.320	1.830

the content of Fe and Zn increased irrespective of the plantations. Eucalyptus also recorded the highest content of Mn in fresh leaf and leaf litter (146.8 and 160 ppm respectively) while the lowest values were observed in Acacia (104.8 and 117 ppm respectively). Acacia leaf as well as leaf litter contained the highest amount of Cu (27.2 and 30 ppm respectively) against the lowest value recorded in natural forest (12.4 and 14 ppm respectively. Similar to other micronutrients Mn and Cu also increased with the age of the leaves.

Nutrient status of Acacia, Eucalyptus and natural forest observed in the investigation falls within the range values reported by various workers (Venkataraman *et al.*, 1983, Byju, 1989, Mohankumar and Deepu, 1992, Sreemannarayan *et al.*, 1994). One important observation relating to the nutrient status of plantation is that nutrient content of Eucalyptus and Acacia is not inferior to natural forest, rather it is superior in many respect. Acacia recorded the highest concentration of N, Mg, S, Fe, Cu and Zn while Eucalyptus recorded the highest amounts of P, Ca, Mn and intermediate in N, K and Cu when compared to Natural forest. Due to the low annual leaf litter production, the nutrient addition to the forest floor by Eucalyptus is very low eventhough it contains highest amount of many of the nutrients. But in the case of Acacia, it is definitely superior to natural forest as far as nutrient addition through litter fall is concerned.

Difference between the nutrient content in the fresh leaf and leaf litter may be due to the difference in mobility of these elements within the plants. Fresh leaf contains the highest amount of N, P, K, Mg and S since these are mobile and transported from the older leaves to younger leaves for various metabolic activities. The difference in content of Ca and Mg status of Eucalyptus compared to Acacia and natural forest were explained by the content of these nutrient in the leaf. Eucalyptus contained very high amount of Ca which is also supported by the report of Haridasan (1985) and Adams and Attiwil (1986). Very high calcium requirement of Eucalyptus and subsequent high mobility within the plant has contributed to low calcium content in the older leaves compared to fresh leaves. In the case of Mg the low Mg requirement of Eucalyptus resulted in low magnesium content in younger leaves. Transportation of nutrient from older leaves to younger leaves is very slow in the case of immobile elements like Ca, Fe, Mn, Cu and Zn which leads to the lower content of these elements in young leaves compared to older leaves.

Significant difference were observed between the biochemical constituents of fresh leaf and leaf litter of various plantations as depicted in table No. 4.

Both in fresh leaf as well as leaf litter, natural forest recorded the highest quantity of water soluble component

(46.06 and 38.44% respectively) followed by Acacia (40.74 and 34.06% respectively) and lowest in Eucalyptus (33.04 and 31.34% respectively). As compared to fresh leaf, the water soluble components in leaf litter was low irrespective of the plantations. Polyphenol content of fresh leaf followed the order Eucalyptus (2.8%) > Acacia (1.35%) > natural forest 1.05% and that of leaf litter were in the order Eucalyptus (2.8%) > Acacia (2.29%) > natural forest (1.85%). As the age of the leaf increased, the polyphenol content of leaf increased irrespective of the plantations. With respect to lignin content, Eucalyptus had the highest lignin content for fresh leaf (20.73%) and leaf litter (25.95%). Natural forest contained the lowest lignin content of 13.5% in fresh leaf and 22.11% in leaf litter. Lignin content also increased with aging in all the plantations. Cellulose content of fresh leaf followed the order Acacia (31.18%) > Eucalyptus (26.93%) > natural forest (23.52%) and leaf litter also followed the same order but recorded high cellulose content than that of fresh leaf (40.97, 33.33 and 31.32% respectively).

Biochemical composition of leaf as well as leaf litter is very important from the point of view of litter decomposition dynamics. The relative importance of labile (water soluble component) and resistant component, to a large extent determined the mass loss dynamics of leaf litter (Dominique *et al.*, 1994). Highest quantity of water soluble component in natural forest is an important factor which determines its easy decomposition. Low content of water soluble components in leaf litter compared to fresh leaf may be due to the conversion of simple soluble components into more complex material and this conclusion is further supported by high content of lignin and cellulose in leaf litter then fresh leaf. Allelochemicals comes under the category of polyphenolics (Rice, 1974) and the high polyphenol content of Eucalyptus and Acacia obtained in the present study supports the high allelopathic effects of Eucalyptus and Acacia reported by (Kohli *et al*. (1988) and Jadhev and Gayner, (1992). Lignin and cellulose content of various plantations obtained in the present investigation falls within the range of values reported by Byju (1989), Mohankumar and Deepu (1992) and Jamaludheen (1994). Due to the accumulation of lignin and cellulose with age, the leaf litter recorded the higher content than fresh leaf.

4.3 Leaf litter decomposition

Mass of litter remaining in the litter bag after decomposition for a period of 12 months (June 1995 - May 1996) under field condition is shown in Table 5. Critical analysis of the data showed that there was significant difference in leaf litter decomposition of various plantations. Monthly decomposition also showed significant difference irrespective of the plantation. Litter mass remaining in the litter bags decreased linearly with time and at the end of one year only 22.84% (mean) of the initial weight remained in the bags. Initially there was a rapid decomposition (8.14%) which decreased subsequently to 6.46% at the 3rd month of decomposition and then increased to 8.36% at the 6th month. Subsequently the decomposition rate decreased and reached 3.16% at the end of one year. Initial rapid loss of dry matter may be due to the leaching of inorganic as well as water soluble organic components from the litter. According to Swift *et al*. (1979) up to 40% of the initial dry weight of litter material can be lost by leaching of inorganic as well as organic components within a period of 4 months. Later the weight loss is brought about by microbial degradation. Low rate of degradation after 6th month may be due to the accumulation of resistant components of organic matter like lignin and cellulose.

With respect to individual species, there was significant difference in annual weight loss in different plantations Fig. 2. Litter bags of natural forest lost 85.5% of the initial mass followed by acacia (80.1%) and lowest degradation was recorded in Eucalyptus (65.88%) after one year. Monthly loss of dry matter from litter bags also showed marked difference in all the species studied. In Acacia 8.18% of the initial litter was lost during the 1st month of decomposition. The rate of decomposition substantially reduced during the following months and recorded a value of 4.68% during 3rd month. Then the rate of decomposition increased to 10.24% at the end of

Table 5 Mass of litter remaining in litter bags over months (g)

Months	Acacia	Eucalyptus	Natural forest	Mean
Initial	50.00	50.00	50.00	50.00
June 1995	45.91	46.68	45.22	45.93
July	42.30	43.49	40.65	42.14
August	39.96	41.35	35.42	38.91
September	36.12	38.90	29.88	34.96
October	31.99	35.44	25.06	30.83
November	26.87	31.77	21.92	26.65
December	22.37	27.59	18.20	22.72
January 1966	18.06	24.33	15.69	19.38
February	14.78	22.39	12.94	16.79
March	12.75	20.49	11.07	14.77
April	11.12	18.80	9.08	13.00
May	9.95	17.06	7.25	11.42
CD (0.05)		Bet. int. 0.48	Within pln. 0.84	

6th month followed by a progressive decrease in rate to 2.34% at the end of one year decomposition (Fig. 2). Monthly weight loss from litter bags of Eucalyptus leaf litter was 6.64% during 1st month which subsequently decreased to 4.28% during the 3rd month of decomposition. Then the monthly dry weight loss from litter bags increased and the loss was 8.36% during 7th month of decomposition. This rate of decomposition was followed by a linear decrease to 3.48% at the end of 12th month. In natural forest the monthly loss of leaf litter from litter bag was 9.56% during the 1st month of decomposition. After a slight decline during the 2nd month, the decomposition rate increased and recorded a value of 11.08% during the 4th month. Subsequently the monthly rate of decomposition decreased and reached 3.66% during the 12th month (Fig. 2).

It can be inferred that weight lost from litter bags that natural forest leaf litter which had the highest annual weight loss also showed the highest monthly dry matter loss during the initial months. Annual weight loss of litter bags of various plantations obtained in the present investigation is in accordance with the reports of Mary and Sankaran (1991), Mohankumar and Deepu (1992) and Sankaran *et al*. (1993). Initial rapid phase of decomposition in natural forest may be due to the leaching loss of water soluble components from the leaf litter rather than microbially mediated decomposition. High content of water soluble components present in the leaf litter of natural forest (48.18%) strongly support this conclusion. Subsequent degradation brought about by degrading soil organisms also showed significant difference among plantations. Highest loss in dry matter observed in natural forest followed by Acacia and lowest in Eucalyptus may be due to the difference in number of microorganisms associated with decomposition and also the litter quality. Higher content of polyphenol and lignin (4.09 and 25.09% respectively) associated with Eucalyptus may be another reason for its low degradibility. The presence of polyphenols in leaves is known to reduce decomposition rate of litter by inhibiting the microbial enzyme activity (Williams and Gray, 1974). These conclusions are also supported by the findings of Mary and Sankaran (1991). Low decomposition rate of leaf litter with high lignin content has also been reported by many workers (Meentemayer, 1978, Taylor *et al.* 1991, Berg *etal.* 1992). Low water soluble components, thick cuticle on the leaf surface, high polyphenol and cellulose content may be the reason for low degradibility of Acacia leaf litter compared to natural forest. Low decomposibility of Acacia litter may be attributed to the high content of crude fibre in the phyllod and also the presence of a thick cuticle on the phyllode surface (Widjaja, 1980, Byju, 1989). Allelopathic effect of Acacia leaves on decomposer micro organisms reported by Setiadi and Samingan (1978), also support the result of this study.

4.4 Nutrient release on decomposition of leaf litter

4.4.1 Nitrogen

Percentage nitrogen content in the decomposing leaf litter significantly increased as the decomposition proceeded (Table 6). Mean nitrogen content increased from 1.03% to 1.226% at the end of one year decomposition. Absolute quantity of nitrogen in the litter decreased drastically from 0.516 to 0.14 g at the end of one year. Though there is some release of bound nitrogen from decomposing leaf litter as evident from decrease in total nitrogen in the litter bag, the decomposibility of nitrogen containing components compared to other components in the litter was slow which resulted in an increase in percentage nitrogen in the litter as decomposition proceeded. Singh (1969) explained the increase of N as due to the retention of N containing compound in the litter, while non-nitrogenous compounds were being removed.

In Acacia, the percentage N content in the decomposing litter increased from 1.32 to 1.53% at the end of one year and the absolute nitrogen content decreased from 0.66 g to 0.152 g releasing 77% of the initial nitrogen on decomposition Fig. 3. Percentage nitrogen in Eucalyptus increased from 0.91 to 1.15% during one year period and the absolute quantity decreased from 0.445 g to 0.196 g releasing 57% of the initial nitrogen. In natural forest, the percentage nitrogen content in the litter

Table 6 Nitrogen release on leaf litter decomposition

Month	Acacia		Eucalyptus		Natural forest		Mean	
	N (%)	Abs. N (g)	N (%)	Abs. N (g)	N (%)	Abs. N (g)	N (%)	Abs. N (g)
Initial	1.320	0.660	0.910	0.455	0.868	0.434	1.033	0.516
June 1995	1.344	0.617	0.952	0.444	0.892	0.403	1.063	0.488
July	1.434	0.606	0.984	0.427	0.960	0.390	1.126	0.475
August	1.428	0.571	1.000	0.413	0.934	0.330	0.121	0.438
September	1.496	0.540	1.054	0.410	0.986	0.294	1.179	0.415
October	1.568	0.502	1.050	0.372	1.056	0.264	1.225	0.379
November	1.512	0.406	1.100	0.349	1.030	0.219	1.214	0.325
December	1.406	0.314	1.122	0.309	1.042	0.189	1.190	0.271
January '96	1.320	0.238	1.060	0.258	0.964	0.151	1.115	0.215
February	1.038	0.204	1.036	0.231	0.896	0.116	1.104	0.184
March	1.410	0.179	1.080	0.221	0.916	0.101	1.135	0.167
April	1.450	0.161	1.120	0.210	0.966	0.087	1.179	0.153
May	1.530	0.152	1.150	0.196	0.998	0.072	1.226	0.140

CD	Between Mon.	0.051	0.010
(0.05)	Within pln.	0.088	0.018

Fig:- 2

Dry matter loss on litter decomposition

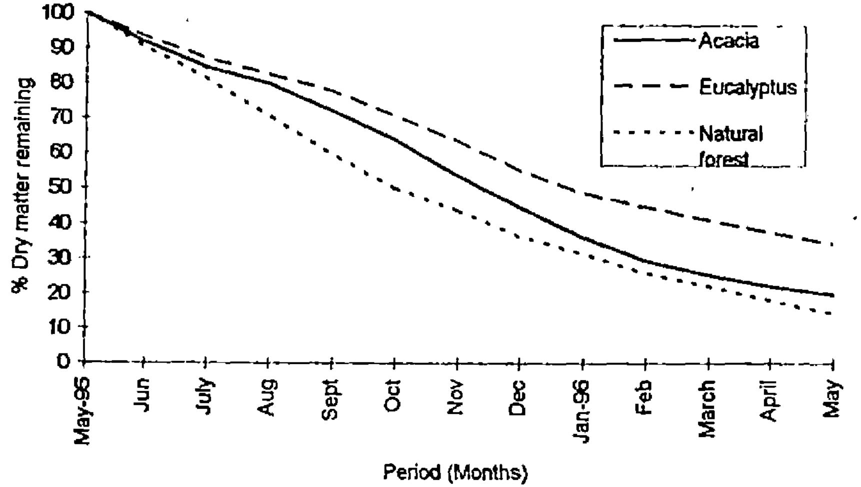


Fig:-3

Nitrogen release on litter decomposition

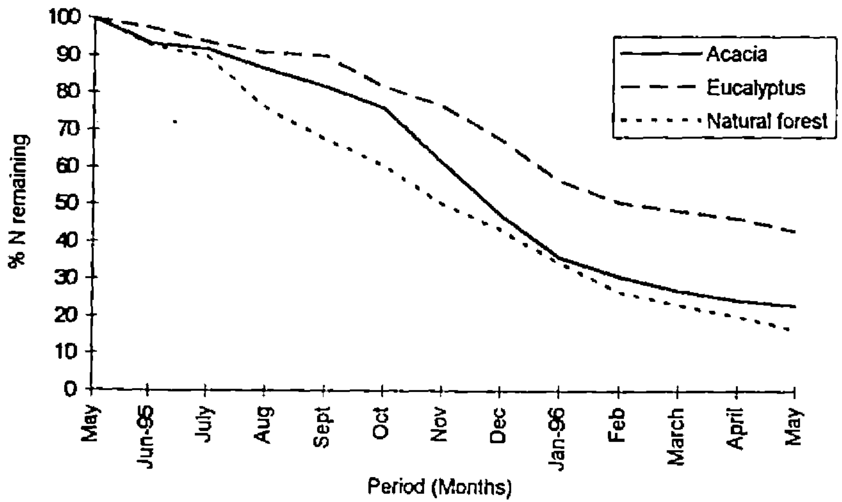


Fig:-4

Phosphorus release on litter decomposition

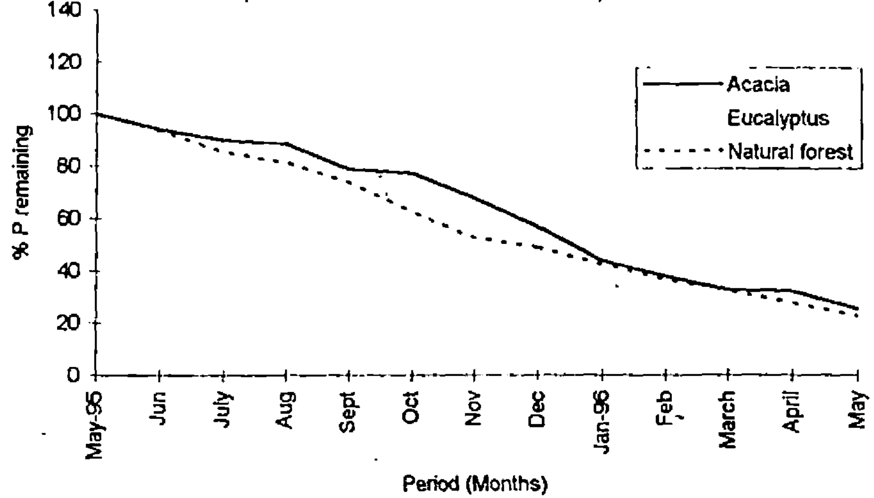
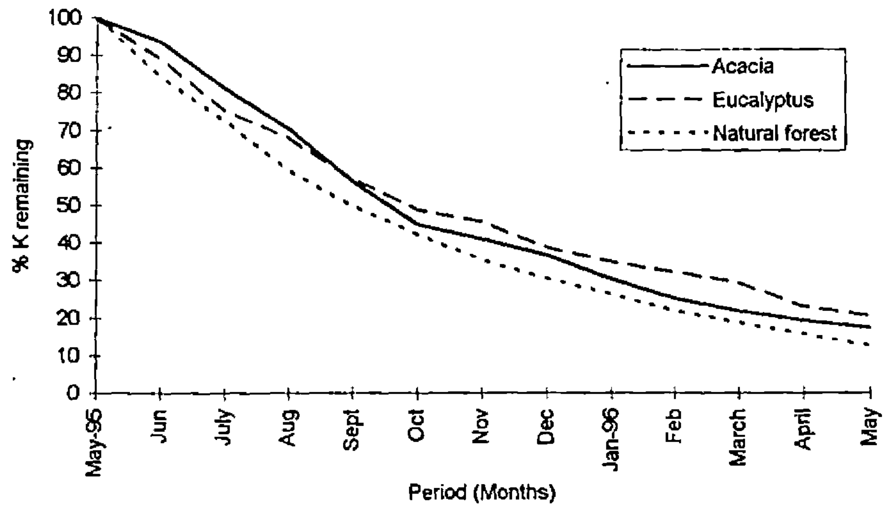


Fig:-5

Potassium release on litter decomposition



bag sample increased from 0.865 to 0.998% at the end of one year decomposition. The absolute quantity of nitrogen decreased from 0.434 g to 0.072 g during the decomposition releasing 83.5% of the initial nitrogen (Fig. 3).

It may be inferred that the species with high decomposibility released highest quantity of percentage nitrogen and initial nitrogen content is not the only factor which determines the nitrogen release on decomposition. But in terms of quantity of N 0.408 g N was released from Acacia, 0.259 g from Eucalyptus and 0.362 g from natural forest. Eventhough the percentage release was highest in natural forest, the quantity of N released was maximum in Acacia. High N content in the decomposing litter is the reason for such a phenomenon.

4.4.2 Phosphorus

Phosphorus dynamics from decomposing leaf litter given in Table 7 showed that there was significant increase in percentage P content as decomposition proceeded. Mean P content increased from 0.068% to 0.093% at the end of one year decomposition. The absolute P content of 0.034 g increased slightly during the 1st month followed by a linear decrease upto the 12th month (0.01g). In Acacia the percentage P content increased from 0.076 to 0.109% at the end of one year decomposition and the absolute quantity decreased from 0.038 g to 0.0097 g, releasing 74.5% of the initial quantity (Fig. 4).

Table 7 Phosphorus release on leaf litter decomposition

Month	Acacia		Eucalyptus		Natural forest		Mean	
	P (%)	Abs. P (g)	P (%)	Abs. P (g)	P (%)	Abs. P (g)	P (%)	Abs. P (g)
Initial	0.076	0.038	0.068	0.034	0.059	0.029	0.068	0.034
June 1995	0.078	0.035	0.088	0.041	0.061	0.027	0.076	0.035
July	0.081	0.034	0.091	0.039	0.062	0.025	0.078	0.033
August	0.084	0.033	0.088	0.036	0.068	0.024	0.080	0.031
September	0.083	0.029	0.084	0.032	0.073	0.021	0.080	0.028
October	0.092	0.029	0.085	0.030	0.074	0.018	0.084	0.026
November	0.092	0.025	0.087	0.027	0.073	0.015	0.085	0.023
December	0.096	0.022	0.085	0.023	0.080	0.014	0.087	0.020
January '96	0.097	0.016	0.089	0.021	0.080	0.012	0.087	0.017
February	0.092	0.014	0.086	0.019	0.083	0.011	0.089	0.015
March	0.098	0.012	0.087	0.017	0.087	0.009	0.091	0.013
April	0.098	0.012	0.087	0.016	0.090	0.008	0.096	0.012
May	0.109	0.009	0.087	0.015	0.092	0.006	0.093	0.010

		P (%)	Abs. P (g)
CD (0.05)	Between Mon.	0.005	0.002
	Within pln.	0.009	0.003

Percentage P content increased from 0.0684% to 0.0974% in Eucalyptus on decomposition and the absolute quantity of 0.0342 g increased upto the 3rd month of decomposition and subsequently decreased to 0.014 g at the end of one year releasing 56.5% of the initial quantity. Natural forest leaf litter showed an increase in % P content from 0.059% to 0.0924% after one year decomposition. The absolute quantity of P decreased from 0.0295 g to 0.0067 g releasing 77.3% of the initial quantity (Fig. 4).

It may be inferred from the data that mobility of P from decomposing leaf litter was low compared to the dry matter loss. Increase in absolute quantity of P upto 3 months of decomposition in Eucalyptus may be due to the immobilisation of P from the environment. The quantity of P released from 50 g leaf litter were 0.0283 g in Acacia, 0.0193 g in Eucalyptus and 0.028 g in natural forest. High content of P in leaf litter of Acacia resulted in a higher release of P on decomposition.

4.4.3 Potassium

Potassium release from decomposing leaf litter as given in Table 8 showed that in contrast to N and P, percentage as well as total potassium content decreased as the decomposition proceeded. The mean percentage K decreased from 0.65% to 0.512% at the end of 12 months decomposition and the absolute K content decreased from 0.325 g to 0.0555g. With respect to individual species, the percentage K content in Acacia decreased from 0.51%

Table 8 Potassium release on leaf litter decomposition

Month	Acacia		Eucalyptus		Natural forest		Mean	
	K (%)	Abs. K (g)	K (%)	Abs. K (g)	K (%)	Abs. K (g)	K (%)	Abs. K (g)
Initial	0.510	0.255	0.680	0.340	0.760	0.380	0.650	0.325
June 1995	0.520	0.238	0.650	0.303	0.710	0.320	0.627	0.288
July	0.490	0.207	0.590	0.256	0.660	0.276	0.587	0.247
August	0.450	0.179	0.560	0.231	0.640	0.226	0.550	0.212
September	0.400	0.144	0.500	0.194	0.636	0.189	0.512	0.176
October	0.360	0.115	0.470	0.166	0.640	0.160	0.490	0.147
November	0.390	0.104	0.490	0.155	0.636	0.135	0.505	0.132
December	0.420	0.093	0.480	0.132	0.638	0.115	0.513	0.114
January '96	0.430	0.077	0.490	0.118	0.642	0.100	0.521	0.099
February	0.438	0.064	0.492	0.110	0.646	0.083	0.525	0.086
March	0.442	0.056	0.492	0.100	0.652	0.072	0.529	0.076
April	0.448	0.049	0.420	0.078	0.662	0.060	0.510	0.063
May	0.452	0.044	0.416	0.071	0.668	0.048	0.512	0.055

		K (%)	Abs. K (g)
CD	Between. Mon.	0.030	0.008
(0.05)	Within pln.	0.052	0.014

to 0.36% at the end of 5th month of decomposition and subsequently increased to 0.452% at the end of 12th month. The absolute quantity of K decreased linearly from 0.255 g to 0.448 g after one year decomposition releasing 82.5% of the initial K content (Fig. 5). In Eucalyptus the percentage K content decreased from 0.68% to 0.47% at the end of 5th month and subsequently increased to 0.416%. The absolute quantity of K content continuously decreased from 0.34 g and reached 0.071 g at the end of 12th month releasing 79.15% of the initial K content. The % K content of natural forest litter decreased from 0.76% to 0.636% at the end of 6th month followed by a linear increase to 0.668% at the end of one year decomposition. The absolute quantity of K content decreased from 0.38 g to 0.0483 g during one year decomposition releasing 87.3% of the original K content.

From decomposing leaf litter the mobility of potassium is faster than the dry matter loss especially during 1st 6 months of decomposition as evident from the decrease in K content from litter bag on decomposition upto 6th month. Since K in plant is not a structural component and K is highly mobile in plant, leaching loss may be the reason for its rapid loss on decomposition. Attiwill (1968) also reported that K is the most mobile element during litter decomposition and returned to the soil at the earliest. Highest mobility of K was also reported by Stephen *et al*. (1992) and Robert and Ted (1995).

4.4.5 Calcium

The mean calcium content of decomposing leaf litter increased from 0.896% to 1.003% at the end of one year decomposition and the absolute quantity of calcium decreased from 0.448 g to 0.118 g during the same period (Table 9).

In Acacia the percentage calcium content increased from 0.794% to 0.914 at the end of 1 year and the absolute calcium content decreased from 0.397 g to 0.0907 g releasing 77.2% of the initial quantity on one year decomposition. Percentage calcium content increased from 0.97 to 1.113% in Eucalyptus and the absolute quantity decreased from 0.485 g to 0.1927 g releasing 60.3% of the initial Ca content. Natural forest litter contained 0.924% Ca which increased to 0.964% at the end of one year decomposition. The absolute quantity of Ca decreased from 0.462 g to 0.069 g during the same period releasing 85% of the original calcium content (Fig. 6).

Calcium is also a highly mobile element from decomposing leaf litter. On decomposition calcium released from litter of natural forest is parallel to the loss of dry matter but slightly less than the dry matter loss in Acacia and Eucalyptus leaf litter. During one year decomposition, 0.206, 0.292 and 0.392 g. of Ca released from litter bags of Acacia, Eucalyptus and natural forest respectively. Eventhough Eucalyptus leaf litter recorded the lowest rate of litter

Table 9 Calcium release on leaf litter decomposition

Month	Acacia		Eucalyptus		Natural forest		Mean	
	Ca (%)	Abs.Ca (g)	Ca (%)	Abs.Ca (g)	Ca (%)	Abs.Ca (g)	Ca (%)	Abs.Ca (g)
Initial	0.794	0.397	0.970	0.485	0.924	0.462	0.896	0.448
June 1995	0.812	0.372	0.996	0.464	0.896	0.405	0.901	0.414
July	0.816	0.345	1.020	0.443	0.922	0.374	0.919	0.388
August	0.788	0.314	1.040	0.429	0.938	0.331	0.922	0.359
September	0.798	0.288	1.060	0.412	0.940	0.280	0.933	0.327
October	0.786	0.251	1.070	0.378	0.932	0.233	0.929	0.288
November	0.778	0.209	1.070	0.339	0.928	0.197	0.925	0.249
December	0.812	0.181	1.090	0.300	0.931	0.169	0.945	0.217
January '96	0.846	0.152	1.090	0.265	0.956	0.149	0.965	0.189
February	0.836	0.123	1.100	0.245	0.960	0.124	0.965	0.164
March	0.862	0.109	1.110	0.227	0.946	0.104	0.973	0.147
April	0.880	0.097	1.110	0.208	0.958	0.086	0.983	0.131
May	0.914	0.090	1.130	0.192	0.964	0.069	1.000	0.118

CD	Between Mon.	0.013	0.053
(0.05)	Within pln.	0.023	0.092

Fig:-6
Calcium release on litter decomposition

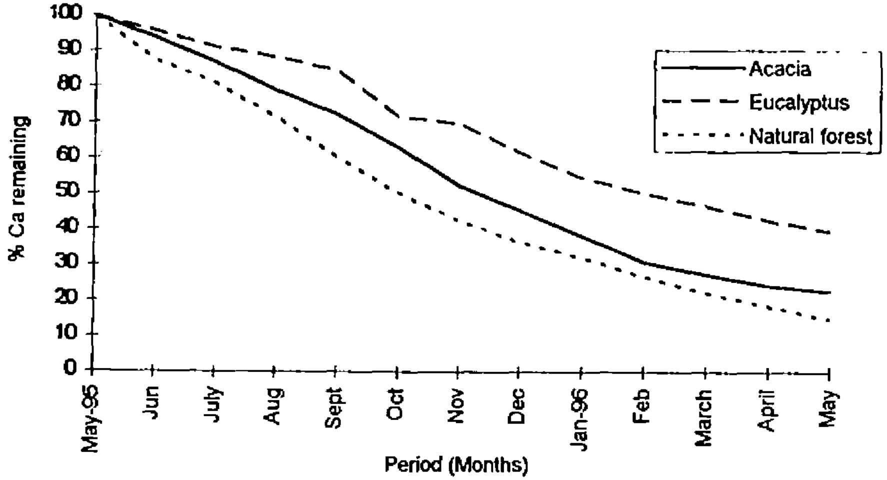


Fig:-7
Magnesium release on litter decomposition

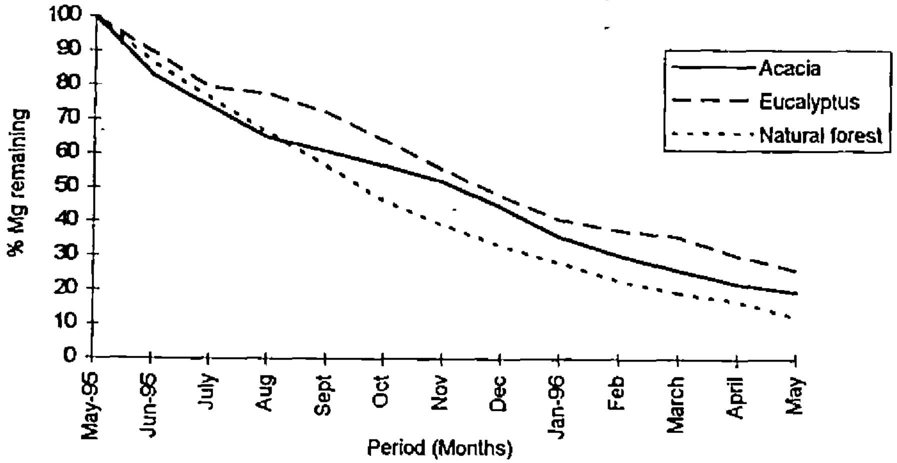
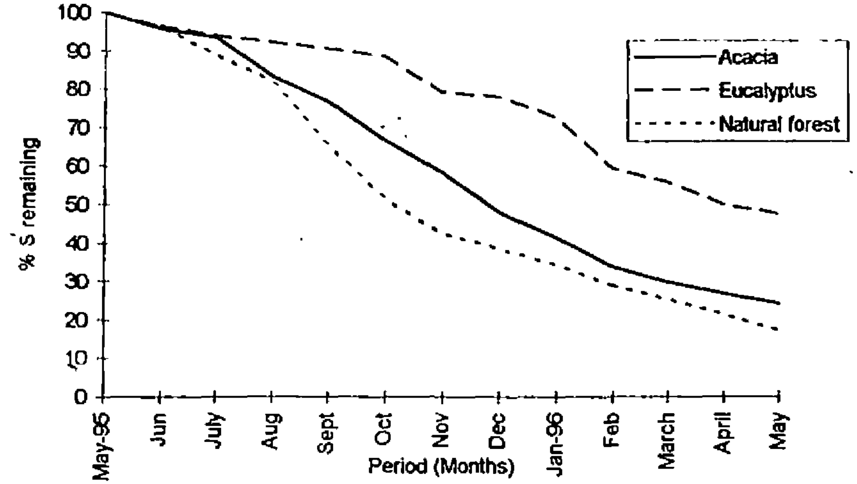


Fig:- 8
Sulphur release on litter decomposition



decomposition, release of calcium higher than that from Acacia is due to the high content of calcium in the leaf litter of Eucalyptus.

4.4.6 Magnesium

The magnesium dynamics associated with litter decomposition (Table 10) showed that Mg content of leaf litter decreased from 0.289% to 0.261% during one year decomposition and the absolute quantity also decreased from 0.145 g to 0.026 g during the same period. In Acacia the percentage magnesium content did not show any significant difference between months indicating that release of Mg is parallel to the loss of dry matter on decomposition. The absolute quantity of Mg showed a drastic decrease from 0.16 g to 0.0317 g on one year decomposition releasing 80.2% of the initial quantity. The percentage magnesium content in Eucalyptus decreased from 0.168% to 0.13% and the absolute quantity also decreased from 0.084 g to 0.0221 g releasing 73.7% of the initial Mg content. In natural forest leaf litter, the initial magnesium content of 0.38% decreased to 0.334% on one year decomposition and the absolute quantity decreased from 0.19 g to 0.024 g releasing 87.37% of the initial mg content (Fig. 7).

