NUTRIENT RECYCLING UNDER MONOCULTURE CONDITIONS IN THE TROPICAL FOREST ECOSYSTEMS

BY

S. PREMA KUMARI

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DECLARATION

I hereby declare that this thesis entitled "Nutrient Recycling under Monoculture Conditions in the Tropical Forest Ecosystems" 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 title of any other University or Society.

S. PREMAKUMARI

Vellayani,
30-10-87

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Certified that this thesis entitled "Nutrient Recycling under Monoculture Conditions in the Tropical Forest Ecosystems" is a record of research work done independently by Smt. S.Premakumari under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Alice Abraham

(ALICE ABRAHAM)
Chairman,
Advisory Committee,
Professor of Soil Science
and Agricultural Chemistry.

Vellayani,
30-10-87

APPROVED BY

Chairman :

Dr. Alice Abraham

Members :

1. Dr. R.S. Aiyer 3.12.87

2. Shri. M. Abdul Hameed 5/XII/87

3. Dr. P. Saraswathy

External Examiner:

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INTRODUCTION

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In natural forests and man made protected plantations recycling of nutrients is an important aspect. The nutrient recycling in forest ecosystem comprises of cyclic circulation of nutrients between forest sites and plants through the processes of nutrient uptake, retention and restitution. Considerable amounts of nutrients are returned to the soil periodically through litter fall of leaves, branches, bark and fruits. The dead vegetation on the floor decomposes liberating minerals for reuse by the growing stand. The nutrient recycling in the forest ecosystem is thus a rather complex system of geological, chemical and biological cycling that the soil organic matter and nutrients are lost and maintained ensuring continuous productivity of the soil.

Investigators on forest soils have long recognised the profound influence of soil physical properties on the growth and distribution of crops. But the importance of soil chemical properties of forests was recognised and studied only during the last two or three decades. It has been widely accepted that there is a strong relationship between the important physico-chemical properties of a soil and the major trees and plants inhabiting the area.

In the tropical forests of Kerala where plantations of eucalyptus, teak and rubber are grown for continuously long periods of time after the denudation of natural forests, the soil properties are liable to be altered by these vegetation inspite of the similarity in parent material and other factors of soil formation. A study on the physico-chemical properties of these soils will reveal how each tree type has altered these characters.

The Forest Research Institute in Peechi, Kerala has taken pioneer steps to systematically investigate the characteristics of the soils in Nilambur forests. Thomas (1955) and Thomas (1964) have made some preliminary studies on the forest soils of Kerala and came to the conclusion that forests are the cause rather than the effects of fertility. The investigations conducted in the Nilambur forest area (Alexander et al. 1981) have revealed that with the clear felling of natural or plantation forests and continuous teak cropping, significant changes in soil properties may occur. Such changes should be of concern as they may have effects on the succeeding teak plantation.

However, not much study has been conducted on the subject of nutrient recycling in the different plantations in Kerala forests.

In the light of these considerations, the present investigation has been undertaken with the following main objectives.

1. To determine the extent of nutrient recycling in eucalyptus, teak and rubber plantations.

2. To find out the influence of these plantations on the morphological and physico-chemical properties of the tropical forest soils.

3. To study the distribution of nutrients in the different horizons of the soil profiles of the plantations in comparison with the adjacent natural forests.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The extent of nutrient recycling under forest ecosystems is decided by the type of vegetation, the amount of litter available for recirculation, its nutrient status etc. which in turn may affect the characteristics of the forest soils. A brief review of the more important literature on these aspects is presented here.

I. Amount of litter

The amount of litter that accumulates in a forest ecosystem is mainly dependent on the type of vegetation. It was reported to be about 246.3 lbs/acre of oven dry material from seven common coniferous species of North East United States by Robert and Chandler (1943). Seth et al. (1963) from a study on nutrient cycle and return of nutrients in plantations at New forest in Forest Research Institute, Dehradun reported that Tectona grandis produced about 5328.81 kg, Shorea robusta 5018.04 kg, Pinus roxburghii 7039.92 kg, Araucaria cunninghamii

5904.35 kg and Dendrocalamus strichus 3209.28 kg of litter/ha/year.

The annual litter production was estimated to be about 4 tons/ha in a 65 year old Pinus halepensis forest (Rapp, 1967) and 4062.5 kg/ha in Quercus ilex and Quercus coccifera Spp. (Rapp and Lossaint, 1967).

In loblolly pine plantation ecosystem, during the initial 20 years of development, the total biomass increased from 10 to about 90 tons (Switzer and Nelson, 1972).

Belize et al. (1981) have estimated the total above ground biomass in a 45 year old seasonally dry tropical hardwood forest to be approximately 56,000 kg/ha oven dry weight.

Perala and Alban (1982) ranked the relative species in above ground tree biomass as Pinus resinosa > Populus > Picea > Pinus banksiana.

The annual litter production was reported to be about 7799 kg/ha and 4884 kg/ha in loblolly and long Pine in Coastal South Carolina (Gresham, 1982) and only 5.5 tons/ha annually in the 50 year old humid tropical forest of Meghalaya in India (Jasbir Singh and Ramakrishnan, 1982).

Maghembe et al. (1983) showed that in a 6 year old Prosopis juliflora plantation at Kenya the total biomass contribution was 216 tons/ha.

Venkataraman et al. (1983) have reported that Eucalyptus globulus (bluegum) in Nilgiris in Tamil Nadu add annually 1935 kg of litter/ha. According to them the maximum leaf fall (223 kg/ha) was during September when the plant begins to flower in Nilgiris, and the leaf fall in bluegum was observed more during winter months when minimum temperature values were low.

In a comparative study of the annual litter production in four prominent Coniferous species Singh et al. (1984) have observed that annual litter production was maximum in Picea smithiana (10.91 kg/ha/yr) followed by Cedrus deodara (9.12 kg) Abies Pindrow (6.89 kg) and Pinus wallichiana (2.38 kg).

A comparison of the annual litter production in different parts of India made by Durani et al. (1985) indicates that sal and teak produce 5.3 ton ha^{-1} yr^{-1} of litter and the deciduous forests of Varanasi and Udaipur produce 1.01 - 6.21 ton ha^{-1} yr^{-1} and 4.04 ton ha^{-1} yr^{-1} respectively.

Ramprasad and Mishra (1985) in a study of the litter productivity of dry deciduous teak forest stand of Sagar in Madhya Pradesh have revealed that teak alone produce more than 1/3rd of the total litter production of the entire stand. Teak which showed a normal distribution of tree density contributed the maximum litter production partly due to greater density and larger size of leaves. Higher density values of trees showed higher values for their leaf litter. Other factors which influence leaf litter frequency are weight, size, shape and maturity of leaves.

In 4 to 14 year old Pinus patula plantation of Darjeeling hills, Bhartari (1986) observed that the total standing biomass ranged from 31.12 to

125.97 t/ha of which an average 84.7% was contributed by the above ground portion.

In eucalyptus hybrid plantation of five years stand, George (1986) observed that the total biomass (above ground + below ground) was 68,344 kg/ha/a and the productivity of non-photosynthetic biomass was 12,935 kg/ha/a.

Pande and Sharma (1986) have reported that leaf fall in plantations was in the order of sal > eucalyptus > teak > pine while total litter was in the order of sal > pine > eucalyptus > teak.

<u>Nutrient composition of forest litter</u>

Just as the amount of litter fall is found to vary from plantation to plantation, the nutrient composition of forest floor and freshly fallen litter also show large variations. Such variations are extreme even within closely related species of plantations indicating the direct and indirect influence of soil and climatic factors in deciding the nutrient composition of the litter.

C/N ratios exceeding 20:1 are very common in forest litter. It may range from 57:1 in a stand of Douglas fir (Issac and Hopkins, 1937) to 10:1 in long Pine soils (Heyward et al. 1936).

Seth et al. (1963) have described the annual return of nutrients through leaf fall in a mixed plantation at New forest in Dehradun. The figures in percent range from 0.56 to 1.05 for N, 0.15 to 0.28 for P, 0.42 to 0.56 for K, 0.66 to 2.85 for Ca and 0.08 to 0.29 for Mg. The mineral constituents of the fresh leaves also showed such variation, eventhough their content was much higher than the corresponding figures for the freshly fallen leaves.

Rapp (1967) has estimated the annual nutrient contribution through litter fall by Quercus species, as 33 kg N, 41 kg Ca, 5 kg each of P, K and Mg and 1 kg of Na.

Voigt and Steucek (1969) showed that an average annual nitrogen accretion of about 85 kg/ha takes place in an Alder stand.

Ashton (1975) has reported that the litter in Eucalyptus regrans forest return the maximum amount of various nutrient elements.

The nutrients in kg returned through leaf litter of eucalyptus hybrid plantation in Coimbatore, Tamil Nadu have been estimated by George (1979) as 150 for K, 40.2 for Ca, 29.8 for N, 5 for Mg and 1.6 for P.

Wells and Jorgensen (1975) have shown that the forest floor of a 16 year old loblolly Pine plantation produced quantities of N and P approximately equal to that of the tree component.

According to Protector et al. (1983) the element concentration in the litter fall differed greatly between each forest types. The concentration of all elements except calcium from litter fall was below or within the ranges reported for other tropical forests.

In a comparative study of the nutrient return between eucalyptus and shola in Nilgiris in Tamil Nadu, Venketaraman et al. (1983) have reported that leaf litter of shola contained a higher percentage of nutrients especially N, P, Ca and organic matter than that of eucalyptus. They also 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 - 1.10%), K (0.14 to 0.32%) and Mg (0.07 to 0.19%).

Singh et al. (1984) have reported that different species of Conifers in Himachal Pradesh contained calcium as the most important base in all the species while sodium as the least. The status of nutrients in the litter was in the decreasing order of Ca, N, P and Na. The litter of conifers release more N and P than eucalyptus. They are also of the view that P concentration in litter will be significantly higher in Alpine forests consisting of Eucalyptus panciflora and Eucalyptus delegatensis.

Bhartari (1986) based on his studies of the Pinus patula plantation of Darjeeling hills has reported a higher concentration of all nutrients in needle and least in wood. The concentration of the nutrients in litter decreases as N > Ca > K > Mg > P.

In eucalyptus hybrid plantation of East Dehradun division in Uttar Pradesh, George (1986) has observed that the nutrient content in leaves was of the order of 41, 5, 37, 6 and 9 kg/ha/yr of N, P, K, Ca and Mg respectively.

According to Kerstinhuss-Danell (1986) most of the N released from Alnus incana was from N rich leaf and shoot litter.

Seasonal or climatic variation

Reports on the variation that can arise due to seasonal or climatic changes on the amount and nutrient composition of the forest litter are also available.

Mirchandani (1941) has reported that the teak plantation shed all foliage early in dry weather and for nearly six or seven months, the forest floor remain exposed to burning sun and wind.

According to Marion (1979), the biomass production in mature forests is highest in the tropical forest, intermediate in the temperate forest and lowest in the boreal forests.

From a study on leaf fall and forest floor characters in loblolly pine plantation in South Carolina, Van Lear and Goebel (1976) showed that the peak period of leaf fall occurred from October through December.

James et al. (1977) from a study on the biomass and nutrient accumulation in a cottonwood plantation showed that 76% of the above ground biomass was accumulated during August-September. Foliar N, P, and K concentration was highest in early summer and steadily decreased until leaf fall in November. The Ca and Mg content in the foliage increased throughout summer to a maximum at the time of leaf fall in November. They have also found that of the total quantity of 26% N, 33% P, 28% K, 62% Ca and 51% Mg fell with abscised leaves in September and 61% N and 53% P were translocated to other tissues prior to leaf fall.

Daniere et al. (1986) studied the seasonal litter fall in alder forest (Alnus incana) at an altitude of 1450 M near cold'ornon and estimated the total return of combined N by annual litter fall at 72 kg/ha for the thicket stage and 42.5 kg/ha for the forest stage. At the forest stage N production attained 50 kg/ha.

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 months of March-April. Eucalyptus recorded a bimodel pattern of leaf fall, one peak (22%) shown during October-November and the other (18.8%) during April-May.

II. <u>Nutrient recycling</u>

The litter fall in various forest ecosystems is seen to contribute appreciable amounts of nutrients to be recycled.

Robert and Chendler (1943) have reported that the average total nutrients returned annually to an acre of ground were in the decreasing order as Ca 26.5, N 23.6, K 6.5, Mg 4.5 and P 1.8 in lbs/acre.

Remezov (1959) has shown that as a plantation matures, the rate of nutrient uptake decreases and is accompanied by a corresponding reduction in litter fall.

According to Weetman (1962), N became the limiting factor for tree growth in forest ecosystem because it is largely immobilized in the materials accumulated on the forest floor.

In a comparative study of five plantations (sal, teak, pinus, araucaria and dendrocalamus) Seth et al. (1963) have observed that the greatest uptake of Ca is in sal species. It was also found that in hardwood like sal and teak, absorption of 8-10% of total K and P result in a depletion of the soil to the extent of 200 and 100 kg of K and P respectively.

Misra (1969) studied the nutrient cycling in a monsoon forest and reported that the major portion of the total uptake of various nutrients was returned to the soil in the form of fallen leaves and twigs.

From a study on N mineralization and uptake from Douglas fir forest floor, Youngberg (1978) showed that the net mobilization or the uptake of N by two successive crops of fir seedlings ranged from 0.34 to 9.89% of the total amount of organic matter returned to the forest floor.

Wells and Jorgensen (1975) studied the nutrient changes in decomposing loblolly pine forest floor and found that in the older stand the forest floor release accounted for 86, 104, 73, 72 and 71% respectively of N, P, K, Ca and Mg indicating that as the stand mature, and the canopy closure is reached the gross annual uptake of nutrients tended to be relatively constant.

Van Lear and Goebel (1976) recognised that in loblolly pine plantation in South Carolina, the nutrients stored in the forest floor components in the youngest stand ranged from 171 kg/ha for N and

16 kg for K. Approximately 16.3, 2.2, 4.4, 1.8 and 4.8 kg/ha of N, P, K, Ca and Mg respectively were returned in annual leaf fall. The forest floor has a differential ability to store nutrients. Concentration of N and P increases as leaf litter decomposes probably because of slow mineralization rates and rapid immobilization by microorganism.

According to Turner (1982), the uptake of N, P, K and Mg increased and Ca uptake remained stable as the stand matured while the proportion of nutrient uptake fulfilled by mass flow tended to increase with age.

In a study conducted by Vitousek (1982) on nutrient cycling and nutrient use efficiency, it has been reported that the forest ecosystem systematically produced more litter fall drymass per unit of N in sites with less above ground N circulation. This pattern was observed both within and among tropical, temperate and deciduous forests. The difference among sites was related to difference in soil N availability pattern and N use for root and wood production probably reinforced by the litter fall results. The pattern of N circulation and N use efficiency in forests has important implications for ecosystem level properties including the development of low N availability in soil.

During a study on biomass and nutrient assimilation of intensively cultured black locust on Eastern kentucky mine soil, Creighton et al. (1983) have pointed out that the N, P & K assimilated in the entire above ground portion of the Rohinia pseudo acacia stands amounted to 12.2, 63.3 and 35.7% of the sites reserve of these elements in the top 15 cm of the soil.

Venketaraman et al. (1983) have reported that the recycling of nutrients in the Eucalyptus globulus plantation in Nilgiris in Tamil Nadu keeps the land under high fertility status with a rich top soil and dense vegetation.

According to Adams and Attiwill (1985), litter fall is the major pathway for return of

N, P, Ca and usually Mg to the soil. In general, nutrient turnover was related to the rate of organic matter turnover.

Frederick et al. (1985) have studied the drymatter production and nutrient content of five year old Eucalyptus nitens growing on soil mounds in Newzealand and showed that the stands have a total drymatter accumulation of 72.6 t/ha at an annual rate of 14.5 t/ha. Nutrient accumulation was variable, the greatest accumulation of N and P being in foliage and live branches, where relative to stem material there was a higher nutrient concentration.

