EFFECT OF CONTINUOUS CULTIVATION OF RUBBER *(HEAVEA BRASILIENSIS)* ON SOIL PROPERTIES

By

M. KARTHIKAKUTTY AMMA

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DECLARATION

I hereby declare that this thesis entitled "Effect of continuous cultivation of Rubber (*Hevea brasiliensis*) on Soil properties" is a bonafide record of research work done by me and that no part of the thesis has been presented earlier for any degree, diploma, fellowship of similar title of any other University.

M. Karthikakutty Amma
Senior Scientist,
Rubber Research Institute of India
Kottayam.

Kottayam,
27-06-1995.

CERTIFICATE

This is to certify that the thesis entitled "Effect of continuous cultivation of Rubber (*Hevea brasiliensis*) on Soil properties" is an authentic record of work carried out by Smt. M. Karthikakutty Amma under my supervision and guidance and that no part of this has been presented before for any other degree.

Dr. R. S. Aiyer
Professor & Head,
Dept. of Soil Science & Agrl. Chemistry
(Retd.)
Kerala Agricultural University
College of Agriculture,
Vellayani 695 522

Vellayani,
27-06-1995.

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KOTTAYAM
27.06.1995

M. KARTHIKAKUTTY AMMA

Dedicated

to

the fond memory

of my

beloved parents

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1. INTRODUCTION

Hevea brasiliensis, a tree native to the tropical rain forests of Amazon is the source of 99 per cent of the natural rubber produced in the world. The tree was introduced in the eastern hemisphere towards the end of the nineteenth century by Sir Henry Wickam. In India though the crop was introduced only during the dawn of this century, rubber is now the third largest crop next to rice and coconut in Kerala. Rubber plantations occupy about 16 per cent of the geographical area and makes significant contribution to the economy of the state. The consumption of natural rubber in the country which was barely 15,000 tons in 1951, has now reached 4.45 lakh tons during 1993-94.

India ranks as the fourth largest producer of natural rubber next only to Thailand, Indonesia and Malaysia. However, it accounts only 5.3 per cent of the total area under rubber plantation in the world. The cultivation of this crop had been confined to a narrow tract in the south western side of Western ghats upto 1960's till plantations of rubber were raised on a trial basis in some non-traditional regions as in north eastern India. Nevertheless, about 93 per cent of the production and 86 per cent of the area are in the traditional rubber growing region, comprising of Kerala and the adjoining districts of Tamilnadu and Karnataka.

Rubber plantations were earlier raised mostly in freshly cleared forest areas where soil fertility conditions were better compared to cultivated areas of the same agroclimatic zones. The economic life span of rubber tree is around 30-32 years and hence the plantations will have to be replanted after the above period. Already rubber plantations in Kerala have entered the third replanting cycle and the continuous relay cropping which involves significant recycling of nutrients and import/export of biomass will have profound influence on soil health.

The forests of Kerala comprises of evergreen, semi-evergreen and moist deciduous types accounting for 84 per cent of the total forest cover. Many species existed in the original dense forest have been destroyed chiefly by man which included raising of plantations (Mehr-Homji, 1980). Analysis of topographic maps and Landsat imagery indicate that the natural vegetation cover of the state has come down from, 44 per cent in 1905 to 14 per cent in 1983. According to Chattopadhyaya et al. (1985), with the deforestation rate of 0.30 per cent, the entire natural vegetation cover is likely to get depleted in another 40-50 years, if the present trend continues.

In the humid tropics, soils are often highly acidic due to intense leaching and hence suffer multiple deficiencies of nutrients (Sumner and Hylton, 1994). Forest soils are also no exception to this. The luxuriant vegetation found in tropical forests depends mainly on the recycling of nutrients rather than on the soils themselves. These forests are a vital link in the conservation of the fragile ecosystem. Rubber plantations have replaced such fragile ecosystem by the adoption of agromanagement practices including growing of leguminous cover crop. After the economic life span of rubber plantation, the trees are cut down enmasse and removed which leads to removal of biomass to the tune of around 400 to 450 tonnes per cycle per hectare.