Results on magnesium release characteristics from decomposing leaf litter indicate that loss of magnesium is parallel to the loss of dry matter from decomposing leaf litter

Table 10 Magnesium release on leaf litter decomposition

Month	Acacia		Eucalyptus		Natural forest		Mean	
	Mg (%)	Abs.Mg (g)	Mg (%)	Abs.Mg (g)	Mg (%)	Abs.Mg (g)	Mg (%)	Abs.Mg (g)
Initial	0.320	0.160	0.168	0.084	0.380	0.190	0.289	0.145
June 1995	0.290	0.133	0.162	0.075	0.366	0.165	0.273	0.125
July	0.280	0.118	0.154	0.067	0.358	0.145	0.264	0.110
August	0.260	0.103	0.158	0.065	0.358	0.126	0.249	0.099
September	0.270	0.097	0.156	0.061	0.362	0.108	0.263	0.089
October	0.284	0.090	0.152	0.054	0.354	0.088	0.263	0.078
November	0.310	0.083	0.148	0.047	0.352	0.075	0.270	0.068
December	0.320	0.071	0.146	0.040	0.348	0.063	0.271	0.058
January '96	0.320	0.057	0.142	0.034	0.344	0.054	0.269	0.049
February	0.330	0.048	0.142	0.032	0.340	0.044	0.271	0.041
March	0.330	0.042	0.140	0.028	0.336	0.037	0.269	0.036
April	0.320	0.035	0.136	0.025	0.356	0.032	0.271	0.031
May	0.320	0.031	0.130	0.022	0.334	0.024	0.261	0.026

CD	Between Mon.	0.022	0.006
(0.05)	Within pln.	0.039	0.010

and unlike the K release characteristics, release of magnesium is distributed throughout the 12 month period of decomposition studied. Magnesium is the highly mobile element in decomposing leaf litter and recorded the highest mobility in natural forest litters. Higher rate of mobility of Mg next to K was also reported by many workers (Behuguna *et al.*, 1990 and Stephen *et al.*, 1992).

4.4.7 Sulphur

Sulphur releasing characteristics of decomposing leaf litter is depicted in Table 11. The data showed that the mean percentage S content increased from 0.3% to 0.371% during one year decomposition. But the absolute quantity of S showed a significant decrease from 0.15 g to 0.037 g during the same period. In individual plantations the percentage S content increased from 0.47 to 0.576% in Acacia, 0.12% to 0.168% in Eucalyptus and 0.31% to 0.37% in natural forest. In contrast, the absolute S content in the litter bag samples significantly decreased from 0.235 g to 0.0572 g in Acacia, 0.06 g to 0.0286 g in Eucalyptus and 0.1555 g to 0.0267 g in natural forest releasing 75.68%, 52.34% and 82.8% of the initial S present in the litter bag samples respectively (Fig. 8).

Sulphur release characteristics showed that the release of S from decomposing leaf litter is slower than the loss in dry matter on decomposition irrespective of the plantation, but

Table 11 Sulphur release on leaf litter decomposition

Month	Acacia		Eucalyptus		Natural forest		Mean	
	S (%)	Abs. S (g)	S (%)	Abs. S (g)	S (%)	Abs. S (g)	S (%)	Abs. S (g)
Initial	0.470	0.235	0.120	0.060	0.310	0.155	0.030	0.150
June 1995	0.490	0.224	0.124	0.057	0.330	0.149	0.315	0.144
July	0.520	0.219	0.130	0.056	0.340	0.138	0.330	0.138
August	0.490	0.195	0.134	0.055	0.360	0.127	0.328	0.126
September	0.500	0.180	0.140	0.054	0.340	0.101	0.327	0.112
October	0.490	0.156	0.150	0.053	0.320	0.079	0.320	0.096
November	0.510	0.136	0.150	0.047	0.310	0.066	0.323	0.083
December	0.530	0.118	0.170	0.046	0.330	0.058	0.343	0.075
January '96	0.540	0.097	0.180	0.043	0.340	0.050	0.353	0.065
February	0.540	0.079	0.160	0.035	0.350	0.045	0.350	0.053
March	0.552	0.070	0.164	0.033	0.360	0.039	0.359	0.048
April	0.570	0.063	0.160	0.030	0.370	0.033	0.367	0.042
May	0.576	0.057	0.168	0.028	0.370	0.026	0.371	0.037

CD	Between Mon.	0.007	0.029
(0.05)	Within pln.	0.012	0.050

the order of percentage release is in accordance with the rate of degradation of the litter bag material.

4.4.8 Iron

Iron dynamics in decomposing leaf litter (Table 12) showed that mean iron content recorded a significant increase from 391.33 ppm to 832.3 ppm during one year decomposition and the absolute quantity of Fe decreased from 19.56 mg to 8.51 mg during the same period. There was no significant difference in Fe content upto the 4th month which was followed by a significant decrease. Due to the one year decomposition of leaf litter, the Fe content in Acacia leaf litter increased from 520 ppm to 1138 ppm and the absolute quantity of Fe decreased from 26 mg to 11.3 mg releasing 56.5% of the initial Fe content (Fig. 9). But the Fe content upto the 5th month of decomposition did not show any significant change. The Fe content in Eucalyptus leaf litter increased from 274 ppm to 450 ppm on one year decomposition and the absolute quantity of Fe decreased from 13.7 mg to 7.66 mg releasing 44% of the initial quantity. Upto 5th month of decomposition there was no significant difference in Fe content. Natural forest leaf litter showed an increase in Fe content from 380 ppm to 909 ppm during one year decomposition and the absolute quantity of Fe decreased from 19.0 mg to 6.56 mg releasing 65.48% of the initial Fe content. Significant quantity of Fe released from 3rd month of decomposition onwards.

Table 12 Iron release on leaf litter decomposition

Month	Acacia		Eucalyptus		Natural forest		Mean	
	Fe (ppm)	Abs.Fe (mg)	Fe (ppm)	Abs.Fe (mg)	Fe (ppm)	Abs.Fe (mg)	Fe (ppm)	Abs.Fe (mg)
Initial	520	26.00	274	13.70	380	19.00	391.33	19.56
June 1995	560	25.69	296	13.81	422	19.05	426.00	19.52
July	598	25.28	324	14.07	460	18.68	460.66	19.34
August	635	25.35	337	13.92	525	18.54	499.00	19.27
September	716	25.60	348	13.52	583	17.39	547.00	78.84
October	790	25.24	374	13.23	638	15.96	600.60	18.14
November	887	23.82	370	11.71	694	14.77	650.33	16.77
December	922	20.60	389	10.72	740	13.41	683.66	14.91
January '96	983	17.70	396	9.62	802	12.57	727.00	13.29
February	1035	15.27	410	9.15	851	10.99	765.33	11.80
March	1091	13.86	421	8.61	884	9.77	798.66	10.74
April	1112	12.33	438	8.21	892	8.07	814.00	9.54
May	1138	11.30	450	7.66	909	6.56	823.30	8.61

CD (0.05)	Between Mon.	33.89	0.71
	Within pln.	58.70	1.23

Fig:-9
Iron release on litter decomposition

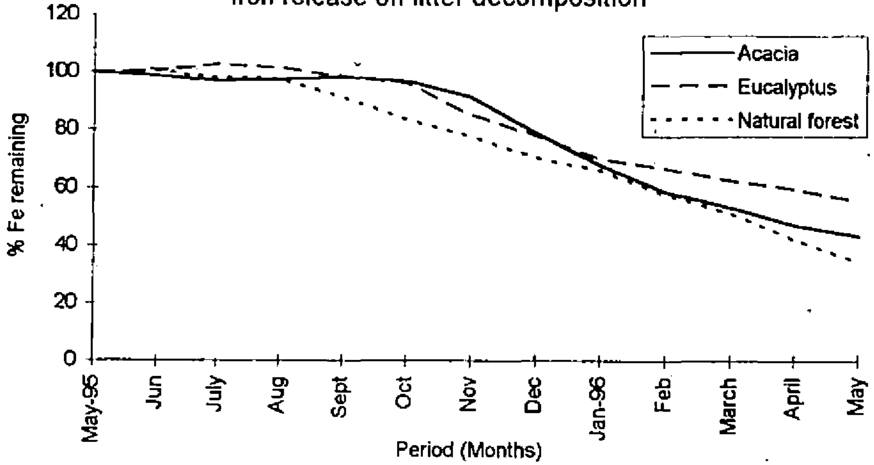


Fig:-10
Manganese release on litter decomposition

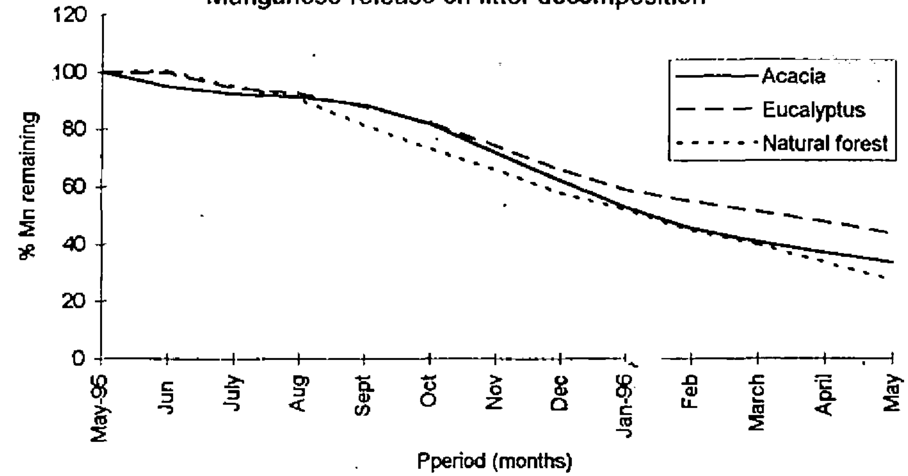


Fig:- 11
Copper release on litter decomposition

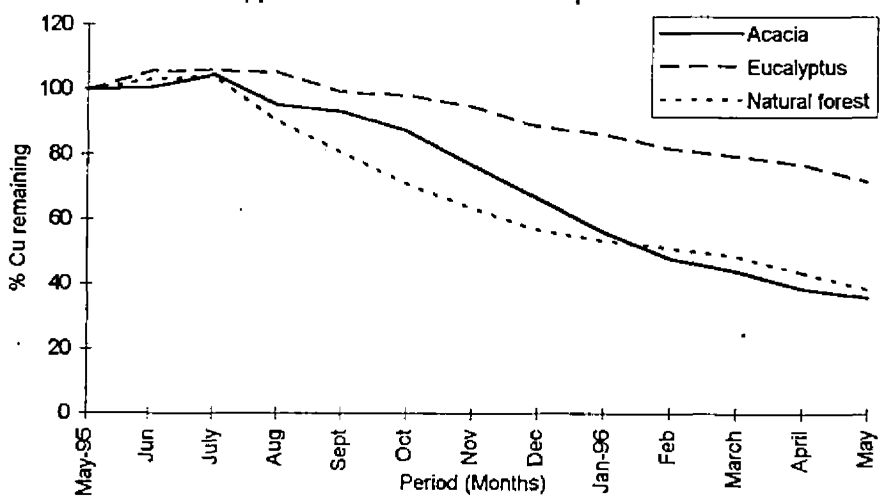
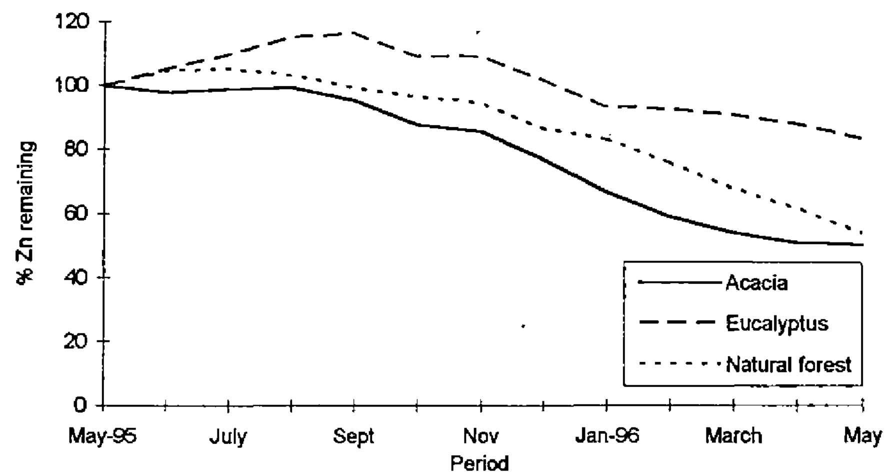


Fig: 12
Zinc release on litter decomposition



Comparison of Fe releasing characteristics of individual plantations showed that natural forest litter released significant quantity of Fe much earlier than that of Acacia and Eucalyptus. In Eucalyptus, the immobilisation of Fe was noticed up to the end of 3rd month though the change was insignificant. (Fig. 9). Low initial Fe content coupled with low decomposition rate in Eucalyptus and low rate of degradation in initial months may be the reason for delay in net Fe release characteristics in Acacia and Eucalyptus.

4.4.9 Manganese

Manganese release characteristics of decomposing leaf litter given in Table 13 revealed that mean Mn content in leaf litter significantly increased from 136.66 ppm to 219.66 ppm during one year decomposition. The absolute quantity of Mn decreased from 6.83 mg to 2.44 mg during the same period. Nutrient release characteristics of individual plantations showed that the Mn content of decomposing leaf litter increased from 117 ppm to 199 ppm in Acacia, 160 ppm to 206 ppm in Eucalyptus and 135 ppm to 254 ppm in natural forest during one year decomposition. The decrease in absolute quantity of Mn during the same period were 5.85 mg to 1.97 mg (66.33%) in Acacia, 8 mg to 3.51 mg (56.13%) in Eucalyptus and 6.65 mg to 1.83 mg in natural forest during the same period (Fig. 10).

Comparison of the nutrient release characteristics of individual plantations revealed that though the percentage

Table 13 Manganese release on leaf litter decomposition

Month	Acacia		Eucalyptus		Natural forest		Mean	
	Mn (ppm)	Abs.Mn (mg)	Mn (ppm)	Abs.Mn (mg)	Mn (ppm)	Abs.Mn (mg)	Mn (ppm)	Abs.Mn (mg)
Initial	117	5.85	160	8.00	133	6.65	136.66	6.83
June 1995	121	5.55	171	7.98	148	6.68	146.66	6.74
July	128	5.41	174	7.56	156	6.33	152.66	6.43
August	134	5.35	179	7.39	170	6.01	161.00	6.25
September	144	5.19	181	7.03	182	5.43	169.00	5.88
October	150	4.79	186	6.58	195	4.88	177.00	5.42
November	157	4.21	188	5.96	207	4.40	184.00	4.86
December	163	3.64	192	5.29	213	3.86	189.33	4.26
January '96	172	3.10	195	4.73	222	3.47	196.33	3.77
February	181	2.67	197	4.40	231	2.98	203.00	3.35
March	188	2.39	201	4.11	240	2.65	209.73	3.05
April	196	2.17	204	3.83	248	2.24	216.00	2.75
May	199	1.97	206	3.51	254	1.83	219.66	2.44

CD (0.05)	Between Mon.	6.33	0.116
	Within pln.	10.98	0.202

release of Mn from decomposing leaf litter follow the order of dry matter loss (Natural forest > Acacia > Eucalyptus) the absolute quantity of Mn released from the same quantity of leaf litter were highest in natural forest (4.82 mg) followed by Eucalyptus (4.49 mg) and lowest in Acacia (3.88 mg). Low Mn status of Acacia leaf litter may be the reason for its lowest Mn release.

4.4.10 Copper

Copper dynamics in decomposing leaf litter given in Table 14 revealed that the mean Cu content of decomposing leaf litter significantly increased from 20.66 ppm to 43.66 ppm during one year decomposition. The absolute quantity of Cu expressed a slight increase during first two months from 1.03 mg to 1.08 mg followed by a gradual decrease to 0.487 mg at the end of one year decomposition. In Acacia leaf litter, the Cu content increased from 30 ppm to 55 ppm during 12 month of decomposition. The absolute quantity of Cu initially increased from 1.5 mg to 1.56 mg during 2nd months of decomposition followed by a linear decrease to 0.54 mg at the end of one year, releasing 64% of the initial quantity. On decomposition the Cu content increased from 18 to 38 ppm in Eucalyptus, and 14 to 38 ppm in natural forest during one year period. With respect to the absolute quantity, it decreased from 0.9 - 0.647 mg (28.10%) in Eucalyptus and 0.7 - 0.271 mg (61.29%) in natural forest (Fig.11). Similar to Acacia,

Table 14 Copper release on leaf litter decomposition

Month	Acacia		Eucalyptus		Natural forest		Mean	
	Cu (ppm)	Abs.Cu (mg)	Cu (ppm)	Abs.Cu (mg)	Cu (ppm)	Abs.Cu (mg)	Cu (ppm)	Abs.Cu (mg)
Initial	30	1.50	18	0.90	14	0.70	20.66	1.03
June 1995	33	1.51	20	0.95	16	0.72	23.13	1.06
July	37	1.56	22	0.95	18	0.73	25.66	1.08
August	36	1.43	23	0.94	18	0.63	25.66	1.00
September	39	1.40	23	0.89	19	0.56	27.00	0.95
October	41	1.31	25	0.88	20	0.49	28.66	0.89
November	43	1.15	27	0.85	21	0.44	30.33	0.81
December	45	1.00	29	0.79	22	0.39	32.00	0.73
January '96	47	0.84	32	0.77	24	0.37	34.33	0.66
February	49	0.72	33	0.73	28	0.35	36.66	0.60
March	52	0.66	35	0.71	31	0.34	39.33	0.57
April	53	0.58	37	0.69	34	0.30	41.33	0.52
May	55	0.54	38	0.64	38	0.27	43.66	0.48

CD (0.05)		Cu	Abs.Cu
	Between Mon.	3.00	0.07
	Within pln.	5.20	0.12

Eucalyptus and natural forest leaf litter also recorded a non significant increase in absolute quantity of Cu during initial 2-3 months of decomposition.

Copper release characteristics revealed that the rate of copper mobility from decomposing litter is very slow compared to dry matter loss indicated by significant increase in Cu (in ppm) on leaf litter decomposition. Increased absolute quantity of copper observed in the first 2-3 months of decomposition may be due to the immobilisation of copper from the soil environment. High Cu content in Acacia leaf litter resulted in a very high percentage of Cu release from decomposing leaf litter on one year decomposition.

4.4.11 Zinc

Zinc release characteristics from decomposing leaf litter (Table 15) revealed that there was significant increase in Zn content on decomposition. The mean Zn content increased from 30.4 ppm to 89.00 ppm during one year decomposition. The absolute quantity of Zn showed an increasing tendency from 1.52 mg up to the end of 4th month and then decreased to 0.9 mg during one year decomposition. With respect to individual plantations, on decomposition the Zn content increased from 39.2 to 100 ppm in Acacia, 22 to 53 ppm in Eucalyptus and 30 to 114 ppm in natural forest. The absolute quantity of Zn present in the litter bag material decreased from 1.96 mg to 0.99 mg (49.5%) in Acacia, 1.1

Table 15 Zinc release on leaf litter decomposition

Month	Acacia		Eucalyptus		Natural forest		Mean	
	Zn (ppm)	Abs.Zn (mg)	Zn (ppm)	Abs.Zn (mg)	Zn (ppm)	Abs.Zn (mg)	Zn (ppm)	Abs.Zn (mg)
Initial	39	1.96	22	1.10	30	1.50	30.40	1.52
June 1995	42	1.92	25	1.16	35	1.57	34.00	1.55
July	46	1.94	28	1.21	39	1.58	37.46	1.58
August	49	1.95	31	1.27	44	1.55	41.33	1.59
September	52	1.87	33	1.28	50	1.49	45.00	1.54
October	54	1.72	34	1.20	58	1.45	48.66	1.45
November	63	1.68	38	1.20	67	1.42	56.00	1.44
December	68	1.51	41	1.12	72	1.30	60.33	1.31
January '96	73	1.31	44	1.06	80	1.25	65.66	1.21
February	79	1.16	46	1.02	89	1.14	71.33	1.11
March	84	1.06	49	1.00	93	1.02	75.33	1.03
April	91	1.00	52	0.97	104	0.94	82.33	0.97
May	100	0.99	53	0.92	104	0.81	89.00	0.90

CD	Between Mon.	4.06	0.089
(0.05)	Within pln.	7.03	0.154

to 0.92 mg (16.37%) in Eucalyptus and 1.5 - 0.81 mg (46%) in natural forest (Fig. 12). Zinc immobilisation upto 5th and 4th months were observed in leaf litters of Eucalyptus and Natural forest respectively.

Zinc release characteristics revealed that significant increase in Zn content (in ppm) on decomposition may be due to the low mobility of Zn on decomposition compared to dry matter loss. Among plantations highest percentage as well as quantity of Zn was released from Acacia followed by natural forest. High initial Zn content in Acacia may be the reason for its higher Zn release characteristics.

Nutrient release characteristics on leaf litter decomposition is given in Table 16. The order of the absolute quantity of nutrient released and the order of the percentage release of each nutrient is different in individual leaf litter. The order of the absolute quantity of nutrient released were N> Ca > K > S > Mg > P > Fe > Mn > Zn > Cu for Acacia, Ca > K > N > Mg > S > P > Fe > Mn > Cu > Zn for Eucalyptus and Ca > N > K > Mg > S > P > Fe > Mn > Zn > Cu for natural forest. With respect to the percentage of nutrient released on decomposition the decreasing order of nutrient release for various leaf litter were K > Mg > Ca > N > S > P > Mn > Cu > Fe > Zn for Acacia, K > Mg > Ca > N > P> Mn > S > Fe > Cu > Zn for Eucalyptus and Mg > K > Cu > N > S > P > Mn > Fe > Cu > Zn in natural forest. The order of absolute qunatity of nutrient release is determined by the

Table 16 Nutrient release characteristics of leaf litter on one year decompostion

Nutrient	% release			Absolute quantity release (mg) per 50 g litter		
	Acacia	Eucal-yptus	Natural forest	Acacia	Eucal-yptus	Natural forest
Nitrogen	76.97	56.93	83.42	508.00	259.000	362.000
Phosphorus	74.48	56.44	77.29	28.30	19.300	22.800
Potassium	82.43	79.15	87.29	210.20	269.100	331.700
Calcium	77.16	60.27	85.00	306.30	292.300	392.600
Magnesium	86.19	73.70	87.37	128.30	61.900	166.000
Sulphur	75.66	52.34	82.81	177.80	31.400	128.300
Iron	56.54	44.10	65.48	14.70	6.040	12.440
Manganese	66.33	56.13	72.49	3.88	4.490	4.820
Copper	64.00	28.12	61.29	0.96	0.253	0.429
Zinc	49.49	16.37	46.00	0.97	0.150	0.690

Table 17 Decomposition parameters of dry matter and nutrients

Nutrient	Acacia			Eucalyptus			Natural forest		
	'K'	T_{50}	T_{95}	'K'	T_{50}	T_{95}	'K'	T_{50}	T_{95}
Dry matter	0.865	6.79	22.70	0.910	9.34	37.05	0.850	6.26	20.43
Nitrogen	0.868	6.93	24.83	0.924	10.82	40.16	0.854	6.38	20.97
Phosphorus	0.887	7.82	27.17	1.019	11.08	44.18	0.883	7.58	26.09
Potassium	0.857	6.50	21.61	0.879	7.39	25.33	0.844	6.08	19.75
Calcium	0.873	7.13	24.20	0.920	10.41	38.35	0.853	6.38	20.96
Magnesium	0.876	7.26	24.74	0.893	8.14	28.56	0.843	6.07	19.61
Sulphur	0.878	7.34	25.10	0.938	12.93	49.21	0.859	6.56	21.71
Iron	0.928	11.27	42.08	0.945	14.24	54.94	0.917	10.07	36.88
Manganese	0.906	9.01	32.34	0.927	11.26	42.03	0.896	8.33	29.39
Copper	0.908	9.18	33.04	0.969	24.15	97.75	0.917	9.99	36.57
Zinc	0.936	12.47	47.28	0.979	34.65	143.10	0.950	15.51	60.40

nutrient content in the leaf litter, whereas the order of percentage release determined by the decomposition rate of the leaf litter. Highest percentage mobility of K followed by Mg on decomposition of various leaf litter was reported by many workers (Behuguna *et al*. 1990, Stephen *et al*. 1992). Among the micro nutrients, the highest mobility for Mn and lowest mobility for Zn was also reported by Backheim and Leide (1986).

Decomposition parameters of dry matter as well as various nutrients given in Table 17 showed that all the indices of decomposition i.e decomposition constant (K) and time taken to degrade or release 50% and 95% of the original quantity (in months) was lowest in the case of natural forest followed by Acacia and Eucalyptus. But in the case of copper and Zn Acacia recorded the lowest value it may be due to the high content of Cu and Zn Acacia leaf litter than that of other plantation. The t^{50} value observed in the present study is comparable with the reports of Mary and Sankaran (1990), Sankaran *et al*. (1993), Pande and Sharma (1993) Illangovan and Kailash Paliwal (1996).

4.5 Changes in soil properties associated with litter decomposition

4.5.1 Chemical properties

4.5.1.1 pH

Changes in soil pH brought about by decomposition of leaf litters of various plantations given in Table 18 showed that

Table 18 Changes in soil pH and organic carbon on litter decomposition

Month	pH				Organic carbon (%)			
	Acacia	Eucalyptus	Natural forest	Mean	Acacia	Eucalyptus	Natural forest	Mean
Initial	4.89	4.79	5.25	4.98	3.06	2.72	3.26	3.01
June 1995	4.86	4.74	5.33	4.97	3.12	2.76	3.22	3.03
July	5.05	4.87	5.50	5.14	3.16	2.82	3.26	3.08
August	5.16	5.04	5.51	5.24	3.22	2.87	3.32	3.14
September	5.17	4.99	5.29	5.15	3.25	2.86	3.36	3.16
October	5.02	4.94	5.34	5.01	3.26	2.96	3.34	3.19
November	5.25	5.09	5.40	5.25	3.30	2.94	3.40	3.21
December	5.33	5.13	5.57	5.34	3.35	2.98	3.38	3.24
January'96	5.45	5.17	5.64	5.42	3.36	3.08	3.41	3.28
February	5.27	5.24	5.63	5.38	3.38	3.19	3.41	3.33
March	5.37	5.28	5.65	5.43	3.41	3.21	3.45	3.35
April	5.35	5.19	5.60	5.38	3.42	3.22	3.46	3.36
May	5.37	5.26	5.65	5.43	3.46	3.24	3.48	3.39
Mean	5.19	5.06	5.49		3.29	2.99	3.36	

CD (0.05)		pH	Organic carbon
	Bet.Pln.	0.036	0.027
	Bet.Mon.	0.076	0.056
	Within Pln.	0.132	0.098

natural forest soil had the highest mean pH of 5.49 followed by Acacia (5.19) and Eucalyptus (5.06). Data showed that as the decomposition proceeds the mean soil pH increased from 4.98 to 5.43 at the end of 12 month, though the change in pH was non significant in majority of the intervals. The increase in pH on litter decomposition was 4.89 to 5.37 in Acacia 4.79 to 5.26 in Eucalyptus and 5.25 to 5.65 in natural forest during one year decomposition of the respective leaf litters.

Increase in soil pH brought about by the decomposition of overlying litter bag may be due to the release of basic cations especially Ca, Mg and K from the decaying litter. It is further supported by the fact that higher pH was observed in natural forest followed by Acacia which released more Ca and Mg and K on decomposition than Eucalyptus.

4.5.1.2 Organic carbon

Organic carbon dynamics associated with litter decomposition is given in Table 18. Close scrutiny of the data showed that mean organic carbon content between plantations varied significantly and the highest organic carbon content was recorded in natural forest (3.36%) followed by Acacia (3.29%) and Eucalyptus (2.99%). Monthly variation in organic carbon content associated with leaf litter decomposition showed that it gradually increased from 3.01 to 3.39% as the decomposition proceeded to one year. The variations was non significant

Fig:- 13
Variation in soil organic carbon on litter decomposition

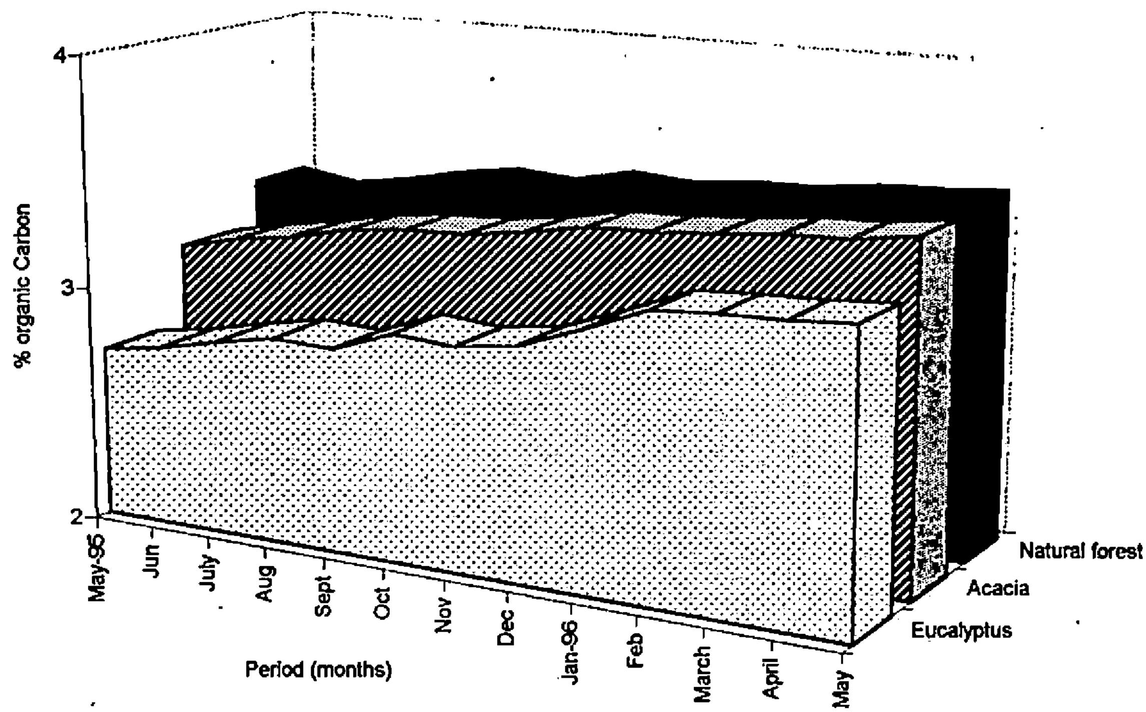
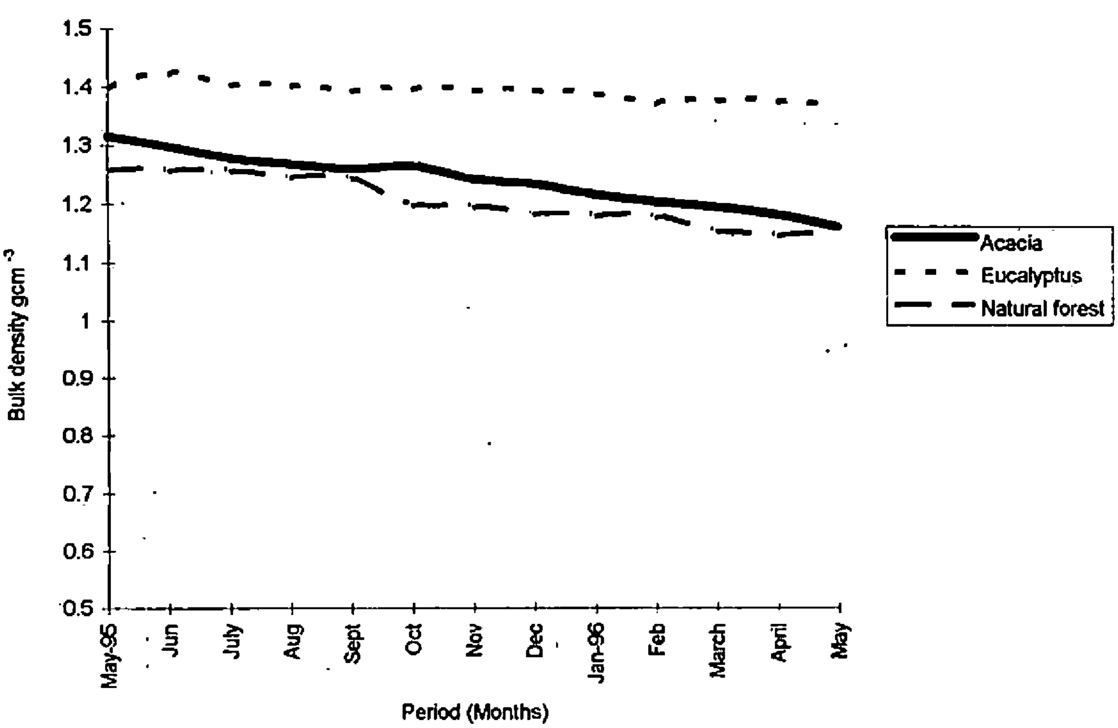


Fig : 14
Variation in Bulk density on litter decomposition



between adjacent months in majority of the intervals. During the period of one year decomposition the organic carbon content of soil increased from 3.06 to 3.46% in Acacia, 2.92 to 3.24% in Eucalyptus and 3.26 to 3.45% in natural forest. The increase in organic carbon on decomposition between adjacent intervals was not significant in all the plantations except Eucalyptus where significant increase in organic carbon content in soil took place in 5th and 9th month of decomposition.