Bhartari (1986) has shown that in Pinus patula plantation, out of the total uptake of nutrients 49% N, 23% P, 35% K, 39% Ca and 46% of Mg were returned to the soil through litter fall.

Charles et al. (1986) have reported that nutrient availability in some northern California annual range soils was at a minimum in summer and early autumn months and month to month variation was lowest during the annual period of drought.

From a study on the nutrient uptake and recycling in eucalyptus hybrid plantation, George (1986) has shown an annual uptake of 69.6 kg N, 11 kg P, 59.3 kg K, 228.4 kg Ca and 23.8 kg of Mg. Out of this 54, 83.6, 52.3, 76.9 and 69.7% respectively of N, P, K, Ca and Mg were retained in the non-photosynthetic biomass components and the rest returned to the soil. Thus, the maximum retention was found to be for P and Ca eventhough the maximum uptake was for N and Ca.

III. Effect of forest trees on the physico-chemical properties of soils

The physico-chemical properties of forest soils are known to differ in several respects with similar properties of the adjacent non-forest soils. These differences might have arisen out of the specific impact of nutrient recycling characteristic of the forest ecosystem compared to the non-forest ecosystem which is more frequently subjected to disturbances and alterations by human intervention.

a. Physical properties

Engler (1919) has observed a lower porespace for agricultural and pastural soils compared to that of adjacent forest soils. Newland and Beume (1922) showed that eventhough no direct correlation between the chemical properties of soils and the growth of teak in Java was noted, some of the physical properties of the soils showed a correlation with the quality of teakwood. A soil with a high WHC and low permeability in the top compared to the lower layers appeared to be conducive for good teak growth. Teak is believed to cause soil deterioration as the plantation becomes old. They observed that the site quality decreased as a result of regular planting with teak after the felling of the old woods.

Champion (1932) has concluded that soil samples from teak plantations and adjacent natural forests did not differ significantly in the distribution of different sized particles and chemical properties. However, the soils under plantations were found to be comparatively much harder due to a greater exposure.

Blanford (1933) has reported that teak cropping leads to serious soil erosion especially due to the removal of undergrowth and soil erosion has been identified as the main form of soil deterioration of teak plantations in Burma.

According to Castens (1933), the soils of teak plantation do not get altered in their composition relative to the natural soils in the surrounding forests.

Davis (1940) believed that laterite rock was neither exposed nor formed consequent to planting of teak.

Laurie and Griffith (1942) have suggested that deterioration of soil occurs hand in hand with the lowering of site quality in teak plantations. According to them, laterization may be one of the factors responsible for soil deterioration.

Griffith and Gupta (1947) showed that there was little change in chemical nature of the soil as a result of continuous teak cropping.

According to Livingston (1949), where the colorado forest and grass lands occur side by side, forest lands were coarse textured soils with a conglomerate substrate while the soils of grassland in the contiguous areas were fine textured.

While studying the effects of teak plantation on soils of evergreen forest in East Bengal, Ghani (1951) noted that the soils in these forests were in a delicate balance with the opposing forces of laterisation and podzolization.

According to Mc Donald (1955), there was no change in the physical properties of soil as a result of clear felling. The soils from forest and the cleared area showed no difference in their moisture content.

From a comparative study of the physico-chemical properties of soils under cultivation and forest cover, Pathak et al. (1964) showed that porosity, WHC, moisture and CEC of soils under forest cover were higher than those of the soils under cultivation. The forest soils exhibited more aggregation than cultivated soils.

Robinson et al. (1966) observed no significant difference in physical properties of soils under indigenous forest and under a sixteen year old tree plantation.

Florence (1967) showed that continuous cropping with Pinus radiata in Australia, resulted in an increase in the bulk density of soil.

Yadav (1968) pointed out that soils under different forest vegetation differed considerably in their physical and chemical characteristics.

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

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

It was also observed by Alexander & Thomas (1985) that among the properties of soils under eucalyptus, gravel content was the most and particle density was the least variable factor. Sand, silt and clay contents were highly variable whereas WHC, pore space, bulk density were only intermediate.

b. <u>Chemical properties</u>

Doyne (1935) has shown that the surface soils were generally less acidic than the deeper layers because of the stand of species of trees whose foliage contain a high content of bases.

Issac et al. (1937) have found that the C/N ratio of forest floor materials of Douglas fir stands to be about 57:1 and in the underlying mineral soil to be about 24:1. C/N ratio exceeding 20:1 are very common in forest soils.

Kadambi (1937) reported that teak growing soils were characterised by an adequate supply of calcium.

Griffith and Gupta (1947) have stated that in Nilambur plantation which supported good quality teak, the soils contained a large amount of calcium and magnesium.

Wilson (1949) obtained no significant difference in the humus content of soils under different forest vegetations.

Duchaufour (1950) estimated humus content and its C/N ratio in the A_1 horizon of 42 well aerated forest soils and found that the lowest ratio occurred within the pH range 5 to 7. In the neighbourhood of pH 5, the C/N ratio increased considerably. The total organic matter content of this horizon tended to increase as the C/N ratio increased but remained low in podzols as a result of its downward movement to the illuvial horizon.

Puri and Gupta (1951) have observed that the humus in coniferous forest of Kulu (Himalaya) showed no significant correlation between organic matter, nitrogen and calcium content. Both sodium and calcium increased with increase in organic matter. The amount of organic matter and nitrogen decreased considerably in the lower layers of soil.

According to Duchafour (1953), the destruction of forest cover led to heavy leaching and loss of plant nutrients.

In a study of the teak forests of Madhya Pradesh, Bhatia (1954) obtained a direct correlation between teak growth and soil fertility factors, such as pH, exchange capacity, Ca, Mg and P but no correlation was found for N, organic matter and C/N ratio.

Zaitsev (1956) has found that the N reserve in the top soil was much higher under oak than under spruce plantation.

Nye and Bertheux (1957) have observed more P in forest soils than the Savannah soils. C/P ratio averaged 233 in the forest soils and 247 in the Savannah soils while N/P ratio for forest soils was

21.6 as against 19.5 for the Savannah soils.

Bates and Baker (1960) have observed a greater accumulation of P in the surface soil. Below 2" there was a marked fall in the amount of organic P. Thereafter the total P content was fairly constant down the profile.

Yadav and Pathak (1963) have found that soils of different forests in India exhibited greater variation in the amount of available P ranging from 0.1 to 21 mg/100 g of soil. Their studies have also revealed that a high accumulation of organic matter led to pronounced reduction in P availability. The distribution pattern of P in the profile showed that total P was more in the surface than in the subsoil. But no definite trend with depth was discermable. They also observed that the C/N ratio of forest soils of India varied from 1.1 to 25.4.

Yadav (1963) studied the soil profiles in Chakrata division in Uttar Pradesh and reported that N content varied from 0.013 to 0.427 percent in the forest soils, organic carbon from 0.172 to 8.13 per-cent and the C/N ratio between 1.5 and 25.4. No relation was observed between the depth of profile and C/N ratio. He also found that cation exchange capacity of the soils varied from 9.4 to 44 me/100 g soil. The top A_1 horizon had the highest CEC resulting from an accumulation of humus. Ca was greater in A horizon and decreased markedly in the lower horizons. Mg manifested an erratic behaviour with depth of profile and no definite pattern of distribution with depth was noticed in the case of K.

Pathak et al. (1964), from a study of the physico-chemical properties of soils under cultivation and forest cover showed that the cation exchange capacity was higher for soils under timber while silica-sesqioxide ratio was lower in them.

Thomas (1964) has reported that a higher degree of acidity and more clay content were obtained in soils of moist deciduous forests, while soils supporting evergreen vegetation were generally higher in organic matter and N. The C/N ratio of these soils varied from 2.8 to 20.7. Both carbon and N content decreased with depth down the profile. Organic matter and N were leached to a greater depth in deforested areas compared to natural forests.

According to Florence (1967), continuous cropping with Pinus radiata in Australia has resulted in a decrease in organic matter and N and a consequent depletion of cationic nutrients.

According to Jose (1968), Ca and Mg contents were highest in the surface soils and these elements decreased with depth in most of the profiles under teak. In all the profiles, the maximum amount of K_2O was present in the second layer. The surface soils of natural forests contained higher amount of K, Ca and Mg than teak plantations. Teak plantations were richer in these nutrients in the lower layers alone. The surface soils of natural forests exhibited higher values for C/N ratio and in all profiles, C/N ratio decreased with depth. The surface soil of natural forests were slightly more acidic than those of teak plantation. Relatively higher amounts of P were obtained in the surface layers of forest soil.

Lundgren (1978) showed that the effect of man-made forest on soil properties varied considerably and soils under natural vegetation were always rich in organic matter than those under plantations.

Alexander et al. (1981) have reported relatively higher levels of organic carbon and CEC in the surface horizon of the profiles under Eucalyptus.

Balagopalan and Jose (1982) have pointed out that soils under teak were more acidic than those under mahogany. The content of organic matter decreased with depth and accumulation of organic carbon was more under mahogany vegetation. This was true in the case of total N also. The C/N ratio of the soil was little influenced either by depth or by the type of vegetation. The ratio of the total N to available N increased with increase in depth of profile under both type of vegetations.

Balagopalan and Alexander (1983) showed that organic carbon values in teak plantations at Thora remained close to that of natural forests and teak has not caused any drastic change in the organic carbon content of soils.

Balagopalan and Alexander (1983) have shown that eucalyptus plantation at Kadassery have a relatively lower content of organic carbon than that of natural forests. They have also shown that compared to natural forests, higher levels of organic carbon occurred in teak, eucalyptus and albizia plantation of Kollathirumed. Being leguminous, albizia plantation caused an enhancement in nitrogen fixation as well as organic carbon build up in the soil.

Venketaraman et al. (1983) studied the return of nutrients by the leaf litter on bluegum plantation in Nilgiris in Tamil Nadu. He has shown that the status of organic carbon, total N, exchangeable Ca and exchangeable K were very high in 0-15 cm soil layers as compared to 30-60 cm soil layers.

From a study on the seasonal changes in N and P fractions and autumn retranslocations in evergreen and deciduous trees, Chapin and Kedrowski (1983) concluded that trees have not adapted to nutrient stress through major changes in bio-chemical use of N and P. However, during the growing season there are important changes in allocation of N and P to different chemical fractions associated with changing plant requirements.

Samra et al. (1983) were of the view that under natural wood land ecosystem, vegetation is one of the most important factors affecting the course of soil development. Under natural wood land with deep rooted vegetation about 4 times more of Ca and Mg phytocycled. Hence A horizon gets enriched with Ca and Mg as compared to B and C horizons. The high content of organic carbon throughout the profile is indicative of the dominent role played by vegetation in the genesis of these soils.

According to Tofey et al. (1986), weathering process seems to be quite active in soils under teak followed by eucalyptus cover. Ratio of clay to non-clay fraction, thickness of A horizon, organic matter content, CEC, exchangeable Ca and Mg were more under teak than under eucalyptus. Soil pH was lowered more under eucalyptus plantation than teak plantation. Soluble salts were also more under eucalyptus.

MATERIALS AND METHODS

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The pattern of nutrient recycling under monoculture conditions in the tropical forest eco-system of Kerala has been investigated with reference to three types of plantations viz. eucalyptus, teak and rubber. For this, plant tissues, forest floor samples and soil samples were collected from selected locations and analysed for their nutrient status. The morphological and physico-chemical properties, downward distribution of nutrients etc. in the typical soil profiles of the above plantations were also determined.

Location of site

Four sites at an altitude of 400-450 M and at a distance of about 5-10 km in the Palode village of Kulathupuzha forest range in Trivandrum District coming under similar climatic conditions and of uniform parent material were selected for the study. Four locations where eucalyptus, teak and rubber have been planted for 20-30 years and an adjoining virgin forest to serve as the check sample were selected in these sites. The details of the locations are given below:-

Sl. No.	Location	Plantation
1	Valiyathodu	Eucalyptus, Teak
2	Pottamavu	Eucalyptus, Teak
3	Sastanada	-do-
4	Madathara (Santhimathi Estate)	Rubber
5	-do	-do-
6	(Muthoot Estate)	-do-

Forest floor samples

Three samples of forest floor (leaf litter) were collected from each of the above locations, at an interval of four months for a period of one year. The first collection was made in January 1986 and the subsequent collections in May and October during the same year.

Method of collection

In each site for each plantation, three

different spots were selected. From each spot an area of 10 M^2 was marked out with coir, the undergrowth was carefully removed and the thickness of the forest floor measured using a meter scale. The litter was then heaped with a broom and the entire litter collected in plastic bags and the weight determined, using a spring balance. Duplicate samples weighing about 1 kg each were taken from the pooled litter from the three spots for further chemical analysis.

Collection of plant samples

Mature and freshly fallen leaves were collected during October 1986 from the three plantations in the different sites.

Collection of soil samples

Two profile pits of size 3 x 3 x 6' were dug in each of the three plantations and in the adjoining virgin forest in the different locations. Altogether 24 pits were opened. The field description of typical pedons including the distribution of roots was made by adopting the procedure prescribed in the Revised Soil Survey Manual published by the All India Soil and Land Use Survey Organisation (IARI, New Delhi) in 1971. Various soil layers (horizons), the thickness of which varied from 9 to 90 cm in the different pits were collected in plastic bags and brought to the laboratory for analysis. The mean depth of the horizons in the different profiles is indicated below:

	Natural forest	Teak	Eucalyptus	Rubber
h_1	0-18 cm	0-11 cm	0-9 cm	0-10 cm
h_2	18-50 "	11-30 "	9-33 "	10-30 "
h_3	50-80 "	30-55 "	33-66 "	30-60 "
h_4	80-140 "	55-130 "	66-108 "	60-150 "

<u>Analysis of plant samples</u>

Average leaf area

Average leaf area was measured by drawing the outline of freshly collected individual leaves on a graph paper. The weight of the same leaves was determinted in a chemical balance and the ratio of the average leaf area to average weight was determined.

The fresh leaves, freshly fallen leaves and the forest floor litter samples were dried in an air oven at 80 $\pm$ 5°C, powdered in a Sumeet dry grinder and used for further analysis.

Loss on ignition

Loss on ignition was determined by igniting a known weight of the powdered sample in a muffle furnace at 800°C to attain constant weight. Loss in weight on ignition was determined gravimetrically and expressed as percent (Sankaram, 1966).

Ash content

The ash obtained by igniting a known weight of the powdered sample at 800°C was estimated gravimetrically and expressed as percent (Jackson, 1973).

Acid insoluble residue

The ash was dissolved in 1:1 HCl, boiled and filtered through Whatman No.42 filter paper. The residue was transferred completely to the filter paper with the help of a Policeman, washed several times with distilled water and allowed to drain. The filter paper containing the acid insoluble residue was then dried in an air oven at 100-105°C to attain constant weight and the percentage of acid insoluble residue calculated.

Chemical analysis

1 g each of the powdered sample was digested with a mixture of concentrated H_2SO_4 and H_2O_2 (Jackson, 1973). The digest was filtered and made upto 100 ml with distilled water. Known aliquots of the extract were used for the determination of nitrogen, phosphorus, potassium, calcium and magnesium by adopting standard analytical procedures as detailed below.

Nitrogen	-	Microkjeldahl distillation method	Jackson, 1973
Phosphorus	-	Vanado-molybdo phosphoric yellow colour method in nitric acid system - by using Klett Sumerson Photoelectric Colorimeter.	"
Potassium	-	By using flame photometer	"

Calcium and Magnesium -	By using Atomic Absorption Spectro photometer (model PE 3030) and the Spectrum of absorption was determined at wave lengths 422.7 nm and 285.2 nm respectively for calcium and magnesium	Jackson, 1973

Analysis of soil samples

The soil samples collected from the various horizons of the profile pits were air dried, powdered, passed through a 2 mm sieve and used for further analysis.