Rubber trees are found to sustain on majority of soils of the tropics with good soil depth and a pH range 4.0 to 6.5, but the crop will tolerate pH in the range 3.8 to 8.0

(Dijikman, 1951). It has already been established that soil physical and physiographical features contribute significantly to the growth of rubber (Chan et al., 1974). Trial plantings carried out in Sri Lanka, Sumatra and Java established that this tree has wider adaptability to various situations.

Rubber cultivation in India is mainly confined to the soil orders alfisols and ultisols (Krishnakumar, 1989). Eventhough deficient in both organic matter and essential plant nutrients, these soils possess ideal physical properties which are more important for the growth of tree crops.

Voluminous literature is available on the impact of forestry plantations on the forest ecosystem (Evans, 1982). But specific comparison of rubber plantations at various cycles with natural forest is lacking.

The *Hevea* ecosystem can attain levels similar to that of the more luxuriant humid tropical evergreen forest systems. Further it may be possible by extra, than normal, manuring to further enhance the biomass potential of *Hevea* stands as well as its true nutrient bank status and native soil fertility levels. This requires a detailed study of the rubber ecosystem and its effect on the soil during the first, second and third cycles continuously in different locations.

In future, plantation activities in Kerala will mostly be in areas subjected to continuous cropping with rubber (beyond three cycles) and an indepth knowledge on the attributes of the soil is required to evolve sustainable yield and soil health.

The present invenstigation were carried out in this context with the following objectives :

1. To study the various soil properties in natural forest and to compare these with soils under rubber in the third planting cycle,

2. To monitor the sequential changes in nutrient status of soil under rubber in different planting cycles,

3. To assess the nutrient removal from rubber plantations during each planting cycle and

4. To suggest possible changes in nutrient management to be adopted for refining the package of practices.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Conversion of natural forests to agricultural land was mainly done to meet the ever increasing demand for land by the growing population. Forest lands are converted to agricultural lands mainly in two ways. In one situation widely referred to as shifting cultivation (popularly known as 'Jhumming' in India) forest lands are cleared, the organic residues burnt and put for the cultivation of annual crops for three or four years. These lands will be abandoned when the soil productivity declines. Nye and Greenland (1960) observed that 'Jhumming' resulted in increased run off and soil erosion resulting in the deterioration of soil physical properties. In the other situation, forest lands are cleared and put under plantation of tree crops like rubber, cocoa, teak, oil palm, tea, etc. Here the practice is to do monoculturing of a particular species after replacing the diverse population of plants in the forest.

Evans (1982) made a critical assessment of increasing importance of forest plantations in the tropics because of the much reduced diversity of plantation ecosystem, the susceptibility of forest plantations to pests and diseases and maintenance of productivity in the long term. Plantations consist of a few species only but rain forest consists of 70-100 species/ha. Even though exotic species may be present in a plantation, natural forest is obviously made up of all the native ones. In plantations, trees are of the same age and show relatively small variation in size whereas in natural forests all ages and all sizes of trees are represented. A plantation consists essentially of one layer, but forests have many layers, emergent trees, upper and lower canopy trees, tall shrubs, ground vegetation and plants such as lichens and ephiphytes which add further to the diversity for forest structure. Within the soil, monoculture crops use less available rooting space than multispecies vegetation. Nair (1977) found that pure stands of coconut occupied only 23% of the potential rooting zone. Prichett (1979) also has compared forest soils with agricultural soils. In forests the continued deposition of leaves and other debris creates a kind of organic mulch in surface soil which results in a more stable soil microclimate and provides conditions for a wider spectrum of soil animals and microorganisms. The activity of these organisms and the leaching of organic acids and other decomposition products result in substantial differences in chemical, physical and biological properties of the two groups of soils.