Increase in organic carbon content of soil at monthly intervals by the leaf litter decomposition observed in the present study was supported by the reports of Vijaya and Naidu (1995). Increase in organic carbon content was maximum in Eucalyptus (0.52%) followed by Acacia (0.4%) and natural forest (0.22%). This result was contradictory to the dry matter loss on decomposition which was maximum in natural forest and minimum in Eucalyptus. The high decomposition in natural forest and Acacia as compared to the organic carbon addition resulting in greater loss of carbonaceous materials may be the reason for the high organic carbon addition in soil by Eucalyptus on litter decomposition. In Eucalyptus eventhough the rate of litter decomposition was slow, slow and incomplete decomposition resulted in accumulation of carbanaceous material rather than loss as CO_2

4.5.1.3 Available N, P, K

Changes in available N, P, K status of soil due to the decomposition of litter bags of various plantations are given in Table 19. The mean nitrogen status of various plantations varied significantly and highest value observed in natural forest (323.3 kg ha^{-1}) followed by Acacia (313.5 kg ha^{-1}) and Eucalyptus (292.31 kg ha^{-1}). Monthly nutrient addition due to litter decomposition showed that there was a net decrease in nitrogen content during the 1st month of decomposition from 290.27 to 278.72 kg ha^{-1} which subsequently increased to 325.8 kg ha^{-1} at the end of 12th month. Nitrogen content of soils under decomposing litter bags of various plantations increased from 292.4 to 323.6 kg ha^{-1} in Acacia, 266.0 to 317.9 kg ha^{-1} in Eucalyptus and 312.3 to 338.8 kg ha^{-1} in natural forest. The increase in nitrogen content due to litter decomposition was non significant between adjacent months and upto 3rd and 6th month of decomposition there was no net increase in Eucalyptus and natural forest plantations.

Initial decrease in soil nitrogen content observed in the present study especially in soils under natural forest and Eucalyptus leaf litter may be due to the low nitrogen status of leaf litter in natural forest and low decomposition of Eucalyptus litter bags. The increase in soil nitrogen status associated with litter decomposition is well supported by the decrease in

Table 19 Changes in soil available N, P, K on litter decomposition

Month	N (kg h^{-1})				P_2O_5 (kg h^{-1})				K_2O (kg h^{-1})			
	Acacia	Eucaly-ptus	Natural forest	Mean	Acacia	Eucaly-ptus	Natural forest	Mean	Acacia	Eucaly-ptus	Natural forest	Mean
Initial	292.46	266.05	312.29	290.27	34.12	31.50	36.46	34.03	351.17	312.90	405.44	356.50
June 1995	291.18	246.94	298.43	278.92	33.77	32.04	35.86	33.89	354.20	315.22	415.71	361.71
July	302.82	368.34	299.76	290.31	33.94	32.51	36.21	34.22	359.94	318.62	410.21	362.92
August	311.76	287.82	310.65	303.41	34.36	32.29	35.19	33.93	362.18	320.74	417.26	366.72
September	314.52	283.33	311.64	303.16	34.53	32.15	36.21	34.30	366.07	320.12	420.00	368.73
October	316.70	283.46	323.64	307.94	34.95	33.18	36.79	34.97	367.31	319.95	426.45	371.23
November	315.26	301.76	333.26	316.76	35.17	33.44	36.90	35.17	367.75	320.44	425.10	371.09
December	315.61	299.96	339.53	318.37	35.01	32.69	36.71	34.80	370.46	322.77	427.95	373.72
January'96	323.34	305.80	343.81	324.31	35.22	33.04	36.66	34.97	374.84	324.56	428.29	375.90
February	323.39	306.76	343.05	324.40	35.19	33.12	36.99	35.10	375.18	327.85	431.34	378.12
March	321.24	313.30	338.10	324.15	35.20	33.22	37.50	35.31	376.09	328.05	437.36	380.50
April	324.45	318.64	339.88	327.66	35.65	33.41	36.80	35.28	376.36	328.80	439.36	381.51
May	323.62	317.89	335.84	325.79	35.60	33.56	37.43	35.55	377.53	330.67	440.47	382.89
Mean	313.57	292.31	325.37		34.83	32.78	36.59		367.62	322.36	425.00	

CD (0.05)		N	P_2O_5	K_2O
	Bet.Pln.	4.26	0.41	2.45
	Bet.Mon.	8.88	0.85	5.12
	Within Pln.	15.38	1.47	8.86

absolute quantity of nitrogen from litter bag as shown in (Fig. 3).

Soil phosphorus dynamics associated with litter decomposition as given in Table 19 revealed that the mean phosphorus content between plantations varied significantly. The natural forest recorded the highest mean P content of 36.6 kg ha^{-1} followed by Acacia (34.8 kg ha^{-1}) and Eucalyptus (32.7 kg ha^{-1}). Monthly variation in P status showed that the initial soil P content of 34.03 kg ha increased to 35.55 kg ha^{-1} during one year decomposition and the change in P status at monthly interval was non significant. Soil P status of individual plantations increased from 34.12 to 35.68 kg ha^{-1} in Acacia, 31.50 to 33.56 kg ha^{-1} in Eucalyptus and 36.46 to 37.43 kg ha^{-1} in natural forest.

The result of phosphorus release study revealed that increase in soil P status due to the litter decomposition was minimum for natural forest and was non significant even at the end of one year decomposition. Low P addition to soil by natural forest litter compared to Eucalyptus and Acacia may be due to its low initial phosphorus content.

Data given in Table 19 revealed the potassium addition to the soil through litter decomposition of various plantations. There was significant difference in mean K content between various plantations. Natural forest soil recorded the highest K content of 425 kg ha^{-1} followed by Acacia (367.6 kg ha^{-1}) and Eucalyptus (322.36 kg ha^{-1}). During the period of one year decomposition the mean soil K content increased from 356.5 kg ha^{-1} to 382.9 kg ha^{-1}. During the 1st month of decomposition, a significant increase in K content took place followed by linear but non significant increase upto the 12th month. Available K content of soils under the litter bags of various plantations increased from 351.1 to 377.5 kg ha^{-1} in Acacia 312.9 to 330.6 kg ha^{-1} in Eucalyptus and 405.4 to 440.5 kg in natural forest. Potassium addition to the soil by litter decomposition was non significant between adjacent months in all the plantations except in the first month of natural forest.

Pattern of potassium addition to the soil by way of litter decomposition revealed that increase in soil potassium status was maximum during the initial phase of decomposition compared to the later stages. Since potassium is not a structural component, leaching loss of K was maximum during the initial phase of decomposition which leads to high K addition to the under lying soil. Eventhough K was the highest mobile element from decomposing leaf litter (Table 16), substantial increase in soil K status was not observed. Loss of potassium from decomposing litter by leaching may be the reason for the same.

4.5.1.4 Exchangeable Ca, Mg and S

Enrichment of soil below the litter bags of Acacia, Eucalyptus and natural forest with calcium, magnesium and sulphur on litter decomposition are given in Table 20. There was significant difference in mean calcium content between plantations. Monthly variation in calcium content due to litter decomposition revealed that the exchangeable calcium content of soil increased from 474.2 to 519.4 ppm during one year decomposition and the variation between adjacent months of decomposition was not significant. Calcium content of soil lying below the litter bag increased from 469.6 to 522.2 ppm in Acacia, 415.4 to 441.6 ppm in Eucalyptus and 537.6 to 594.4 ppm in natural forest. Monthly increase in soil calcium content were non significant in all the plantations.

With respect to magnesium, the mean magnesium content of plantations differed significantly. The highest Mg content of 260.73 ppm were observed in natural forest followed by Acacia (199.9 ppm) and Eucalyptus (150.12 ppm). The monthly variation in exchangeable magnesium content in soils due to litter decomposition were non significant. With respect to individual plantations Mg content increased from 182.4 to 224.6 ppm in Acacia, 136.1 to 162.2 ppm in Eucalyptus and 239.5 to 283.9 ppm in natural forest. In all the plantations the increase in Mg content of soil at monthly intervals were non significant.

Table 20 Changes in soil exchangeable Ca, Mg, S on litter decomposition

Month	Ca (ppm)				Mg (ppm)				S (ppm)			
	Acacia	Eucalyptus	Natural forest	Mean	Acacia	Eucalyptus	Natural forest	Mean	Acacia	Eucalyptus	Natural forest	Mean
Initial	469.60	415.40	537.60	474.20	182.38	136.06	239.54	185.99	104.82	90.67	117.72	104.40
June 1995	470.40	419.00	542.20	477.20	180.20	136.54	242.60	186.44	105.75	89.98	119.63	105.12
July	467.20	419.60	550.60	479.13	183.18	141.42	243.68	189.42	106.08	90.94	120.12	105.71
August	478.20	416.80	548.20	481.06	184.50	144.46	248.66	192.54	108.13	92.62	123.14	107.96
September	476.60	416.00	562.00	484.86	191.86	142.24	253.36	195.82	113.70	94.49	126.27	111.49
October	496.80	420.00	572.20	496.33	197.18	145.88	253.40	198.82	115.14	96.06	126.56	112.59
November	498.40	424.40	570.80	497.86	196.48	150.84	255.56	200.96	116.10	97.62	128.56	114.09
December	501.20	432.20	577.20	503.53	196.40	158.52	262.82	205.91	118.89	103.13	132.39	118.13
January'96	504.20	431.60	591.60	509.13	207.92	157.26	270.08	211.75	123.16	106.54	134.81	121.50
February	509.20	433.60	594.00	512.26	215.70	159.28	276.18	217.05	124.98	108.57	135.08	122.88
March	518.60	432.60	593.20	514.80	217.26	158.28	279.54	218.36	126.71	110.82	135.70	124.41
April	519.40	439.00	592.40	516.93	221.46	158.62	280.18	220.08	126.89	114.32	135.46	125.56
May	522.20	441.60	594.40	519.40	224.60	162.22	283.94	223.58	128.02	116.03	136.87	127.06
Mean	494.76	426.29	571.26		199.93	150.12	260.73		116.80	100.93	128.64	

CD (0.05)		Ca	Mg	S
	Bet.Pln.	5.17	4.04	3.31
	Bet.Mon.	10.78	8.42	6.89
	Within Pln.	18.67	14.59	11.94

The mean sulphur content of soil below the litter bag was highest in natural forest (128.6 ppm) followed by Acacia (116.8 ppm) and lowest in Eucalyptus (100.9 ppm). Monthly sulphur addition to soil due to litter decomposition showed that the available sulphur content increased from 104.4 to 127.1 ppm during one year decomposition and the monthly increase was non significant. With respect to individual plantations the increase in sulpher content of soil below the litter bag was 104.8 to 128.0 ppm, 90.7 to 116.3 ppm and 117.7 to 136.4 ppm for Acacia, Eucalyptus and natural forest respectively.

Increase in exchangeable calcium, magnesium and sulphur status of soil below the litter bags of various plantations revealed that substantial increase in soil status of these nutrients occurred when the initial soil nutrient and nutrient status at the end of one year decomposition were compared. It is obviously due to the release of nutrients from decomposing litter lying over the soil. But non significant increase of these nutrients between adjacent months revealed that the release was slow and distributed through out the period of decomposition.

4.5.1.5 Available Fe, Mn, Cu and Zn

Available Fe dynamics associated with litter decomposition is given in Table 21. Soil Fe status was maximum in natural forest (51.93 ppm) followed by Acacia (43.5 ppm) and Eucalyptus (33.3 ppm). Available Fe content of soil increased

Table 21 Changes in available iron and managanese in soil on litter decomposition

Month	Iron (ppm)				Manganese (ppm)			
	Acacia	Eucalyptus	Natural forest	Mean	Acacia	Eucalyptus	Natural forest	Mean
Initial	38.60	30.50	48.90	19.33	3.83	2.55	5.78	4.06
June 1995	38.70	30.40	48.50	39.20	3.99	2.66	5.72	4.12
July	40.10	31.00	48.60	39.90	4.00	2.69	5.91	4.20
August	41.00	32.30	49.10	40.80	4.10	2.71	6.24	4.35
September	41.70	33.80	51.20	42.23	4.30	2.71	6.16	4.39
October	41.60	32.70	50.20	41.50	4.38	2.97	6.39	4.58
November	43.00	32.10	51.20	42.10	4.63	2.97	6.26	4.62
December	44.50	34.10	53.30	43.96	4.90	3.09	6.44	4.81
January'96	44.70	34.40	53.90	44.30	4.97	3.11	6.97	5.02
February	46.60	34.80	53.90	45.10	5.04	3.13	7.07	5.08
March	47.60	34.80	55.40	45.93	5.18	3.26	7.50	5.31
April	48.30	35.80	54.90	46.33	5.48	3.25	7.67	5.47
May	49.10	36.30	56.10	47.16	5.73	3.34	7.67	5.58
Mean	43.50	33.30	51.93		4.66	2.96	6.60	
CD (0.05)	Bet.Pln.	0.99				0.10		
	Bet.Mon.	2.07				0.21		
	Within Pln.	3.59				0.37		

from 39.3 to 47.16 ppm during 1 year decomposition of leaf litter and the increase in Fe content at monthly interval was non significant. Available Fe content,of soils below the litter bags of individual plantations increased from 38.6 to 49.1 ppm in Acacia, 30.5 to 36.3 ppm in Eucalyptus and 48.9 to 56.1 ppm in natural forest. Changes in available Fe content at monthly intervals were non significant irrespective of the plantations.

Mean manganese content was significantly high in natural forest (6.6 ppm) followed by Acacia (4.6 ppm) and lowest in Eucalyptus (2.96 ppm) (Table 21). During one year period of litter decomposition, the available Mn status of soil increased from 4.06 to 5.58 ppm. With respect to individual plantations the Mn status of soil below the litter bag increased from 3.83 to 5.73 ppm in Acacia, 2.55 to 3.34 ppm in Eucalyptus and 5.78 to 7.67 ppm in natural forest due to one year decomposition of respective leaf litters. Monthly increase in available Mn content of soil due to Mn release from decomposing leaf litter were non significant in Acacia and Eucalyptus. But in natural forest increase in soil Mn content were significant at 8th and 10th month of decomposition compared to preceeding months.

Available copper status of soil associated with litter decomposition are given in Table 22. The mean copper status of the soils differered signifiantly and followed the order natural forest (0.817 ppm) > Eucalyptus (0.574 ppm) > Acacia (0.522 ppm).

Table 22 Changes in available copper and zinc in soil on litter decomposition

Month	Copper (ppm)				Zinc (ppm)			
	Acacia	Eucaly-ptus	Natural forest	Mean	Acacia	Eucaly-ptus	Natural forest	Mean
Initial	0.450	0.514	0.700	0.555	0.320	0.222	0.636	0.393
June 1995	0.464	0.500	0.724	0.563	0.312	0.226	0.644	0.394
July	0.458	0.520	0.736	0.581	0.362	0.220	0.696	0.426
August	0.492	0.530	0.738	0.587	0.390	0.250	0.712	0.451
September	0.518	0.540	0.754	0.604	0.412	0.240	0.718	0.457
October	0.504	0.542	0.780	0.609	0.400	0.280	0.734	0.471
November	0.516	0.572	0.798	0.629	0.436	0.278	0.754	0.489
December	0.522	0.606	0.816	0.648	0.444	0.290	0.792	0.509
January'96	0.540	0.610	0.848	0.666	0.452	0.294	0.828	0.525
February	0.552	0.624	0.872	0.683	0.489	0.326	0.838	0.548
March	0.566	0.622	0.936	0.708	0.520	0.360	0.880	0.587
April	0.582	0.644	0.944	0.723	0.516	0.386	0.916	0.606
May	0.588	0.644	0.976	0.736	0.536	0.396	0.960	0.631
Mean	0.522	0.574	0.817		0.429	0.290	0.778	
CD (0.05) Bet.Pln.	0.023				0.018			
CD (0.05) Bet.Mon.	0.049				0.038			
CD (0.05) Within Pln.	0.085				0.066			

The mean monthly nutrient addition to the soil due to litter decomposition revealed that soil copper content increased from 0.555 ppm to 0.736 ppm during one year decomposition and the monthly increment was non significant. Available copper status of soil increased from 0.45 to 0.558 ppm in Acacia, 0.514 to 0.644 ppm in Eucalyptus and 0.7 to 0.976 ppm in natural forest. The monthly increase in all the plantations were non significant.

Available zinc status of soils were high in natural forest (0.778 ppm) followed by Acacia (0.429 ppm) and Eucalyptus (0.29 ppm) (Table 22). Mean zinc content of soil increased from 0.393 to 0.631 ppm during the one year period of leaf litter decomposition. The available zinc status of soils increased from 0.32 to 0.536 ppm in Acacia, 0.222 to 0.396 ppm in Eucalyptus and 0.636 to 0.96 ppm in natural forest due to the decomposition of leaf litter for a period of one year.

In general the increase in micronutrient content of soil due to the decomposition was more in natural forest and lowest in Eucalyptus. It may be due to the high decomposition rate and high micronutrient status of natural forest leaf litter. Eventhough substantial increase in available micro nutrient status of soils at the end of one year decomposition of over lying leaf litter were noticed, the monthly increment was non significant. Slow rate of micro nutrient release from decomposing leaf litter may be the reason for the same.

When the nutrient release from litter bags and nutrient addition to the soil due to litter decomposition were compared, significant changes were observed at the end of one year in all the plantations. But in majority of the instances, the nutrient release and nutrient addition at monthly intervals were nonsignificant. This result leads to the conclusion that comparison of nutrient release as well as nutrient addition from decomposing leaf litter is more meaningful if we compare at wider intervals, so as to draw valid conclusions and monthly interval is a too short period for such comparison.

4.5.2 Soil physical properties

4.5.2.1 Bulk density, WHC and Porosity

Variation in soil physical properties viz. bulk density, water holding capacity and porosity of various plantations brought about by the decomposition of over lying litter bags are given in Table 23.

Data revealed that soils under natural forest leaf litter have the lowest bulk density (1.204 g cm^{-3}) followed by Acacia (1.243 g cm^{-3}) and Eucalyptus (1.392 g cm^{-3}). Monthly variation in bulk density due to litter decomposition showed that the bulk density of soil decreased from 1.32 g cm^{-3} to 1.23 g cm^{-3} during 1 year decomposition. Monthly variation in bulk density were non significant. During the one year

Table 23 Changes in soil physical propertis on litter decomposition

Month	WHC (%)				Porosity (%)				Bulk density (gcm^{-3})			
	Acacia	Eucalyptus	Natural forest	Mean	Acacia	Eucalyptus	Natural forest	Mean	Acacia	Eucalyptus	Natural forest	Mean
Initial	38.11	32.86	40.54	37.17	44.12	41.11	46.05	43.76	1.316	1.398	1.258	1.324
June 1995	38.58	34.28	40.41	37.76	44.53	41.16	46.72	44.14	1.298	1.422	1.256	1.325
July	38.76	34.54	42.42	38.58	45.14	41.68	46.74	44.52	1.280	1.404	1.256	1.313
August	39.76	35.73	43.25	39.58	45.46	42.14	47.64	45.08	1.270	1.402	1.244	1.305
September	39.96	35.66	43.81	39.81	45.44	42.38	47.72	45.18	1.262	1.394	1.244	1.300
October	40.86	36.96	44.43	40.75	45.43	42.55	48.34	45.44	1.268	1.398	1.200	1.289
November	40.52	36.91	45.51	40.98	45.66	42.51	48.81	45.66	1.246	1.396	1.196	1.279
December	41.48	37.47	45.25	41.40	46.06	43.49	49.63	46.39	1.238	1.396	1.184	1.273
January'96	41.74	37.94	47.21	42.30	46.44	43.87	50.25	46.85	1.220	1.390	1.180	1.263
February	42.51	38.71	47.12	42.78	46.11	44.06	50.56	46.91	1.208	1.374	1.180	1.254
March	43.29	39.46	47.25	43.33	47.82	44.28	51.54	47.88	1.200	1.380	1.156	1.245
April	43.72	39.62	47.63	43.66	47.90	44.62	52.55	48.35	1.186	1.378	1.148	1.237
May	44.61	40.45	48.44	44.51	48.82	45.93	53.40	49.55	1.164	1.370	1.152	1.229
Mean	41.07	36.97	44.87		46.07	43.06	49.27		1.243	1.392	1.204	

CD (0.05)		WHC (%)	Porosity (%)	Bulk density (gcm^{-3})
	Bet.Pln.	0.41	0.23	0.009
	Bet.Mon.	0.85	0.49	0.019
	Within Pln.	1.47	0.84	0.033

decomposition, the bulk density of soil decreased from 1.32 to 1.15 in Acacia, 1.39 to 1.37 g cm^{-3} in Eucalyptus and 1.26 to 1.15 g cm^{-3} in natural forest. Eventhough significant decrease in bulk density were recorded at the end of 1 year the monthly variations were non significant in all the plantations.

Mean water holding capacity of various plantations were significantly different and maximum value recorded in natural forest (44.87%) followd by Acacia (41.07%) and Eucalyptus (36.97%). Monthly variation in water holding capacity showed a linear increase from 37.17% to 44.5% and at monthly intervals increase in water holding capacity at 3rd, 5th, 8th and 12th month of decompositions were significantly higher than preceeding months. Due to the litter decomposition, the soil water holding capacity increased from 38.11 to 44.61% in Acacia, 32.86 to 40.45% in Eucalyptus and 40.54 to 48.44% in natural forest. Monthly increase in waterholding capacity were significant only in 2nd and 8th month of decomposition in natural forest.

There was significant difference in mean porosity of soils under various plantations. Soils under natural forest recorded the highest porosity of 49.27% followed by Acacia (46.00%) and Eucalyptus (43.06%). Changes in soil porosity with leaf litter decomposition revealed that the soil porosity increased from 43.76% to 49.55% during one year decomposition of leaf litter. Significant increase in porosity at monthly intervals were observed at 3rd, 7th and 12th months of decomposition. Increase in porosity due to one year decomposition of respective leaf litters were 44.12 to 48.82% in Acacia, 41.11 to 45.93% in Eucalyptus and 46.05 to 53.90% in natural forest.

Results on the variation in physical properties of soil due to litter decomposition revealed that significant decrease in bulk density and increase in water holding capacity and porosity occurred in all the plantations studied. It is obviously due to the incorporation of organic matter to the soil by the decomposition of over lying leaf litter. Changes in physical properties due to leaf litter decomposition is more prominant in natural forest which got the highest quantity of soil organic matter during the initial as well as at the end of one year decomposition of leaf litter.

4.5.2.2 Soil temperature

The mean soil temperature as well as monthly variation in soil temperature under different plantations are given in Table 24. There was significant difference in mean soil temperature between various plantations.

The highest mean soil temperature was noticed in Eucalyptus followed by natural forest and Acacia. The mean monthly variation in soil temperature showed significant difference between different months. The lowest soil temperature

Table 24 Monthly variation in soil temperature, earthworm and nematode population

Month	Soil temperature (°C)				Earthworm (No m^{-3})				Nematode (No 100^{-}ml soil)			
	Acacia	Eucalyptus	Natural forest	Mean	Acacia	Eucalyptus	Natural forest	Mean	Acacia	Eucalyptus	Natural forest	Mean
Initial	25.30	26.70	25.60	25.86	14.80	8.80	23.60	15.73	58.00	30.00	54.00	47.33
June 1995	24.78	25.90	25.80	25.49	24.00	11.20	40.40	25.13	82.00	40.00	66.00	62.66
July	25.70	26.80	28.10	26.86	34.00	12.80	63.20	36.66	78.00	62.00	84.00	74.66
August	25.90	26.90	27.70	26.83	44.80	15.80	67.80	42.80	100.00	60.00	70.00	76.66
September	25.70	27.40	27.10	26.73	45.20	19.00	74.60	46.26	106.00	86.00	98.00	96.66
October	25.90	27.70	27.10	26.90	38.00	25.00	51.00	38.00	120.00	50.00	122.00	97.33
November	23.30	24.40	24.40	24.03	36.00	18.40	38.00	27.46	110.00	60.00	106.00	92.00
December	24.30	25.00	25.90	25.06	18.80	20.40	31.20	23.46	116.00	40.00	118.00	91.33
January'96	24.60	25.80	26.20	25.53	10.40	12.00	19.20	13.86	68.00	60.00	90.00	72.66
February	25.10	28.30	26.50	26.63	8.80	8.00	15.60	10.80	96.00	38.00	106.00	80.00
March	25.60	27.30	26.00	26.30	11.40	6.60	18.20	12.06	100.00	26.00	92.00	72.66
April	26.00	27.40	25.40	26.26	10.00	5.40	20.40	11.93	82.00	24.00	64.00	56.66
May	25.60	26.50	25.30	25.80	13.60	8.00	27.00	16.20	74.00	36.00	72.00	60.66
Mean	25.21	26.62	26.23		23.06	13.18	37.69		91.53	47.07	87.84	
CD (0.05)	Bet.Pln.	0.14				1.20				5.15		
	Bet.Mon.	0.31				2.49				10.72		
	Within Pln.	0.53				4.32				18.57		

was noticed in November (24.03°C) followed by December (25.06°C) and highest soil temperature of 26.9°C was noted in October followed by July (26.86°C). In Acacia the monthly variation in soil temperature was non linear and the highest temperature was noted in April (26°C) and lowest in November (23.3°C). In Eucalyptus the highest soil temperature was in February (28.3°C) and lowest in November (24.4°C). Highest soil temperature of 28.1°C was noted in July and lowest in November (24.4°C) in natural forest.

The soil temperature is decided by the biological activity of the soil, organic matter content, atmospheric temperature, canopy cover etc. An ideal condition is one which keeps a high soil temperature during cooler periods and low temperature during summer months. In natural forest high temperature during the South West monsoon season (June to November) may be due to higher biological activity in soil. But in the case of Eucalyptus the higher soil temperature recorded during dry period of the year may be due to the low canopy cover which exposed the soil to direct sunlight leading to high soil temperature.

4.5.3 Biological properties

4.5.3.1 Earth worm

Earth worm population in Acacia, Eucalyptus and natural forest at monthly intervals are given in Table 24. The highest

Fig: 15
Monthly variation in Earthworm population

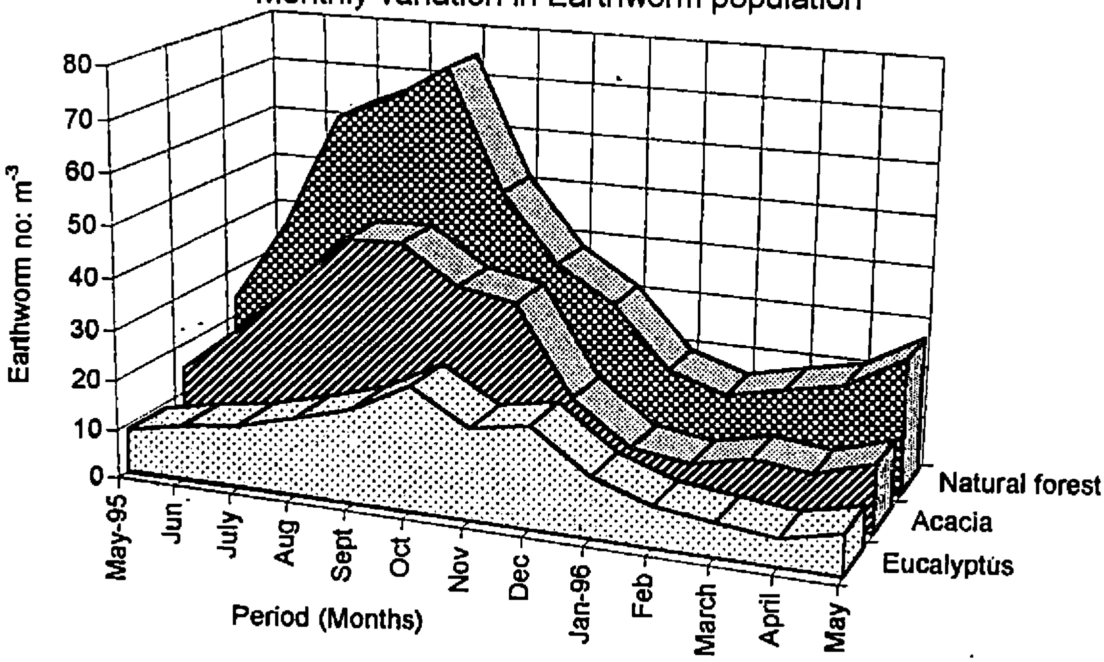
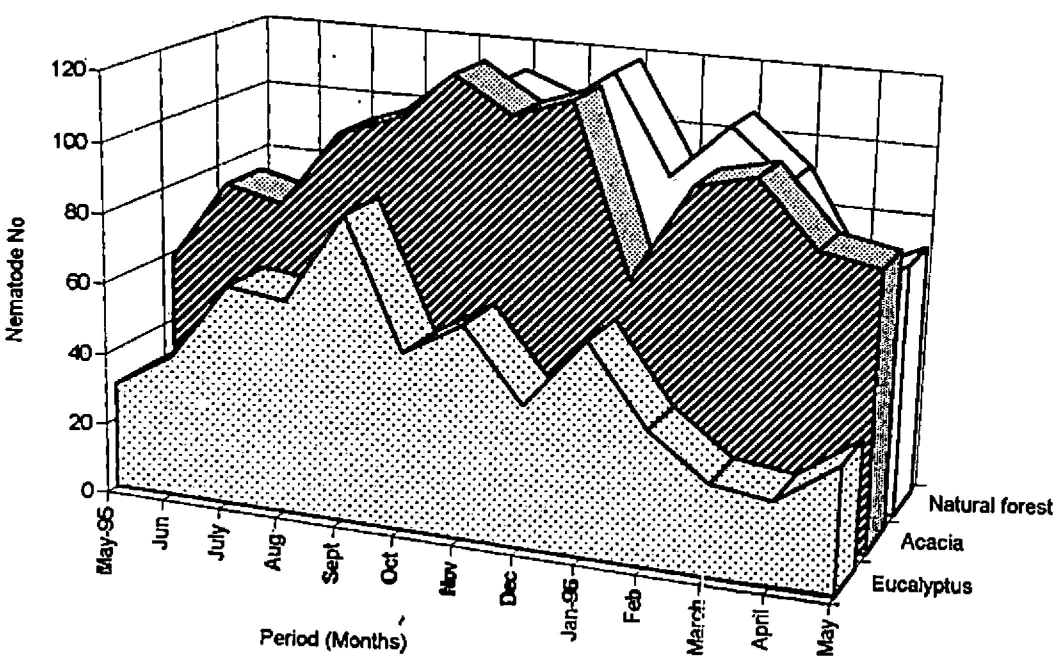


Fig: 16
Monthly variation in nematode population



number of earth worms was recorded in natural forest (37.7 m^{-3}) followed by Acacia (23.06 m^{-3}) and Eucalyptus (13.18 m^{-3}). Monthly variation in earth worm population showed that during May the population was 15.73 cm^{-3} which increased to 46.26 during September and then declined to 16.2 m^{-3} during next May. In Acacia the earth worm population varied from 8.8 to 45.2 cm^{-3}. Earth worm populations ranged between 5.4 - 25 m^{-3} in Eucalyptus and 15.6 - 74.6 cm^{-3} in natural forest.

Data on earthworm population revealed that natural forest soil contain highest number of earth worm compared to plantation soils. This observations is in accordance with the reports of Senapati *et al*. (1993). Low earthworm population associated with Eucalyptus and Acacia plantation may be due to the presence of some chemicals in the leaf litter which are nonpreferred by earthworms. Leaf litter with polyphenols are reported to be distasteful to soil fauna which affect their population in the soil. (Jensen, 1974). Within each plantation the earthworm population at different months of the year was decided by the rainfall and temperature. Population was maximum during rainy periods and lowest in summer months, irrespective of the plantations.