The physico-chemical characters of the samples such as mechanical composition, single value constants, pH, electrical conductivity, loss on ignition, cation exchange capacity, organic carbon, total nitrogen, phosphorous, potassium, available nitrogen, phosphorous and exchangeable potassium, calcium and magnesium were determined by adopting standard analytical procedures as detailed below.

Mechanical analysis -	Bouyoucos Hydrometer method	Black (1965)

Single value constants -	Troells method by using Keen Raczkowski box	Wright (1939)
pH -	Using a Perkin Elmer pH meter	Jackson (1973)
Electrical conductivity -	Solubridge method	"
Loss on ignition -	Ignition method	Sankaram (1966)
Cation exchange capacity -	Neutral Normal ammonium acetate method	Jackson (1973)
Organic carbon -	Walkley and Black's rapid titration method	"
Total nitrogen -	Modified Microkjeldahl method	"
Total phosphorous-	Chloro Stannous reduced molybdo-phosphoric blue colour method in H_2SO_4 system in H_2SO_4 extract	"
Total potassium -	Flame photometer method in H_2SO_4 extract	"

Available nitrogen	-	Alkaline permanganate method	Subbiah and Asija (1956)
Available phosphorous	-	Dickman and Brang's molybdenum blue method after extraction with Bray 1 reagent	Jackson (1973)
Exchangeable potassium	-	Neutral normal ammonium acetate extract by using Flame Photometer	"
Exchangeable calcium and magnesium	-	Neutral normal ammonium acetate extract by using Atomic Absorption Spectro Photometer at a wave length of 422.7 nm and 285.2 nm respectively for calcium and magnesium	"

Statistical analysis

Data pertaining to the various characteristics were analysed statistically by applying the technique of analysis of variance. Simple correlations were worked out between different soil characteristics from the analytical data as given below.

ANOVA

Source	DF
Between plantations (P)	3
Between horizons (H)	3
P x H	9
Error	80
Total	95

Correlation coefficients were estimated for various soil characteristics.

RESULTS

Soil studies

Morphological feature

The field description of typical soil profiles of the three plantations and natural forest is given.

MORPHOLOGICAL CHARACTERS OF SOIL PROFILES

Typical Profile of Natural Forest

Location	:	Valiyathodu Thavarna, Palode Village, Kulathupuzha range, Nedumangad Taluk, Trivandrum District.
Elevation	:	400 - 450 M
Land form	:	Sloping upland
Relief	:	Normal
Parent material	:	Granite gneiss
Natural vegetation	:	*Hopea parviflora*, *Artocarpus hirsuta*, *Hidnocarpus laurifolia*, *Polialthia fragrans*, *Artocarpus lakoocha*, *Holigarna arnotiana*

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Horizon	Depth (cm)	Description
A_1	0-7	Dark yellowish brown (10 YR 3/4) moist; gravelly loam; weak, medium, granular structure; friable, non-sticky and non-plastic; few medium roots and few fine roots; moderately rapid permeability; clear smooth boundary.
B_1	7-28	Dark reddish brown (5 YR 3/3) moist; gravelly loam; moderate, medium, subangular blocky structure; firm, slightly sticky and slightly plastic; few medium roots and very few fine roots; moderate - permeability; clear smooth boundary.
B_2	28-68	Dark reddish grey (5 YR 4/2) moist; gravelly loam; moderate, medium, subangular blocky structure; firm, sticky and plastic; few medium roots and very few fine roots; moderately slow permeability; gradual smooth boundary.
B_3	68-120	Dark reddish brown (5 YR 3/4) moist; gravelly clay loam;

		moderate, medium, subangular blocky structure; firm, sticky and plastic; few medium roots and few coarse roots; soil mixed with gneissic boulders; moderately slow permeability.
C	120^+	Gneiss

Typical profile of Eucalyptus plantation

Location : Valiyathodu, Thavarna, Palode village, Kulathupuzha range, Nedumangad Taluk, Trivandrum District.

Elevation : 400 - 450 M

Land form : Sloping upland

Relief : Normal

Parent material: Gneissic

Natural vegetation : 20-30 year old Eucalyptus plantation

Horizon	Depth (cm)	Description
A_1	0-9	Dark yellowish brown (10 YR 3/4) dry; dark brown (10 YR 3/3) moist; gravelly clay loam; weak, medium, granular structure;

		loose, friable, slightly sticky and slightly plastic, few medium roots and few fine roots, moderately rapid permeability; clear smooth boundary.
B_1	9-29	Dark brown (7.5 YR 3/2) moist; gravelly clay loam; moderate, medium, subangular blocky structure, friable, slightly sticky and slightly plastic, very few fine and few medium roots, moderate permeability, gradual smooth boundary.
B_2	29-52	Reddish brown (5 YR 4/3) moist; gravelly clay; moderate, medium, subangular blocky structure; firm, sticky and plastic; few medium roots; moderate permeability, gradual smooth boundary.
B_3	52-145	Yellowish red (5 YR 5/6) moist; gravelly clay; moderate, medium, subangular blocky structure, firm, very sticky and very plastic; few medium roots and very few coarse roots, moderately slow permeability.

Typical Profile of Teak plantation

Location	:	Valiyathodu Thavarnna, Palode village, Nedumangad Taluk, Kulathupuzha range, Trivandrum District.
Elevation	:	400 - 450 M
Land form	:	Sloping upland
Parent material	:	Gneissic
Natural vegetation	:	20-30 year old teak plantation

Horizon	Depth (cm)	Description
A_1	0-8	Dark yellowish brown (10 YR 3/4) dry; dark brown (10 YR 3/3) moist; gravelly loam; weak, medium, granular structure; loose friable, non sticky and non plastic; few medium roots and few fine roots; moderate permeability; clear smooth boundary.
A_3	8-21	Dark brown (10 YR 3/3) dry; dark yellowish brown (10 YR 3/4) moist; gravelly loam; moderate, medium, subangular blocky structure; slightly hard, friable, slightly sticky and

		slightly plastic; very fine and few medium roots; moderate permeability; clear wavy boundary.
B_2	21-36	Dark reddish brown (5 YR 3/4) dry; dark reddish brown (5 YR 2/2) moist; gravelly clay loam; moderate, medium, subangular blocky structure; slightly hard, friable, sticky and plastic; very few fine and few medium roots; moderate permeability; clear wavy boundary.
B_3	36-150	Dark reddish grey (5 YR 4/2) moist; gravelly clay loam; moderate, medium, subangular blocky structure; firm, sticky and plastic; few medium and very few coarse roots; soil mixed with gneissic boulders; Slow permeability.

Typical Profile of Rubber plantation

Location	:	Santhimathi estate, Madathara village, Kulathupuzha range.
Elevation	:	400 M

Land form : Sloping upland

Relief : Normal

Parent material : Gneissic

Natural vegetation : 20-30 year old, rubber plantation

Horizon	Depth in cm	Description
A_p	0-12	Yellowish brown (10 YR 5/8) dry; yellowish brown (10 YR 5/6) moist; gravelly clay loam; weak medium granular structure; loose, friable, slightly sticky and slightly plastic; few medium roots and few fine roots; moderately rapid permeability; clear smooth boundary.
B_1	12-30	Strong brown (7.5 YR 5/6) moist; gravelly clay loam; moderate medium subangular blocky structure; firm, slightly sticky and slightly plastic; very few fine and few medium roots; moderate permeability; gradual smooth boundary.
B_2	30-65	Yellowish red (5 YR 5/6) moist; gravelly clay; moderate, medium, subangular blocky structure;

		firm, sticky and plastic; few medium roots; moderately slow permeability gradual smooth boundary.
B_3	65-100	Reddish brown (2.5 YR 4/4) moist; gravelly clay; moderate, medium subangular blocky structure; very firm; very sticky and very plastic; very few medium and few coarse roots; slow permeability.

I. Physical properties

Gravel content

Rounded and subrounded fragments of 2.75 mm diameter were included in gravel. It may be seen that in the soil profiles of the natural forest and different plantations (eucalyptus, teak and rubber) (Table 1) the gravel content increased with depth and the highest content of gravel was noticed in the lowermost horizon.

Mechanical analysis

The mean values for the various fractions

PHYSICAL PROPERTIES OF THE SOILS

Table 1 Gravel (percent)

Profile	h_1	h_2	h_3	h_4	Mean p
Natural forest	18.67	22.17	26.00	40.33	26.79
Eucalyptus	19.17	22.00	24.00	27.83	23.25
Teak	18.83	22.17	32.67	40.17	28.46
Rubber	20.83	24.17	26.00	34.83	26.46
Mean h	19.38	22.63	27.17	35.79	

CD (marginal means) = 3.78
CD (combinations) = 7.56

Table 2 Sand (percent)

Profile	h_1	h_2	h_3	h_4	Mean p
Natural forest	39.93	38.02	36.20	36.07	37.56
Eucalyptus	40.90	38.48	35.92	33.48	37.20
Teak	46.27	44.00	38.57	37.70	41.63
Rubber	42.37	40.17	35.90	33.45	37.97
Mean h	42.37	40.17	36.65	35.18	

CD (marginal means) = 1.17
CD (combinations) = 2.34

obtained on mechanical analysis of the soils are given in Tables 2, 3 and 4 and the analysis of variance in appendix 1.

Sand

The average sand content presented in Table 2 showed a decreasing tendency with increase in depth in the natural forest as well as in the different plantations. The highest content of 41.63% sand was present in teak plantation which was significantly higher than that in the other two plantations and the natural forest. No significant difference in sand content was noted in the other two plantations and natural forest.

Silt

The distribution of silt showed no regularity in the different horizons in the profiles of natural forest and plantations (Table 3). However, the mean value for silt was significantly higher in the natural forest (32.34%) compared to the plantations. In the eucalyptus plantation, a decrease in silt content with increase in depth was noticed, which trend was

Table 3 Silt (percent)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	32.30	36.40	38.97	21.73	32.34
Eucalyptus	28.17	27.20	21.15	19.48	24.00
Teak	29.55	28.57	25.50	26.13	27.43
Rubber	19.27	20.77	22.85	20.97	20.96
Mean h	27.32	28.22	27.10	22.08	

CD (marginal means) = 2.54
CD (combinations) = 5.09

Table 4 Clay (percent)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	25.67	24.32	23.80	38.15	27.98
Eucalyptus	29.70	33.02	41.80	45.92	37.61
Teak	23.07	26.50	34.67	36.35	30.15
Rubber	36.83	38.02	40.43	44.62	39.98
Mean h	28.82	30.46	35.18	41.26	

CD (marginal means) = 2.96
CD (combinations) = 5.93

not seen in the case of rubber, teak and natural forest.

Clay

From Table 4 it may be seen that the clay content was maximum in the 4th horizon in all the plantations as well as in the natural forest. In the three plantations it showed a tendency to increase with an increase in depth while, clay content was not significantly different in the first three horizons in rubber plantation and natural forest but significantly high in natural forest. In the three plantations clay content was not significantly different in the third and fourth horizons.

The clay content was high in rubber (39.98 percent) which was on par with that in eucalyptus (37.61 percent) and significantly higher than that in natural forest and teak plantation. Clay content in the horizons of eucalyptus plantation showed a greater variation than that of teak and natural forest in the third and fourth horizons.

By referring to the textural diagram for soils proposed by USDA (1971) these soils were found to belong to the following textural classes.

Profile	h_1	h_2	h_3	h_4
Natural forest	Gravelly loam	Gravelly loam	Gravelly loam	Gravelly clay loam
Eucalyptus	Gravelly clay loam	Gravelly clay loam	Gravelly clay	Gravelly clay
Teak	Gravelly loam	Gravelly loam	Gravelly clay loam	Gravelly clay loam
Rubber	Gravelly clay loam	Gravelly clay loam	Gravelly clay	Gravelly clay

Single value constants

The mean values for the single value constants of the soils are given in Tables 5, 6, 7, 8 and 9 and the analysis of variance in appendix 2.

Bulk density

In all the profiles studied, the bulk density steadily increased with depth (Table 5), the highest value (1.25) being recorded for the soils of the lowest horizon of eucalyptus plantation. Significant variation in bulk density was not noticed in the first

Single Value Constants

Table 5 Bulk density (g/cc)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	0.99	1.03	1.04	1.05	1.03
Eucalyptus	1.12	1.14	1.20	1.25	1.18
Teak	1.05	1.08	1.13	1.18	1.11
Rubber	1.13	1.15	1.19	1.22	1.17
Mean h	1.07	1.09	1.14	1.18	

CD (marginal means) = 0.03
CD (combinations) = 0.06

Table 6 Particle density (g/cc)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	2.01	2.03	2.04	2.06	2.03
Eucalyptus	2.02	2.05	2.07	2.15	2.07
Teak	2.04	2.08	2.09	2.14	2.09
Rubber	2.13	2.20	2.27	2.31	2.23
Mean h	2.05	2.09	2.12	2.16	

CD (marginal means) = 0.04
CD (combinations) = 0.08

three horizons of different plantations but significantly higher in fourth horizon as compared to the first and second horizons. Not much variation was noticed between eucalyptus and rubber plantation although the bulk density of soils from the teak and natural forest showed significantly lower values.

Particle density

As in the case of bulk density, the particle density of the soil increased with depth in all the profiles (Table 6). Particle density did not show any significant difference in natural forests at various depth but it was high in the fourth horizon in the three plantations compared to the first two horizons. Significant variation was exhibited between different plantations and natural forest except between eucalyptus with teak and natural forest. Particle density was highest for soils of rubber plantation (2.23) and lowest for natural forest soils (2.03) which was on par with that of eucalyptus plantation.

Waterholding capacity

From Table 7 it may be seen that the WHC was

Table 7 Waterholding capacity (percent)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	46.32	42.75	38.67	36.33	41.02
Eucalyptus	43.45	39.45	35.33	33.95	38.05
Teak	39.62	37.42	36.12	33.33	36.62
Rubber	36.73	32.90	29.37	25.32	31.08
Mean h	41.53	38.13	34.87	32.23	

CD (marginal means) = 1.48

CD (combinations) = 2.97

Table 8 Pore space (percent)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	50.8	49.7	48.8	47.8	49.3
Eucalyptus	44.6	44.0	42.8	41.8	43.3
Teak	48.1	47.9	46.4	44.2	46.7
Rubber	48.4	47.8	47.5	47.1	47.7
Mean h	47.9	47.4	46.4	45.2	

CD (marginal means) = 1.09

CD (combinations) = 2.19

maximum in the 1st horizon in all the plantations as well as in the natural forest and it showed a tendency to decrease with depth. Waterholding capacity of the soils in the horizons of different plantations showed significant variation. Natural forest recorded higher values for WHC compared to other plantations (41.02).

Pore space

The mean values for pore space given in Table 8 showed a decreasing tendency with increasing depth though the differences in values were not significantly different in the first two horizons. Maximum pore space was noticed for soils in the upper horizons in all the soils which was on par with that of second horizon. Pore space was maximum in natural forest and minimum in eucalyptus plantation. It was not significantly different in teak and rubber plantations.

Volume expansion

Table 9 shows the mean values for volume expansion in soils of different profiles. Volume

Table 9 Volume expansion (percent)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	9.60	8.04	6.71	5.69	7.51
Eucalyptus	8.12	7.27	6.38	5.40	6.79
Teak	6.78	6.76	5.67	4.60	5.97
Rubber	7.33	7.09	7.07	6.52	7.03
Mean h	7.96	7.30	6.48	5.56	

CD (marginal means) = 0.44

CD (combinations) = 0.88

expansion was maximum for soils of natural forest (7.51%) and minimum in teak plantation and was not significantly different in eucalyptus and rubber plantations. There was significant difference in volume expansion between the soils of different horizons of natural forest and eucalyptus plantation. The variation was not significantly different in rubber plantation at all horizons and at the first two horizons of teak plantation. The surface layer of natural forest showed a relatively higher volume expansion and in all the profiles it decreased with depth.