The implications of land degradation in the tropics are far reaching. At the global scale, degradation of natural resources leads to loss of gene pools and biological diversity, exacerbation of climate change through the increase of green house gases in the atmosphere and altered hydrological cycles (Brown et al., 1994). A review of the investigations on the physical and chemical changes happening to forest soil as a consequence of replacing the forest mostly by monoculture tree plantations is attempted here. Mention is also made regarding the biomass removal in forests and monoculture rubber plantations.

Physical porperties

Desirable physical properties are needed for favourable growth of plant roots and also to supply moisture and nutrients to the plants. Texture and structure of the soil are the two major criteria deciding the physical properties of soil and thereby affecting plant growth. Similarly increase in bulk density of a soil reduces porosity and degree of soil aeration and adversely affect the growth and development of roots. Trouse and Humbert (1961) reported that such effects make the roots flattened resulting in root growth restriction.

The impact on soil physical properties when natural forests were converted into teak plantation was studied by Jose and Koshy (1972). They observed that physical properties of 120 year old teak plantations were similar to natural forests and plantation in other ages were inferior to forests.

Greenland (1977) reported that the structural changes in the surface soils are mostly reversible, although several years under pasture may be required for a change to native physical conditions. Changes in the subsoil are much less easily reversed.

Jha *et al*., (1979) while investigating the changes occuring as a result of adopting the practice of 'Jhumming' in the forests of Tripura, North Eastern India, observed that 'Jhumming' resulted in lowering of the water holding capacity of the soil as compared to forest soils. This difference was attributed to the lower levels of organic matter in the surface layers of jhummed areas. Similar observations were made by Woodmasse and Wallah (1981). They attributed the high rate of organic matter decomposition and high microbial activity in the jhummed area as the possible reason for soil degradation. Such condition favoured surface run off and erosion.

The change in soil properties due to continuous teak cropping was studied by Alexander et al., (1981). They took soils from the profiles of teak preservation plots under first and second rotations in two locations. In one location there was no significant difference while in the other location the particle size distribution was different with respect to forest lands. Sand content decreased and silt and clay increased with depth in deforested soil.

Deforestation and continuous cropping resulted in an increase in bulk density and particle density and a reduction in pore space of surface soil due to the destruction of organic matter (Prichett, 1979).

Russel (1983) compared the particle size distribution and bulk density of plantations of different ages ranging from six months to eight years, with natural forest at Jari, Para, Brazil. No significant difference was observed by him in the above properties.

Reena and Nair (1985) compared the moisture retention characters of soils of cultivated lands and forests. The forest soils had high moisture retention capacities. Clay and silt showed significant positive correlation with moisture retention capacity while organic carbon failed to show any relation.

Prasad et al., (1985) studied the changes occuring due to the conversion of natural forests (moist decidious) with mixed and teak plantation. After a 40 year period of establishing the plantation, they observed initiation of illuviation process in teak plantation. However, morphological feature remained unaffected. Adejuwon and Ekanade (1987) investigated the deterioration caused due to the cultivation of cocoa adjacent to natural forests in Nigeria. Bulk density, total porosity and particle size distribution were estimated and substantial increase in bulk density was noticed in cocoa planted areas.

Aweto (1987) studied the physical and chemical properties of soils under rubber plots of 1, 7, 11, 14 and 18 years of age along with natural forests to examine the trend of change in soil properties over time. The change in bulk density over time was not significant. While judging the physical status of the soil on the basis of porosity and bulk density values, it was concluded that secondary forests were only slightly better than rubber plantations of 18 years age.

Ekanade (1985) also reported that the texture, bulk density and total porosity of soils under cocoa plantations are degraded when compared with soils under natural forest. Regarding texture, the sand and clay contents differed significantly between the two situations. From this observation, it was concluded that when forests were converted to cocoa plantation, notwithstanding the evergreen nature of cocoa vegetation, the physical properties deteriorate significantly.