4.5.3.2 Nematode population

The mean nematode population in soils of various plantations is given in Table 24. It is seen that the mean nematode population in Acacia and natural forest was on par (91.53 and 87.84 respectively) which is significantly higher than that of Eucalyptus. The monthly variation in nematode population revealed that from the initial value of 47.33 in May 1995 number increased to 97.33 during October and then subsequently decreased to 60.66 during May 1996. With respect to individual plantations, the nematode population ranged between 58-120 in Acacia, 30 to 86 in Eucalyptus and 54 to 122 in natural forest.

Nematode population in Eucalyptus plantation was low compared to natural forest and Acacia. Many reasons such as low undergrowth, low organic matter content, unfavourable soil conditions such as temperature and moisture and allelopathic influence of Eucalyptus leaves on nematode can be attributed to low nematode population in Eucalyptus plantations. High nematode population in August-September and low population in April-May can be attributed to the difference in soil moisture content.

4.5.3.3 Microbial population

Monthly variation in bacteria, fungi and actinomycete population in soil below the litter bags of various plantations are given in Table 25.

There was significant difference in bacterial population between the plantations. The bacterial population ranged between 5.06 to 12.73 x 10^8 in Acacia, 2.93 to 6.39 x 10^8 in

Table 25 Changes in microbial population in soil on litter decomposition

Month	Bacteria (10^8)				Fungus (10^4)				Actinomycetes (10^6)			
	Acacia	Eucalyptus	Natural forest	Mean	Acacia	Eucalyptus	Natural forest	Mean	Acacia	Eucalyptus	Natural forest	Mean
Initial	8.26	3.26	10.52	7.35	5.39	4.26	7.33	5.66	2.59	2.00	4.26	2.95
June 1995	12.73	6.39	17.13	12.08	9.46	3.39	6.86	6.57	2.73	2.46	3.86	3.01
July	9.33	4.26	7.59	7.06	17.06	5.46	9.39	10.64	2.79	1.60	3.66	2.68
August	10.73	4.33	12.79	9.28	9.936	6.73	13.33	9.99	3.19	2.00	4.00	3.06
September	7.66	3.86	8.39	6.64	10.59	5.13	11.46	9.06	4.33	2.59	4.53	3.81
October	7.19	3.86	6.93	5.99	7.66	4.33	7.46	6.48	3.60	2.13	5.13	3.62
November	6.06	4.13	6.99	5.73	6.53	3.59	6.73	5.62	3.86	2.86	4.80	3.84
December	5.59	5.06	7.59	6.08	3.93	4.12	5.53	4.52	3.73	3.20	5.46	4.13
January'96	5.06	4.59	8.06	5.90	3.33	2.99	6.12	4.15	4.40	3.20	5.93	4.51
February	5.99	4.19	8.93	6.37	3.53	3.39	5.46	4.13	4.00	3.53	6.39	4.64
March	7.06	3.39	10.33	6.93	4.26	3.33	6.13	4.57	3.99	3.66	6.40	4.68
April	6.66	2.93	9.79	6.46	6.73	3.53	6.79	4.99	4.33	3.33	6.33	4.66
May	6.46	2.93	9.13	6.17	5.13	4.13	6.93	5.28	4.86	4.00	6.80	5.22
Mean	7.60	4.09	9.55		7.01	4.18	7.65		3.72	2.81	5.19	
CD (0.05)	Bet.Pln.	0.07				0.19				0.17		
	Bet.Mon.	0.14				0.41				0.25		
	Within Pln.	0.25				0.71				0.37		

Fig: 17
Variation in soil bacteria on litter decomposition

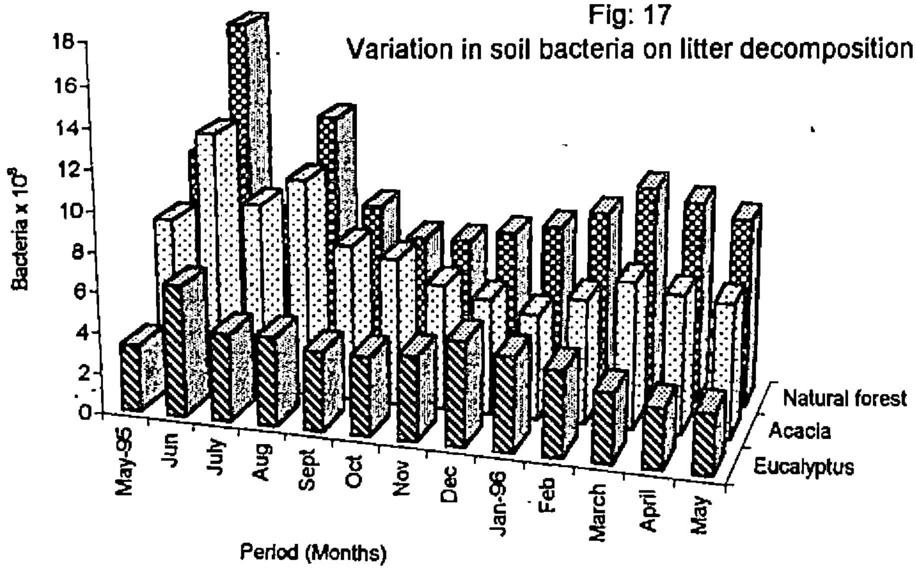


Fig 18
Variation in soil fungi on litter decomposition

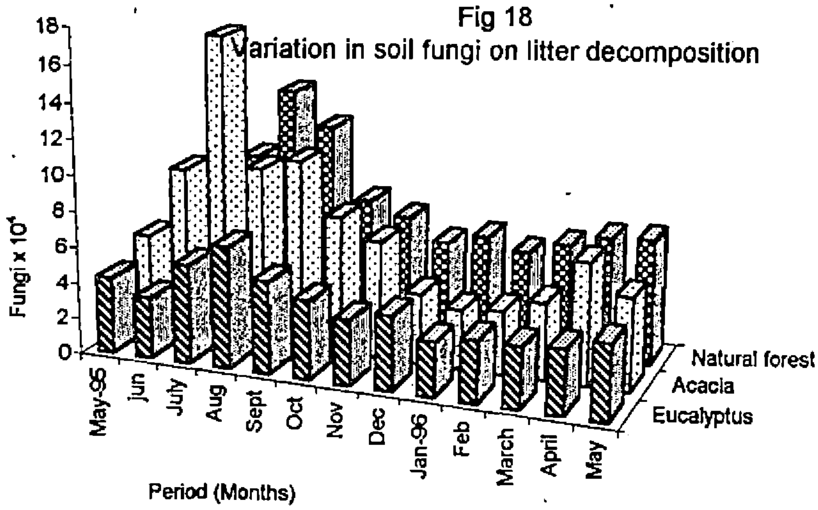
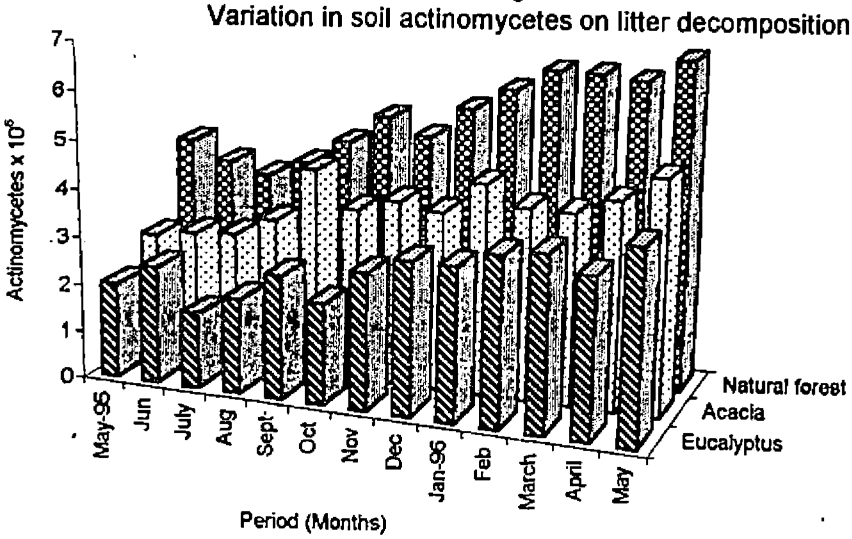


Fig: 19
Variation in soil actinomycetes on litter decomposition



. 6.93 to 17.13×10^8 in natural forest. There was a ...ase in the number of bacteria during the initial ... of decay especially during the 1st month and low during ...dvanced stages of decomposition.

The number of fungi per gram of soil below the litter layer varied between 3.33 to 17.06×10^4 in Acacia, 2.99 to 6.73×10^4 in Eucalyptus and 5.53 to 13.33×10^4 in natural forest with mean values of 7.01, 4.18 and 7.65×10^4 respectively. Similar to bacteria, the population of fungi recorded a rapid increase during the initial months of litter decomposition. In Acacia, the highest population was observed in July. During August the highest fungus population was observed in Eucalyptus and natural forest.

The mean population of actinomycetes per gram of soils were 3.72×10^6 in Acacia, 2.81×10^6 in Eucalyptus and 5.19×10^6 in natural forest. The counts varied between 2.59 to 4.86×10^6 in Acacia, 1.6 to 4.0×10^6 in Eucalyptus and 3.66 to 6.8×10^6 in natural forest. Unlike the population of bacteria and fungi the population of actinomycetes were low during the initial periods of litter decomposition which increased as the decomposition proceeded and resulted the highest population in the 12th month of decomposition irrespective of the plantation.

It is now well established that the decomposition of plant litter on the soil surface is brought about by a variety of microorganisms including bacteria, fungi and actenomycetes. (Jansen 1974, Swift *et al*. (1979). The results of the present study showed that the population of bacteria, fungi, and actinomycetes colonizing in the decomposing litter vary significantly between the soils under the litters of various species. Soils under Eucalyptus litter harbour lesser number of bacteria, fungi and actinomycetes followed by Acacia when compared to natural forest. The absolute and relative differences in the counts of microorganism of the various litter species reflected the predominant influence of substrate composition on the microflora (Mary and Sankaran 1991). The population of bacteria and fungi showed a rapid increase during the initial stages of decomposition which declined after a peak, when the process of decomposition progressed. The initial rapid increase in number of bacteria and fungi on decomposing litters was reported by several workers. (Gray *et al*. 1974, Rai and Srivastava (1982), Vijaya and Naidu (1995). This is evidently due to the availablity of large quantity of nutrients from fresh litter. The less favourable climatic conditions and a gradual depletion in nutrients in the decomposing litters might have caused the decrease in microbial population during the advanced stages of decomposition.

With regard to actinomycetes, the maximum population was observed during the advanced stages of litter decomposition. The low population of actinomycetes during the initial periods of decomposition may be due to their weak competitive ability with bacteria and fungi. They are known to become prominent on decomposing organic matter only when the nutrients become limiting factor and the pressure of the more effective competitors like bacteria and fungi diminishes (Mary and Sankaran 1991). Actonomycetes are also known for their ability to degrade relatively resistant components like lignin and cellulose which accumulate during the later stages of litter decomposition.

4.6 Soil profile characterisation of Acacia, Eucalyptus plantation and natural forest

4.6.1 Mechanical composition

Mean values of various soil fractions obtained on mechanical analysis of soils are given in Table 26.

The coarse sand content of various plantations revealed that Acacia soil contained the highest quantity of coarse sand (40.87%) followed by Eucalyptus (36.23%) and natural forest (32.8%). Coarse sand content decreased with increase in depth in Acacia and natural forest, but in Eucalyptus as the depth increases, the coarse sand content increased from 34.32 to 38.12% from surface to 100 cm depth. Significant difference with depth were noticed only in Acacia.

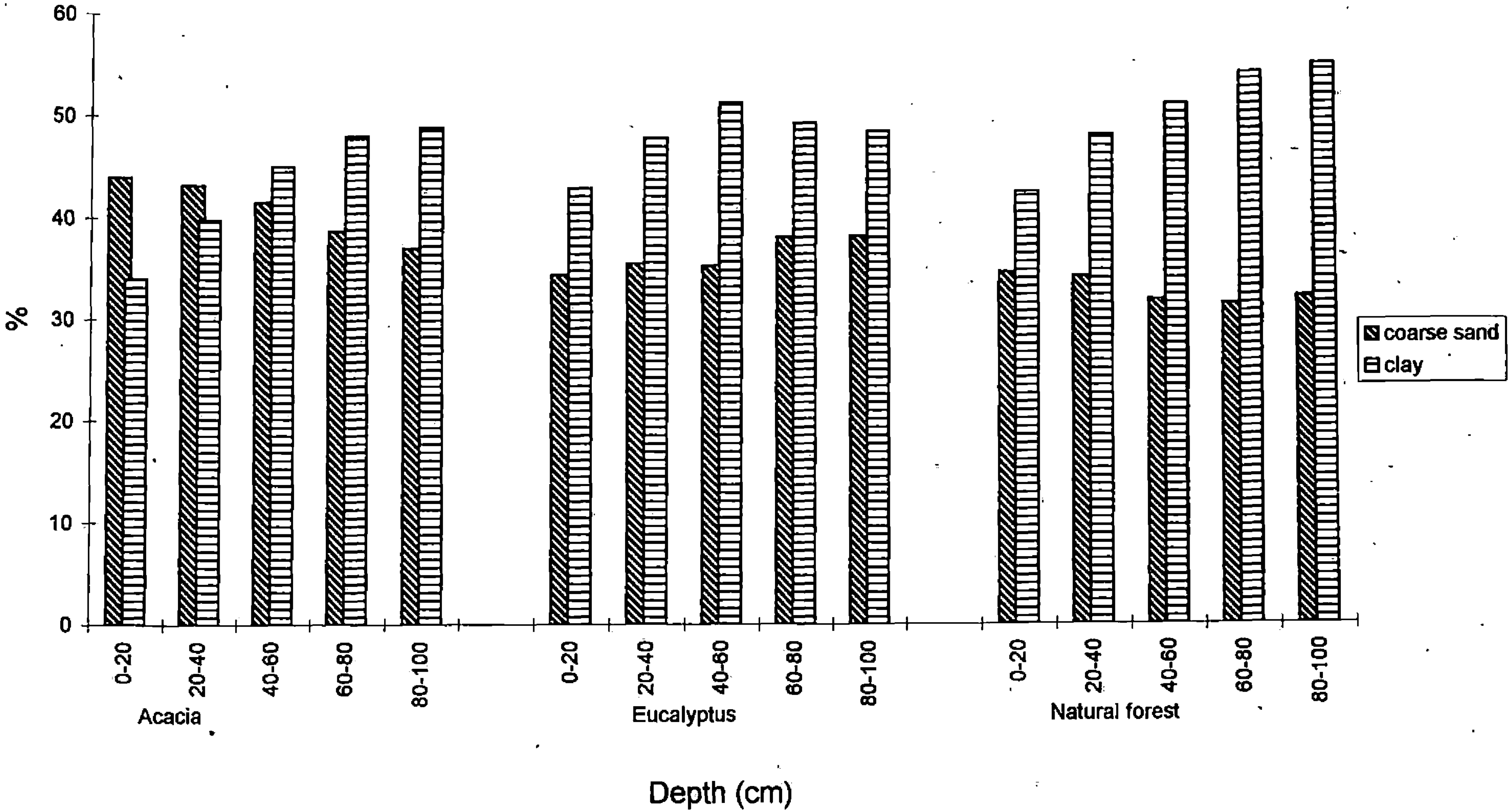
There was significant difference in fine sand content between plantations. Natural forest soil recorded the highest

Table 26 Variation in mechanical composition between plantation

Plantation	Textural fraction (%)	Depth (cm) 0-20	20-40	40-60	60-80	80-100	Mean
Acacia	Coarse sand	44.01	43.20	41.54	38.67	36.95	40.87
	Fine sand	8.92	8.26	6.38	5.61	6.04	7.04
	Silt	12.98	8.52	6.83	7.54	8.02	8.78
	Clay	34.00	39.80	45.00	48.00	48.80	43.12
	Textural class	Sandy clay loam	Sandy clay	Clay	Clay	Clay	Clay
Eucalyptus	Coarse sand	34.32	35.41	35.23	38.07	38.12	36.23
	Fine sand	10.88	8.64	7.05	6.02	6.13	7.74
	Silt	11.77	7.90	6.40	6.56	6.87	7.90
	Clay	42.80	47.80	51.20	49.20	48.40	47.80
	Textural class	Clay	Clay	Clay	Clay	Clay	Clay
Natural forest	Coarse sand	34.57	34.12	31.83	31.44	32.06	32.80
	Fine sand	11.20	9.67	7.69	6.41	6.11	8.21
	Silt	11.68	7.98	9.09	7.90	6.46	8.62
	Clay	42.40	48.00	51.00	54.00	54.80	50.04
	Textural class	Clay	Clay	Clay	Clay	Clay	Clay

CD (0.05)	Coarse sand	Bet.pln.	1.57	Bet.depth	2.03
	Fine sand	Bet.pln.	0.46	Bet.depth	0.59
	Silt	Bet.pln.	1.26	Bet.depth	1.62
	Clay	Bet.pln.	1.32	Bet.depth	1.70

Fig : 20
Depthwise variation in coarse sand and clay fractions of plantations



fine sand content of 8.21% followed by Eucalyptus (7.74%) and Acacia (7.04%). In all the plantations studied, the fine sand fraction decreased as the depth from the surface increases.

There was no significant difference in mean silt content between Acacia, Eucalyptus and natural forest plantations. Eventhough the surface soil recorded the highest silt content, changes in silt content with increase in depth was irregular.

With respect to the clay content, there was significant difference in mean clay content between plantations. Natural forest soil contained the highest quantity of clay (50.04%) followed by Eucalyptus (47.8%) and Acacia (43.12%). Natural forest and Acacia soil showed a progressive increase in clay content as the soil depth increases. In Eucalyptus upto 40-60 cm depth the clay content increased from 42.8 to 51.2% and further the clay content decreased as the depth increases.

The mechanical composition of depth wise samples of various plantations showed that in general the plantation soils have higher sand content and lower clay content compared to natural forest. Increase in sand and decrease in clay content by monoculture plantations such as Eucalyptus and Teak was also reported by Balagopalan *et al*. (1992), and Balagopalan and Jose (1993a). Coarsening of soil texture associated with monoculture plantations pointed out by Jaiyeoba (1995) also support the findings of present investigation. In depth wise samples of various plantations, the sand content decreased and clay content increased with depth. This observation is in agreement with the findings of Premakumari (1987). Higher quantity of sand and low clay content in surface soil may be due to the loss of clay particle from the surface soil either by caly migration to deeper layers or loss of clay particle by soil erosion. It is also infferred that though the surface soils of Acacia and Eucalyptus contained low quanity of clay, a corresponding increase in the clay in lower layers did not take place and in Eucalyptus increase in clay content was only upto 40-60 cm depth. This observation revealed that low clay and high sand content in the surface soils of plantations are not completely due to clay migration to lower depth but due to substantial loss of clay particle by soil erosion. Higher soil erosion under monoculture plantations have been reported by Gupta (1986). Textural class of soils under various plantations are clayey except in Acacia, where surface soil was sandy clay loam and soil at 20-40 cm depth was sandy clay. It may be due to the excessive removal of clay from the surface 0 - 40 cm by leaching and erosion.

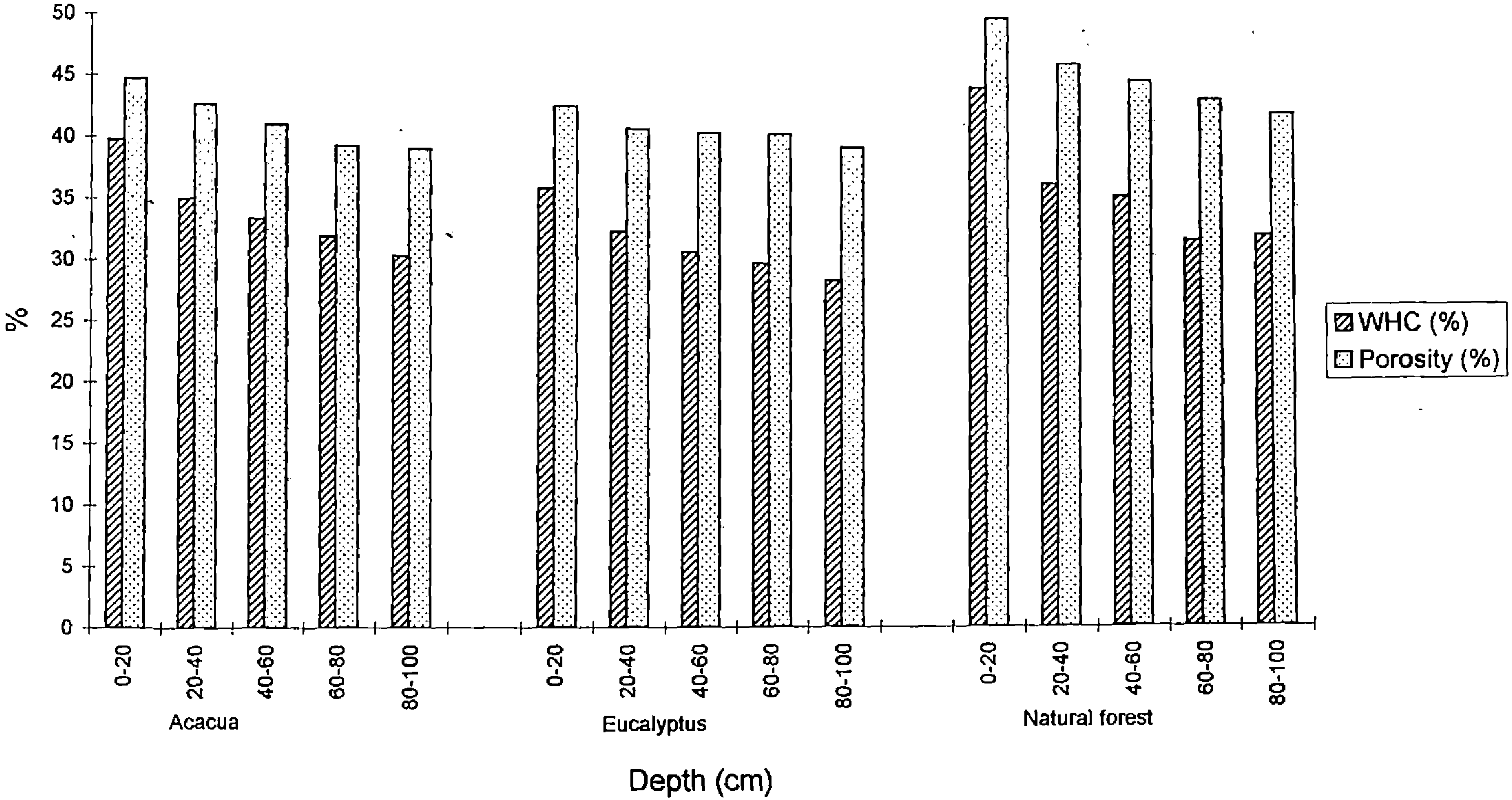
4.6.2 Single value constants

Mean values of single value constants viz. bulk density, particle density, water holding capacity and porosity of profile samples of various plantations are given in Table 27.

Table 27 Variation in single value constants among plantations

Single value constant	Plantation	Depth (cm) 0-20	20-40	40-60	60-80	80-100	Mean
Bulk density ($g\ cm^{-3}$)	Acacia	1.28	1.37	1.41	1.45	1.47	1.40
	Eucalyptus	1.42	1.49	1.52	1.54	1.56	1.50
	Natural forest	1.19	1.32	1.37	1.41	1.44	1.35
	CD	Bet.pln. 0.01			Bet.depth 0.02		
Particle density ($g\ cm^{-3}$)	Acacia	2.32	2.39	2.40	2.40	2.42	2.38
	Eucalyptus	2.46	2.51	2.54	2.57	2.58	2.53
	Natural forest	2.36	2.43	2.45	2.46	2.46	2.43
	CD (0.05)	Bet.pln. 0.013			Bet.depth 0.017		
WHC (%)	Acacia	39.78	35.00	33.36	31.89	30.26	34.06
	Eucalyptus	35.72	32.16	30.49	29.52	28.10	31.20
	Natural forest	43.72	35.88	34.86	31.29	31.61	35.47
	CD (0.05)	Bet.pln. 1.03			Bet.depth 1.33		
Porosity (%)	Acacia	44.73	42.67	41.00	39.21	38.96.	41.31
	Eucalyptus	42.41	43.53	40.19	40.03	38.93	40.42
	Natural forest	49.31	45.54	44.20	42.67	41.49	44.64
	CD (0.05)	Bet.pln. 0.65			Bet.depth 0.84		

Fig : 21
Depthwise variation in WHC and Porosity of plantations



The mean values of bulk density varied significantly among plantations. The highest bulk density observed in Eucalyptus (1.5 g cm^{-3}), followed by Acacia (1.4 gm^{-3}) and natural forest (1.35 g cm^{-3}). In all the profiles studied, the bulk density steadily increased with depth, the highest value being recorded for the soil of the lowest depth of Eucalyptus (1.56 g cm^{-1}) and lowest value recorded for the surface soils of natural forest (1.19 g cm^{-3}).

Particle density of profile samples of various plantations revealed that there was significant difference in mean particle density between plantations. Eucalyptus soil had the highest particle density (2.53 g cm^{-3}) followed by natural forest (2.43 g^{-3}) and Acacia (2.38 g cm^{3}) in all the plantations, the particle density increased with depth, though the increase at lower depths was nonsignificant.

Data on water holding capacity of profile samples of various plantations given in Table 27 revealed that there was significant decrease in WHC due to monoculture plantations. The mean WHC was highest for natural forest (35.47%) followed by Acacia (34.06%) and lowest for Eucalyptus (31.2%). Water holding capacity decreases as the soil depth increases irrespective of the plantations.

Mean values of soil porosity varied significantly among plantations. Natural forest soil had the highest porosity of

44.64% followed by Acacia (41.31%) and Eucalyptus (40.42%). In all the plantations, the porosity decreased as the soil depth increased.

It can be inferred that due to the planting of Acacia and Eucalyptus, significant adverse effect on physical properties occurred, when compared to the natural forest. Such an adverse effect on bulk density, particle density, water holding capacity and porosity have been reported by Balagopalan and Jose (1993a), Bargali *et al*. (1993), Ravikumar *et al*. (1993) and Balagopal and Jose (1995). The single value constants are mainly influenced by the organic matter and clay content of the soil. Organic matter was highest in natural forest followed by Acacia and Eucalyptus (Table 29) and it decreases with depth. Thus the low bulk density and particle density and high WHC and porosity associated with forest soil and surface soils of forest as well as plantation can be attributed to this organic matter content. Eventhough the clay content increased with depth it is unable to bring about a favourable impact on these properties. The decrease in organic matter content with depth is a more decisive factor than the clay content in causing a favourable effect on these properties.

4.6.3 Soil moisture constants

Mean values of soil moisture constants of Acacia, Eucalyptus and natural forest soil are furnished in Table 28.

Table 28 Variation in soil moisture constants among plantations

Depth (cm)	Field capacity (%)			Wilting coefficient (%)			Available moisture (%)		
	Acacia	Eucalyptus	Natural forest	Acacia	Eucalyptus	Natural forest	Acacia	Eucalyptus	Natural forest
0 - 20	20.04	21.62	23.08	14.19	18.01	17.06	5.84	3.60	6.01
20 - 40	19.87	22.72	23.47	15.58	20.06	18.98	4.28	2.65	4.49
40 - 60	22.83	23.66	24.95	17.54	20.64	20.22	5.29	2.87	4.73
60 - 80	25.73	23.78	25.71	20.72	20.91	20.62	5.02	2.86	5.09
80 - 100	26.34	25.19	26.93	20.68	20.39	21.32	5.66	4.98	5.59
Mean	22.96	23.39	24.83	17.74	20.00	19.64	5.22	3.39	5.18
CD (0.05)	Bet.pln.		0.88			0.95			0.21
	Within pln.		1.13			1.23			0.26

Mean content of soil moisture at field capacity (0.3 bar) was 24.8% in natural forest which was significantly higher than that of Acacia and Eucalyptus. As the soil depth increased, the moisture content at field capacity also increased giving the highest moisture content at lower depths. The moisture content at wilting coefficient (15 bar) was highest in Eucalyptus (20%) followed by natural forest (19.64%) and Acacia (17.74%). Moisture content at 15 bar in Acacia soil was significantly lower than Eucalyptus and natural forest. Similar to field capacity, the moisture content at wilting coefficient also increased with soil depth. Mean available moisture content of Acacia and natural forest soils were on par (5.22 and 5.18% respectively) which was significantly higher than that of Eucalyptus (3.39%). As the depth increased, the available moisture content of soil decreased, eventhough the changes were irregular.

Result obtained on the soil moisture characteristics of various plantations revealed that due to the monoculture plantations, moisture content at field capacity was significantly reduced and the Eucalyptus soil recorded the lowest content of available moisture. Eventhough the Acacia soil recorded lowest field capacity moisture content it recorded the highest available moisture. It is due to the fact that the moisture content at tension higher than 15 bar (pwp) was low in Acacia than Eucalyptus and natural forest. while the Eucalyptus soil retained the highest amount of water at tension more than 15 bar resulting in a lowest available moisture content. Moisture content at 33 and 15 bar are highly influenced by the clay and organic matter content (Sharma *et al*., 1990) and low clay content coupled with lowest organic matter in Eucalyptus soils may be the reason for its lowest available moisture content.

4.6.4 Chemical properties

4.6.4.1 pH and EC

Table 29 showed the mean values of soil pH of various plantations at definite depth intervals. All the soils were acidic in reaction and the Eucalyptus soil recorded the lowest pH value of 4.7 followed by Acacia (4.86) and natural forest (5.11). In all the plantations, the pH decreased with depth and the decrease was significant only when compared to the pH of surface soils. Electrical conductivity was negligible in the soils of all the plantations.

It is noteworthy that the monoculture plantations increased the soil acidity when compared to natural forest and decrease in soil pH due to monoculture plantations have been reported by Byju (1989), Feilho *et al*. (1991), Revikumar *et al*. (1993) and Rhoades and Binkley (1996). Loss of basic cations from soil due to leaching may be the reason for high acidity in plantations. Neutralisation of soil exchange complex (depletion of basic cations) attributed to the lowering of soil pH under

Eucalyptus and Albizia by Rhoades and Binkley (1996) also support this conclusion. High soil pH in surface soil may be due to the accumulation of basic cations in the surface layer by way of biocycling, where the basic cations like, Ca, Mg and K are absorbed from deeper layer and deposited in the surface by way of litter fall and decomposition.