Chemical properties

The mean values for the chemical properties of the soil samples are given in Tables 10 to 23 and the analysis of variance in appendix 3.

Organic carbon

Table 10 and Fig. 1 shows the mean values relating to the organic carbon content of different profiles. In all the profiles, the highest amount of organic carbon was present in the surface horizon and

CHEMICAL PROPERTIES OF SOILS

Table 10 Organic carbon (percent)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	2.09	1.77	0.67	0.35	1.22
Eucalyptus	1.73	1.17	0.61	0.39	0.98
Teak	1.59	1.29	0.78	0.60	1.06
Rubber	1.21	1.02	0.76	0.40	0.85
Mean h	1.66	1.31	0.70	0.43	

CD (marginal means) = 0.076

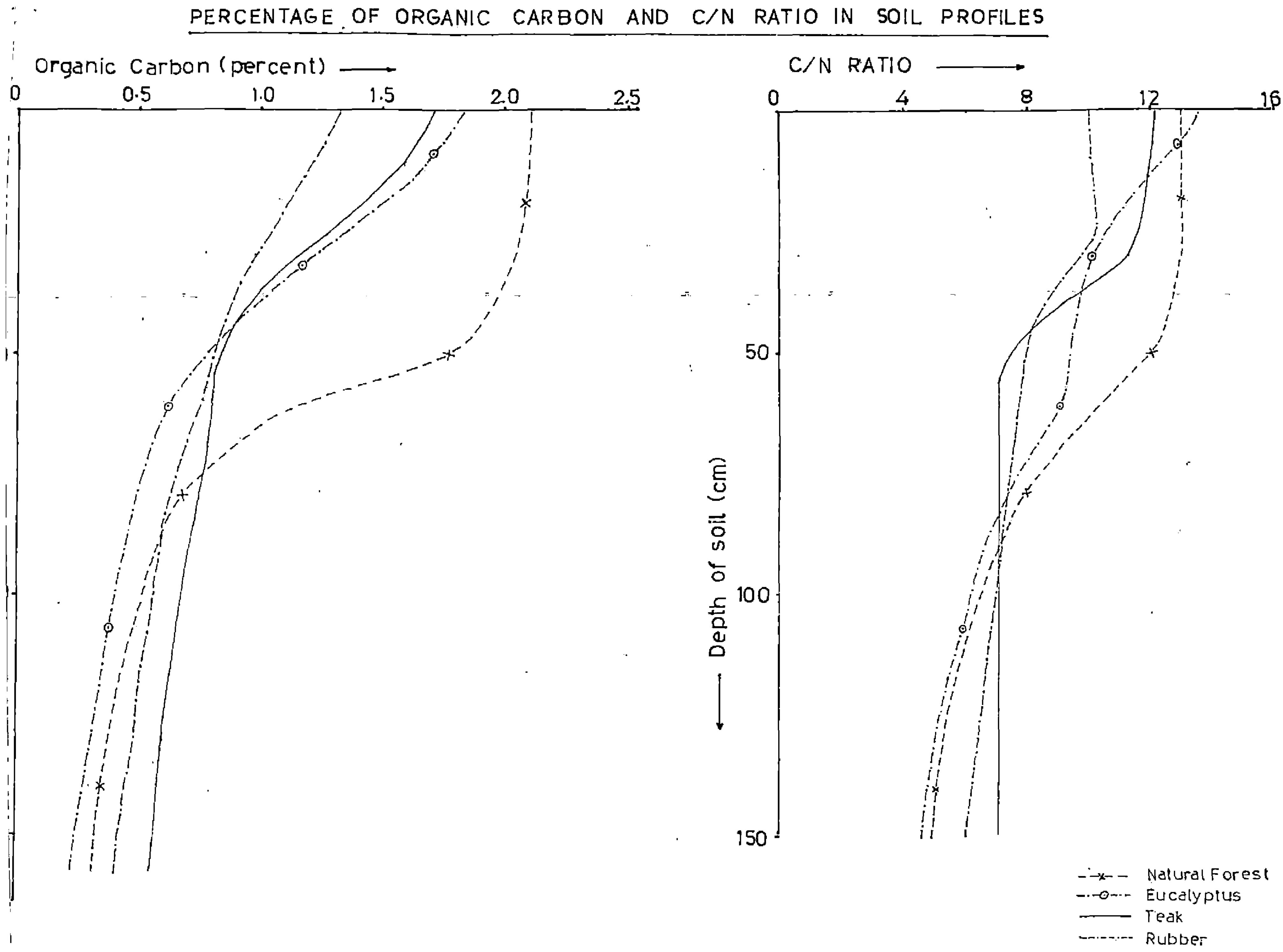
CD (combinations) = 0.14

Table 11 Loss on ignition (percent)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	9.30	8.18	6.87	7.15	7.88
Eucalyptus	6.93	7.10	7.02	6.83	6.97
Teak	6.27	5.80	4.62	4.15	5.21
Rubber	5.47	4.75	4.25	3.70	4.54
Mean h	6.99	6.46	5.86	5.46	

CD (marginal means) = 1.05

CD (combinations) = 2.10


PERCENTAGE OF ORGANIC CARBON AND C/N RATIO IN SOIL PROFILES
Organic Carbon (percent)
0
0.5
1.0
1.5
2.0
2.5
C/N RATIO
0
4
8
12
16
Depth of soil (cm)
50
100
150
Natural Forest
Eucalyptus
Teak
Rubber

it tend to decrease steadily with depth. It may be noted that among the different soils, the highest level of organic carbon (2.09%) was obtained in the top layer of soil from natural forest. Organic carbon content varied significantly among the different horizons in all the plantations.

Loss on ignition

The loss on ignition of the soils of different plantations (Table 11) ranged from 9.30% in the surface horizon of natural forest to 3.70% in the 4th horizon of rubber plantation. It tended to decrease steadily with depth in most of the profiles. Loss on ignition of natural forest varied significantly with that of teak and rubber but it was on par with that of eucalyptus. Loss on ignition of the soils of eucalyptus plantation was significantly different from that of teak and rubber.

Total nitrogen

The variation in nitrogen content of the horizons of different plantations showed significant

Table 12 Total nitrogen (percent)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	0.156	0.146	0.082	0.065	0.112
Eucalyptus	0.137	0.120	0.074	0.061	0.098
Teak	0.132	0.117	0.107	0.078	0.109
Rubber	0.154	0.107	0.096	0.071	0.107
Mean h	0.145	0.122	0.089	0.069	

CD (marginal means) = 0.013

CD (combinations) = 0.026

Table 13 Carbon/Nitrogen ratio

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	13	12	8	5	10
Eucalyptus	13	10	9	6	9
Teak	12	11	7	7	9
Rubber	10	10	8	6	8
Mean h	12	11	8	6	

CD (marginal means) = 0.6

CD (combinations) = 1.2

DISTRIBUTION OF TOTAL AND AVAILABLE NITROGEN IN SOIL PROFILES

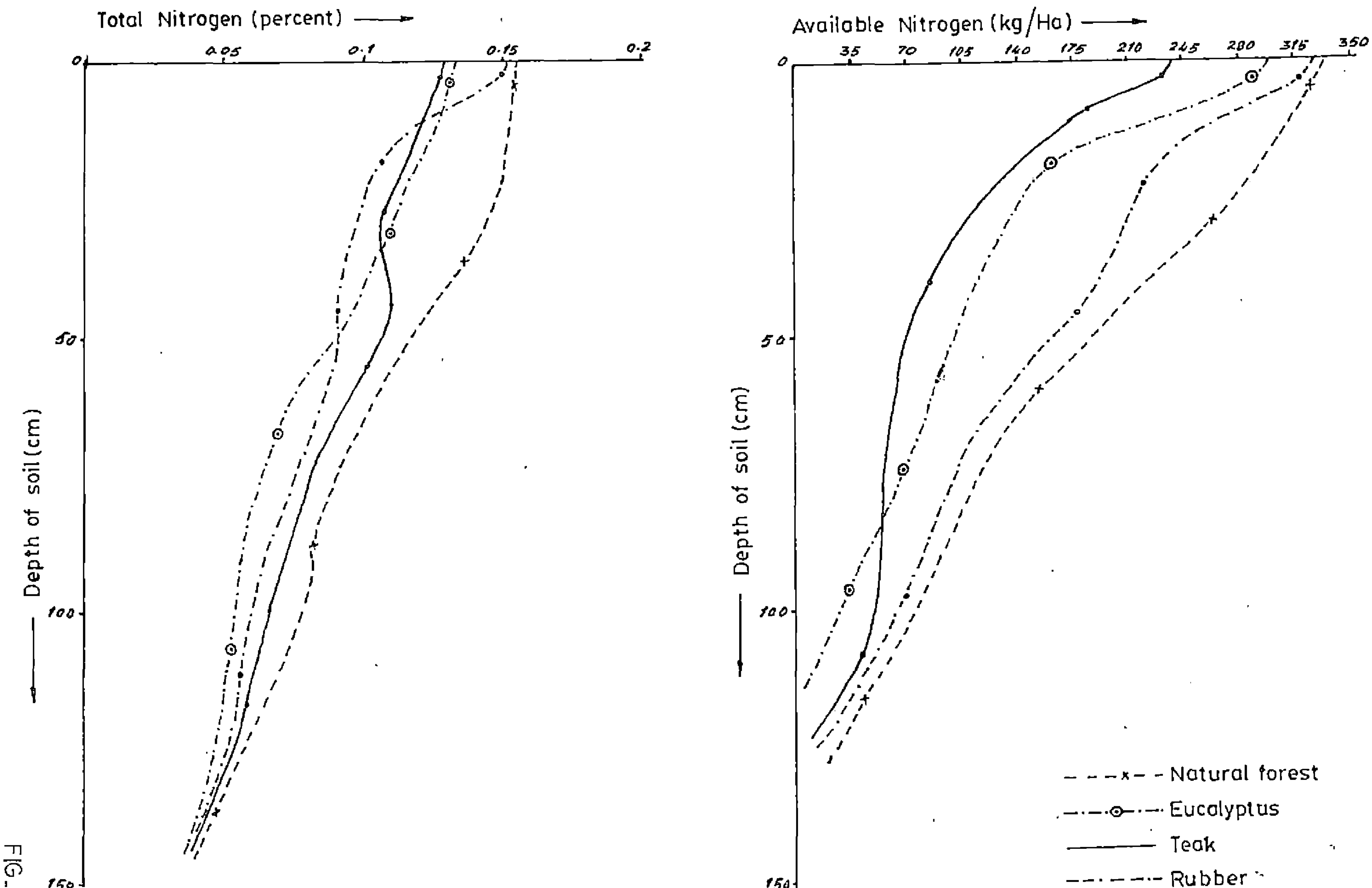


FIG. 2

variation as seen from Table 12 and Fig. 2. The amount of nitrogen in all the four profiles decreased with depth and it varied significantly in the different horizons of all plantations and natural forest. The highest value (0.156% N) was recorded in the surface soil of natural forest followed by the surface soil in rubber (0.154%). The lowest value for total nitrogen was recorded in the 4th horizon of eucalyptus (0.061%) profile.

C/N ratio

The C/N ratio also showed a tendency to decrease down the horizons in the profiles (Table 13, Fig.1) showing a significant variation among the horizons. The C/N ratio ranged from 13 in the surface soil of natural forest to 5 in the lowest horizon of natural forest. The average C/N ratio was maximum in natural forest (10) and minimum in rubber (8).

Available nitrogen

Available nitrogen content of the different soils are presented in Table 14 and Fig. 2. It showed

Table 14 Available nitrogen (kg/ha)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	325.00	253.33	156.67	43.33	194.58
Eucalyptus	283.00	160.00	82.67	42.67	142.08
Teak	239.33	196.00	93.67	61.67	147.67
Rubber	320.00	224.17	180.00	88.33	203.13
Mean h	291.83	208.38	128.25	59.00	

CD (marginal means) = 25.18

CD (combinations) = 50.36

Table 15 Total phosphorus (percent)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	0.131	0.136	0.098	0.110	0.119
Eucalyptus	0.071	0.110	0.079	0.080	0.085
Teak	0.084	0.097	0.066	0.079	0.082
Rubber	0.102	0.124	0.083	0.105	0.103
Mean h	0.097	0.117	0.081	0.093	

CD (marginal means) = 0.011

CD (combinations) = 0.022

a tendency to decrease with depth in all the soils. There was appreciable variation among the different horizons and the content was higher in the natural forest and rubber compared to that in teak and eucalyptus plantations.

Total phosphorus

The status of total phosphorus in the soils ranged from 0.082 to 0.119% (Table 15 and Fig. 3) the lowest value of 0.082% being present in the teak plantation and the highest value of 0.119% in the natural forest. In all the profiles it showed a tendency to accumulate in the 2nd horizon. Significant difference was noticed between the various plantations and natural forest in almost all the horizons.

Available phosphorus

The mean values are presented in Table 16 and Fig. 3. It may be noted that the soils were generally low in available phosphorus. The highest value (69.79 kg/ha) was recorded in the soils of teak.

DISTRIBUTION OF TOTAL AND AVAILABLE PHOSPHORUS IN SOIL PROFILES

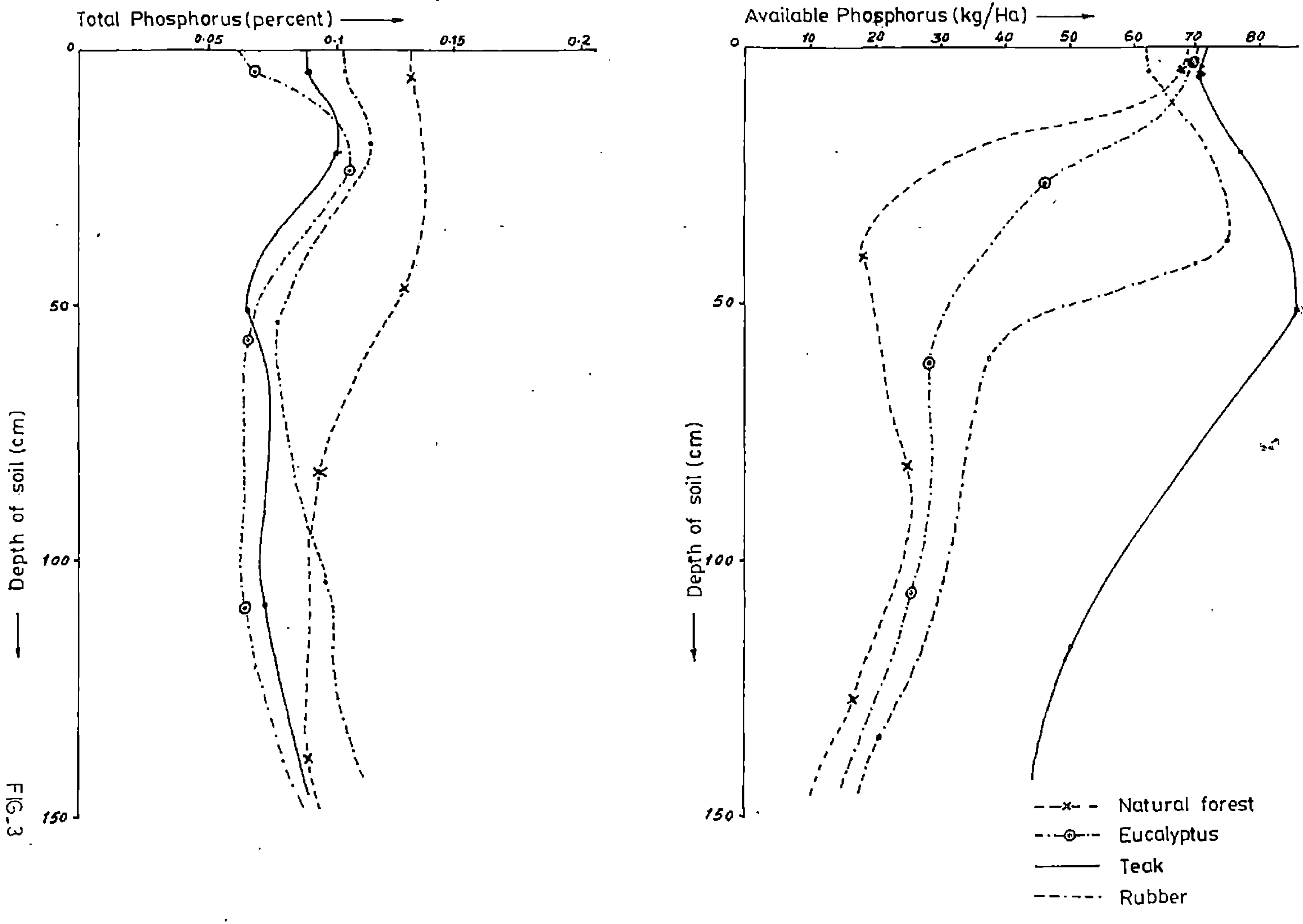


FIG_3

Table 16 Available phosphorus (kg/ha)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	64.83	17.50	24.33	17.67	31.08
Eucalyptus	66.33	48.33	29.33	24.33	57.08
Teak	67.83	77.33	82.00	52.00	69.79
Rubber	60.83	70.83	33.83	19.33	46.21
Mean h	64.96	53.50	42.38	43.33	

CD (marginal means) = 17.50

CD (combinations) = 35.00

Table 17 Total potassium (percent)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	0.137	0.142	0.111	0.100	0.121
Eucalyptus	0.122	0.202	0.123	0.125	0.143
Teak	0.097	0.123	0.101	0.114	0.109
Rubber	0.101	0.156	0.113	0.106	0.119
Mean h	0.114	0.156	0.112	0.110	

CD (marginal means) = 0.018

CD (combinations) = 0.036

No regularity in the distribution of available phosphorus was noticed from the data. Significant difference was obtained between the content of available phosphorus in the soils.