Elizebeth, C. (1988) in a study of physicochemical and biological properties of high elevation tea soils of Ponmudi in Kerala, India has reported that texture of tea soils of Ponmudi is of uniform clay loam type, indicating the dominance of clay compared to silt and sand fractions. Higher values for bulk density and particle density were observed in the soils. A higher content of clay (39.88 per cent) in rubber, and 37.61 per cent in eucalyptus plantations compared to 27.98 per cent in natural forest probably indicated a higher degree of weathering and clay formation under the influence of rubber and eucalyptus (Premakumari, 1987).

Ministry of Agriculture, Malaysia (1989) conducted a study on the impact of clearing a rain forest for oil palm cultivation. It was noticed that the rate of soil erosion dramatically increased as the forest was cleared. Increased gradients of land had aggravated this problem. In the cleared land, rate of infiltration was also lower. But when the legume cover crop was well established, this problem could be reduced and could reach levels similar to those noticed in the forest lands. A well managed mono culture of oil palm could be as good as a forest.

Norhayati, and Lau (1990) conducted studies on fertility changes that occured in 50 months after rubber cultivation in Malaysia. Both in the top soil and subsoil, land clearing resulted in breakdown of soil physical properties. Bulk density values increased after the removal of forest vegetation. In the top soil bulk density increased from 0.8 Mgm^{-3} under jungle to 1.5 Mg m^{-3} after burning, then with the cultivation of legume cover, bulk density gradually decreased but never reached the original level noticed in the forest.

Krishnakumar et al., (1990) quantified the influence of rubber plantation on soil physical properties with special reference to moisture retention in Tripura, North Eastern India. It was reported that rubber plantation adopting proper management practices helped in the enrichment of organic matter which subsequently improved physical properties such as bulk density, soil porosity, moisture retention and infiltration.

Mongia et al., (1991) has reported that conversion of tropical rainforest into red oil palm plantations without adopting soil conservation measures resulted in the increase of silt load, in Little Andaman islands, Andaman. Soil loss was only 3.5 tons/ha under forest while it was 4.27 tons/ha in two year old plantation. The soil loss from 11 year old plantation at two sites differing in physiographic features was 45.8 tons per hectare and 11.8 tons per hectare respectively. As a result of the thick canopy in older plantations, there was no surface cover underneath. Water trickles directly from the fronds, hits the soil surface and detaches the soil to be carried away with run off water. Bulk density also increased from 0.92 Mg m^{-3} to 1.28 Mg m^{-3} in 11 years of plantation establishment. Profile moisture storage capacity was also found to be considerably reduced which was caused by a decrease in retention time of water intake rate of soil.

Aswalam *et al.*, (1991) investigated the effect of rubber cultivation on soil properties in Nigeria. They observed that conversion of forest to rubber plantations resulted in increased clay content and a decrease in sand content.

Mathan and Kannan (1993) studied the variation in physical properties in Kodaikanal hills of Tamilnadu as influenced by different vegetations. Sand fraction and bulk density were found to be high in plantation crop (teak + silver oak) area when compared to forest area. Considerable reduction in hydraulic conductivity was noticed in plantation areas.

Aweto and Ishola (1994) studied the impact of a 20 year old cashew plantation on physical properties of soil by comparing the soil under cashew with the adjoining logged natural forest in southern Nigeria. There was no significant difference in the sand, silt or clay contents in 10 - 20 cm of soil, but the sand content was smaller and silt and clay components greater in 0-10 cm layer under cashew plantation.

Chemical properties

The humid tropical forest lands in Kerala is predominantly occupied by the highly weathered soils with very low nutrient reserve. The degradation happening to soil organic matter makes the soil impoverished and reduces soil productivity. Natural forest is a closed ecosystem and there will be recycling of nutrients. When such lands are put to other cultivation, there will be a lot of change happening to the physico chemical properties of soils. A brief review of the chemical changes occuring to the soil when forest vegetation is removed and put for other agricultural uses is attempted here.