4.6.4.2 Organic carbon

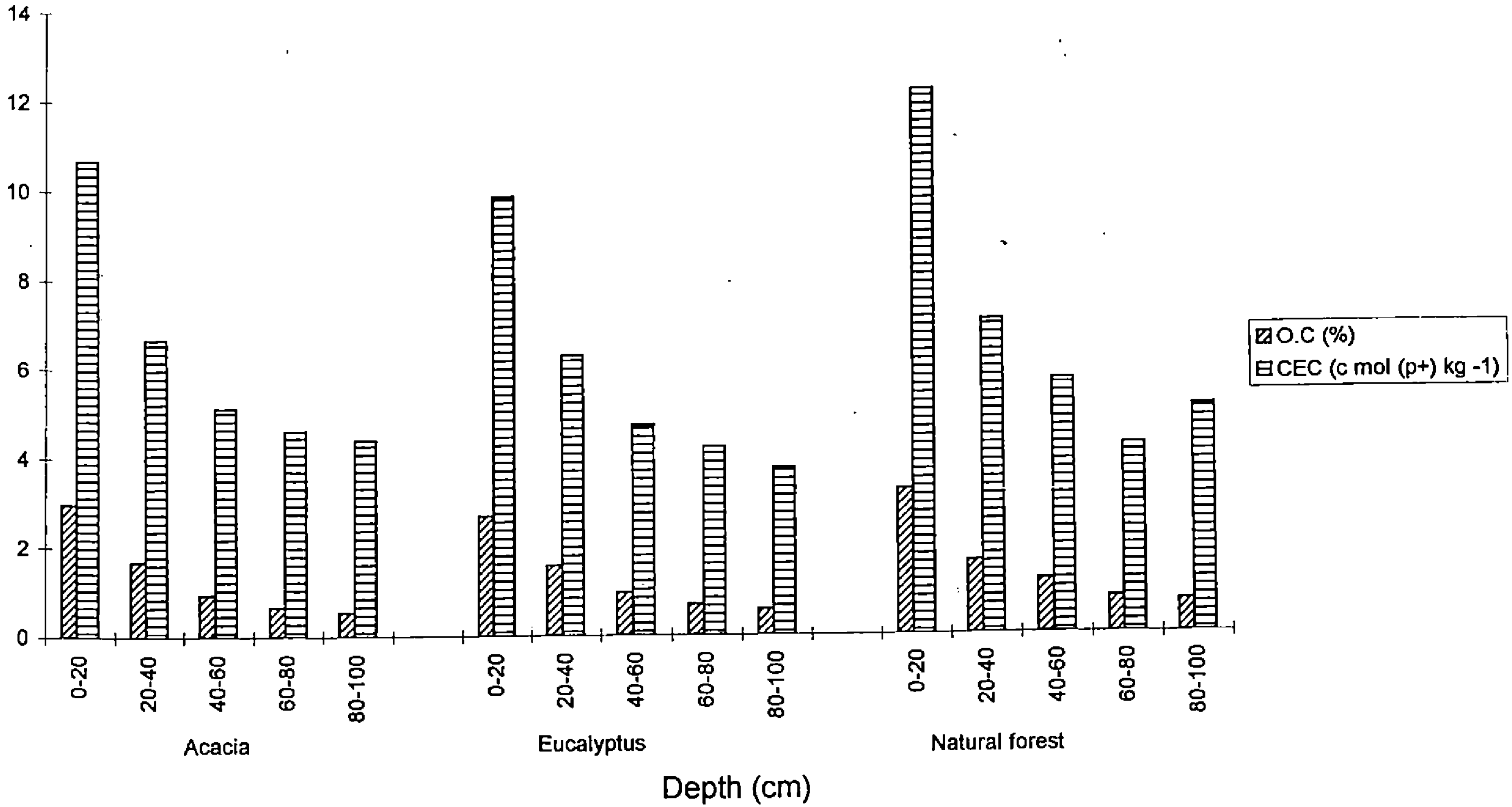
Mean values of soil organic carbon content of various plantations depicted in Table 29 revealed that there was significant decrease in organic carbon content due to monoculture plantations. Eucalyptus soil recorded the lowest organic carbon content of 1.3% followed by Acacia (1.35%) against the natural forest (1.52%). With respect to depth, the organic carbon content decreased with depth irrespective of the plantations. However, natural forest soil maintained the highest content of organic carbon through out the profile compared to the plantation soils. On volume basis i.e. 1 m^2 area, to a depth of one meter computed from bulk density and percentage organic matter, the organic matter content was 33.8 kg in natural forest, 32.9 kg in Eucalyptus and 31.5 kg in Acacia.

Higher organic carbon content in soils under natural forest compared to the monoculture plantations obtained in the present study support the findings of Balagopalan and Alexander (1983), Premakumari (1987) and Jaiyeoba (1995). Higher organic

Table 29 Variation in chemical properties among plantations

Chemical properties	Plantation	Depth (cm)					Mean
		0-20	20-40	40-60	60-80	80-100	
pH	Acacia	4.97	4.83	4.74	4.75	5.01	4.86
	Eucalyptus	4.83	4.63	4.64	4.69	4.70	4.70
	Natural forest	5.38	4.98	5.06	5.03	5.10	5.11
	CD (0.05)	Bet.pln. 0.06			Bet.depth 0.08		
Organic carbon (%)	Acacia	2.97	1.68	0.94	0.65	0.53	1.35
	Eucalyptus	2.68	1.57	0.96	0.69	0.57	1.30
	Natural forest	3.25	1.63	1.20	0.79	0.72	1.52
	CD (0.05)	Bet.pln. 0.05			Bet.depth 0.06		
CEC (c mol p+ kg-1	Acacia	10.67	6.65	5.11	4.60	4.39	6.28
	Eucalyptus	9.84	6.26	4.71	4.21	3.74	5.75
	Natural forest	12.18	7.02	5.68	5.22	5.09	7.04
	CD (0.05)	Bet.pln. 0.16			Bet.depth 0.21		
ECEC (c mol p+ kg-1	Acacia	6.14	4.84	3.63	3.14	3.00.	4.15
	Eucalyptus	5.81	4.60	3.51	3.20	2.84	3.99
	Natural forest	6.49	4.63	3.77	3.51	3.33	4.35
	CD (0.05)	Bet.pln. 0.09			Bet.depth 0.11		
Exchange acidity (c mol p+ kg-1)	Acacia	1.51	1.72	1.44	1.18	1.14	1.39
	Eucalyptus	1.82	1.80	1.74	1.56	1.36	1.65
	Natural forest	0.88	1.06	1.14	1.24	1.24	1.11
	CD (0.05)	Bet.pln. 0.06			Bet.depth 0.08		

Fig: 22
Depthwise variation in organic carbon and CEC of various plantations



carbon content in the surface soil was obviously due to the litter addition and decomposition. Since the erosion hazard is minimum and the disturbance to the soil is less, incorporation of organic matter to deeper layers was more in natural forest. This is in agreement with the earlier observations of Balagopalan and Alexander (1983), Balagopalan and Jose (1986), Byju (1989) and Balagopalan *et al.* (1992). The lower content of organic carbon observed in monoculture plantations could be due to slower decomposition of litters (Mary and Sankaran 1991). Rapid mineralisation of litter substrate of diverse origin and litter quality associated with natural forest may be the reason for its high organic carbon content.

4.6.4.3 Cation exchange capacity

There was significant difference in the CEC of plantation soils compared to the natural forest (Table 29). Highest mean CEC values were observed in natural forest (7.04 C mol (p+) kg^{-1}) followed by Acacia (6.28 cmol (p+) kg^{-1} and Eucalyptus (5.75 cmol (p+) kg^{-1}). Cation exchange capacity decreased with depth irrespective of the plantations. Highest CEC value was recorded in the surface soil of natural forest (12.18 cmol (P+) kg^{-1}) and lowest value (3.74 cmol (p+) kg^{-1}) in the lowest layer of Eucalyptus.

The decrease in CEC due to deforestation followed by afforestation with Eucalyptus and Acacia observed in the present study may be due to the loss of organic matter in plantation soils. Reduction in CEC values of soils under plantations has been reported by Balagopalan and Jose (1986), (1993a) and (1995). Higher CEC values observed through out the profile of natural forest compared to Eucalyptus and Acacia is parallel to the organic carbon content as these two are highly related (Lundgran 1978).

4.6.4.4 Effective cation exchange capacity

The effective CEC values of depth wise soil samples of various plantations given in Table 29 revealed that there was significant difference in mean ECEC values of various sites. Highest ECEC was recorded in natural forest (4.35 cmol (p+ kg^{-1}) followed by Acacia (4.15 cmol(p+ kg^{-1}) and Eucalyptus (3.99 cmol (p+ kg^{-1}). As the soil depth increased the ECEC values significantly decreased irrespective of the plantations.

Soils under monoculture plantations recorded the low ECEC values compared to natural forest soils may be due to the low organic matter content in plantation soils and, similar to CEC, ECEC values of soils are mainly determined by the organic matter content. Higher organic matter addition and deeper incorporation of these organic matter in natural forest contribute to the high ECEC values in all the depth of soil compared to plantation soils.

4.6.4.5 Exchange acidity

Mean values of exchangeable acidity (exchangeable H & Al) are given in Table 29. There was significnat difference in exchangeable acidity between plantations and natural forest. Highest value observed in Eucalyptus (1.65 cmol (p^{+}) kg^{-1}) followed by Acacia (1.39 cmol (p^{+}) kg^{-1}) and natural forest (1.11 cmol (p^{+}) kg^{-1}. Depth wise distribution of exchangeable acidity did not have any uniform pattern among the plantations. Highest value was observed in the surface soils of Eucalyptus and lowest value recorded in the surface soils of natural forest.

High content of exchange acidity in Eucalyptus and Acacia plantations compared to natural forest observed in the present study supports the low pH values of plantation soils. High exchangeable aluminium and titratable acidity in the Eucalyptus soils were also reported by Failho *et al*. (1991). Removal of basic cations from the exchange site by leaching and crop removal may be the reason for high exchangeable acidity in plantation soils.

4.6.4.6 Exchangeable cations and Base saturation percentage

Data on exchangeable K, Ca, Mg, Na and Base saturation percentage of depthwise soil samples of Acacia, Eucalyptus and natural forest are given in Table 30.

Table 30 Variation in exchangeable cations among plantations

Exchangeable cations	Plantation	Depth (cm) 0-20	20-40	40-60	60-80	80-100	Mean
K ($c\ mol_{p^+}\ kg^{-1}$)	Acacia	0.412	0.356	0.272	0.236	0.192	0.294
	Eucalyptus	0.390	0.321	0.240	0.213	0.250	0.263
	Natural forest	0.466	0.386	0.306	0.262	0.234	0.331
	CD (0.05)	Bet.pln. 0.015		Bet.depth 0.020			
Ca ($c\ mol_{p^+}\ kg^{-1}$)	Acacia	2.366	1.676	1.230	1.148	1.046	1.493
	Eucalyptus	2.224	1.608	0.982	0.870	0.752	1.287
	Natural forest	2.800	1.954	1.462	1.258	1.176	1.730
	CD (0.05)	Bet.pln. 0.058		Bet.depth 0.074			
Mg ($c\ mol_{p^+}\ kg^{-1}$)	Acacia	1.470	0.890	0.530	0.474	0.456	0.764
	Eucalyptus	1.072	0.680	0.496	0.456	0.386	0.618
	Natural forest	2.034	1.030	0.736	0.656	0.602	1.012
	CD (0.05)	Bet.pln. 0.050		Bet.depth 0.065			
Na ($c\ mol_{p^+}\ kg^{-1}$)	Acacia	0.260	0.200	0.148	0.106	0.072	0.157
	Eucalyptus	0.304	0.212	0.152	0.100	0.066	0.167
	Natural forest	0.318	0.204	0.142	0.102	0.086	0.170
	CD (0.05)	Bet.pln. 0.013		Bet.depth 0.016			
Base saturation (%)	Acacia	42.22	47.00	43.08	42.32	41.08	43.14
	Eucalyptus	40.56	44.86	38.40	39.06	37.55	40.08
	Natural forest	46.22	50.94	46.53	43.58	41.24	45.70
	CD (0.05)	Bet.pln. 0.94		Bet.depth 1.22			

Fig : 23
Depthwise variation in Base saturation percentage among plantations

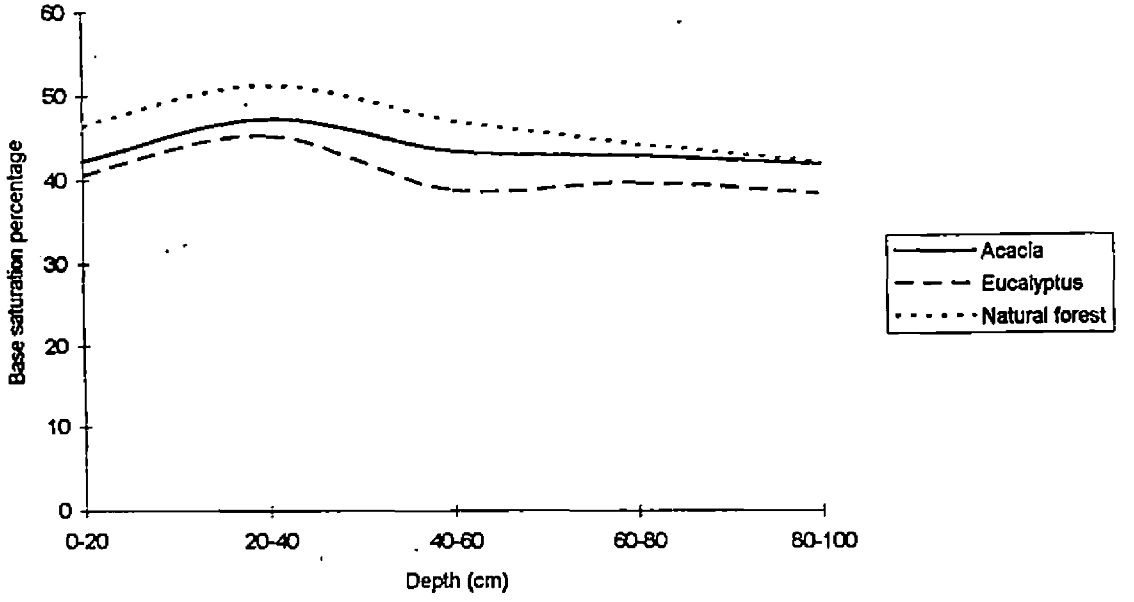
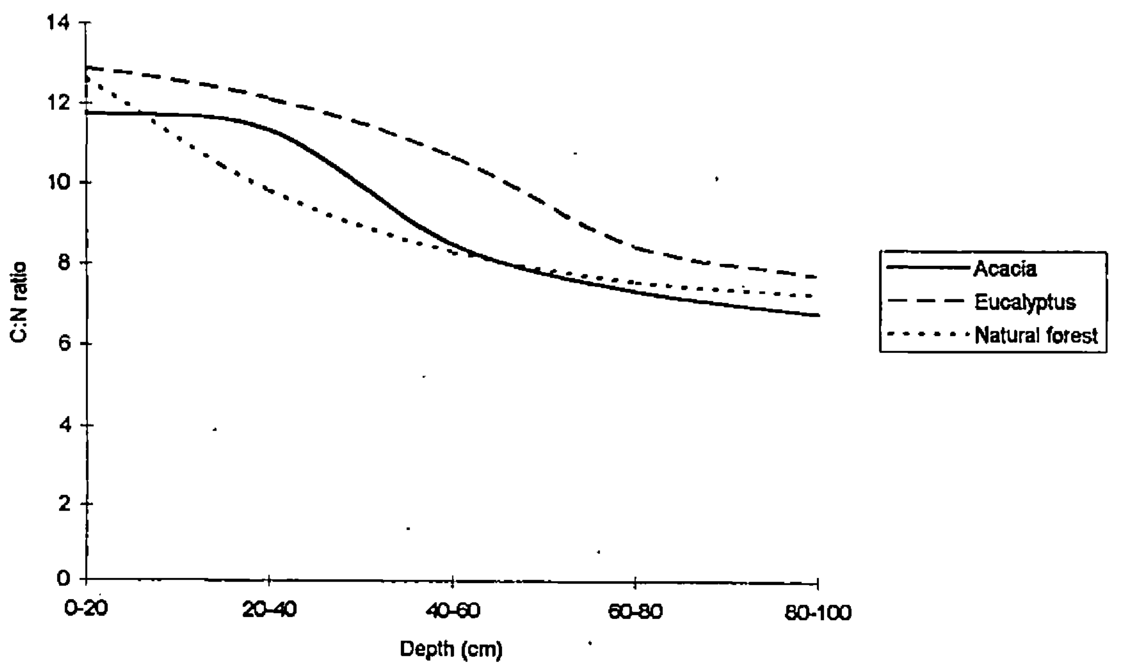


Fig : 24
Depthwise variation in C:N ratio among plantations



Exchangeable K content showed significant difference among plantations. The highest value recorded in natural forest (0.33 cmol (p^+) 1kg^{-1}) followed by Acacia (0.294 cmol (p^+) 1kg^{-1}) and Eucalyptus (0.263 cmol (p^+) kg^{-1}). Exchangeable K decreased with depth irrespective of the plantations.

Soils under natural forest recorded the highest value for exchangeable Ca (1.73 cmol (p^+) kg^{-1}) followed by Acacia (1.49 cmol (p^+) kg^{-1}) and Eucalyptus (1.28 cmol (p^+) kg^{-1}). These values differed significantly. Decrease in exchangeable calcium content with increase in soil depth was also observed in all the plantations.

Exchangeable Mg also followed the same trend as that of Ca and highest value observed in natural forest (1.02) followed by Acacia (0.76 cmol (p^+)kg$^-$) and Eucalyptus (0.618 cmol (p^+) kg^{-1}). In all the plantations surface soil contained the highest quantity of exchangeable magnesium which decreased substantially as the depth decreased.

Mean values of exchangeable Na content of various plantations did not show any significnat difference. But the surface soils of Acacia, Eucalyptus and natural forest contained the highest quantity and it followed the order 0.308, 0.260 and 0.318 cmol (p^+) kg^{-1}) respectively. Exchangeable Na content decreased with depth irrespective of the plantations.

Perusal of the data given in Table 30 shows that exchangeable cations viz. Ca, Mg, Na and K were highest in natural forest compared to Eucalyptus and Acacia. Low content of exchangeable bases in soils under monoculture plantations were also reported by Byju (1989) and Balagopalan *et al*. (1992). Low CEC, high exchangeable acidity and high removal of basic cations from the soil by leaching and plant uptake may be the reason for low basic cations in monoculture plantations. The general nature of the deciduous trees to add more bases to the surface soil (Pritchett 1976) also supports the relatively high content of exchangeable bases in natural forest compared to Eucalyptus and Acacia plantations.

Mean values of base saturation percentage given in Table 30 showed that there was significant difference in base saturation percentage between plantations. Natural forest soil recorded the highest base saturation percentage of 45.7 followed by Acacia (43.14%) and Eucalyptus (40.08%). Variation in base saturation percentage with depth indicate that there was a sudden increase in the second layer which subsequently decreased as the depth increases. This pattern was followed in all the plantations.

High base saturation percentage associated with natural forest compared to monoculture plantations observed in the present study is in concurrence with the reports of Byju (1989).

is is a good index
ment of natural forest
ediate increase in the
rd movement of basic cations
Low base saturation percentage
exchangeable acidity in Eucalyptus
reason for low pH under monoculture

phosphorus

a on the available P content of depthwise samples of plantations are given in Table 31. The data revealed there was significant difference in available phosphorus tent among plantations. Natural forest soil contained the highest quantity of phosphorus (28.4 kg/ha) followed by Acacia (26.9 kg) and Eucalyptus (25.85 kg). Analysis of depthwise samples revealed that surface soil recorded the highest quantity of phosphorus which decreased with depth in all the plantations.

Low available phosphorus status associated with soils under monoculture plantations compared to adjacent natural forest observed in the present study is in concurrence with the reports of Byju (1989) and Jayeoba (1995). The depth wise variation in available phosphorus status may be due to the variation in organic matter content since organically bound form is a dominant fraction of available phosphorus.

Table 31 Variation in available phosphorus and sulphur among plantations

Depth (cm)	P_2O_5 (kg ha^-)			S (ppm)		
	Acacia	Eucalyptus	Natural forest	Acacia	Eucalyptus	Natural forest
0-20	34.35	33.35	36.17	106.46	90.62	118.07
20 - 40	31.33	30.32	33.78	80.57	75.78	82.32
40 - 60	26.27	23.49	26.83	65.18	61.16	70.12
60 - 80	22.92	21.20	24.04	40.62	38.82	48.18
80 - 100	19.66	19.38	21.15	34.01	29.55	39.88
Mean	26.90	25.55	28.40	65.37	59.18	71.71

CD Bet.pln. 0.64 Within pln. 0.82 Bet.pln. 3.16 Within pln. 4.08
(0.05)

4.6.4.8 Available sulphur

Mean values of available sulphur content of soils under various plantations are given in Table 31. Eucalyptus soil recorded the lowest sulphur content of 59.18 ppm followed by Acacia (65.37 ppm) and natural forest (71.79 ppm). Depthwise variation in available sulphur status of various plantations showed that there was drastic decrease in available sulphur content with depth irrespective of the plantations.

Higher sulphur content associated with natural forest may be due to the presence of high organic matter as organic form of sulphur is a dominant fraction of available sulphur. The depth wise decrease in sulphur status observed in all the plantations can also be attributed to the decrease in organic matter content.

4.6.4.9 Forms of available Nitrogen

Values of different forms of nitrogen (NO_3^--N and NH_4^+-N) of depth wise samples of Acacia, Eucalyptus and natural forest depicted in Table 32 showed that soils under Acacia plantation contained the highest quantity of NO_3^--N (5.25 ppm) followed by natural forest (4.64 ppm) and lowest value in Eucalyptus plantations (3.84%). The nitrate nitrogen decreased with depth of the soil. The ammoniacal form of nitrogen in Acacia was on par with that of natural forest (8.46 and 8.64 ppm

Table 32 Variation in NO_3^-N and NH_4^+-N among plantations

Depth (cm)	NO_3^-N(ppm)			NH_4^+-N (ppm)		
	Acacia	Eucalyptus	Natural forest	Acacia	Eucalyptus	Natural forest
0-20	8.87	6.94	8.22	14.75	11.98	17.42
20 - 40	5.82	4.59	4.95	9.65	6.01	8.96
40 - 60	4.71	3.36	3.73	7.37	4.98	6.55
60 - 80	3.83	2.30	3.33	6.30	4.08	5.63
80 - 100	3.02	2.02	2.97	4.23	3.02	4.64
Mean	5.25	3.84	4.64	8.46	6.01	8.64
CD (0.05)	Bet.pln. 0.17	Within pln. 0.22		Bet.pln. 0.32	Within pln. 0.41	

respectively) which were significantly higher than that of Eucalyptus (6.01 ppm). Similar to the nitrate nitrogen, ammoniacal nitrogen also decreased with depth irrespective of the plantations.

Among the monoculture plantations, Eucalyptus soil contained the lowest quantity of available form of nitrogen compared to natural forest and Acacia. This observation is supported by the reports of Balagopalan and Jose (1986). This was based on the relationship of organic carbon, total nitrogen as well as different forms of nitrogen (Rowe and Hegel (1974). The available nitrogen content of the soil in general was about 10% of the total nitrogen. Thus the soils under natural forest retained more NO_3^+-N and NH_4^--N possibly due to its high total nitrogen and organic matter content (Guruswamy 1963). More over low pH associated with Eucalyptus soil hinders the nitrification process (Federer 1983). But in the case of Acacia, eventhough soils are low in organic carbon content (Fig. 22), it recorded high content of both forms of nitrogen. Since Acacia is a leguminous tree, Rhizobium mediated nitrogen fixation and subsequent release to the soil may be the reason for the high content of available nitrogen. Depth wise decrease in different forms of nitrogen irrespective of the plantations are obviously due to the decrease in organic matter content.

4.6.4.10 Total N, P, K and C:N ratio

Table 33 gives the depthwise distribution of total N, P, K content in various plantations. There was significant difference in total N content between plantations. The natural forest soil recorded the highest nitrogen content (0.155%) followed by Acacia (0.137%) and Eucalyptus (0.117%). Significant difference was also observed in total phosphorus and potassium content among the plantation soils studied. Natural forest soil recorded the highest P content (0.041%) followed by Acacia (0.035%) and Eucalyptus (0.03%). Highest total K content was recorded in natural forest (0.276%) followed by Acacia (0.247%) and lowest in K content (0.241%) observed in Eucalyptus soil. Total N, P, K content was highest in the surface soil which decreased with depth, irrespective of the plantations.

Significant reduction in total N, P, K associated with the clearfelling and afforestation of a natural forest with monoculture plantations like Acacia and Eucalyptus observed in the present investigation is in accordance with the reports of Premakumari (1987), Byju (1989) and Bargali (1993). Since the different plantations coming under the experimental area got the same parent material and enjoyed similar climatic conditions, the variation in P and K cannot be attributed to the difference in mineral content. Inefficient biocycling associated with plantations compared to natural forest and losses from the system

Table 33 Variation in total NPK and C:N ratio among plantations

	Plantation	Depth (cm) 0-20	20-40	40-60	60-80	80-100	Mean
Total nitrogen (%)	Acacia	0.2530	0.1482	0.1134	0.0896	0.0804	0.1370
	Eucalyptus	0.2088	0.1302	0.0906	0.0828	0.0748	0.1170
	Natural forest	0.2576	0.1662	0.1452	0.1046	0.1008	0.1550
	CD (0.05)	Bet.pln. 0.0049		Bet.depth 0.0063			
Total phosphorus (%)	Acacia	0.0576	0.0414	0.0342	0.0230	0.0208	0.0350
	Eucalyptus	0.0494	0.0366	0.0298	0.0186	0.0136	0.0300
	Natural forest	0.0622	0.0490	0.0384	0.0300	0.0268	0.0410
	CD (0.05)	Bet.pln. 0.0010		Bet.depth 0.0013			
Total potassium (%)	Acacia	0.3058	0.2822	0.2346	0.2122	0.2014	0.2470
	Eucalyptus	0.2962	0.2672	0.2358	0.2086	0.1952	0.2411
	Natural forest	0.3374	0.2986	0.2748	0.2356	0.2320	0.2760
	CD (0.05)	Bet.pln. 0.0040		Bet.depth 0.0052			
C : N ratio	Acacia	11.75	11.33	8.47	7.31	6.74	9.12
	Eucalyptus	12.88	12.10	10.67	8.41	7.67	10.34
	Natural forest	12.62	9.82	8.27	7.52	7.19	9.08
	CD (0.05)	Bet.pln. 0.26		Bet.depth 0.42			

by leaching and erosion may be the reasons for low P and K content in plantation soils. Data on C : N ratio of soil under various plantations given in Table 31 revealed that mean C : N ratio is highest in Eucalyptus (10.34) which was significantly higher than that of Acacia and natural forest. Eucalyptus forest recorded the highest C : N ratio throughout the profile and Acacia recorded the lowest C : N ratio in surface layer as well as at 60-80 and 80-100 cm layer. In all the soils studied the C:N ratio decreased with depth. Russel (1961) stated that variation in C : N ratio might be due to the difference in the state of decomposition of organic matter in different layers and the preferential eluviation of mineralised form of nitrogen over carbon. Wide C : N ratio associated with Eucalyptus may be due to the slow decomposition of organic matter. A decrease in C:N ratio with depth has been pointed out earlier in teak plantation by Jose (1968) and in Eucalyptus plantations by Balagopalan and Jose (1983). Narrow C:N ratio observed in the surface soils of Acacia may be due to the high content of nitrogen in the leaf litter of Acacia released during decomposition.

4.6.4.11 Available micronutrients

Depthwise variation in available micronutrient status of various plantations is given in Table 36.

Natural forest soil recorded the highest Fe content of 24.52 ppm followed by Acacia (18.84 ppm) and Eucalyptus (15.02 ppm) and differed significantly. High Mn content of 2.12 ppm was

Table 34 Variation in available micronutrients in various plantations

Micro-nutrients	Plantation	Depth (cm) 0-20	20-40	40-60	60-80	80-100	Mean
Iron (ppm)	Acacia	40.90	23.60	16.80	8.70	8.20	18.84
	Eucalyptus	31.10	18.70	11.00	7.80	5.50	15.02
	Natural forest	49.10	34.10	17.50	13.30	8.60	24.52
	CD (0.05)	Bet.pln. 1.17			Bet.depth 1.51		
Manganese (ppm)	Acacia	4.24	2.86	1.37	0.74	0.45	1.93
	Eucalyptus	2.49	1.67	0.91	0.82	0.51	1.28
	Natural forest	6.04	2.84	0.84	0.52	0.36	2.12
	CD (0.05)	Bet.pln. 0.28			Bet.depth 0.36		
Zinc (ppm)	Acacia	0.486	0.374	0.172	0.170	0.064	0.253
	Eucalyptus	0.566	0.368	0.220	0.140	0.102	0.279
	Natural forest	0.902	0.574	0.346	0.178	0.128	0.426
	CD (0.05)	Bet.pln. 0.029			Bet.depth 0.037		
Copper (ppm)	Acacia	0.326	0.156	0.152	0.144	0.138	0.183
	Eucalyptus	0.172	0.132	0.132	0.112	0.096	0.129
	Natural forest	0.736	0.286	0.192	0.132	0.128	0.295
	CD (0.05)	Bet.pln. 0.020			Bet.depth 0.026		

recorded in natural forest followed by Acacia (1.93 ppm) and Eucalyptus (1.28 ppm). Copper content of Acacia and Eucalyptus was on par (0.253 and 0.279 ppm respectively) which was significantly lower than that of natural forest (0.426 ppm). There was significant difference in zinc content among the plantations. Eucalyptus soil recorded the lowest copper (0.129 ppm) followed by Acacia (0.183 ppm) and natural forest (0.295 ppm). Depth wise variation of all the micronutrients showed that highest value was observed in the surface soil which declined as the depth increases irrespective of the plantations.

The above result clearly indicated that the Eucalyptus and Acacia soils contained significantly low quantity of available micronutrient when compared to a natural forest. Since the soil organic matter plays a key role in converting the unavailable form of micronutrients to available form by forming soluble organic chelates, the lower organic matter content associated with plantation soil can be projected as a good reason for such a drastic difference in micronutrient status of soils under Acacia and Eucalyptus.

4.7 Allelopathy

The germination and growth of rice and cowpea seeds treated with various concentrations of fresh leaf leachate of different plantations are presented in Table 35.