Total potassium

From the data presented in Table 17 and Fig. 4 it may be seen that the status of total potassium in the soils of eucalyptus was considerably higher than that of other plantations. In all the profiles the total potassium content in the second horizon was generally higher than that of the other layers.

Exchangeable potassium

Exchangeable potassium in the soils under study was comparatively low, ranging from 0.378 meq/100 g soil in teak plantation to 0.215 meq/100 g soil in eucalyptus plantation (Table 18 and Fig. 4). With regard to the distribution of exchangeable potassium in the different horizons of the soil profile, a steady decrease with depth was observed and the content in the 4th layer was found to be the lowest

DISTRIBUTION OF TOTAL AND EXCHANGEABLE POTASSIUM IN SOIL PROFILES

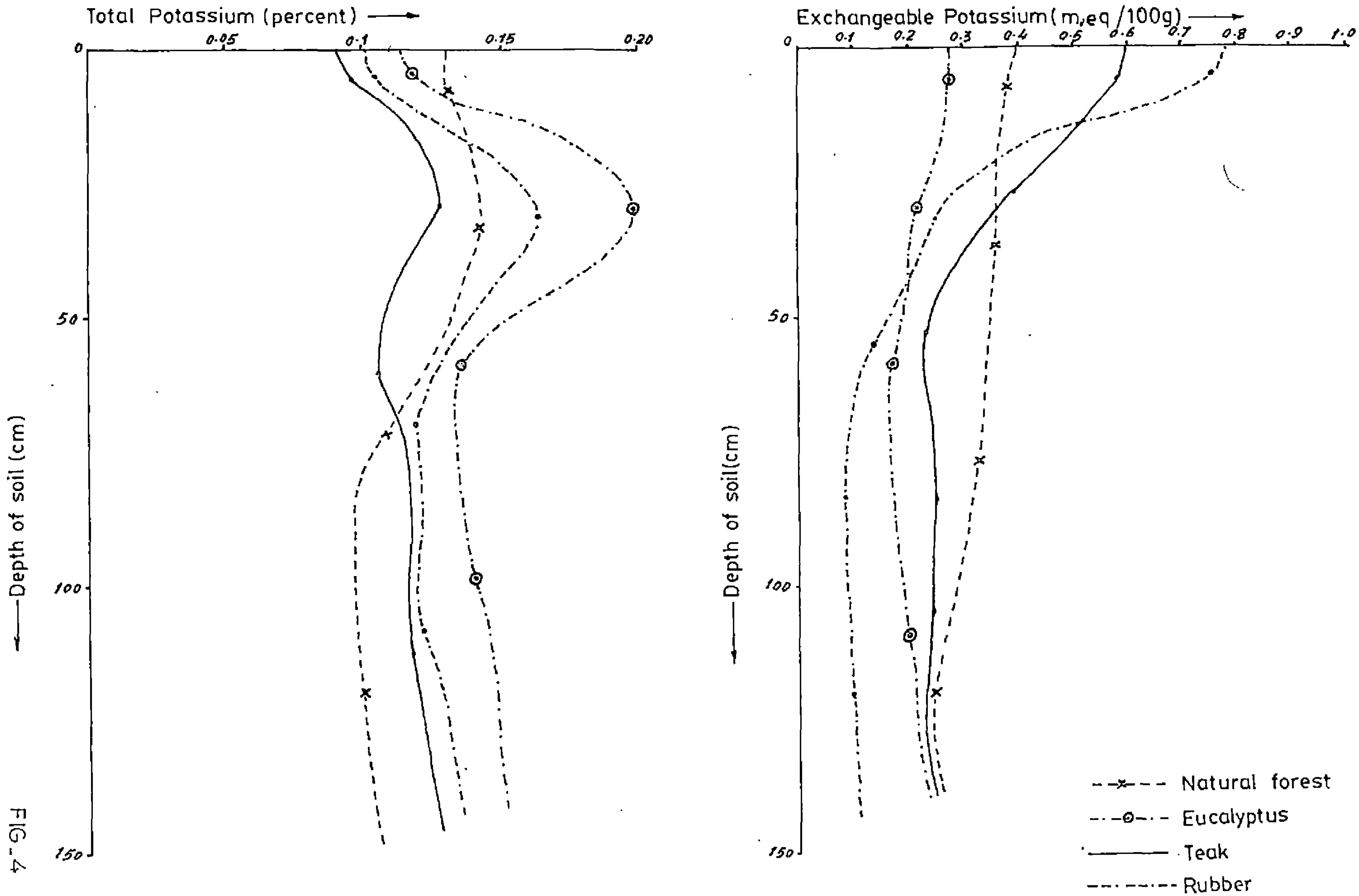


FIG. 4

Table 18 Exchangeable potassium (meq/100 g)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	0.363	0.333	0.315	0.285	0.324
Eucalyptus	0.280	0.202	0.178	0.202	0.215
Teak	0.578	0.390	0.295	0.248	0.378
Rubber	0.740	0.232	0.143	0.098	0.303
Mean h	0.490	0.289	0.232	0.208	

CD (marginal means) = 0.063

CD (combinations) = 0.126

Table 19 Exchangeable calcium (meq/100 g)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	0.990	0.680	0.473	0.622	0.691
Eucalyptus	1.173	0.990	1.152	0.907	1.055
Teak	0.787	0.832	0.747	0.558	0.731
Rubber	0.400	0.138	0.133	0.137	0.202
Mean h	0.838	0.660	0.626	0.559	

CD (marginal means) = 0.089

CD (combinations) = 0.178

in all profiles except in eucalyptus. Considerable variation in exchangeable potassium was noticed in the surface soil compared to the lower horizon.

Exchangeable calcium

Table 19 and Fig. 5 shows the mean values for exchangeable calcium in the different profiles. No regularity was noticed in its distribution. The highest value of 1.055 meq/100 g soil was observed in eucalyptus plantation and the lowest value (0.202 meq/100 g) in the rubber plantation.

Exchangeable magnesium

The exchangeable magnesium content in the soils varied from 0.148 to 0.627 meq/100 g soil (Table 20 and Fig. 5). It was highest in natural forest and lowest in rubber plantation. Teak and eucalyptus plantations showed a decrease in exchangeable magnesium with depth, whereas a slight increase of this constituent was noticed in the 3rd horizon of natural forest and 4th horizon of rubber.

DISTRIBUTION OF EXCHANGEABLE CALCIUM AND MAGNESIUM IN SOIL PROFILES

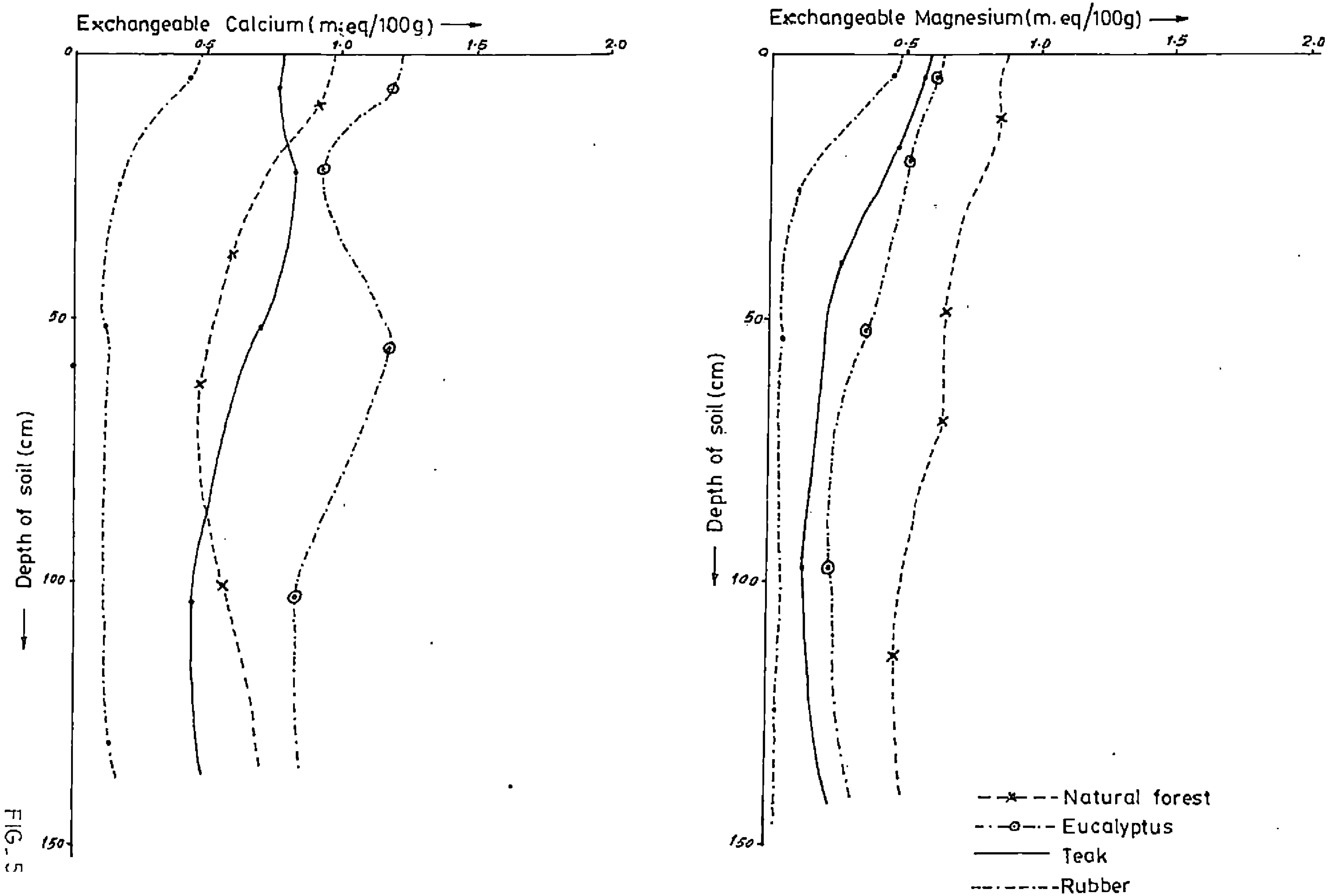


FIG. 5

Table 20 Exchangeable magnesium (meq/100 g)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	0.828	0.597	0.648	0.435	0.627
Eucalyptus	0.650	0.505	0.415	0.342	0.478
Teak	0.605	0.478	0.288	0.205	0.394
Rubber	0.402	0.080	0.052	0.058	0.148
Mean h	0.621	0.415	0.315	0.260	

CD (marginal means) = 0.108

CD (combinations) = 0.216

Table 21 Cation exchange capacity (meq/100 g)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	8.62	7.34	4.69	4.08	6.18
Eucalyptus	7.50	6.62	4.30	3.84	5.56
Teak	6.27	5.40	4.82	3.70	5.04
Rubber	5.60	4.06	4.04	3.16	4.21
Mean h	7.00	5.75	4.46	3.70	

CD (marginal means) = 0.21

CD (combinations) = 0.42

Cation exchange capacity

Mean values for CEC of different soils are presented in Table 21. The values varied from 4.21 to 6.18 meq/100 g soil. It showed a decreasing tendency with depth in all the profiles. Marked difference in their distribution among the plantations and natural forest as well as among the horizons was noted. Highest CEC was observed in the surface layers of natural forest (8.62 meq/100 g).

Base saturation

The percentage of base saturation of the various profiles is given in Table 22. It was found to vary from 14.40 to 32.89%. No significant difference among horizons except between h_1 and h_2 was noticed from the data. Base saturation in rubber plantation was very low and appreciable variation of base saturation in rubber with that of other plantations and natural forest was noticed.

pH & Electrical conductivity

The pH values of the profiles are shown in

Table 22 Base saturation (percent)

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	24.39	21.90	30.92	33.11	27.58
Eucalyptus	26.83	26.86	40.31	37.57	32.89
Teak	30.90	31.52	27.01	29.44	29.72
Rubber	27.53	12.68	8.21	9.16	14.40
Mean h	27.41	23.24	26.61	27.32	

CD (marginal means) = 3.52

CD (combinations) = 7.04

Table 23 pH

Profile	h_1	h_2	h_3	h_4	Mean P
Natural forest	5.0	5.0	5.1	5.3	5.1
Eucalyptus	5.3	5.3	5.5	5.4	5.4
Teak	5.5	5.5	5.5	5.5	5.5
Rubber	5.2	5.1	5.1	5.1	5.1
Mean h	5.3	5.2	5.3	5.3	

CD (marginal means) = 0.05

CD (combinations) = 0.10

Table 23. All the soils were acidic in reaction, the pH ranging from 5.0 to 5.5. The soils of natural forest and rubber plantation were more acidic. In natural forest pH increased with depth but in eucalyptus pH was higher in the 3rd horizon. In the case of teak no change in pH with depth was noticed and in rubber, the value for pH was lower in the subsurface layers compared to the surface layers. Marked variation in pH within plantations was noticed except in rubber and natural forest. Electrical conductivity was negligible in the soils of all the profiles.

Analysis of Forest litter

Weight and Thickness

The mean values of the weight and thickness of the forest litter are presented in Tables 24 and 25 and the analysis of variance in appendix 4.

It may be observed from the results that the weight of the forest floor was maximum in eucalyptus and rubber during January and in teak it was higher in May. The weight of forest floor showed significant

Table 24 Weight of Forest Litter (kg/10 m^2)

	January	May	October
Eucalyptus	7.83	1.85	4.31
Teak	3.07	2.53	2.57
Rubber	2.00	0.60	0.64
CD	2.37	1.68	1.65

Table 25 Thickness of forest litter (cm)

	January	May	October
Eucalyptus	1.43	0.37	0.77
Teak	1.57	0.67	0.45
Rubber	2.80	1.17	1.07
CD	0.35	0.06	0.06

variation among the plantations during October. In January, the variation was significant between eucalyptus and teak, and eucalyptus and rubber. Significant variation in weight was observed only between teak and rubber during May.

Thickness of forest floor was higher in rubber during all the periods. Variation in thickness among the plantations in all periods was significant except the variation between teak and eucalyptus during January.