Kowal and Tinker (1959) noticed substantial decline in the level of cationic nutrients (K, Mg and Ca) in the soil in Urhobo district, Benin, Southern Nigeria during the twenty years of plantation establishment.

While studying the changes happening due to forest clearing and plantation establishment, Nye and Greenland (1964) observed a rapid loss of organic matter in the first year after forest clearing. This was due to the rapid oxidation of unhumified materials. The CEC and nutrient contents were also low in the cultivated land.

In Kenya the conversion of indigenous forest land into <u>Cupressus lustanica</u> (exotic softwood) plantations resulted in a drop in organic carbon and phosphorus content (Robinson 1967).

Cornforth (1970) found that on coarse textured soils in Trinidad, Pinus caribea had led to a depletion of Nitrogen and most mineral nutrients compared with natural forests. Juo and Lal (1977) compared the properties of continuously soyabean cultivated soil with natural forest and noticed decline in soil organic matter and pH in cultivated fields. They suggested that in order to maintain soil organic matter in surface soil at a level comparable to soils under secondary forest two to three application of a total amount of 16 MT/ha/yr of dry plant material are required when the material is applied as surface mulch.

An increase in total exchangeable basic nutrients under broad leaves plantation was reported by Iyambo (1973) and Chijicke (1980).

Valentine (1976) working with distinctive changes following clear cutting and burning in the Karsi forest division of South Western Australia has reported that organic matter content, total soluble salts and exchangeable Calcium, Magnesium and Potassium declined rapidly in the first seven years.

While exploring the changes occuring in soil due to the cultivation of *Pinus caribaea* in Kaduna, Nigeria after clearing natural forest, no significant changes in exchangeable bases was observed (Kadeba and Onweluzo 1976).

Broughton (1977) reviewed research on leguminous cover crops under rubber in Malaysia and concluded that when using a mixture of creeping legumes, the initial growth rates of rubber were faster and the soil generally contained more Nitrogen, Calcium and Magnesium than under grass or natural weed cover. Leguminous cover under rubber fixed an average of 150 kg Nitrogen $ha^{-1}yr^{-1}$ over a five year period. Ninety six per cent of the biomass benefit of the leguminous cover was attributed to root proliferation of rubber and four per cent to nitrogen fixation.

According to Pushparajah and Tan, (1976) the advantage of the legume cover crop may be due to reduction in soil erosion and weed control. They had observed that 1100 kg ha^{-1} of Nitrogen fertilizer had to be applied to grass cover over 5 years to achieve similar yields to those obtained with an understorey legume.

The benefit of growing a legume could be seen in the production of rubber even 20 years after the plantation was established eventhough the legumes had died out 4 to 5 years after establishment.

Lundegren (1978) in his investigation on soil conditions and nutrient cycling under natural and plantation forest in Tanzanian high lands observed lower pH in conifer plantation as compared to adjacent natural forest. This was attributed to the humic acid which was formed as a result of the slow and inhibited litter decomposition in conifer plantation. The organic matter status was also reported to be low in the manmade plantation which is always having only a defined environment. A thourough review of the effect of fast growing tree plantations on soil dynamics in tropical highlands and sub tropical regions was made by him. He proposed a conceptual model for the dynamics of organic matter, nutrients and bulk density during the seven different stages of plantation development. According to this model soil organic matter decreases after clearing, burning and plantation establishment. After canopy closure - the fallow enrichment phase - organic matter increases but then decreases during the maximum production phase, which terminates with the harvest of the first rotation. Organic matter decreases after felling, logging, burning and the start of the second rotation. Bulk density follows a pattern opposite to that of organic matter. Mineral nutrients increase after clearing, but then decrease throughtout the three stages of the first rotation.