Table 35 Allelopathic effect of fresh leaf extract of plantations on test crops - Rice and Cowpea

Plantation	Concentration	Rice			Cowpea		
		Germination (%)	Plumule length (mm)	Radicle length (mm)	Germination (%)	Plumule length (mm)	Radicle length (mm)
Acacia	1 : 2	83.33	25.66	28.53	56.66	48.61	19.86
	1 : 5	89.33	33.33	43.70	69.66	58.36	26.36
	1 : 10	94.66	39.46	50.60	85.66	86.83	49.88
	Mean	89.13	32.82	40.94	70.66	64.60	32.02
Eucalyptus	1 : 2	51.66	2.96	0	26.66	31.53	6.33
	1 : 5	76.66	6.93	0	46.00	36.98	8.56
	1 : 10	90.00	9.60	0.17	66.00	42.76	14.30
	Mean	72.77	6.50	0.05	46.22	37.09	9.73
Natural forest	1 : 2	86.66	31.26	15.90	65.33	51.60	20.16
	1 : 5	92.00	35.83	35.00	81.66	71.60	38.83
	1 : 10	95.33	41.43	46.10	91.66	94.10	45.33
	Mean	1.33	36.17	32.35	79.55	72.43	34.77
Control		97.00	48.10	59.60	94.30	95.61	46.30
CD (0.05)	Bet.pln.	5.11	4.15	4.91	3.95	6.36	4.28
	Within pln.	2.95	2.40	2.83	2.27	3.67	2.47

Fig : 25
Allelopathic effect of fresh leaf extract on rice germination

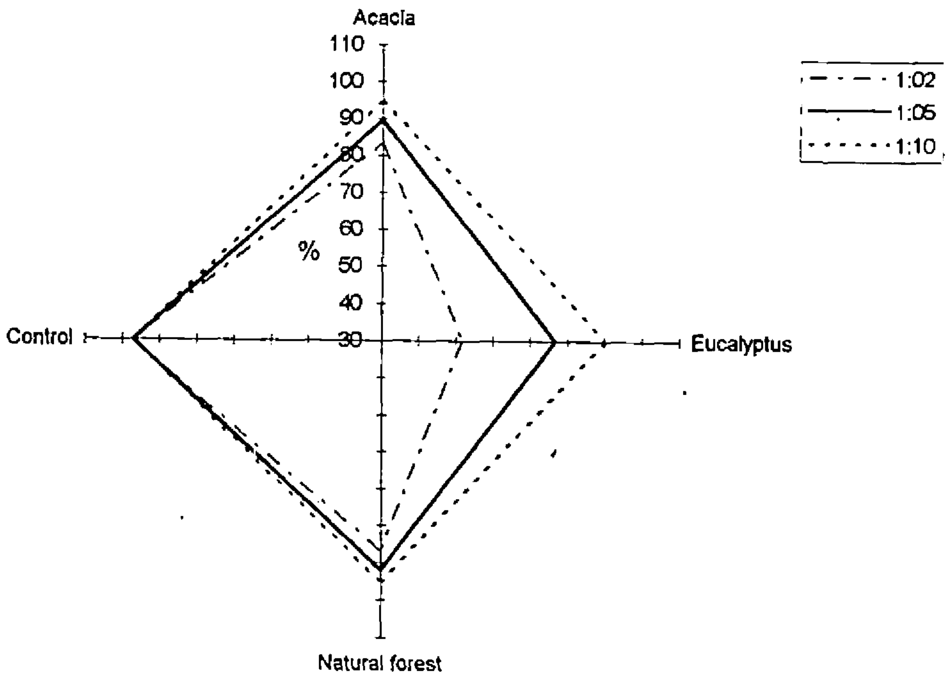
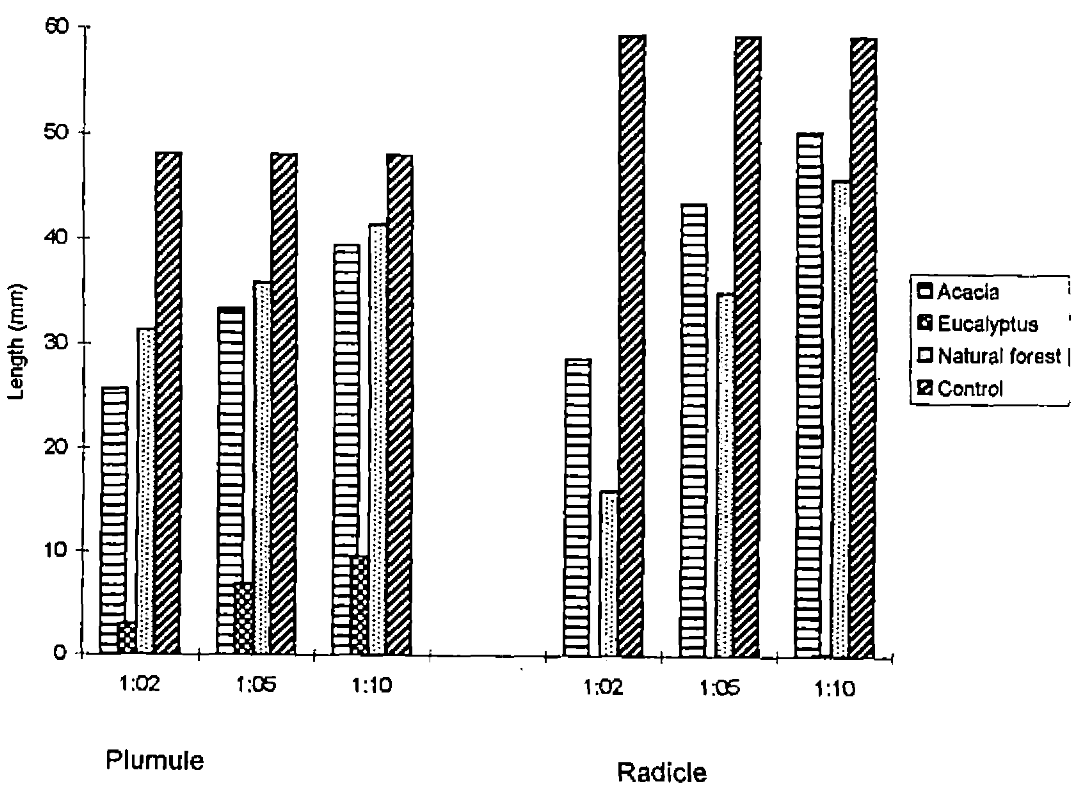


Fig : 26
Allelopathic effect of fresh leaf extract on rice growth



There was significant reduction in percentage germination of rice seeds due to various treatments. The mean germination percentage was minimum for Eucalyptus (72%) followed by Acacia (89%) and natural forest (91%) compared to control (97%). With respect to individual plantations, as the concentration of leaf leachate increased, the percentage germination of rice seeds decreased. The increase in percentage germination due to the decrease in concentration is more pronounced in Eucalyptus than in Acacia and natural forest (Fig. 25). The plumule length suffered severe inhibition from various treatments. The mean plumule length were 6.5 mm in Eucalyptus, 32.8 mm in Acacia and 36.1 mm in natural forest compared to control (48.1 mm). Significant increase in plumule length was observed in all the samples as the concentration decreased from 1:2 to 1:5 and 1:10 (Fig. 26). The radicle length of germinating rice seeds was severely retarded by various treatment compared to control (Fig. 28). The radicle length was 59 mm for control as against 0.05 mm for Eucalyptus, 32.35 mm for natural forest and 40.94 mm for Acacia. The retardation of radicle length was more in Eucalyptus where no radicle growth was observed for 1:2 and 1:5 concentration of leaf leachate. In all the plantations, the inhibition of radicle length decreased as the dilution of leaf leachate increased.

In cowpea the allelopathic interaction of fresh leaf extracts of various plantations given in Table 35 revealed that

Fig : 27
Allelopathic effect of fresh leaf extract on cowpea germination

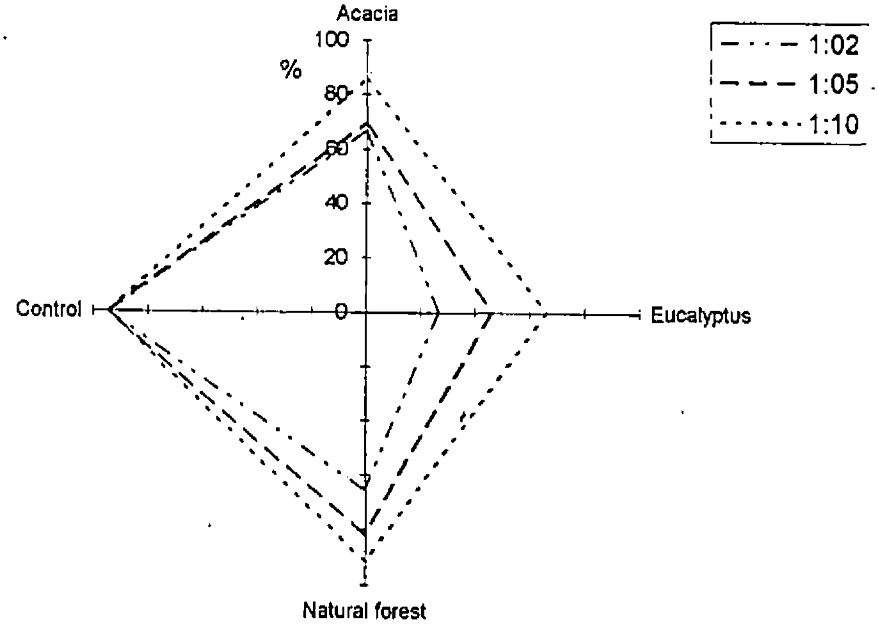
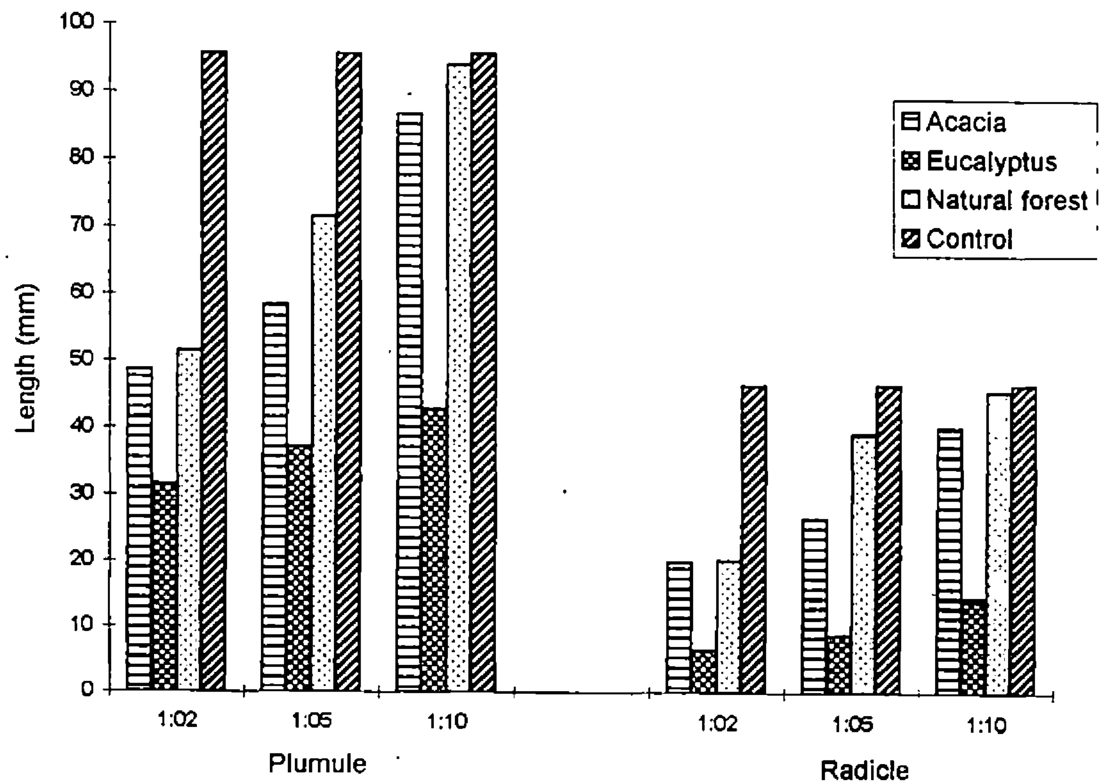


Fig : 28
Allelopathic effect of fresh leaf extract on cowpea growth



there is severe reduction in percentage germination due to various treatment. The mean germination percentage decreased from 94.3% (control) to 79.55% in natural forest, 70.66% in Acacia and 46.22% in Eucalyptus. The germination percentage increased with decrease in concentration of leaf leachate as depicted in (Fig. 27). The mean plumule length was lowest for leaf leachate of Eucalyptus (37.07mm) followed by Acacia (64.6 mm) and natural forest (72.43 mm) as against the control (95.61 mm). The mean radicle length of germinating cowpea seeds decreased from 46.3 mm (control) to 34.77 mm (in natural forest) 32.02 mm (in Acacia) and 9.73 mm (in Eucalyptus). Reduction in the plumule length and radicle length were noticed with increase in concentration of leaf leachate (Fig. 28).

The result of the study revealed that there was severe allelopathic interaction of the leaf leachate of Acacia, Eucalyptus and natural forest on rice and cowpea. The observation is in conformity with the findings of Rao *et al*. (1994) and Pheomina and Srivasuki (1996). Among the plantations, Eucalyptus produced most severe allelopathic interaction with rice and cowpea. This is coroborated by the findings of Suresh and Vinaya Rai (1987). The inhibitory effect on the germination and growth characters of test crops were directly proportional to the increase in concentration of leaf extracts of various tree species. This is in conformity with the observations of Lines and Fournier (1979) and Rao *et al*. (1994). The increase in allelopathic interaction with the increase in concentration of leaf leachate may be due to the higher concentrations of the allelochemicals.

The allelopathic effect of Eucalyptus has been attributed to the production of several volatile terpenes (De Moral and Muller 1969 and 1970) and some water soluble inhibitors (Al-Mousawi and Al-Naib, 1975). Presence of water soluble phenolics, terpenes and triterpenes as allelochemicals are also reported in Eucalyptus sp (De Moral *et al.* 1978 and Furuya *et al.* 1987). The inhibition due to Acacia leaf leachate was attributed to the presence of tannins (Swaminathan *et al.* 1989). Natural forest leaf also contained the allelochemials, though the inhibitory effect was lower than Eucalyptus and Acacia, it may be due to the presence of polyphenoles in the leaf.

Allelopathic interaction of leaf litter extracts of Acacia, Eucalyptus and natural forest on rice and cowpea are given in Table 36.

In rice there was significant inhibition to mean percentage germination due to leaf litter leachate of various plantations. The percentage germination decreased from 85 to 49% in Eucalyptus, 64% in Acacia and 67.2% in natural forest (Fig. 29). With respect to plumule length lowest value recorded in Eucalyptus (28.7 mm) followed by Acacia (50.1 mm) and natural forest (57.6 mm) compared to control (88.5 mm) (Fig. 32). The

Table 36 Allelopathic effect of leaf litter extract of plantations on test crops - Rice and Cowpea

Plantation	Concentration	Rice			Cowpea		
		Germination (%)	Plumule length (mm)	Radicle length (mm)	Germination (%)	Plumule length (mm)	Radicle length (mm)
Acacia	1 : 2	52.66	27.96	16.18	85.00	65.40	42.69
	1 : 5	62.66	51.70	52.63	89.33	86.66	58.62
	1 : 10	76.66	70.73	85.36	96.66	97.13	62.40
	Mean	64.00	50.13	51.39	89.00	83.06	54.57
Eucalyptus	1 : 2	35.66	13.09	2.66	70.33	30.50	7.24
	1 : 5	51.33	29.73	3.36	83.33	34.23	11.23
	1 : 10	60.00	43.43	4.23	87.33	40.60	13.63
	Mean	49.00	28.75	3.42	80.33	35.12	10.70
Natural forest	1 : 2	55.00	39.41	21.10	90.33	59.66	35.49
	1 : 5	68.00	56.15	53.73	93.66	79.11	51.31
	1 : 10	78.66	77.23	96.03	95.66	87.36	59.27
	Mean	67.22	57.60	56.95	93.22	75.38	48.69
Control		85.00	88.30	88.80	97.30	105.43	63.19
CD (0.05)	Bet.pln.	3.53	2.12	2.04	3.84	9.71	7.20
	Within pln.	2.03	1.22	1.18	2.22	5.60	4.16

Fig : 29
Allelopathic effect of leaf litter extract on rice germination

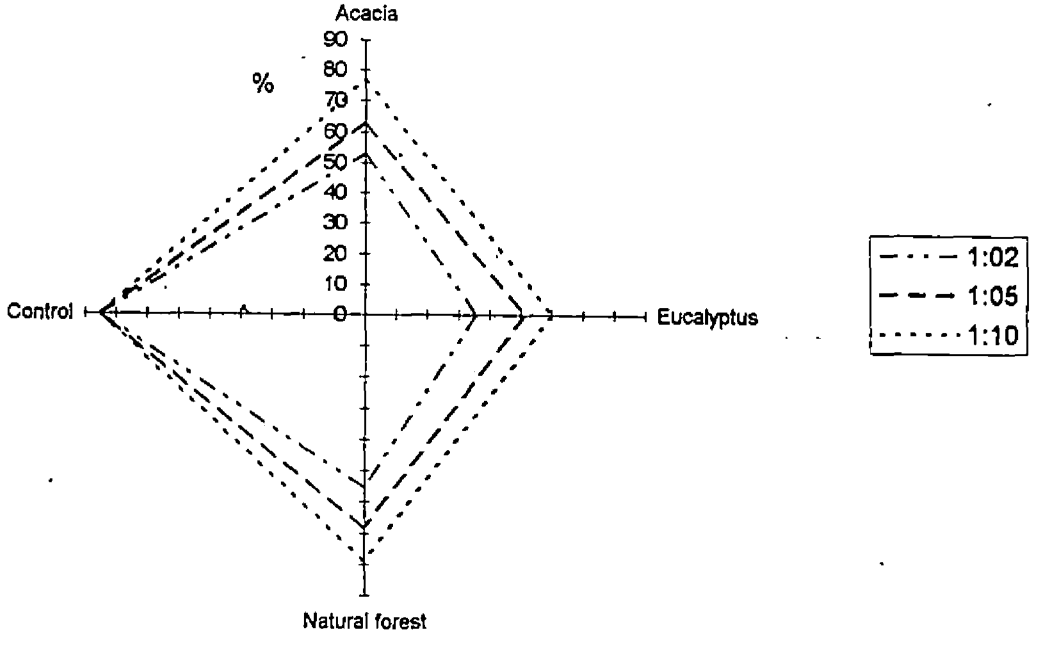
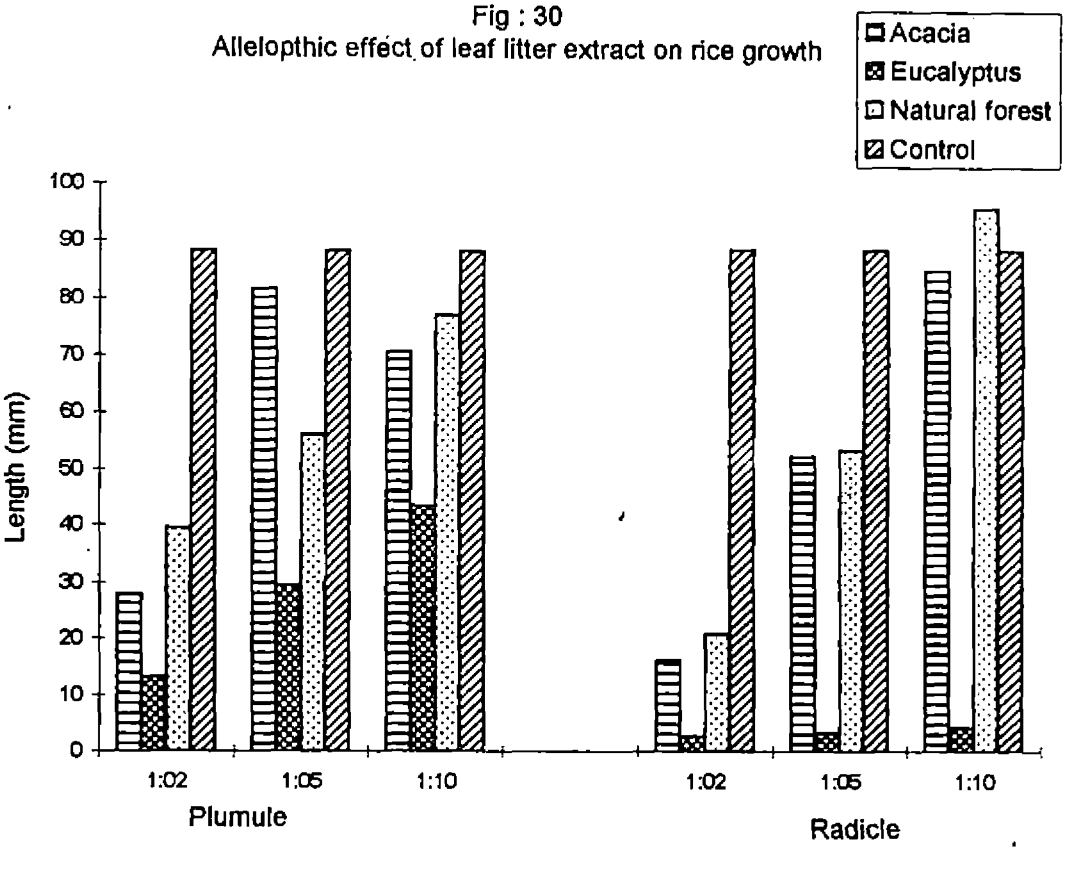


Fig : 30
Allelopthic effect of leaf litter extract on rice growth



radicle length of germinating seeds were also severely affected and it decreased from 88.8 mm (control) to 3.42 mm in Eucalyptus, 51.4 mm in Acacia and 56.9 mm in natural forest (Fig. 30). As the concentration of leaf leachate increased, the inhibitory effect on percentage germination, plumule length and radicle length were also increased irrespective of the leaf litter leachate.

The inhibitory effect of various leaf extract on germinating cowpea seeds given in Table 36 showed that there was severe reduction in germination percentage of cowpea seeds moistened with leaf litter extracts of various plantations. The lowest germination percentage was observed in Eucalyptus (80.33%) followed by Acacia (89%) and natural forest (93.2%) compared to control (97.3%). There was significant increase in germination percentage of cowpea seeds as the concentration of leaf leachate decreased except in natural forest leaf extract in which the germination percentage was on par at 1:5 and 1:10 concentration (Fig. 31). The mean plumule length of germinated cowpea seeds was drastically reduced by various treatment from 105.4 mm (control) to 35.12 mm in Eucalyptus, 75.38 mm in natural forest and 83.06 mm in Acacia (Fig. 32). The radicle length of cowpea seeds moistened with Eucalyptus leaf litter extract was the lowest (10.7 mm) followed by natural forest (48.7 mm) and Acacia (54.8 mm) against the control (63.2 mm) (Fig. 32). The allelopathic interaction increased with increase in extract concentration irrespective of the plantations.

Fig: 31
Allelopathic effect of leaf litter extract on cowpea germination

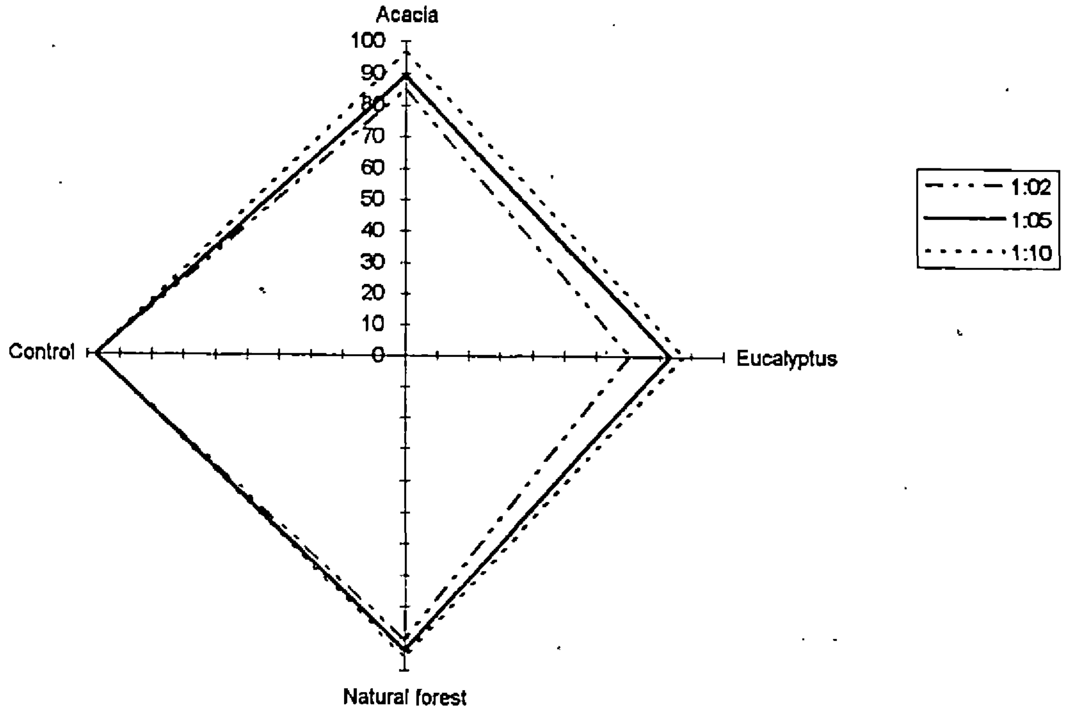
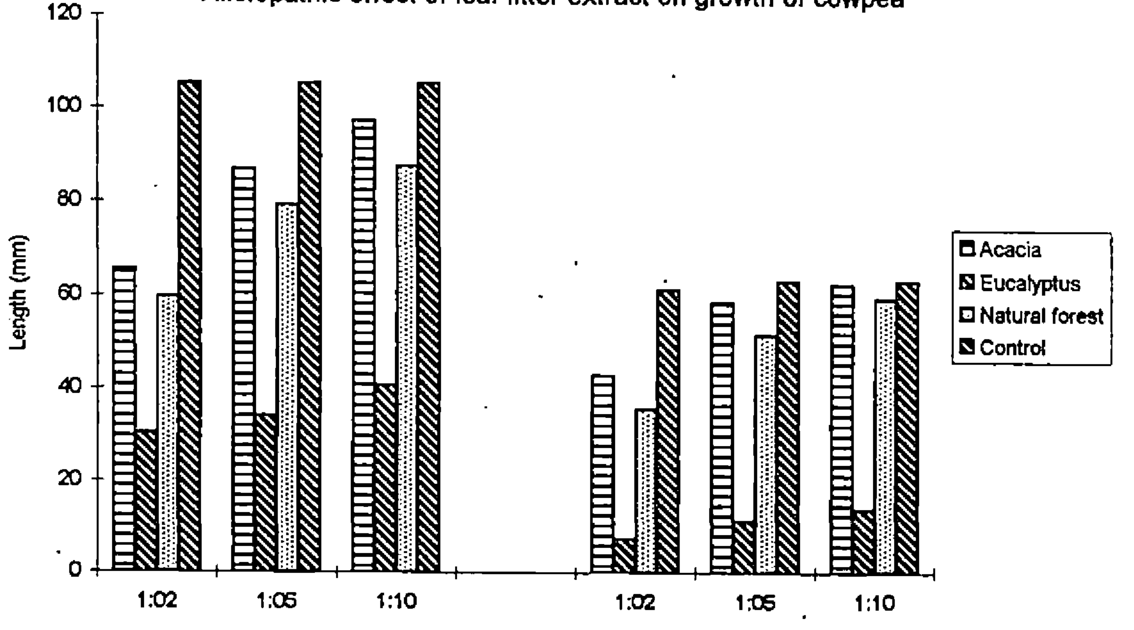


Fig :32
Allelopathic effect of leaf litter extract on growth of cowpea



Similar to the fresh leaf extract, the extracts of leaf litter also showed allelopathic interaction with rice and cowpea. The inhibition on percentage germination, plumule length and radicle length were more severe in Eucalyptus extract. This observation was supported by the findings of Suresh and Vinay Rai (1988). The Acacia leaf leachate was more allelopathic for germination in rice and cowpea and plumule length and radicle length in rice than natural forest extract. The inhibitory effect of Acacia leaf litter extract on rice and cowpea has been reported by Jadhev and Geyner (1992). Allelochemical falls under the category of polyphenolics and high content of polyphenole in fresh as well as leaf litter in Eucalyptus followed by Acacia and natural forest observed in the present study well correlates with their allelopathic effect. Though natural forest leaf leachate exhibited the allelopathic activity, under field condition, due to high rate of decomposition of leaf litter associated with higher activity of soil organisms and heterogenity of litter quality, the expression of allelopathy was low under forest ecosystem as evident from the luxuriant undergrowth noticed as against the sparce undergrowth in monoculture plantations.

4.8 Allelopathic effect of soil extract

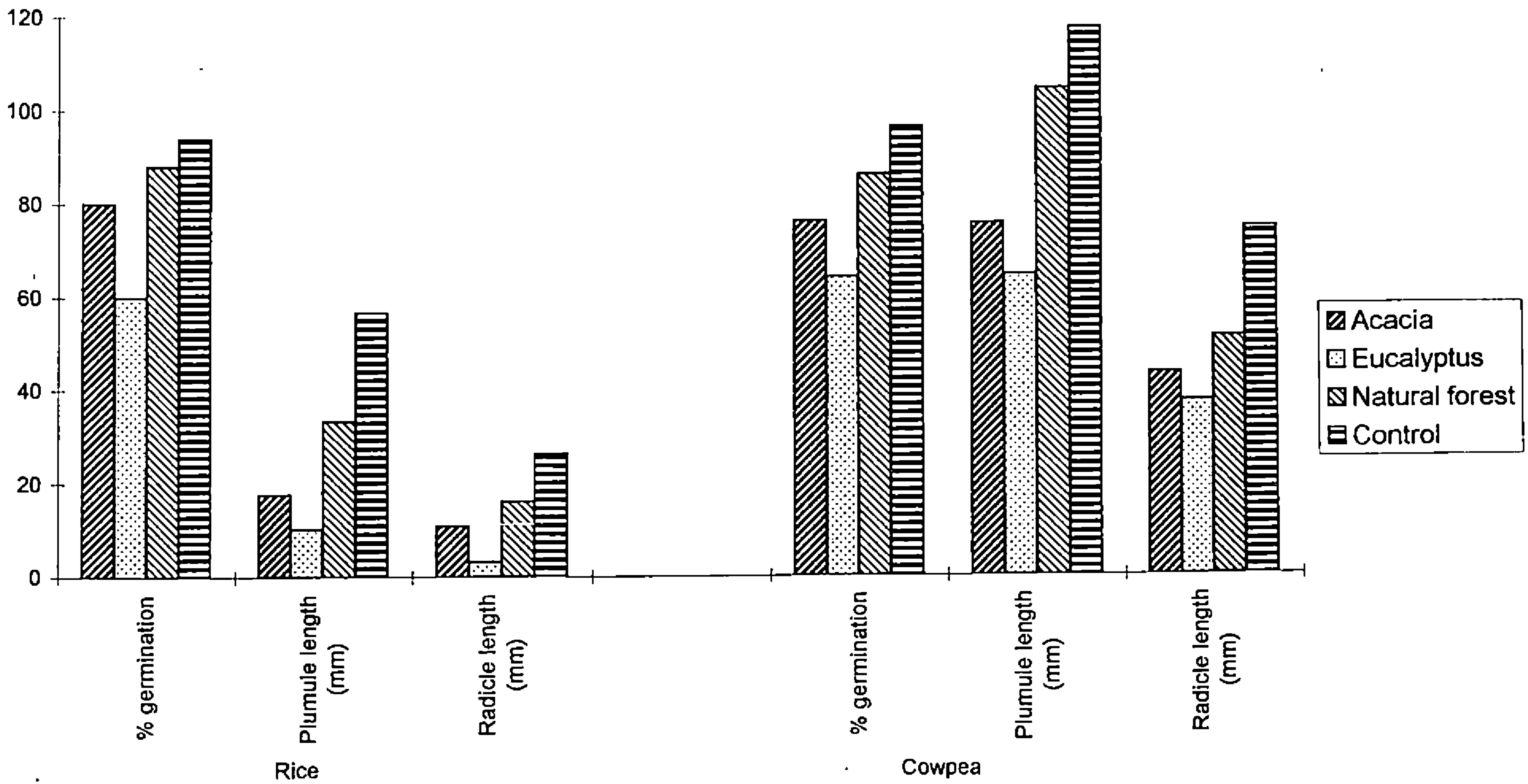
Allelopathic interaction of soil extract of Acacia, Eucalyptus and natural forest on germination and growth of test crops is given in Table 37. There was significant reduction in

Table 37 Allelopathic effect of soil extract on test crops - Rice and Cowpea

Plantation	Rice			Cowpea		
	Germination (%)	Plumule length (mm)	Radicle length (mm)	Germination (%)	Plumule length (mm)	Radicle length (mm)
Acacia	80.00	17.60	10.86	76.00	75.40	43.30
Eucalyptus	60.00	10.20	3.20	64.00	64.60	37.20
Natural forest	88.00	33.40	16.12	86.00	104.10	51.00
Control	94.00	56.60	26.40	96.00	117.00	74.50
CD (0.05)	9.40	5.70	3.28	11.01	8.90	7.10

Fig : 35

Allelopathic effect of soil extract on rice and cowpea



germination percentage in rice seeds by Eucalyptus soil extract (60%) and Acacia (80%) compared to control (94%). Forest soil extract did not have any significant effect on germination. With respect to cowpea, it also followed a similar pattern as that of rice with respect to germination percentage (Fig. 33). The plumule length of rice seedlings significantly reduced by the soil extract from 56.6 mm (control) to 10.2 mm in Eucalyptus, 17.6 mm in Acacia and 33.4 mm in natural forest. Similarly the plumule length in cowpea reduced from 117 mm (control) to 64.6 mm in Eucalyptus, 75.4 mm in Acacia and 104.1 mm in natural forest. The soil extract of Eucalyptus decreased the radicle length of rice from 26.4 mm (control) to 3.2 mm. The radicle length of rice under soil extract of Acacia and natural forest were 10.86 and 16.12 mm respectively. The radicle length of cowpea significantly reduced from 74.5 mm (control) to 37.2 mm, 43.3 mm and 51.00 mm by Eucalyptus, Acacia and natural forest soil extract respectively.

Soil extracts of Eucalyptus followed by Acacia severely inhibited the germination and growth characters of rice and cowpea. Eventhough the germination was not affected, the seedling growth was affected by soil extracts of natural forest also. Paulino *et al*. (1987) observed that top surface soil taken from beneath the trees of *E. tereticornis* reduced germination and growth of blackgram, greengram and cowpea. The Eucalyptus rhizosphere was rich in allelochemicals which were injurious to the vegetation growing nearby (Singh and Kohli 1992). They also reported that litter free soil beneath the *E. tereticornis* plantation contained 300 mg allelochemicals per 100g soil compared with that from open field. Suppression of under story by multipurpose tree species is mainly by the presence of allelochemicals in the soil released from litter decomposition and leaching (Suresh and Vinayi Rai, 1988).

4.9 Soil organic matter

4.9.1 Proximate analysis of soil organic matter

The average quantities and percentage contribution of proximate constituents of soil organic matter namely fats, waxes, resins, free sugars, hemicellulose, cellulose, lignin and protein are presented in Table 38 and in Fig. 34.

The results showed that there is significant difference in fat and wax content among the sites studied. Eucalyptus soils recorded the highest quantity of fat and waxes (72.6 mg). The fat and wax content of Acacia (50.6 mg) was on par with that of natural forest (55.4 mg). The percentage contribution of fat and waxes to organic matter was 1.56 in Eucalyptus and 0.98% in Acacia.