Chemical properties of forest litter

The mean values obtained from the analysis are presented in Tables 26 to 28 and Fig. 6 and the analysis of variance in appendix 4.

Loss on ignition

Significant variation was noticed between the values for loss on ignition for teak with that of eucalyptus and rubber during the three periods of collection. However, the variation between rubber

CHEMICAL PROPERTIES OF FOREST LITTER

(in percent)

Table 26 January

Name of plantation	N	P	K	Ca	Mg	Loss on igni-tion	Ash con-tent	Acid inso-luble residue
Eucalyptus	0.790	0.098	0.400	0.530	0.238	92.63	7.36	17.93
Teak	1.025	0.118	0.228	0.222	0.247	87.96	12.03	64.95
Rubber	1.600	0.117	0.455	0.248	0.250	91.95	8.05	17.16
CD	0.036	0.006	0.058	0.052	0.032	0.36	0.36	2.54

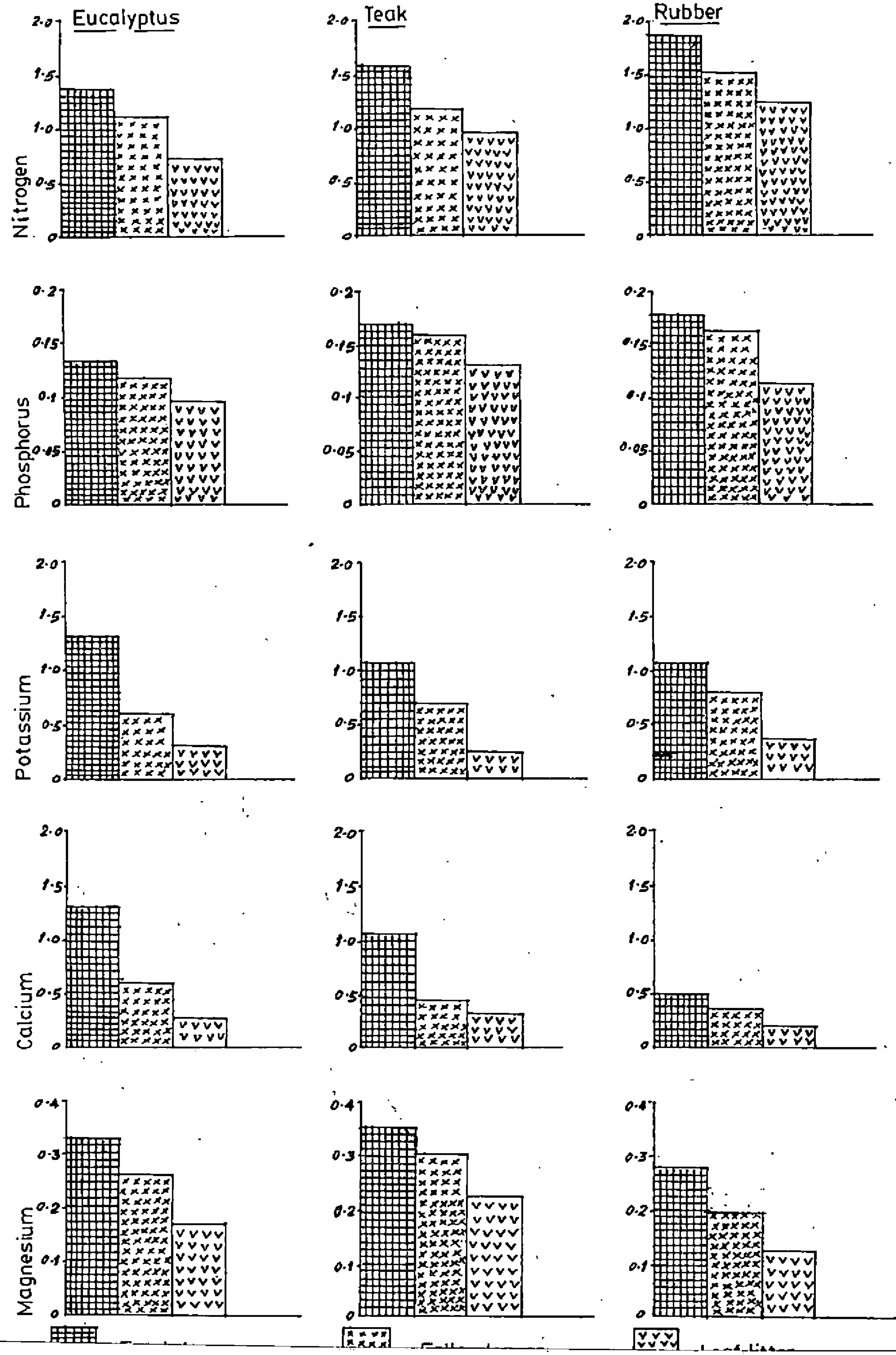
Table 27 May

Name of plantation	N	P	K	Ca	Mg	Loss on igni-tion	Ash con-tent	Acid inso-luble residue
Eucalyptus	0.605	0.093	0.433	0.383	0.145	92.55	7.45	16.62
Teak	1.010	0.120	0.207	0.230	0.163	87.90	12.10	66.57
Rubber	1.335	0.107	0.270	0.250	0.173	92.81	7.18	16.61
CD	0.052	0.011	0.060	0.034	0.032	0.40	0.40	0.66

Table 28 October

Name of plantation	N	P	K	Ca	Mg	Loss on igni-tion	Ash con-tent	Acid inso-luble residue
Eucalyptus	0.745	0.100	0.200	0.283	0.155	92.35	7.65	17.85
Teak	0.960	0.155	0.173	0.255	0.265	87.96	12.03	64.52
Rubber	1.510	0.122	0.177	0.178	0.173	93.91	6.08	15.85
CD	0.038	0.035	0.039	0.062	0.023	0.37	0.37	1.72

NUTRIENT CONTENT (IN PERCENT) IN FRESH LEAVES, FALLEN LEAVES AND LEAF LITTER IN DIFFERENT PLANTATIONS



and eucalyptus was significant only during January and October.

Ash content

The ash content was highest in the case of teak during all the periods and significant variation was observed in the ash content between the plantations.

Acid insoluble residue

An appreciably higher content of acid insoluble residue was noticed in teak than in the other two plantations during all the three periods. Significant variation in this property was noticed between eucalyptus and rubber only during October.

Nitrogen

The nitrogen content in the forest litter was highest in rubber and lowest in eucalyptus plantation during the three periods of collection.

Phosphorus

In the case of phosphorus, the highest value was obtained in teak and lowest value in eucalyptus during the three periods.

Potassium

Potassium content of the forest litter was generally higher in eucalyptus and lower in teak.

Calcium

A higher content of calcium was observed in eucalyptus during all the three periods than rubber and teak plantations. During January and May, the lowest amount of calcium was noticed in teak and in October, the lowest content was observed in rubber.

Magnesium

No significant difference was observed among the plantations except in the case of teak which showed a definite variation with that of eucalyptus and rubber in the litter collected in October.

Analysis of mature and fresh fallen leaves

The nutrient content of mature and fresh fallen

Table 29 CHEMICAL PROPERTIES OF FRESH LEAVES (in percent)

Plant	N	P	K	Ca	Mg	Loss on igni-tion	Ash con-tent	Acid inso-luble Ash
Eucalyptus	1.335	0.133	1.233	1.283	0.340	91.003	8.997	17.283
Teak	1.520	0.178	1.020	1.022	0.357	86.800	13.200	64.032
Rubber	1.970	0.180	1.017	0.430	0.280	88.615	11.385	16.160
CD	0.059	0.011	0.188	0.103	0.029	2.861	0.214	0.408

Table 30 CHEMICAL PROPERTIES OF FRESH FALLEN LEAVES (in percent)

Plant	N	P	K	Ca	Mg	Loss on igni-tion	Ash con-tent	Acid inso-luble ash
Eucalyptus	1.097	0.117	0.570	0.648	0.258	91.357	8.643	18.025
Teak	1.050	0.160	0.657	0.343	0.297	87.588	12.412	62.705
Rubber	1.817	0.168	0.817	0.323	0.193	90.157	9.843	17.263
CD	0.078	0.014	0.343	0.027	0.011	0.375	0.183	0.246

leaves of the three plantations are presented in Tables 29 and 30 and Fig. 6 and the analysis of variance in appendices 5 and 6. It may be seen that the nutrient status of freshly fallen leaves was comparatively lower than that of the mature leaves. The variation in the nutrient status of fresh and fallen leaves of the three plantations was of a more or less uniform pattern.

Mature leaves

Loss on ignition

Loss on ignition showed considerable variation among the different leaves and it was greater in eucalyptus followed by rubber.

Ash content

Ash content in all the leaves varied significantly and the highest content of 13.2% was noticed for teak leaves.

Acid insoluble residue

Considerable variation was noticed in the percentage of acid insoluble residue in teak from that of rubber and eucalyptus. Variation was also significant between eucalyptus and rubber.

Ratio of leaf area to weight

The ratio of leaf area to weight was 34:1 in eucalyptus, 41:1 in teak and 84:1 in rubber.

Nitrogen

Nitrogen content was highest in rubber and lowest in the leaves of eucalyptus. There was significant variation between the nitrogen content of the three types of leaves.

Phosphorus

Content of phosphorus was very low in all the leaves. There was no significant difference between the content of phosphorus in rubber and teak but the difference was significant between rubber and eucalyptus and between teak and eucalyptus.

Potassium

Potassium content was higher in eucalyptus

(1.233%). Significant variation was observed in the content of this element in eucalyptus with that of teak and rubber.

Calcium

The value of this element was comparatively higher in eucalyptus (1.283%) and very low in rubber (0.430%). It varied significantly among the different plantations.

Magnesium

Variation was not significant between teak and eucalyptus but greater variation was noticed in teak with rubber and eucalyptus with rubber.

Fresh fallen leaves

Analytical results are tabulated (mean values) in Table 30 and the analysis of variance in appendix 6.

Loss on ignition

Loss on ignition was highest in eucalyptus (91.35%) and lowest in teak (87.58%). Appreciable variation was noticed between ~~all~~ the samples.

Ash content

More ash content was noticed in teak (12.41%). There was also significant variation among the leaves in their ash content.

Acid insoluble residue

Appreciable variation of this property was noticed in teak with that of eucalyptus and rubber. Variation was also significant between eucalyptus and rubber.

Nitrogen

Nitrogen content was significantly higher in rubber (1.817%) compared to eucalyptus and teak.

Phosphorus

A low content of phosphorus was noticed in all the samples. No significant variation was noticed between the phosphorus content in rubber and teak; which was significantly higher than that in eucalyptus.

Calcium

Calcium was significantly higher in eucalyptus compared to teak and rubber. The values ranged from 0.643% in eucalyptus to 0.323% in rubber.

Magnesium

The magnesium content in the different leaves varied significantly and it was maximum in teak and minimum in rubber.

DISCUSSION

DISCUSSION

The present investigation is aimed at studying the pattern of nutrient recycling in eucalyptus, teak and rubber plantations and the specific effect of these trees on the physico-chemical properties of the tropical soils in the Kulathupuzha range of forests in Trivandrum District. The properties of these soils are compared with similar properties of adjacent virgin forest and the salient findings are discussed and presented in this chapter.

The deep rooted trees are able to send their roots down into the subsoil and scavenge a considerable volume of the soil for their mineral nutrition. The falling leaves, twigs, barks etc. which form a cover on the forest floor along with the canopy overhead provides a unique microclimate which supports a population of soil microorganisms quite different from that associated with other soils. The organic acids, phenols etc. resulting from the decay of the forest debris under the influence of the microbial population aid in the leaching of bases and in the movement of organically bound cations like iron, manganese and aluminium (cheluviation) which may be deposited at various depths in the soil profile. The extent and magnitude of these dynamic processes is related to the physical and chemical nature of the organic debris undergoing decomposition which inturn differs with the respective tree cover of each location.

Nature of the plantation

Amount of litter fall

Although many environmental factors affect the composition and decomposition of the litter, the actual amount of litter fall in the different plantations decides the quantity of nutrients that become available for recycling. It may be seen from the results presented earlier that maximum litter fall in all plantations has taken place in January compared to other months. The approximate estimate of annual litter fall in a hectare of the plantation is highest in eucalyptus (14,000 kg) followed by teak (8170 kg) and rubber (3240 kg). The highest ratio of leaf mass to volume in the case of eucalyptus (0.0294) resulting in a greater mass of unit area of leaf has accounted for the highest amount of litter fall. Teak and rubber leaves with a relatively lower density (0.0244 and 0.0120) have yielded only much lesser amount of the litter inspite of the comparatively thicker deposit of the litter on the soil surface. Pande and Sharma (1986) have reported that leaf fall in plantations was in the order of sal > eucalyptus teak > pine. In the present study also the order of accumulation of litter is obtained as eucalyptus > teak > rubber.

Nutrient recycling

Computations based on the nutrient status and annual litter fall per hectare in each of the plantation presented in Table 31a show that the maximum contribution of all nutrients is made by eucalyptus which has incidentally contributed the maximum amount of litter fall also.

Data on the nutrient status of mature leaves freshly fallen leaves and forest litter samples also show appreciable differences among the samples of the

Table 31a Nutrient contribution by litter fall in kg/ha/year

Name of plantation	N	P	K	Ca	Mg
Eucalyptus	99.8	13.6	48.2	55.8	25.1
Teak	81.6	10.7	16.6	19.2	18.4
Rubber	48.0	3.7	9.7	7.3	6.4

Table 31b Difference in the nutrient composition between mature and freshly fallen leaves (percent)

Name of plantation	N	P	K	Ca	Mg
Eucalyptus	0.238	0.016	0.663	0.635	0.082
Teak	0.470	0.018	0.363	0.679	0.060
Rubber	0.153	0.012	0.200	0.080	0.057

Table 31c Difference in the nutrient composition between freshly fallen leaves and litter (percent)

Name of plantation	N	P	K	Ca	Mg
Eucalyptus	0.352	0.017	0.370	0.363	0.103
Teak	0.090	0.005	0.484	0.088	0.032
Rubber	0.307	0.046	0.640	0.145	0.020

different plantations. The difference in the nutrient status between mature leaves and freshly fallen leaves indicate a difference in the rate of mobilization of nutrients from older to younger leaves. Nutrient mobilization is found to be maximum in the case of teak for nitrogen, phosphorpus and calcium and in eucalyptus for potassium and magnesium. The nutrient content of freshly fallen leaves and the forest litter also shows such variations. Maximum difference for nitrogen, calcium and magnesium is recorded in eucalyptus and phosphorus and potassium in the rubber plantation. This difference in the content of nutrients between freshly fallen leaves and litter indicates the extent of mineralisation of the litter and subsequent leaching of the released nutrients in the different plantations. Litter with a wider difference in the status of nutrients may account for a more rapid and faster rate of mineralisation as well as leaching.

The physical and chemical nature of the leaf tissues are likely to become a limiting factor in their rate of decomposition and the amount of nutrients retained in the forest floor will depend upon their degree and stage of decomposition.

The forest floor litter which is subjected to a continuous process of microbial decomposition release the organically bound nutrients according to the rate at which they are mineralized. The mineralized nutrients may be leached down the soil profile along with the percolating water during the rainy season. The difference in the nature and properties of the lechates from the litter is likely to be reflected in the physico-chemical properties of the soils below.

Physical properties of soils

Results obtained from the present study reveal that remarkable changes in the physico-chemical properties of soils have taken place as a result of the influence of different types of plantations. The variations related to vegetational features may be identified in the morphology of the pedons as well as in their physical and chemical properties.