Koyamu and Nambiar (1978) also believed that the lowering of pH in plantations might be due to the application of acid forming fertilizers, production of organic acids in the process of decomposition of organic matter and uptake of cations from the soil by the crop.

The effect of forest clearing and planting of Gmelina arborea on a fertile alfisol of Omo-Ajebandele was investigated by Chijcke (1980). An increase in available Phosphorous and exchangeable Potassium and a decrease in organic carbon was noticed in the cultivated area.

Covington (1981) recorded a decrease in organic carbon, following clear cutting in northern hard woods.

While comparing plantations of different ages from six months to eight years, with natural forest, Russel (1983) noticed no significant difference in top soil organic carbon and exchangeable nutrients.

Balagopalan and Jose (1984) obtained significant drop in organic carbon and total nitrogen in eucalyptus plantations when compared to adjacent evergreen forests of Kerala.

Sanchez et al., (1985) noticed a 15 per cent reduction in top soil total Nitrogen in a Malaysian ultisol in relation to original forest value when rubber was cultivated continuously for 16 years with legume ground cover in the early years. They also reported that such reductions were 28 per cent when oil palm was cultivated for 14 years after forest clearing in an ultisol of Ivory cost.

Conversion of natural forest into mixed and teak plantation in Coimbatore forest division, Tamilnadu after 40 years resulted in loss of organic carbon, Phosphorous and Magnesium (Prasad et al., 1985). The loss was more under teak plantation than under mixed plantation.

Aweto (1987) investigated the changes in organic carbon and soil mineral nutrient status in rubber plots of 1, 7, 11, 14 and 18 years of age as compared to natural forest. In spite of application of NPK fertilizers, soil mineral nutrient status was found to be lowered after 18 years. Most of the decline occurred during the first eleven years which coincided with the rapid phase of rubber growth (Shorrocks 1965b). However, there was no change in organic carbon by the 18th year.

In cocoa cultivated area in Nigeria adjacent to natural forest, Adejuwon and Ekanade (1987) also observed decline in organic carbon, Nitrate-Nitrogen, Calcium, Sodium, Potassium, Magnesium and CEC of top soil. In subsoil the changes were not significant.

Nath <u>et al</u>., (1988) reported the effect of change of vegetation on alteration of soil properties in a contiguous area of the Kalimpong division of West Bengal. An increase in pH and base saturation was observed in teak cultivated area and the soil was transformed from inceptisol to mollisol. But the cultivation of Shorea robusta (sal) did not change much of the properties of the original soil.

Soil changes consequent upon the replacement of tropical rain forest by Gmelina arborea, Tectona grandis and Terminalia superba were investigated by Adejuwon and Ekanade (1988) in Nigeria. Exchangeable cation under broad leaved plantations were comparable to that of natural forest.

The Malaysian Ministry of Agriculture (1989) conducted a study on the impact of clearing rain forest for oil palm cultivation in Sungei Tekar Experimental Station, Malaysia. The study carried out for seven years indicated decrease in pH in oil palm plantation. Eventhough initially lower organic carbon and CEC were noticed, at the end of seven year period oil palm attained comparable values. Nitrogen and Phosphorous status was also high in oil palm plantation, probably due to the regular application of fertilizers for oil palm crop.

Effect of exotic tree plantations of teak and Gmelina on a forest soil on South Western Nigeria were investigated by Aborisade and Aweto (1990). The study indicated that cultivation of these species resulted in loss of organic matter and nitrogen.

Norhayti and Lau (1990) conducted studies on soil fertility changes following forest clearing and rubber cultivation in Malaysia. Drop in pH was noticed in top soil as well as in subsoil. Organic carbon, total Nitrogen, total Potassium and exchangeable nutrients were low during the initial years of plantation establishment. But by 50th month comparable values with forest situation were recorded in rubber plantation also. Krishnakumar et al., (1991) reported similar results in their investigation on the ecological impact of rubber plantation in North Eastern India. They had also found an increase in organic carbon in rubber cultivated area as compared to shifting cultivation adopted area.