Low decomposition and depletion of these components in Eucalyptus soil due to the inhibition of microbial activity and unfavourable soil condition might have resulted in the

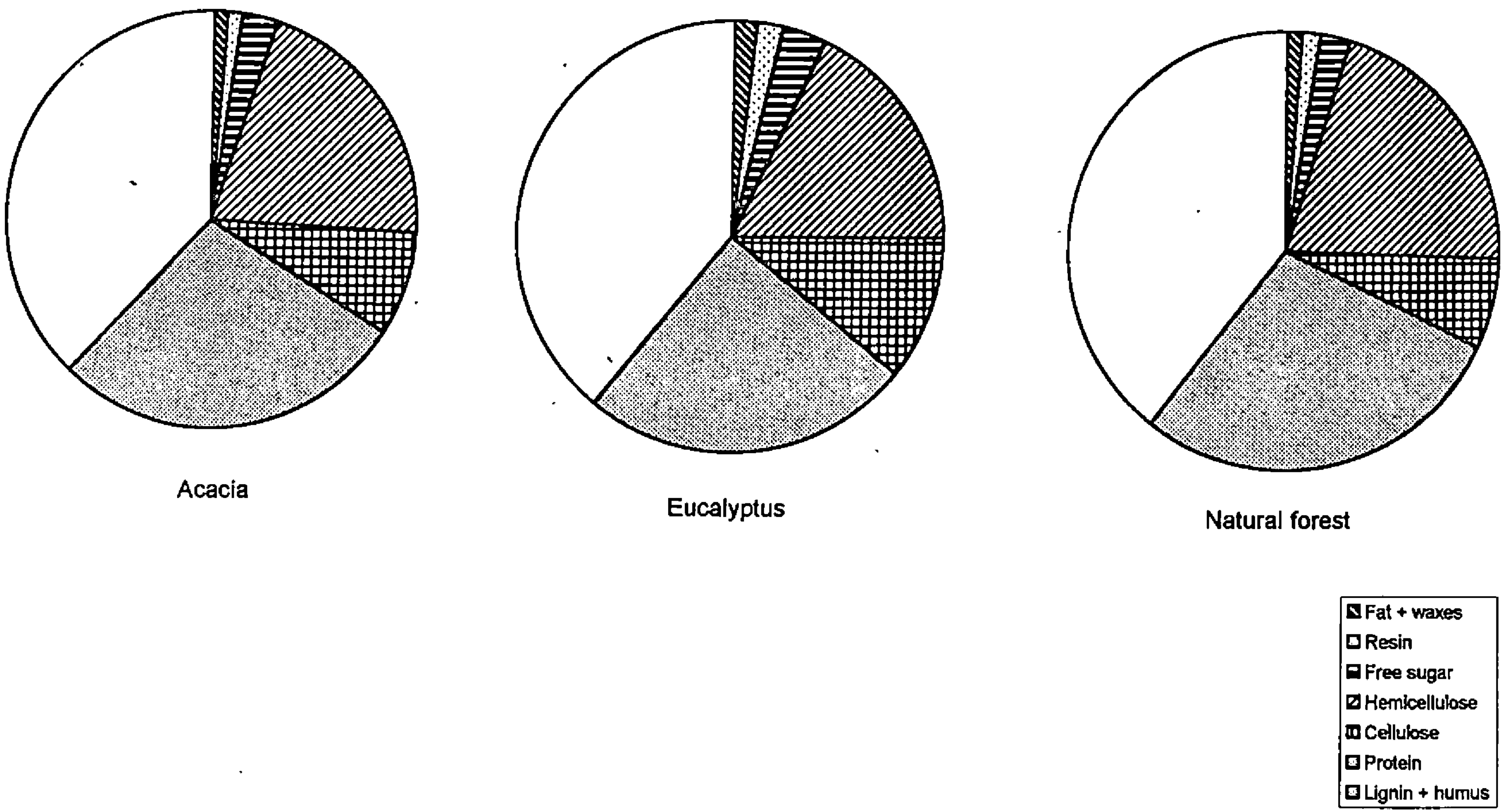
Table 38 Proximate composition of organic matter separated from various plantations

Plantation	Organic matter (%)	Fat wax (mg)	Resin (mg)	Free sugar (mg)	Hemi-cellulose (g)	Cellulose (g)	Protein (g)	Lignin+ humus (g)
Acacia	5.12	50.6 (0.98)	67.0 (1.30)	135.8 (2.65)	1.08 (21.13)	0.41 (8.00)	1.45 (28.28)	1.95 (38.12)
Eucalyptus	4.63	72.6 (1.56)	86.4 (1.86)	161.0 (3.47)	0.81 (17.51)	0.45 (10.66)	1.13 (24.38)	1.78 (38.45)
Natural forest	5.60	55.4 (0.98)	83.2 (1.48)	134.4 (2.39)	1.16 (20.75)	0.38 (6.84)	1.58 (28.26)	2.22 (39.60)
CD (0.05)	0.257	5.42 (0.07)	7.54 (0.07)	7.79 (0.11)	0.06 (1.37)	0.04 (0.39)	0.07 (0.48)	0.10 (0.94)

Values given in the parentheses are the percentage to organic matter

Fig : 34

Proximate composition of soil organic matter



accumulation of fat and waxes. This conclusion corraborates the observations of Wang (1967) and Balagopalan (1995).

The resin content of soil organic matter recorded the highest value in Eucalyptus soils (86.4 mg) followed by natural forest (83.2 mg) and Acacia (67.0 mg). Highest absolute content as well as percentage of resin in Eucalyptus soil is due to the low decomposition rate of this component in soil.

The free sugar content as well as its percentage contribution to organic matter in various plantations shown in Table 38 and Fig. 34 indicated that the free sugar content of Acacia (135.8 mg) and natural forest (134.4 mg) was significantly lower than that of Eucalyptus soils (161.0 mg). Organic matter under Eucalyptus soil contained the highest percentage of free sugar (3.47%) followed by Acacia (2.65%) and natural forest (2.39%). The high proportion of free sugar - the easily decomposible component of organic matter in Eucalyptus and Acacia indicate the low decomposibility of organic matter in these soils. It may be due to the low microbial activity and unfavourable soil conditions. The increase in free sugar content with elevation due to low microbial activity was also reported by Gupta and Sowden (1964) and Balagopal (1995).

There was significant difference in hemicellulose content of soil among various plantations. Natural forest soil contained the highest amount of hemicullulose (1.16g) followed by

Acacia (1.08 g) and Eucalyptus (0.81 g). The percentage contribution of hemicellulose to organic matter in Acacia and natural forest was on par (21.13 and 20.75% respectively) which is significantly higher than that of Eucalyptus (17.51%). The high content of hemicellulose in natural forest and Acacia compared to Eucalyptus might be due to the higher humification. The contribution of microbial biomass especially that of fungus may also lead to the high hemicellulose content. Higher content of hemicellulose is attributed to factors like lignin and protein which tend to form stable complexes with hemicullulose (Gupta, 1967).

The cellulose content of organic matter was much lower than that of hemicellulose. Eucalyptus soils contained the highest quantity of cellulose (0.49 g) which was significantly higher than that of Acacia and natural forest (0.41 and 0.38 of respectively). The percentage content of cellulose among plantations also differed significantly. Eucalyptus soil contained the highest percentage of cellulose in organic matter (10.66%) followed by Acacia(8.07%) and natural forest (6.84%). Low content of cellulose in soil organic matter compared to hemicellulose was also reported by Allison (1973). Schnitzer and Khan (1972) reported that with increasing decomposition, the cellulose is generally depleted to a greater extent than the hemicellulose fraction. Higher cellulose content associated with soils having low microbial activity was also reported by Cheshire *et al*. (1971).

The protein content of soils revealed that there was significant difference among various plantations. Natural forest soil contained the highest quantity of protein (1.58 g) followed by Acacia (1.45 g) and Eucalyptus (1.13g) and the percentage contribution of protein to organic matter of Acacia and natural forest was almost equal (28.2%) which was significantly higher than that of Eucalyptus (24.38%). The encrichment of protein in soil resulted from amino acid resistant to microbial attack (Campell and Lees 1967) and protein and carbohydrate inter action with lignin (Lavina *et al.*, 1970). This might have contributed to high protein content in Acacia and natural forest than that of Eucalyptus.

Lignin plus humus content of soils also showed significant difference among plantations. Natural forest recorded the highest lignin (2.22 g) followed by Acacia (1.95 g) and Eucalyptus (1.78 g) and the percentage lignin plus humus in Acacia and Eucalyptus (38.12 and 38.45% respectively) was on par and significantly lower than that of natural forest (39.6%).

Lignin plus humus fraction is the dominant fraction of the organic component of soil organic matter as reported by Hurnst and Berges (1967) and high proportion of lignin in natural forest may be caused by microorganisms which are able to synthesise stable lignin compounds as proposed by Palaniappan (1975).

4.9.2 Fractionation of Soil Humus

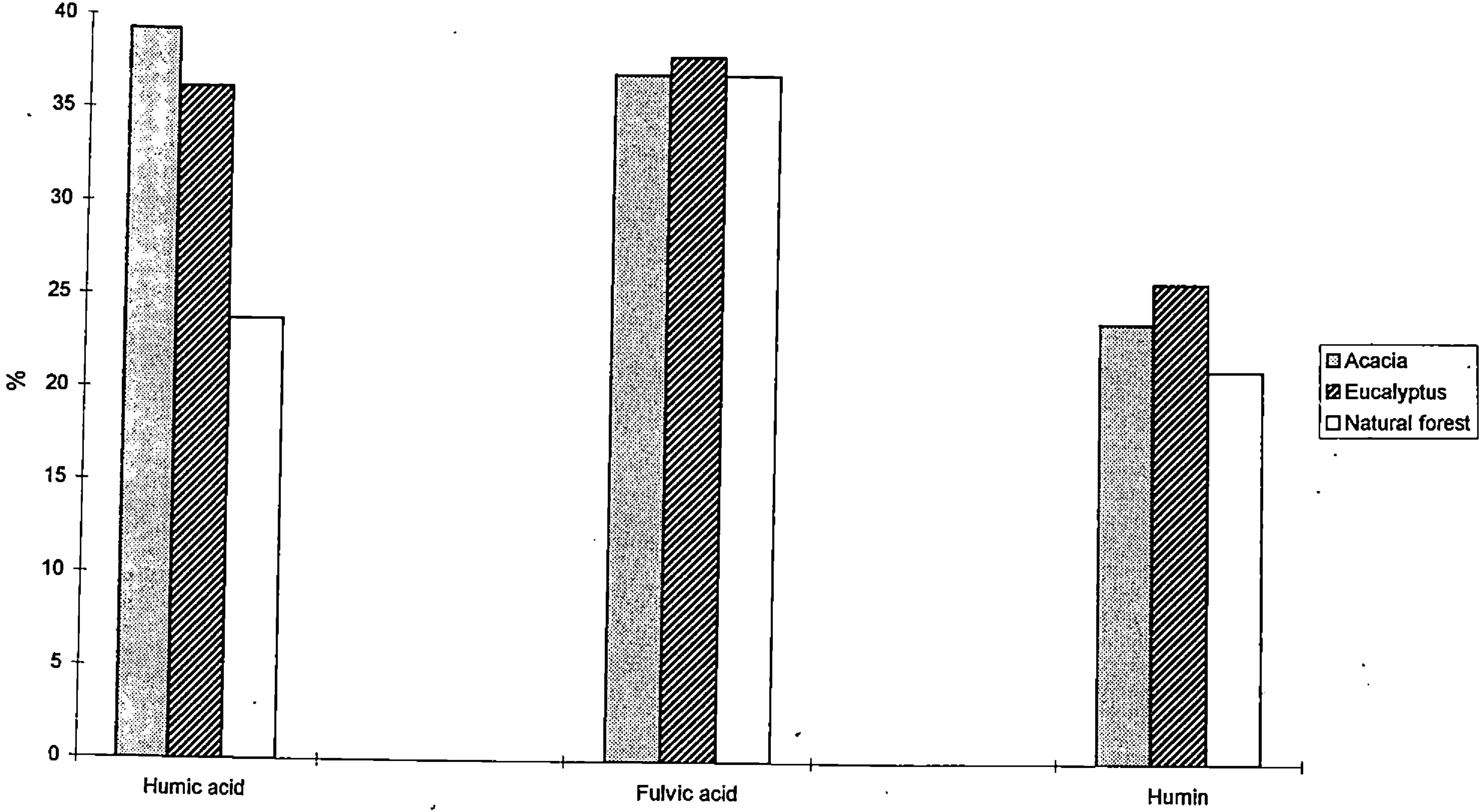
Mean values of humic acid, and fulvic acid in soils of Acacia, Eucalyptus and natural forest are furnished in Table 39. There is significant difference in humic acid content of various plantations. Soil humic acid content were 2.34% in natural forest, 2.01% in Acacia and 1.67% in Eucalyptus. Humic acid contributed 41.86% of organic matter in natural forest , 39.28% in Acacia and 36.18% in Eucalyptus . Humic acid content of soils obtained in the present study is in accordance with the results of Manarino *et al*. (1982), Li (1987) and Balagopalan and Jose (1993b). Continuous supply of raw material through litter fall and the conducive climatic condition and microbial growth contributed to high HA production in natural forest (Allison 1973). Since lignin is the chief contributor of HA, (Hurnst and Burges (1967) and Balagopalan and Jose (1991) the high lignin content in natural forest may also have contributed to high HA content.

Fulvic acid contents of various plantations also differed significantly as given in Table 37. and Fig. 35. Natural forest soil contained 2.07% FA followed by Acacia soil (1.89%) and Eucalyptus (1.74%). The percentage contribution of FA to organic matter was highest in Eucalyptus and high proportion of FA in Eucalyptus compared to a moist deciduous forest were also reported by Balagopalan and Jose (1993b).

Table 39 Soil humic fractions of various plantations

Plantations	Organic matter (%)	Humic acid (%)	Humic acid % of organic matter	Fulvic acid (%)	Fulvic acid % of organic matter	Humic acid/ Fulvic acid	Humic acid+ Fulvic acid (%)
Acacia	5.12	2.01	39.28	1.89	36.98	1.060	76.27
Eucalyptus	4.63	1.67	36.18	1.74	37.93	0.958	73.92
Natural forest	5.60	2.34	41.86	2.07	36.95	1.134	78.82
CD (0.05)	0.25	0.10	0.94	0.11	1.57	0.043	2.44

Fig : 35
Humus fractions of various plantations



The HA : FA ratio of various plantations given in able 34 also showed significant difference. Natural forest soil recorded a HA : FA ratio of 1:13 followed by Acacia (1.06) and Eucalyptus (0.96). The HF : FA ratio less than one of Eucalyptus indicates the dominance of FA in over HA. This observation agrees with the reports of Balagopalan and Jose (1993b), Fulvic acid is primarily considered to be a humic acid precursor (Anderson *et al*. 1974). Higher Fulvic acid content along with high content of easily decomposible resin, waxes, oil and simple sugars indicate low degree of humification in Eucalyptus soils. Reports by Banerjee and Chakkraborthy (1977) indicate that soils which are poor in microbial activity favours the accumulation of fulvic acid and decrease in HA : FA ratio.

The percentage of humic acid and fulvic acid as a whole of organic matter accounted to 78.8% in natural forest, 76.2% in Acacia and 73.9% in Eucalyptus. The balance remaining as unextractable (humin) was very small and based on this, the soils could be classified as humate-fulvic type as proposed by Palaniappan (1975) and Balagopalan (1995). The low humin content under tropical condition is attributed to rapid decomposition of organic matter.

4.9.3 Characterisation of Humic acid, fulvic acid

4.9.3.1 Functional group analysis

Results of the functional group analysis of HA and FA separated from various plantations are furnished in Table No. 40.

Table 40 Functional group and E4/E6 ratio of Humic acid and Fulvic acid seperated from various plantations

Plantation	Total acidity		COOH		Phenolic - OH		E4/E6	
	HA	FA	HA	FA	HA	FA	HA	FA
Acacia	7.12	8.28	4.00	4.75	3.08	3.53	4.25	8.12
Eucalyptus	6.54	8.67	3.68	5.19	2.86	3.47	4.33	8.22
Natural forest	7.58	9.26	4.15	5.49	3.43	3.76	4.17	7.94
CD (0.05)	0.28	0.20	0.22	0.23	0.21	0.07	0.04	0.21

It can be inferred from the table that HA of natural forest contained the highest quantity amounts of total acidity (7.58 meq/g) derived from Carboxyl group (4.15 meq g^{-1}) and phenolic hydroxyl group (3.43 meq g^{-1}). Humic acid of Eucalyptus plantation recorded the lowest value for total acidity (6.54 meq/g), carboxyl group (3.68 meg/g^{-1}) and phenolic hydroxyl group (2.86 meq/g). The high content of functional groups in HA of natural forest may be due to the higher condensation of the building blocks of humic acid subsequent to high rate of organic matter decomposition.

The fulvic acids of natural forest also contained higher total acidity (9.26 meq g^{-1}) contributed by carboxyl group (5.45 meq/g^{-1}) and phenolic hydroxyl group (3.76 meq g^{-1}) compared to Acacia and Eucalyptus. Functional group content of fulvic acid is higher than that of humic acid in all the soils studied and this is in accordance with the reports of Schinitzer (1977). Functional group content of HA and FA obtained in the present study is in close proximity with the reports of Schnitzer (1977) and Kunal Ghosh and Schnitzer (1979). Due to high content of functional groups fulvic acid is more reactive than humic acid in all the plantations and it is more pronounced in Eucalyptus which contained higher proportion of FA than HA.

4.9.3.2 Spectral characterisation of HA and FA

4.9.3.2.1 UV spectra

UV. spectra of humic acid and fulvic acid separated from various plantations are given in Fig. 36 and 37.

Fig. 36 UV Spectra of Humic Acid

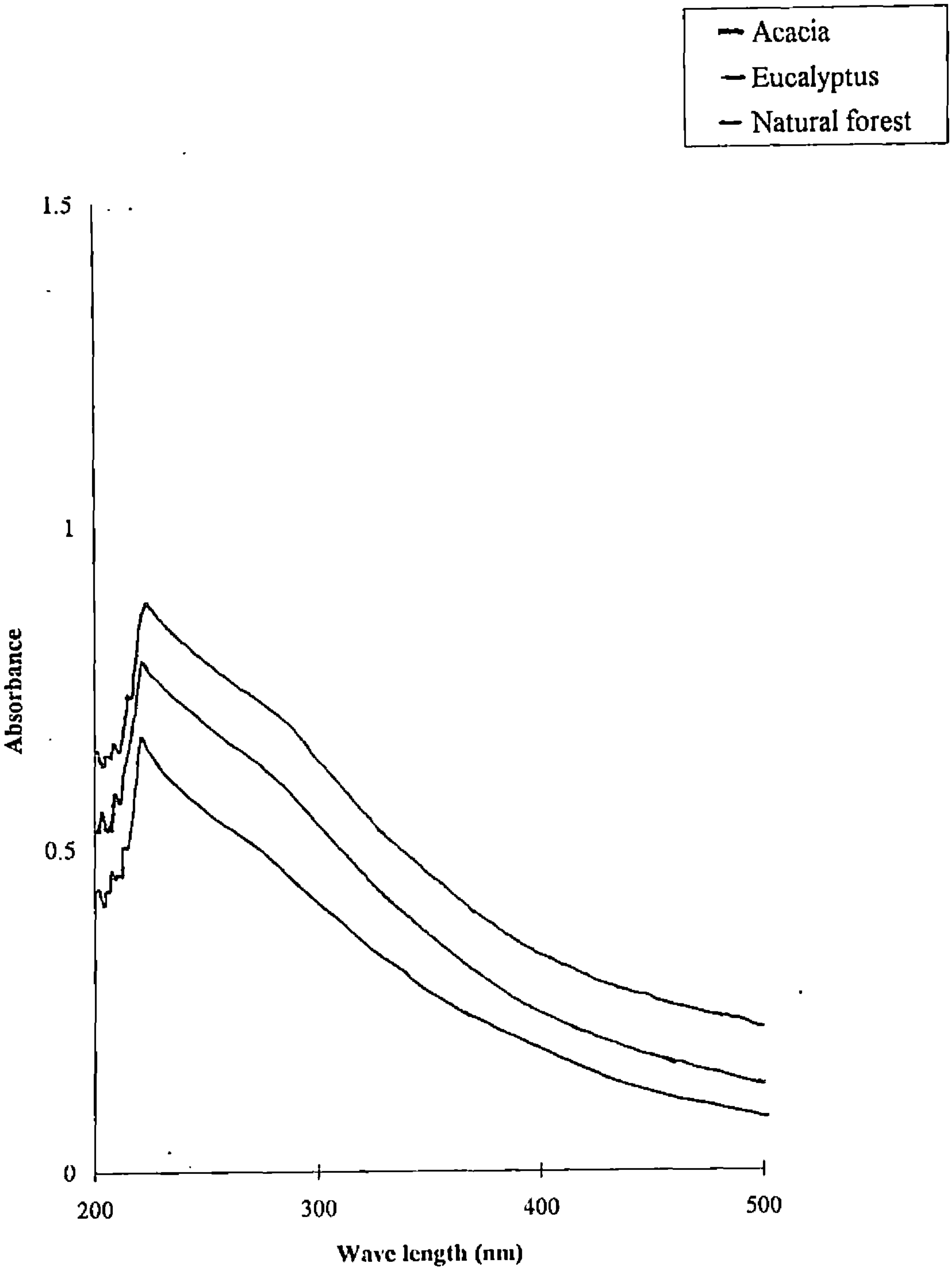
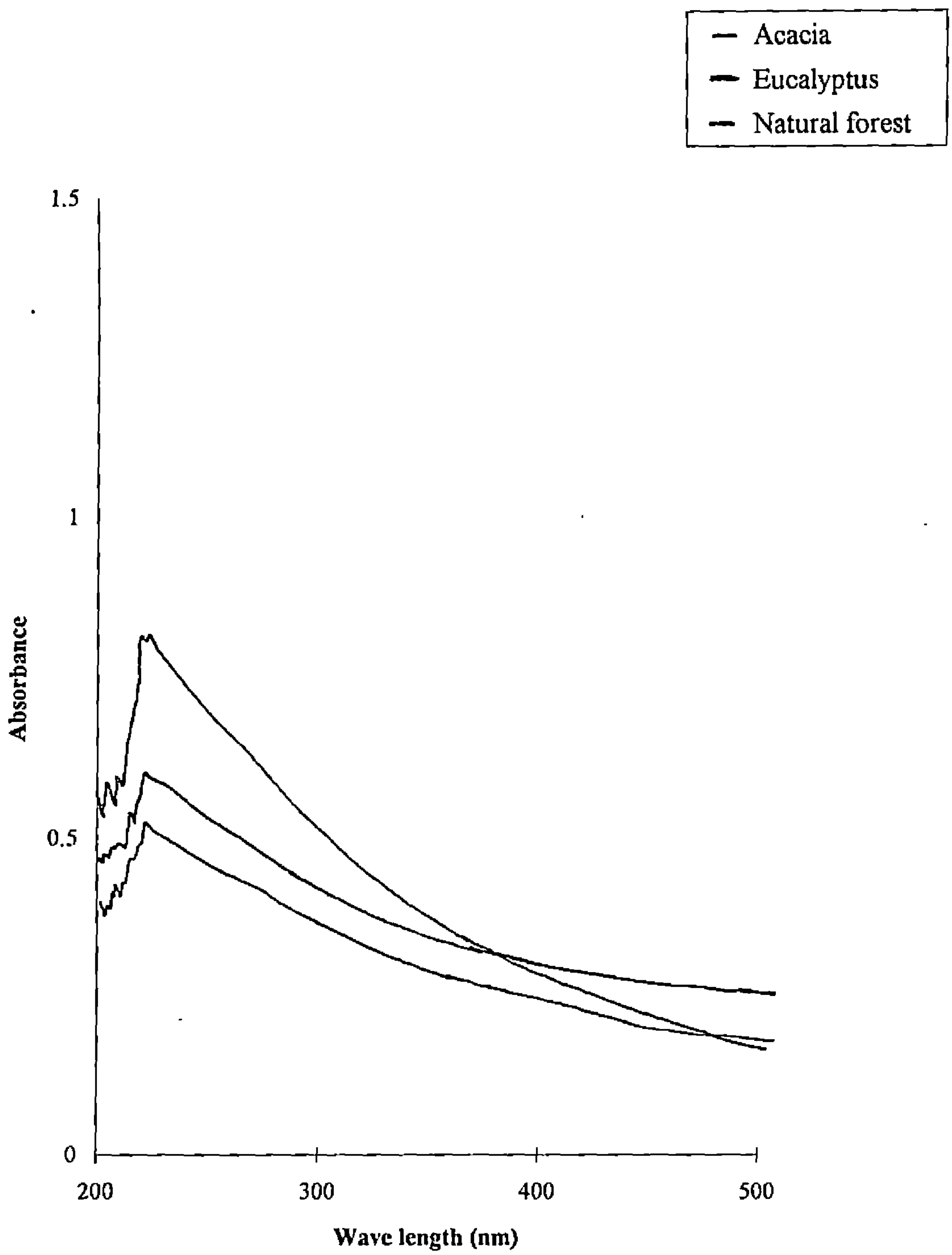


Fig. 37 UV Spectra of Fulvic Acid



The absorption in the UV region is due to the presence of multiple bonds and unshared electron pairs in organic molecules. In all the plantations studied, the optical density decreases with wave length. The U.V. spectra showed a broad shoulder at 225 nm and are very similar in all the 3 plantations. This agrees with the findings of Schnitzer and Khan (1972), Balagopalan and Jose (1993b) and Balagopalan and Jose (1994).

The UV spectra of fulvic acid also showed decrease in optical density with wave length. UV spectra of fulvic acid also have a broad shoulder at 225 nm which is very similar to HA, eventhough they are diverse in origin. Balagopalan and Jose (1994) also made similar observation in their study

4.9.3.2.2 Visible spectra

Since the visible spectra of HA and FA are not characteristic, the ratio of absorbance at 465 and 665 nm ie E4/E6 ratio are recorded and given in Table 40.

E4/E6 ratio of HA is highest in Eucalyptus (4.33) followed by Acacia (4.25) and natural forest (4.17). E4/E6 ratio of FA also followed the same order but with higher values of 8.22, 8.12 and 7.94 in Eucalyptus, Acacia and natural forest respectively. The E4/E6 ratio has been reported to vary for humic materials extracted from different soil types (Kononova 1966, Schnitzer and Khan 1972). Kononova (1966) believed that the magnitude of the E4/E6 ratio is related to the degree of condensation of the aromatic carbon network, with low ratio indicatve of a relatively high degree of condensation of aromatic humic constituents. Low E4/E6 ratio associated with the humic materials of natural forest may be due to the high degree of condensation associated with high humifiation rate. E4/E6 ratio of humic material obtained in the present investigation is supported by the report of Tan and Giddens (1972).

4.9.3.2.3 I.R. Spectra

The IR spectra of HA separated from the soils of Acacia, Eucalyptus and natural forest is given in Fig. 38.

Absorption band at 3400 cm^{-1} in Acacia, Eucalyptus and natural forest is rather strong and broad which arises from H bonded OH group including those of COOH group. A stronger band in Acacia and weaker band in Eucalyptus and natural forest at 3380 cm^{-1} is due to hydrogen bonded OH group which is also supported by absorption band at 2740 cm^{-1}. The absorption in the 2940 cm^{-1} was comparatively strong in all the plantations indicating the presence of large amount of C-H stretch. The 1725 cm^{-1} band due to C=0 of COOH and C=0 of ketonic carbonyl (Schnitzer 1965, Wagner and Stevenson 1965) was relatively strong in intensity in all the cases. A medium absorption band in Acacia and natural forest and stronger band in Eucalyptus at 1695 cm^{-1} indicate COOH vibrations. Stronger absorption band in Acacia and natural forest compared to Eucalyptus at 1630 cm^{-1}

Fig. 38 IR Spectra of Humic Acid

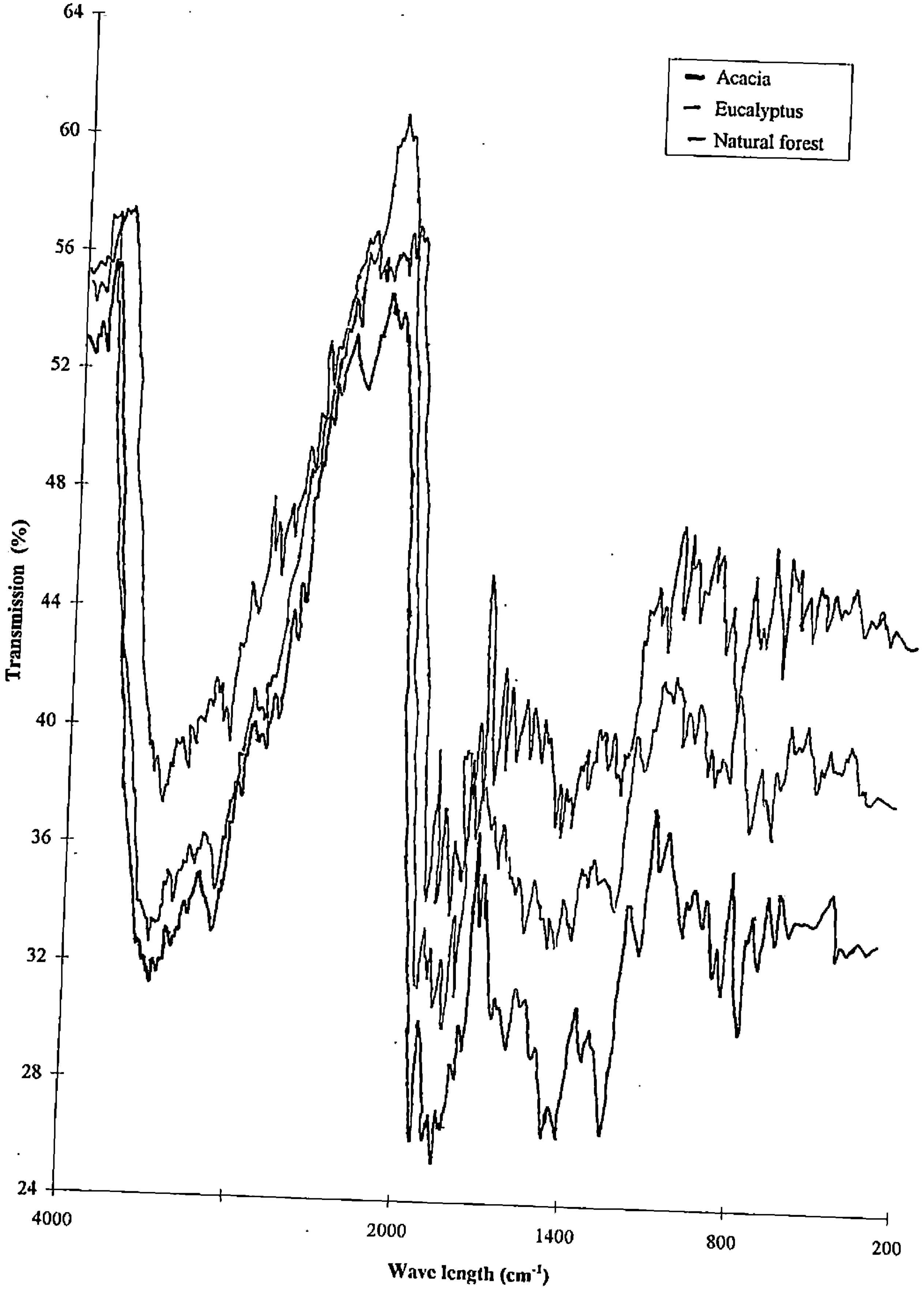
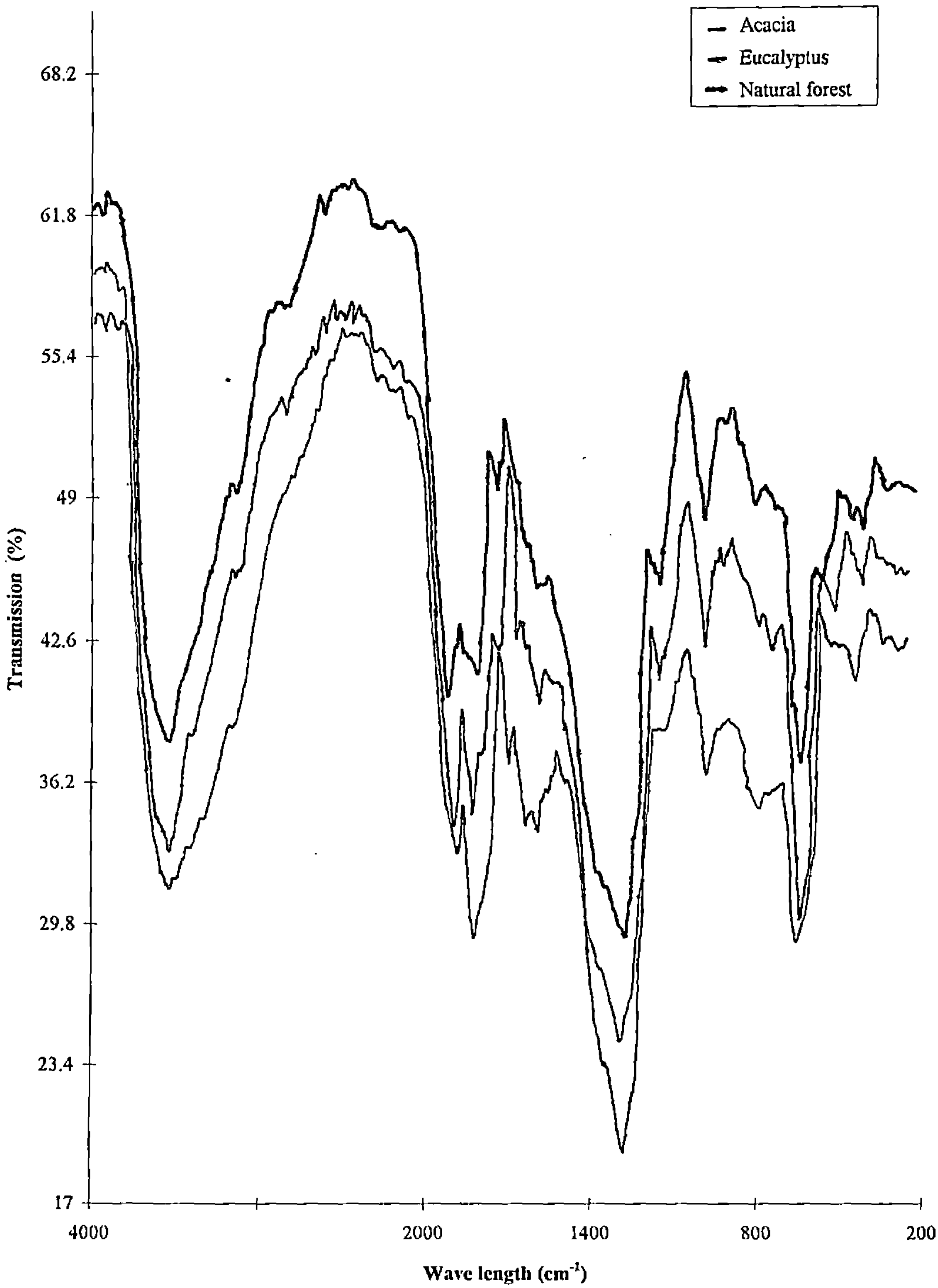


Fig. 39 IR Spectra of Fulvic Acid



indicate the richness of aromatic C=C, hydrogen banded C = 0, double bond conjugated with carboxyl and COO^- vibrations. The absorption band at 1444 cm^{-1} due to C-H stretch of methyl group is weaker in Acacia and natural forest and medium in Eucalyptus. Salt of COOH is high in Acacia and low in natural forest and Eucalyptus indicated by the stronger absorption bond at 1390cm^{-1}. The absorption bond at 1230 cm^{-1} is medium in all the plantation and is due to C-O ester linkage and phenolic C-OH group. C-CH3 vibration is stronger in Acacia and natural forest and weaker in Eucalyptus as shown by the absorption band at 1035 cm^{-}.