Colour

It may be noted from the morphological description that the colour of the soil is generally dark yellowish brown in the surface followed by reddish brown and yellowish red in the subsurface layers in almost all the profiles. The colour of the surface soil is of a uniform hue (10 YR), the intensity of value and chroma alone showing slight variations. The characteristic dark brown colour of the forest soils is not seen to be attained in any of the soils. Probably this might be due to the lack of accumulation of sufficient humified organic matter on the surface due to their faster decomposition. Since canopy closure is not complete and uniform in all the plantations, the penetrating rays of the sun and the higher temperature falling on the soil surface might have hastened the oxidation of the organic matter leading to a reduction in its content in the soil.

The colour of the subsoil is found to be darker as represented by the hue which varies from 7.5 to 5 YR showing a decrease with increase in depth. A lighter hue for the surface soil compared to the subsoil may be attributed to the predominance of hydrated oxides of iron which is characteristic of moist soils overlying a comparatively drier strata of lateritic bed rich in oxides of iron.

Structure

The structure of the soil in the different plantations is not considerably affected by the nature of the trees as evidenced from a more or less uniform granular structure in the surface soil and a subangular blocky structure in the subsoil. Eventhough fine and medium roots are present in the surface horizon of all the profiles, they are mostly absent in the subsoil. A few coarser roots alone seen in the subsoil indicate a poor penetration of roots possibly due to a greater compaction of the subsoil.

Texture

The texture of the soil is found to range from loam to clay loam in the surface and from clay loam to clay in the subsurface. The soils are also associated with more than 18 to 40% of gravel in all the samples. The sand content is significantly higher in the teak plantation, the silt content in natural forest and the clay content in rubber plantation. In most of the profiles the sand and silt content decrease and clay content increase with depth. This observation is in agreement with the findings of Pathak et al. (1964) from their studies on the physical and chemical properties of soil under cultivation and forest cover. A comparatively higher accumulation of clay with increasing depth indicates a high migration rate for clay from surface downwards. A higher content of clay (39.98%) in rubber and eucalyptus (37.61%) compared to 27.98% in the natural forest probably indicate a higher degree of soil weathering and clay formation, under the influence of rubber and eucalyptus. The ratio of non clay to clay fraction in the soils is found to be minimum in rubber (1.5) plantation indicating a higher degree of weathering compared to the natural forest where the ratio is much higher (2.5). In the case of eucalyptus plantation also the clay content is higher giving a ratio of 1.6 compared to 2.3 in teak and 2.5 in natural forest. The ratio is however highest in the case of natural forest indicating the predominance of non-clay fractions contributing to the texture of the soil. A greater degree of weathering is found to take place in soils planted to rubber and eucalyptus compared to teak or natural forests. The significance of rubber and eucalyptus in hastening the weathering and degradation of soil is thus clearly brought out. Many of the earlier scientists like Champion (1932), Castens (1933), Davis (1940) and Griffith and Gupta (1947) have reported that soils of teak plantations do not differ significantly from natural forests. Translocation of clay to subsoil in the different plantations also appears to be steady and at a more rapid rate than in natural forest. Such mechanical eluviation of clay from the top soil and its accumulation in the subsoil has been reported by Pathak et al. (1964) and Thomas (1964).

An examination of the data on single value constants has revealed that the physical conditions of the soils have been appreciably changed as a result of the influence of different plantations.

The bulk density and particle density of all the soils including the natural forest have increased with depth, the highest value for bulk density being recorded in the soils of the lowest horizon of eucalyptus plantation (1.25) and the highest particle density (2.31) in the lowest horizon of rubber plantation. The bulk density in teak soil is significantly lower than other plantations but it is definitely higher than the natural forest. It may be seen from the distribution of organic matter in various soils that its content also decreases with depth in the soil profile. A higher content of organic matter is known to be responsible for decreasing the bulk density of soils. Therefore, the increase in bulk density with depth in the profile may be the direct consequence of a decrease in organic matter which also show a corresponding decrease in content with depth. Higher values of particle density with increasing depth may be similarly due to a lower content of organic matter and a higher amount of minerals like quartz, feldspar, limonite etc. Page (1968) has reported a most significant change in physical parameters of the soil as a result of tree cropping due to the supply of organic matter from the leaf litter. Pathak et al. (1964) have reported higher values for bulk density and particle density and lower values for waterholding capacity, porespace and volume expansion in plantation soils compared to natural forest. Similar variations are observed in the single value constants of the soils of the different plantations and natural forest.

Waterholding capacity

The waterholding capacity of the soils which decreased with depth in the soil profile is highest (41.02%) in the natural forest and lowest (31.08%) in the rubber plantation. There existed a significant difference between this property among the various soils. Waterholding capacity is known to be mostly influenced by the organic matter content of the soil. The natural forest which has the highest amount of organic carbon (1.22%) is found to possess the maximum waterholding capacity and the rubber plantation showing the lowest organic carbon content (0.85%) recording the lowest waterholding capacity. The strong positive correlation (+ 0.7035) found to exist between these two characters in the soils also highlights the influence of organic matter on waterholding capacity of soils.

Pore space

Porosity of the soils also follow a more or less similar pattern, the values decreasing with depth and maximum values being shown in the natural forest (49.3%). Eucalyptus plantation record the lowest value (43.3%) which is appreciably lower than the other plantations. Pathak et al. (1964) have shown that porosity and waterholding capacity were higher in natural forest than the soils under cultivation. Such variations may be attributed to the difference in organic matter as well as clay content in the different soils. The positive correlation obtained between organic carbon and pore space affirm the role of organic matter in determining the porosity of soils.

Volume expansion

The volume expansion of the soils of different plantations also show much variation; the natural forest registering a significantly higher value than the plantations. Here again, the influence of organic matter seems to be critical as the colloidal organic particles can swell and enlarge in the presence of water, and give rise to a higher volume expansion. The significant positive correlation between organic carbon and volume expansion obtained in this study supports this observation. Thus, the physical properties of soils such as bulk density, particle density, waterholding capacity, pore space and volume expansion are found to be controlled by the organic matter content of the soils and, therefore it follows that the organic matter content of a soil is the critical factor in deciding the expression of these characters.

Since the natural forest remain comparatively undisturbed by physical and mechanical influences and maintain a cover of shrubs and grasses on the soil surface, a higher content of organic matter naturally accumulate in these soils. Moreover, a greater extent of canopy closure observed in the natural forest might have also helped in the build up of a higher amount of organic matter than in the plantations where the canopy closure is not uniform and complete. In the eucalyptus plantation, due to the drooping nature of the narrow leaves on the stem, a greater amount of sunlight could reach the soil surface through the year. Rubber and teak with maximum leaf shedding in January also expose the soil surface to a higher temperature for a comparatively longer period of time resulting in a faster rate of organic matter decomposition and consequently, a lower rate of accumulation.

Chemical properties

The pH values of the soils of the plantations and natural forest suggest that they are acidic in reaction. The acidity can be attributed to the long and continued leaching that these soils have been subjected to. Yadav et al. (1970) have pointed out that some evergreen forests of Western Ghats in the States of Mysore, Madras and Kerala are found acidic in reaction and poor in bases. The present investigation has also shown that the soils of natural forest and rubber are slightly more acidic than the soils of teak and eucalyptus plantations. In the case of natural forest the accumulation of organic matter in the surface soil which may give rise to organic acids during their decomposition may be the cause of higher acidity. This fact is in agreement with the findings of Requier (1953). According to him the removal of forest increased the pH of the soil by checking the subsequent accumulation of organic matter. Jose (1968) has also shown that the surface soils of natural forest are more acidic than those of various teak plantations.

The higher acidity in the soils of rubber may be as a result of more drastic leaching as evidenced by the greater downward movement of clay in their profile and also due to the low base status of the soil. This finding is in confirmity with the observation of Hesselman (1926) who found that the soils develop greater acidity if the leaves of trees occupying the land contain higher amount of acid. Fuller (1955) attributed this change in pH to be due to the removal of soluble salts by leaching.

The reason for the lower acidity in teak and eucalyptus than natural forest and rubber may be due to the accumulation of leaf litter of a comparatively higher base status. Doyne (1935) observed a similar condition in places where the leaves of trees contain a high content of bases.

Soil pH is found to be slightly lower under eucalyptus than in teak plantation. Such a finding has been recently reported by Tofey et al. (1986).

The significant negative correlation observed between pH and organic carbon supports the relationship between these two factors in the expression of soil acidity.

Cation Exchange Capacity and Base Saturation

It is seen that the soils of the natural forest which contain the highest amount of organic matter possess the maximum cation exchange capacity also. The higher value of CEC inspite of its lower clay content than the plantations indicates that the CEC is mostly contributed by organic matter in the soils of the natural forest. Such an observation has been previously made by Pathak et al. (1964). Base saturation in rubber plantation is found to be very low, while teak, eucalyptus and natural forest record more or less similar values. The low base saturation of the soils in the rubber plantation may possibly arise out of the very low content of bases released from the litter fall as well as to a comparatively poorer efficiency of the rubber tree in releasing the nutrients in a more mobile form from the total pool. This is indicated by a comparatively lower status of exchangeable bases in the rubber plantation.

Organic Carbon, Nitrogen and C/N ratio

The results have made it clear that organic carbon and total nitrogen are higher in the surface layers of natural forest compared to the three plantations. In all the profiles both organic carbon as well as total nitrogen decrease with depth giving rise to a corresponding narrowing of the C/N ratio. A higher content of carbon and nitrogen in the surface soils of natural forest indicates a slow rate of organic matter decomposition as well as a higher rate of accumulation or as has been pointed out earlier, it may be as a result of both these conditions as well.

From a comparison of the soils in natural forest and in forest cleared and planted with fir, Nakata (1954) has shown that organic matter was lower in the planted area than the natural forest. Lundgren (1978) has also found a higher organic matter content in the soils under natural forest than the plantations. Balagopalan and Alexander (1983) have reported a relatively lower content of organic carbon in eucalyptus plantation than natural forest. According to Kowal and Tinker (1959), clearance of a forest and subsequent cultivation lead to a decrease in the content of organic matter. They have attributed this situation to a greater exposure of the soil organic matter to both biological and chemical processes leading to its destruction.

It is of interest to note that the eucalyptus plantation which has contributed the highest amount of nitrogen through litter fall contain only the lowest amount (0.098%) of total soil nitrogen. The comparatively lower content of soil nitrogen in the eucalyptus plantation may be attributed to a higher uptake of this element from the soil thereby leading to a depletion in its status. At the same time, the rubber plantation which has contributed the least amount of nitrogen (48 kg/ha) through litter fall has maintained a comparatively higher amount of soil nitrogen (0.107%) suggesting a lower uptake of this element. Chapin and Kendrowski (1983) in a study on the seasonal changes in nitrogen in evergreen and deciduous trees concluded that during growing season there are changes in allocation of nitrogen associated with changing plant requirement. Thus, there seems to exist a relationship between the nitrogen content of the soil, the litter and the fresh leaves in a plantation, guided by the magnitude of recycling of the element through plant uptake as well as its release through mineralization.

The C/N ratio narrows to a value of 10 to 8:1 in the lowest horizon compared to 13 to 10:1 in the surface soil indicating a steady rate of leaching of nitrogenous compounds and a better incorporation of organic matter through the different layers of the soil profile. Organic carbon and total nitrogen show positive correlation indicating the intimate relationship between these two characters. This relationship has been proved by Puri and Gupta in 1951. Russel (1961) has attributed the fall in C/N ratio to the inclusion of ammonium ions held by the clay in a form in which they can be displaced only by treatment with a strong acid. He has also stated that the 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 mineralized form of nitrogen over carbon. A decrease in C/N ratio with depth has been pointed out earlier in teak plantation by Jose (1968) and in eucalyptus plantation by Balagopal and Jose (1983). Much higher C/N ratio than that obtained in the present study has been reported by Yadav and Pathak (1963).

Inspite of the comparatively lower content of total nitrogen, the available nitrogen content in rubber plantation has been found to be much higher. This condition points to a rapid rate of mineralization of litter in rubber plantation. Rubber leaves with a very low mass per unit area are more succumb to microbial degradation than teak and eucalyptus which possess a higher density for leaves. The maintenance of a larger pool of available nitrogen in the rubber plantation also reflects a state of very low absorption by the trees. Eucalyptus plantation which has recorded the highest content of nitrogen in the fresh leaves has only the lowest amount of available nitrogen in the soil reflecting a greater uptake. The different levels of available nitrogen in the plantations may thus indicate a dynamic balance between its uptake from the soil and its subsequent release from the biomass.

Available nitrogen shows a tendency to decrease in content with depth in the soil profile in all the plantations. It is considerably lower in the deeper horizons (59 kg/ha) compared to the upper horizons (292 kg/ha) in the same plantation. This may be correlated with a corresponding decrease in the status of total nitrogen in the different horizons. The rate of decrease in the case of available nitrogen is more pronounced compared to total nitrogen which has resulted in a higher ratio of total to available nitrogen with increasing depth. Available nitrogen is positively and significantly correlated with total nitrogen and organic carbon indicating the close linkage of nitrogen to the organic fraction of the soil.

Total and available mineral nutrients

The distribution of total and available phosphorus in the different horizons of the plantations shows a random pattern. Total phosphorus is highest in the natural forest (0.119%) while the available phosphorus is highest in teak plantation amounting to nearly 70 kg per hectare. Incidently, the teak plantation which contains the lowest amount of total phosphorus has exhibited the highest amount of available phosphorus. The status of available phosphorus is found to be much higher in the three plantations compared to the natural forest inspite of the fact that they contain only lower amounts of total phosphorus. Such an increase in the content of available phosphorus in the plantation soils compared to the natural forest tells upon a situation where more of the unavailable phosphorus is coming into the available pool under the specific influence of the plantation. This may be either due to the characteristics of the forest floor or due to the nature of the root system of the trees. A higher status of available phosphorus in the plantations may arise from the decomposition of the forest floor which may contribute about 14 kg/ha of phosphorus. A much higher content of available phosphorus than that can be expected from the contribution through the forest litter might have only arisen due to a greater solubilization of insoluble soil phosphates through the abundant biological activity in the forest floor. A higher status of available phosphorus in the forest soils may also due to the effect of mycorrhizal associations on the roots of forest trees as has often been observed (Alexander, 1977).

Potassium

The potassium status of the soils of eucalyptus plantation record a comparatively higher value (0.143%) than the other plantations. However, exchangeable potassium is the lowest (0.215 meq) in eucalyptus soil while,the teak plantation records the maximum value of 0.378 meq. The contribution of potassium through litter fall is seen to be highest in the case of eucalyptus (48.2 kg) compared to 16.6 kg in the case of teak and 9.7 kg in rubber. The lower status of exchangeable potassium in the soil of the eucalyptus plantation may thus be the net effect of a higher uptake and lesser recycling of potassium in this plantation. From the results on the potassium status of fresh, fallen and forest litter of eucalyptus it may be noted that there is a difference of 0.663%

between fresh leaves and freshly fallen leaves and between freshly fallen leaves and litter the difference is only nearly half of it. The difference between the potassium status of freshly fallen leaves and litter indicates the extent of loss of this nutrient through the processes of mineralization and leaching. It is possible that a greater proportion of potassium liberated from the litter is simultaneously taken up by the plants or leached down as indicated by the lower status of exchangeable potassium in the soil. The eucalyptus plantation thus appears to take up and release more of potassium than teak and rubber as evidenced from a greater proportion of it remaining in the litter of these plantations compared to eucalyptus.

Calcium and Magnesium

Exchangeable calcium is appreciably higher in eucalyptus plantation while the exchangeable magnesium status is higher in the natural forest. Venugopal (1969) has reported a higher content of exchangeable magnesium in natural forest. Among the three plantations, both exchangeable calcium and magnesium are highest in eucalyptus and lowest in rubber plantation. Contribution through annual litter fall is more than double for calcium (55.81 kg) than magnesium and both these figures are much higher than the corresponding figures in teak and rubber plantations. A higher contribution through litter fall may be the reason for the higher status of these elements in eucalyptus plantation. As in the case of potassium this may also bear a relationship with the extent of calcium and magnesium being mineralized from the organic matter, leaching and absorption by the plantation.