In a comparative study of the nutritional properties of rubber and eucalyptus plantations with natural forest, organic matter status was found to be high always in forest situation. Comparing eucalyptus and rubber, the farmer is having low status of organic carbon which was attributed to the lower decomposition of litter and its lower incorporation into the soil (Balagopal 1991).

Mongia et al., (1991) showed that conversion of natural forest into oil palm plantation in South Andaman resulted in decrease in organic matter from 3.12 per cent to 0.69 per cent. Soil chemical characterisitcs in a Cupressus lusitanica plantation had been compared with adjoining natural forest in West Kilimanjaro, Northern Tanzania by Maro et al., (1993). Natural forest had higher amounts of organic matter, total Nitrogen and exchangeable Sodium than in cupressus plantation which is attributed to the rapid mineralisation of litter in the top soil of natural forest. Lack of erosion and also the diversity of the litter substrate under natural forest have been attributed as the reasons for high organic matter and total Nitrogen in natural forest. However, there was no significant difference in available Phosphorous and exchangeable Calcium and Potassium at all profile depths.

Aweto and Obe (1993) investigated the organic matter and nutrient levels in soil under a 26 year old cocoa plantation and areas cropped with cassava and maize in Nigeria and compared the same with those under rain forest. Relative to forest soils, the organic matter and nutrient levels were substantially reduced in soils under cassava and maize. In cocoa cultivated areas, the reduction was only to a lesser extent.

Mathan and Kannan (1993) also observed higher organic matter content in natural forest in Kodaikanal district of Tamil Nadu as compared to tea and silver oak cultivated areas.

Roose (1993) studied the influence of tropical deforestation in organic matter status and found that organic matter and total Nitrogen declined rapidly in deforested areas. Decline in soil fertility after canopy removal was accelerated by soil erosion, loss of litter influx and increased decomposition and mineralisation rates.

Aweto and Ishola (1994) studied the effect of cultivating cashew on chemical properties after conversion of logged natural forest to cashew plantation. After twenty years of cashew growth an increase in exchangeablePotassium was noticed in cashew soil. But no difference was noticed in the levels of organic carbon, pH, nitrogen, available Phosphorous or exchangeable Calcium or Magnesium. They attributed the higher level of exchangeable Potassium in cashew plantation as due to the occurrence of more clayey soil under cashew plantation.

Greenland (1994) had stressed the importance of organic matter level in soil in helping to maintain an active population of soil organisms and to promote mineralisation, and stabilize a favourable physical condition in the soil, there by promoting absorption of nutrients by plant roots. According to him, these effects imply that the level of organic matter may be taken as an indicator of the sustainability of a soil management system.

Mongia and Bandyopadhyay (1994) investigated the changes in nutrient contents following conversion of natural forest with rubber, teak and oil palm in Little Andaman. A drop in total and available Nitrogen, Phosphorous and Potassium resulted due to the conversion of forest lands into agricultural fields. Compared to Pterocarpus dalbergia, teak and red oil palm the loss occured in rubber plantation was less. Annual leaf litter addition from the above plantations were in the order of 3470, 3600, 3890 and 2780 kg/ha respectively as compared to 6850 kg in natural forest. The nutrient addition through litter was also less compared to natural forest.

Veldkamp (1994) estimated the loss in soil organic carbon occurring due to deforestation for an Eutric Hapludand and an Oxic Humitropept in the Atlantic zones of Costa Rica. The net loss occurred was 21.8 Mg ha^{-1} and 1.5 Mg ha^{-1} respectively. The strong stabilization of organic carbon by the Al-organic matter complexes probably caused the relatively small net carbon loss since forest clearing.

Saviozzi et al., (1994) investigated the effect of continuous cultivation of corn for forty years and noticed significant reduction in the content of alkali extractable and water soluble carbon as well as the phenolic and chloroform extractable compounds, while no difference in volatile acids was noticed.