The IR spectra of fulvic acid of Acacia, Eucalyptus and natural forest is given in Fig.39. It can be inferred that the absorption band of fulvic acid is almost similar to humic acid with some deviations. The strong absorption band at 1725 cm^{-1} in fulvic acid by all the plantations showed the predominance of COOH group. The absorption band at 1630 cm^{-1} was strong in Acacia and Eucalyptus and stronger than that of 1725 cm^{-1} in natural forest attributed to very high quinon content in fulvic acid of natural forest (Mathur 1972). The stronger and broad absorption in 1100 cm^{-1} in all the cases are assigned to C-O streching of poly saccharide or poly saccharide like substances (Stevenson and Gho 1972). IR spectra of humic material studied revealed the richness of functional groups in natural forest compared to plantation soils.

4.9.3.2.4 Thermal analysis

The DTA and TG curve of HA separated from Acacia, Eucalyptus and natural forest are given in Fig. 40 and 41). The DTA curve exhibited a small endotherm at 70°C and one prominent exotherm between 478-485°C. The exotherm peak in Eucalyptus was broader than that of Acacia and natural forest. Exothermic peaks in the 460-530°C range have been reported by Michel and Birnie (1970) for peat humic acid. A strong exothermic reaction at 415°C for humic acid also reported by Tan (1978). The DTA curve of humic acids obtained in the present study is similar to the reports of Chen *et al*. 1978.

The TG curve of humic acid showed that the weight loss on heating upto 500°C was maximum for natural forest (80.1%) followed by Acacia (79.18%) and Eucalyptus. After 500°C the weight remained the same upto 700 °C in all the materials studied.

The DTA and TG curves of fulvic acid separated from various plantations are given in (Fig. 42 & 43). There is one peak between 61-81°C and two prominent exotherms between 313.4-358°C and 412-478°C. These two peaks resembled that of purified FA (Kodama and Schnitzar (1970) Chen *et al*. (1978). In the case of fulvic acid separated from natural forest, the 1st exotherm was very weak and 2nd exotherm was very sharp.

Fig. 40 DTA Curve of Humic Acid

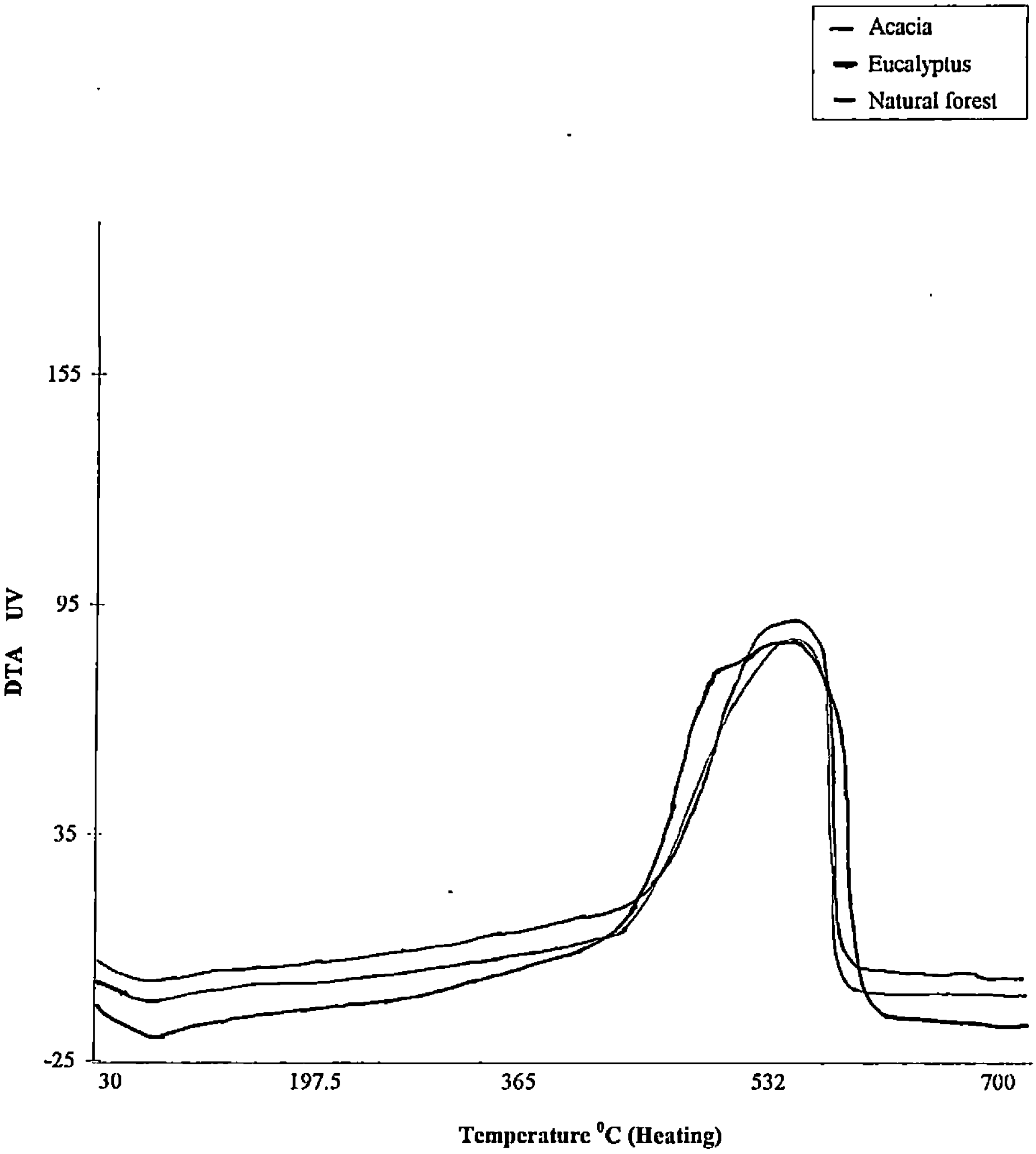


Fig. 41 TGA Curve of Humic Acid

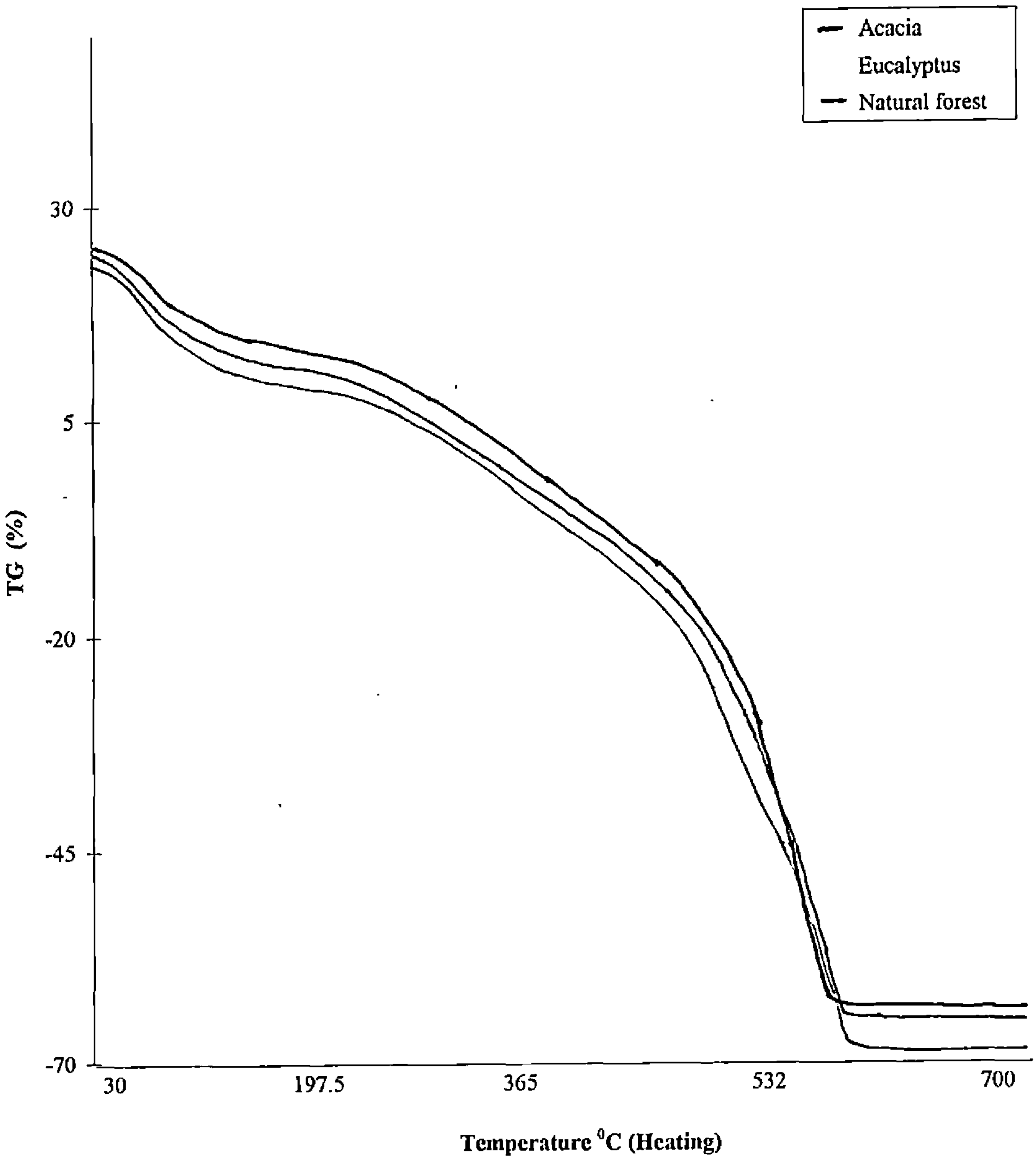


Fig. 42 DTA Curve of Fulvic Acid

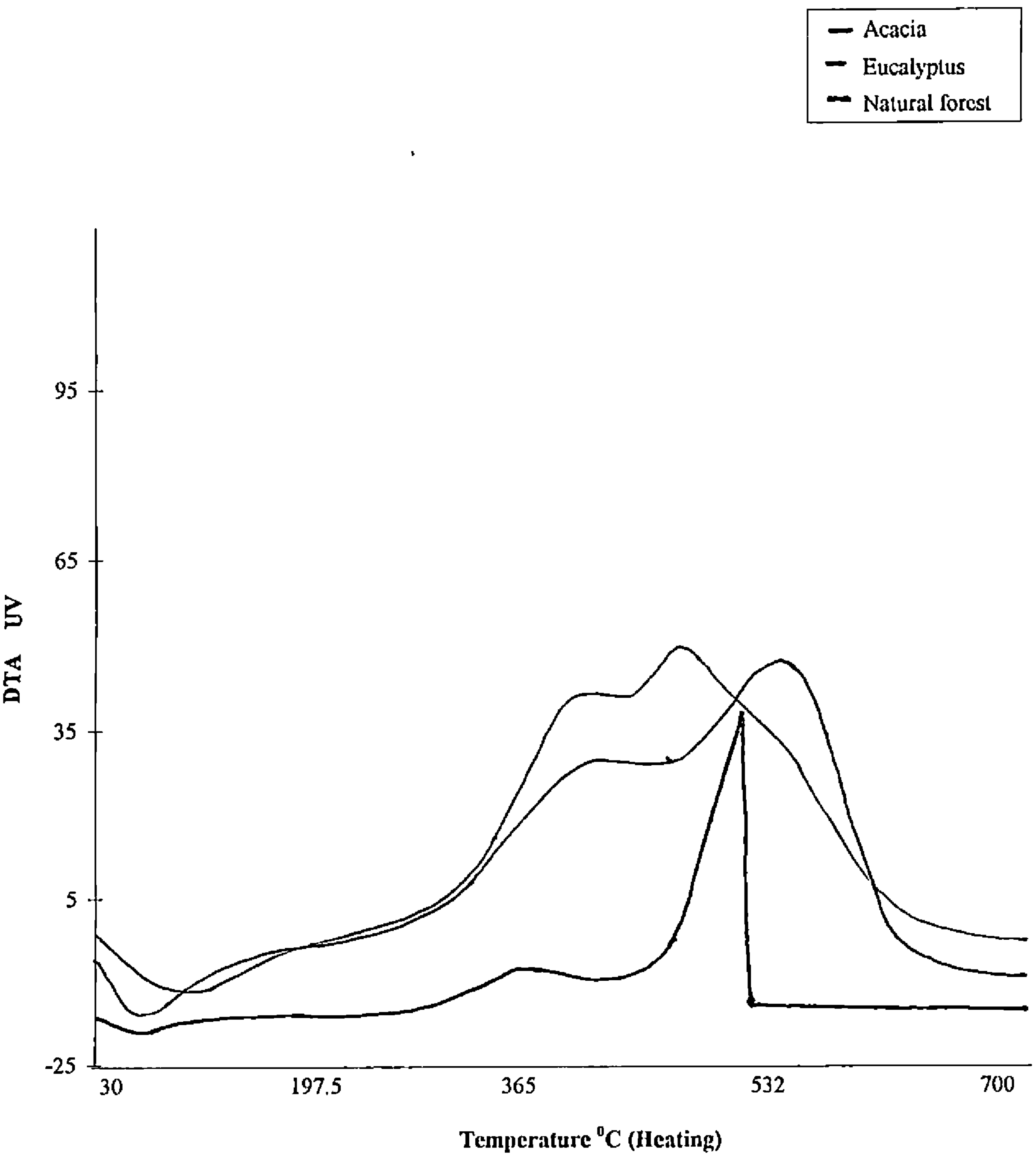
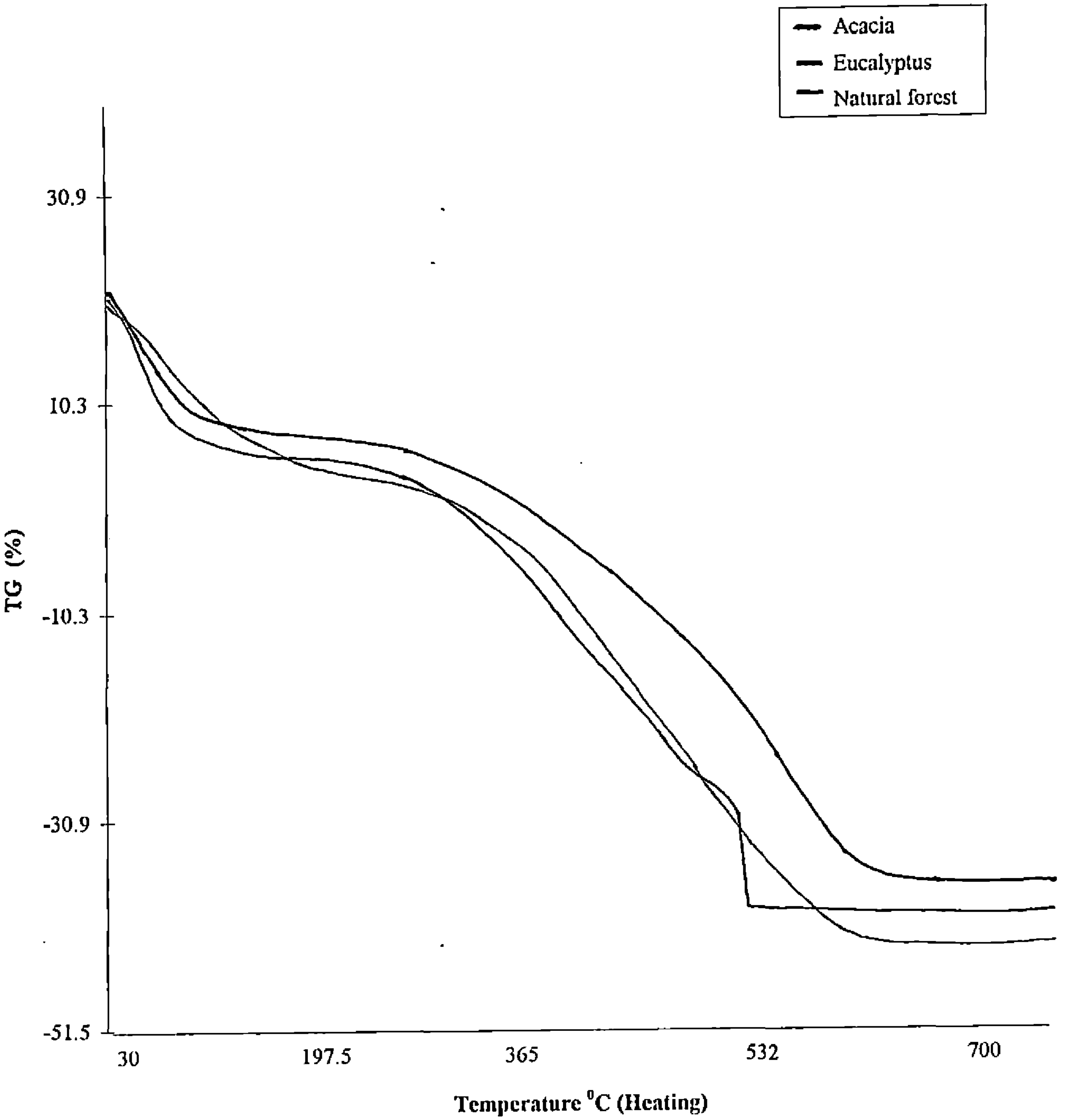


Fig. 43 TGA Curve of Fulvic Acid



The TG curve of fulvic acid showed that upto 560°C there was 45.48 and 47.26% loss in weight in Acacia and Eucalyptus respectively. In the case of natural forest fulvic acid, initial weight loss was 45.87 percentage upto 440°C and then the material remained the same. According to Schintzer and Kodama 1972, thermal stability of humic material depends on the cations involved in the formation of metal humic acid complex. Monovalent cations yield thermal stable complex whereas a trivalant cation cause severe strain in the molecular structure rendering it less stable against heat. Low thermal stability of FA separated from natural forest may be due to the above reason.

SUMMARY AND CONCLUSION

5. SUMMARY AND CONCLUSION

The investigation entitled "Leaf litter dynamics in Acacia and Eucalyptus plantations" was taken up at the College of Agriculture, Vellayani, during 1994-97. The study included a field experiment as well as laboratory analysis. One hectare each of moist deciduous natural forest, Eucalyptus and Acacia plantation coming under the Kulathupuzha range of Kerala Forest Department was selected for the study. Standard litter trap and litter bag technique was used to quantify the leaf litter production, litter decomposition, nutrient release characteristics and associated changes on the physico-chemical and biological properties of the soil. Fresh leaf and leaf litter samples were subjected to detailed chemical and biochemical analysis. Soil profiles excavated from various plantations were analysed for physico-chemical characteristics. The organic matter separated from surface samples was fractionated and analysed. Fresh leaf, leaf litter and soil extracts of various plantations were studied for their allelopathic effects using rice and cowpea as test crops.

Salient conclusions from the investigation are summarised below.

(1) Annual litter fall was highest in Acacia plantation followed by natural forest and Eucalyptus. Maximum litter fall was observed in November and minimum during May.

Litter fall in Acacia and natural forest was unimodal while Eucalyptus followed a bimodal pattern.

(2) Among the plantations compared, the Acacia leaf contained the highest quantity of nitrogen, magnesium, sulphur, iron, copper and zinc. Phosphorus, calcium and manganese content were highest in Eucalyptus. In terms of nutrient status the natural forest leaf litter was inferior to plantations. Decrease in concentration of N, P, K, Mg and S and increase in concentration of Ca; Fe, Mn, Cu and Zn in leaf litter as compared to fresh leaves was noticed in all the plantations and natural forest studied.

(3) Water soluble components were highest while polyphenol, lignin and cellulose were lowest in the litter from natural forest samples. Water soluble components decreased where as polyphenol, lignin and cellulose increased with age of the leaf in all the samples.

(4) Weight loss during leaf litter decomposition was highest in natural forest and lowest in Eucalyptus.

(5) Nutrient release characteristics of decomposing leaf litter showed that as the decomposition proceeded, the percentage/ppm of nutrients in leaf litter increased whereas the absolute quantity of all the nutrients decreased from litter bags of all the plantations. Changes in nutrient content were highest in natural forest and lowest in Eucalyptus.

(6) pH and organic carbon content of soil below the litter layer significantly increased with progress in the decomposition of leaf litter in all the plantations.

(7) Due to one year decomposition of the leaf litter, significant increase in available N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn of soils below the litter bags was observed and in general the increase in soil nutrient content was high in natural forest than the plantations.

(8) Significant changes in the physical properties like water holding capacity, porosity and bulk density of soil below the litter bag were observed due to leaf litter decomposition in all the plantations and natural forest.

(9) Earthworm and nematode population in natural forest was high while in Eucalyptus soil their population remained the lowest, throughout the period of study.

(10) Microbial activity associated with litter production was highest in natural forest and lowest in Eucalyptus during the period of decomposition. Initially there was a rapid increase in bacteria and fungi while actinomycetes increased only during the later stages of decomposition in both the plantations.

(11) Soil profile samples of Acacia and Eucalyptus plantations recorded high coarse sand and low clay content compared to natural forest.

(12) Profile samples of plantations soils indicated that changes in physical properties were brought about by the plantation activity of Acacia and Eucalyptus.

(13) Available moisture content of Eucalyptus soil was significantly lower than that of Acacia and natural forest soil throughout the profile.

(14) Soil pH, organic carbon, CEC and ECEC were significantly lower in plantation soil profile compared to natural forest. Deleterious effect of plantation activity were more severe in Eucalyptus compared to Acacia planations.

(15) Exchange acidity of plantation soils was significantly higher than that of adjacent natural forest.

(16) Profile samples of plantation soils contained low amount of exchangeable cations, available P, S and micronutrients compared to adjacent natural forest.

(17) Nitrate nitrogen in Acacia soil was higher than Eucalyptus and natural forest and ammoniacal nitrogen content was lowest in profile samples of Eucalyptus plantations.

(18) Low total N, P, K content of soil profile samples were observed in Eucalyptus plantation. C:N ratio was highest in Eucalyptus and lowest in natural forest. Significant reduction in total N, P, K and C:N ratio with depth were observed in all the soils studied.

(19) Proximate composition of soil organic matter under Eucalyptus plantations indicated the low rate of decomposition. High contents of components like fat, waxes, resin, free sugar and cellulose and low content of protein and lignin + humus were observed in Eucalyptus soils. The proximate composition of Acacia and natural forest were comparable.

(20) HA/FA ratio less than unity was observed in humus samples of Eucalyptus soils and contribution of HA+FA to total humus was lowest in Eucalyptus and highest in natural forest.

(21) Functional group content of fulvic acid was much higher than humic acid in all the plantations. Total acidity, COOH group and phenolic - OH groups of humic acid and fulvic acid of natural forest were higher than the plantation soils.

(22) Spectral analysis of, the visible range (E4/E6 ratio) had the lowest value for natural forest and UV spectral characteristics of humic acid and fulvic acid separated from organic matter were uniform with peak at 225 nm. in all the plantations.

(23) IR spectra of humic acid separated from various plantations were similar but slightly differed with the IR spectra of fulvic acid.

(24) Results of thermal analysis of humic acid and fulvic acid separated from various plantations are more or less similar.

(25) Fresh as well as leaf litter extracts of Acacia, Eucalyptus, and natural forest severely inhibited the germination and growth of rice and cowpea. The inhibition was severe for Eucalyptus followed by Acacia and natural forest. Allelopathic interaction increased with increase in concentration of the leaf leachate.

(26) Allelopathic effect of soil extract also followed the same effects as leaf extract. Soil extracts severely inhibited the germination and growth of rice and cowpea and it was most severe in the case of Eucalyptus.

The litter production in plantations are not inferior to a natural forest and nutrient addition through litterfall was also high in plantations, especially in Acacia than natural forest. But the rate of decomposition and nutrient release was significantly low in plantations which resulted in low nutrient status and inferior physico-chemical properties. Leaf litters of Acacia and Eucalyptus plantations also contained allelopathic compounds which inhibited the understory, weed growth, soil micro-organisms and macrofauna. Organic matter under plantations also exhibited low humification and low degree of condensation evident from chemical and spectral analysis.

Future line of work

(1) Comparative study on the impact of plantations on the soil environment may be undertaken with indigeneous tree

species against the Eucalyptus and Acacia with uniform age so as to reorient the social forestry programmes with tree species having least deleterious effect on the ecosystem.

(2) Along with the dry matter loss, the changes in specific biochemical constituents like cellulose, hemicellulose and lignin may be investigated so as to study their contribution to total mass loss on decomposition.

(3) Litter decomposition and nutrient release from decomposing leaf litter may be studied under widely differing climatic and soil condition to understand their influence on litter decomposition and nutrient cycling.

(4) Allelopathic study must be carried out using other social forestry plant species and attempts made to identify the allelochemicals, involved.

(5) Humic fractions separated from various plantations must be subjected to detailed analysis so as to elucidate the structural complexity.

(6) The effect of the root biomass and rhizosphere impact on nutrient dynamics and physico chemical parameters of the soil has to be studied.

(7) Monitoring nutrient cycling and nutrient and moisture depletion from soil profiles in monoculture system to test relative sustainability on long term basis, as compared to the natural forests.

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APPENDIX

APPENDIX - I

Meteorological data of the experimental area

Month	Rainfall* (mm)	Min. temp. (°C)**	Max. temp. (°C)**	RH (%)**
June 1995	351	14.5	30.0	78.2
July	302	14.5	29.3	78.4
August	259	14.3	30.6	78.3
September	192	15.6	31.6	79.1
October	329	16.4	33.2	78.2
November	246	13.4	31.8	80.3
December	-	9.8	34.4	73.8
January 96	27	12.4	34.3	75.0
February	10	12.5	35.2	68.4
March	84	12.0	36.0	67.1
April	146	13.7	32.9	71.4
May	126	16.2	34.7	73.0

* Monthly total

** Monthly average

LEAF LITTER DYNAMICS IN ACACIA AND EUCALYPTUS PLANTATIONS

By

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ABSTRACT OF THE THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT

FOR THE DEGREE

DOCTOR OF PHILOSOPHY

FACULTY OF AGRICULTURE

KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE

VELLAYANI

THIRUVANANTHAPURAM

1997

ABSTRACT

An investigation entitled "Leaf litter dynamics in Acacia and Eucalyptus plantations" was undertaken to study the leaf litter production, litter decomposition and nutrient release characteristics, and impact of Eucalyptus and Acacia monoculture plantations on the soil physico-chemical and biological characteristics during 1994-97. One hactare each of *Acacia auriculiformis*, *Eucalyptus tereticornis* and a moist deciduous forest coming under the Kulathupuzha range of Kerala Forest Department were selected for the study. Field experiment were conducted to determine the leaf litter production and decompostion characteristics of plantation and natural forest.

Leaf litter collected at monthly intervals showed that highest litter production was in Acacia (9.4 t ha^{-1} $year^{-1}$) followed by natural forest (6.67 t ha^{-1} $year^{-1}$) and Eucalyptus (4.68 t ha^{-1} $year^{-1}$). Pattern of litter production was unimodal in Acacia and natural forest while in Eucalyptus it was bimodal.

Chemical analysis of litter samples of plantations and natural forest revealed that with respect to nutrient content fresh and leaf litter of Acacia and Eucalyptus is superior to natural forest whereas litter quality in terms of water soluble components, polyphenols, lignin and cellulose were superior in natural forest.

Annual dry matter loss of leaf litter by decomposition followed the order natural forest > Acacia > Eucalyptus. Nutrient release pattern of major and micro nutrients were also worked out for the leaf litter during the process of decomposition and natural forest litter recorded the highest mobility for all the nutrients on decomposition.

Improvement in soil physico-chemical properties were noticed due to leaf litter decomposition in the monoculture plantation and natural forest. Biological activity in terms of earthworm and nematode under monoculture plantation was significantly lower than that of adjacent natural forest. Microbial content of soil below the litter bag during different months of decomposition were low in Eucalyptus and Acacia.

Chemical analysis of the profile samples of various plantations revealed lower nutrient status in respect of major and micronutrients compared to natural forest. The physical properties of the soil also recorded as unfavourable change in the monoculture plantations as compared to the adjacent natural forest.

Proximate analysis of soil organic matter and humus characterisation of the soil organic matter separated from various plantations indicated a low rate of humification and condensation under Eucalyptus. Low humic acid and fulvic acid content in humus and dominance of fulvic acid over humic acid was also noticed in Eucalyptus plantations.

Functional group analysis of humic acid and fulvic acid showed that humic material separated from natural forest contained higher quantity of total acidity, contributed by COOH and phenolic group compared to plantation soils. UV, IR, DTA and TGA analysis of humic acid and fulvic acid separated from various plantations showed no variation with respect to natural forest.

Allelopathic effect of fresh leaf and leaf litter extract of various plantations on the germination and growth of rice and cowpea followed the order Eucalyptus > Acacia > natural forest and as the concentration decreased from 1 : 2 to 1 : 10, the allelopathic inhibition also decreased significantly. Allelopathic effect of soil extract also followed the order Eucalyptus > Acacia > natural forest.

Thus it can computed that though the leaf litter production and litter quality of monoculture plantations are comparable with that of natural forest, leaf litter decomposition and nutrient released were significantly lower than that of natural forest. Soil physico-chemical properties, soil fertility and biological activities were also adversely affected by monoculture plantations.