Data on the percentage of ash obtained from both fresh and fallen leaves indicate a higher ash content associated with a very high proportion of acid insoluble silica in the case of teak. The percentage of ash is found to be lowest in the fresh and fallen leaves of eucalyptus.

It may be noted from the results that maximum contribution of nutrients through litter fall has been provided in the eucalyptus plantation. At the same time, the difference between the status of nutrients in the fresh and freshly fallen leaves of eucalyptus suggest that a greater proportion of these nutrients are retained in the living plant biosystem through translocation from the senile to young tissues.

The results obtained from the present investigation thus point to a situation where the eucalyptus plantation by virtue of its making available a higher quantity of biomass for a recirculation helps to maintain a higher nutrient status in the soil compared to teak and rubber. The percentage of nutrients in the biomass of these two plantations eventhough register a higher magnitude, become less prominent when their contribution for recirculation is considered. At the same time, a greater amount of exchangeable nutrients are retained in the soils grown to teak and rubber where the release from fallen litter more than compensates its uptake.

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

A study has been made on the forest soils of the Kulathupuzha range, Kerala State with a view to investigate the extent to which the morphological, physical and chemical characters of these soils are affected by eucalyptus, teak and rubber plantations. The soils collected from several locations and from adjacent natural forests were made for their physico-chemical properties including profile description and root distribution. Plant and leaf litter samples were also collected from these locations and subjected to detailed chemical analysis to estimate the quantity of nutrients available for recirculation and to follow the effect of each vegetation on the nutrient status of the soil.

The important conclusions from the investigation are summarised below.

1. Maximum litter fall has taken place in January and minimum during October. The annual litter fall in a hectare of the plantation was highest in eucalyptus followed by teak and rubber. The maximum

contribution of all the plant nutrients for recirculation was also made by eucalyptus.

2. There was significant difference between the nutrient status of fresh, freshly fallen and forest litter samples in the different plantations. Mobilization is seen to be maximum in teak for nitrogen and calcium in eucalyptus, for phosphorus and potassium in teak and for magnesium in rubber. Mineralization appears to be higher in the case of rubber as seen from the comparative study of the mature leaves, fallen leaves and forest litter.

3. A higher percentage of ash and acid insoluble residue was noticed in the leaves and litter in teak compared to rubber and eucalyptus.

4. The eucalyptus plantation which provides a greater amount of biomass for mineralisation and recirculation of nutrients has helped to maintain a higher content of nutrients in the soil compared to teak and rubber plantations.

5. In most of the profiles, the colour of the soil

was dark yellowish to dark brown in the surface followed by reddish brown to yellowish in the subsurface layers. The colour of the surface soil was of a uniform hue (10 YR) the intensity of value and chroma alone showing slight variations. The colour of the subsoil was darker and it varied from 7.5 YR to 5 YR which showed an increase with depth of the soil.

6. A more or less uniform granular structure was noticed in the surface soil with fine or medium and subangular blocky structure in the subsoil. The predominance of coarse roots in the subsoil is indicative of a poor penetration of fine roots due to a greater compaction of the subsoil.

7. The texture of the soil ranged from loam to clay loam in the surface and from clay loam to clay in the subsurface. Higher amount of sand was seen in teak, silt in natural forest and clay in rubber plantation. In all the profiles the sand and silt decreased and clay content increased with depth indicating a higher migration rate for clay

from the surface downwards. Translocation of clay to the subsoil in the different plantations was steady and at a more rapid rate than the natural forests.

8. A higher content of clay as well as a narrow ratio of non-clay to clay fraction in the rubber plantation indicating a higher degree of weathering and clay formation in these soils.

9. Higher values for bulk density and particle density and lower values for waterholding capacity, pore space and volume expansion were noticed in plantation soils compared to natural forest where the organic matter content was higher. In all the soils including natural forest, the bulk density and particle density showed a tendency to increase with depth while the values for waterholding capacity, pore space and volume expansion showed a reverse order. All the single value constants were found to be influenced by the organic matter content of the soil which may be considered as a deciding factor in determining these properties of soils.

10. Organic carbon and total nitrogen were higher in the surface soils of natural forests. It indicates a slow rate of decomposition and a higher rate of accumulation made possible by a greater extent of canopy closure in the natural forests.

11. The C/N ratio narrowed from the surface horizon to the lowest horizon in all the profiles indicating a steady rate of leaching of nitrogenous compounds and a better incorporation of the organic matter through different layers of the soil profile.

12. The eucalyptus plantation which contributed the highest amount of biomass nitrogen through litter fall contained only the lowest amount of total and available nitrogen in the soil. This indicates the relationship between the magnitude of plant uptake and its availability for recycling through mineralization of litter. Though the content of total nitrogen was low in rubber plantation, its available nitrogen status was high. This may be due to a lesser plant uptake and rapid rate of mineralization of the litter. Available nitrogen

showed a decreasing tendency with depth in all the profiles. The rate of decrease in available nitrogen was more pronounced with depth compared to total nitrogen leading to a higher ratio of total nitrogen to available nitrogen with increasing depth in the profile.

13. The distribution of total and available phosphorus in the different horizons of the plantations showed a random pattern. Total phosphorus was highest in the natural forest while available phosphorus was highest in teak plantations which incidentally contain the lowest amount of total phosphorus. Available phosphorus was much higher in the three plantations compared to natural forest eventhough the content of total phosphorus was higher in the natural forest. This may be due to more of the phosphorus coming into the available pool under the specific influence of the plantations. A much higher amount of available phosphorus than that could be expected through the contribution from the biomass might have arisen due to a greater

solubilization of insoluble phosphates from the soil due to mycorrhizal activity on the surface of the roots.

14. Though the content of total potassium in the soil and the contribution of potassium through litter fall was higher in eucalyptus, the exchangeable potassium in the soils of this plantation was comparatively very low. This condition reflects an equillibrium between its uptake as well as availability for recycling. The uptake of potassium appears to be lower in teak and rubber than in eucalyptus as evidenced from a greater proportion of its remaining in the litter from teak and rubber compared to eucalyptus. Eventhough the eucalyptus plantation contained the highest amount of calcium, it contained only the lowest amount of magnesium.

15. Soils from natural forest which contain the maximum amount of organic matter possess the highest cation exchange capacity which has been mostly contributed by the organic matter content of the soil.

16. Soils of the natural forest, teak and eucalyptus plantation showed more or less similar values for base saturation. The very low content of bases in rubber plantation might have resulted due to the meagre supply of bases through the mineralisation of litter in this plantation.

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APPENDICES

ANALYSIS OF VARIANCE

APPENDIX 1

PHYSICAL PROPERTIES OF SOIL

SOURCE	df	MEAN SQUARE		
		SAND	SILT	CLAY
TREATMENTS	15			
BETWEEN PLANTATIONS	3	92.26xx	571.51xx	798.03xx
BETWEEN HORIZON	3	219.95xx	185.09xx	747.39xx
PLANTATION x HORIZON	9	19.60xx	102.25xx	62.67x
ERROR	80	4.18	19.70	26.74

xx SIGNIFICANT AT 1% LEVEL

x SIGNIFICANT AT 5% LEVEL

ANALYSIS OF VARIANCE

APPENDIX 2

PHYSICAL PROPERTIES OF THE SOIL (SINGLE VALUE CONSTANTS)

SOURCE	df	MEAN SQUARE				
		BULK DENSITY	PARTICLE DENSITY	WATER HOLDING CAPACITY	PORE SPACE	VOLUME EXPANSION
TREATMENTS	15	0.0347 xx	0.047 xx	165.65 xx	211.45 xx	8.55 xx
BETWEEN PLANTATIONS	3	0.117 xx	0.167 xx	416.37 xx	885.18 xx	10.01 xx
BETWEEN HORIZON	3	0.0502 xx	0.058 xx	389.29 xx	141.06 xx	25.90 xx
PLANTATION x HORIZON	9	0.00205	0.004	7.54	11.01 xx	2.28 xx
ERROR	80	0.0028	0.006	6.70	3.65	0.59

xx SIGNIFICANT AT 1% LEVEL

x SIGNIFICANT AT 5% LEVEL

ANALYSIS OF VARIANCE

APPENDIX 3

CHEMICAL PROPERTIES OF SOIL

SOURCE	df	MEAN SQUARE													
		ORGANIC CARBON	LOSS ON IGNITION	TOTAL NITROGEN	C/N RATIO	AVAILABLE NITROGEN	TOTAL PHOSPHORUS	AVAILABLE PHOSPHORUS	TOTAL POTASSIUM	EXCHANGEABLE POTASSIUM	EXCHANGEABLE CALCIUM	EXCHANGEABLE MAGNESIUM	CATION EXCHANGE CAPACITY	BASE SATURATION	pH
TREATMENT	15	1.80^{xx}	14.73^{xx}	0.006^{xx}	38.32^{xx}	55638.15^{xx}	0.003^{xx}	3473.97^{x}	0.004^{xx}	0.157^{xx}	0.709^{xx}	0.320^{xx}	15.810^{xx}	512.29^{xx}	0.24^{xx}
BETWEEN PLANTATION	3	0.59^{xx}	56.98^{xx}	0.0009	9.79^{xx}	23726.5^{xx}	0.007^{xx}	6478.08^{xx}	0.005^{xx}	0.110^{xx}	2.973^{xx}	0.965^{xx}	18.656^{xx}	1586.96^{xx}	1.05^{xx}
BETWEEN HORIZON	3	7.46^{xx}	11.97^{xx}	0.027^{xx}	162.95^{xx}	242929.2^{xx}	0.005^{xx}	2673.97^{x}	0.012^{xx}	0.393^{xx}	0.345^{xx}	0.565^{xx}	50.566^{xx}	93.21	0.07^{xx}
PLANTATION x HORIZON	9	0.31^{xx}	1.57	0.001^{x}	6.29^{xx}	3845.03	0.0004	2739.26^{xx}	0.002	0.093^{xx}	0.076^{xx}	0.023	3.276^{xx}	293.76^{xx}	0.04^{xx}
ERROR	80	0.01	3.36	0.0005	1.11	1928.74	0.0004	931.80	0.001	0.012	0.024	0.035	0.135	37.72	0.008

xx SIGNIFICANT AT 1% LEVEL

x SIGNIFICANT AT 5% LEVEL

ANALYSIS OF VARIANCE

APPENDIX 4

CHEMICAL PROPERTIES OF FOREST LITTER

SOURCE	df	MEAN SQUARE														
		NITROGEN			PHOSPHORUS			POTASSIUM			CALCIUM			MAGNESIUM		
		January	May	October	January	May	October	January	May	October	January	May	October	January	May	October
FOREST LITTER	2	1.0420^{xx}	0.8026^{xx}	0.9339^{xx}	0.0007^{xx}	0.0011^{xx}	0.0046^{x}	0.0831^{xx}	0.0821^{xx}	0.0013	0.1751^{xx}	0.0417^{xx}	0.0177^{xx}	0.0002	0.0012	0.0208^{xx}
ERROR	15	0.0008	0.0018	0.0009	0.00002	0.00008	0.0008	0.0022	0.0024	0.0009	0.0018	0.00077	0.0025	0.0007	0.0007	0.0004

APPENDIX 4 Contd.

SOURCE	df	MEAN SQUARE														
		LOSS ON IGNITION			ASH CONTENT			ACID INSOLUBLE ASH			WEIGHT			THICKNESS		
		January	May	October	January	May	October	January	May	October	January	May	October	January	May	October
FOREST LITTER	2	38.1094^{xx}	45.8828^{xx}	57.0859^{xx}	38.1116^{xx}	45.8672^{xx}	57.0705^{xx}	4495.842^{xx}	4990.612^{xx}	4557.136^{xx}	62.4022^{xx}	9.1272^{x}	20.1468^{xx}	3.4067^{xx}	0.98^{xx}	0.5644^{xx}
ERROR	15	0.0875	0.1073	0.0948	0.0881	0.1068	0.0944	4.2956	0.2943	1.9543	3.7058	1.8602	1.7960	0.0791	0.0027	0.0024

xx SIGNIFICANT AT 1% LEVEL

x SIGNIFICANT AT 5% LEVEL

ANALYSIS OF VARIANCE

APPENDIX 5

CHEMICAL PROPERTIES OF FRESH LEAVES

SOURCE	df.	MEAN SQUARES							
		NITROGEN	PHOSPHORUS	POTASSIUM	CALCIUM	MAGNESIUM	LOSS ON IGNITION	ASH CONTENT	ACID INSOLUBLE ASH
FRESH LEAVES	2	0.6399 xx	0.0042 xx	0.0925 x	1.1467 xx	0.0097 xx	494.5352 xx	26.6665 xx	4478.363 xx
ERROR	15	0.0023	0.00008	0.0235	0.0071	0.0005	5.4073	0.0303	0.1099

xx SIGNIFICANT AT 1% LEVEL

x SIGNIFICANT AT 5% LEVEL

ANALYSIS OF VARIANCE

APPENDIX 6

CHEMICAL PROPERTIES OF FRESH FALLEN LEAVES

SOURCE	df.	MEAN SQUARES							
		NITROGEN	PHOS-PHORUS	POTA-SSIUM	CALCIUM	MAGNE-SIUM	LOSS ON IGNITION	ASH CONTENT	ACID INSOLUBLE ASH
FRESH FALLEN LEAVES	2	1.1084 xx	0.0046 xx	0.0939	0.1991 xx	0.0164 xx	60.3359 xx	31.3784 xx	4061.828 xx
ERROR	15	0.0041	0.0001	0.0776	0.0005	0.00008	0.0927	0.0221	0.0401

xx SIGNIFICANT AT 1% LEVEL

x SIGNIFICANT AT 5% LEVEL

NUTRIENT RECYCLING UNDER MONOCULTURE CONDITIONS IN THE TROPICAL FOREST ECOSYSTEMS

BY

S. PREMA KUMARI

ABSTRACT OF THE
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COLLEGE OF AGRICULTURE
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ABSTRACT

A study has been made on the forest soils of the Kulathupuzha range in Kerala State with a view to determine the extent to which the morphological, physical and chemical characters of these soils are affected by eucalyptus, teak and rubber plantations. The soils collected from several locations and from adjacent natural forests were studied for their physico-chemical properties including profile description and root distribution. Plant and leaf litter samples were also collected from these locations and subjected to detailed chemical analysis to estimate the quantity of nutrients available for recirculation and to follow the effect of each vegetation on the nutrient status of the soil.

A study of the soils of the three plantations in comparison with the natural forest has shown that considerable variation in their physico-chemical properties has taken place due to the influence of the three plantations.

In all these soils the sand and silt content decreased and clay content increased with depth in the profile. A higher content of clay observed in rubber and eucalyptus plantations compared to teak and natural forest indicates a greater degree of weathering and clay formation in them. The physical properties such as BD, WHC, pore space, volume expansion and CEC were found to be positively influenced by the organic matter content of the soil and were higher in the natural forest which contained a greater amount of organic matter compared to the plantations. In all these soils, the C/N ratio narrowed from the surface to lower horizons.

The eucalyptus plantation which has provided a greater amount of biomass nitrogen for recirculation recorded the lowest amount of soil nitrogen while the rubber plantation which supplied the least amount of nitrogen has maintained a comparatively higher content. The status of soil nitrogen in the plantations may represent a state of dynamic balance between its uptake from the soil and subsequent release from the biomass.

The plantation soils though contain only a lower amount of total phosphorus than the natural forest registered a higher content of available phosphorus. The specific influence of the plantations in making more of available P from the unavailable pool is evident.

The total potassium status in the soils of eucalyptus plantation recorded comparatively higher values while the values for exchangeable potassium were lowest in them. This situation may indicate a lower release as well as a greater uptake of the element. Exchangeable calcium and magnesium were also higher in the eucalyptus plantation compared to the others.

The analysis of the plant tissues indicates a higher ash content associated with a very high proportion of acid insoluble residue in the case of teak.