Arrouays and Pelissier, (1994) investigated the effect of forest conversion to continuous intensive corn cropping on soil organic carbon content. Results suggested that organic carbon declined rapidly during the initial years of cultivation and at a slower rate thereafter.

In another investigation, to quantify the effect of soil organic matter on productivity, Bauer and Black (1994) found that the loss of productivity associated with a depletion of soil organic matter in the northern Great Plains is primarly a consequence of a concomitant loss of fertility.

From the literature available it can be gathered that most of the studies were conducted to estimate the loss occurred in soi organic carbon as a result of forest conversion.

Biomass removal and nutrient recycling

The economic life span of rubber trees is 30-32 years and after this period the trees are felled and removed from the rubber fields. The result is considerable loss of nutrients from rubber plantations. Shorrocks (1965a), conducted studies on uptake of nutrients by trees of different age groups by weighing the different parts of rubber tree and calculating the nutrient uptake from nutrient concentration in various parts. For older trees this was limited to above ground parts only. The biomass production in mature plantation each year was worked out to be 24,000 kg/ha. This is comparable to that reported for a secondary forest in Ghana (24,400 kg per ha per annum), (Watson, 1989).

Sivanandyan and Norhayati (1992) in reviewing the consequences of trasnforming tropical rain forest into rubber plantations reported that the biomass accumulation in rubber ecosystem is comparable to natural forest. The biomass estimated for humid tropical forest in various countries ranged between 210 ton/ha and 664 ton/ha in Malaysia. The value obtained in Amazon jungle was 473 ton/ha. When forests are replaced by rubber, due to the fast growing nature of rubber trees (12 cm/year for rubber and 7.6 cm/year for forest trees), the stand of rubber can be expected to reach maximum biomass potential earlier in a relatively shorter time than the trees in the forest situation. The biomass of rubber ecosystem reaches comparable levels in about 30 years. In about 33 years it was 445 tons/ha, very close to forest ecosystem in Brazil and Malaysia. The biomass values computed for oil palm was 69.5 ton/ha and that for rubber 206 ton/ha, suggesting that oil palm ecosystem is not as efficient as the rubber ecosystem.

In the humid low land utisols of Sri Lanka, components of nutrient cycling were compared and contrasted in a study of a rain forest and a 5 year old rubber plantation, (Myers et al., 1994). Total annual litterfall was similar in both systems, but litter quanlity and decomposition rate differed. The species diversity of mixed forest contributed towards a fairly constant supply of nutrients becoming available through litter decay. In the less diverse *Hevea* rubber plantation (a diciduous tree monocrop with a legume or grass ground cover) litterfall showed a more or less overlapping peak with a relatively faster decomposition rate than in natural forest, due to lower C/N ratio of the former. Judging from the timing of the litter fall and the decomposition rate of rubber, legume or grass litter, the annual flushes of plant nutrients more or less coincide with the refoliation of the rubber tree suggesting that the system is in partially synchronous state.

3. MATERIALS AND METHODS

A. Effect of long term cultivation of rubber on soil properties

The cultivation of rubber (*Hevea brasiliensis*) is mainly confined to the western side of the western ghats. More than 90 per cent of this area comes under Kerala State. Further the first plantation in India were also started in Kerala. Knowledge of the history of rubber cultivation in Kerala has enabled the Rubber Research Institute to locate the areas and plantations where rubber was first cultivated and where rubber trees are even currently grown in the third cycle. On this basis regions were located in four agroclimatic zones representing the traditional rubber growing belt in India. In these regions, sites for soil profile and surface sample collection were located both in rubber plantations and nearby undisturbed natural forests of similar physiography. Such a selection enabled an assumption that they were not having different initial properties. The limitations of such selections are well understood (Lundgren, 1978; Ollagnier *et al*., 1978). In these sites rubber is currently being cultivated as a third consecutive cyle (approximately more than ninety years).

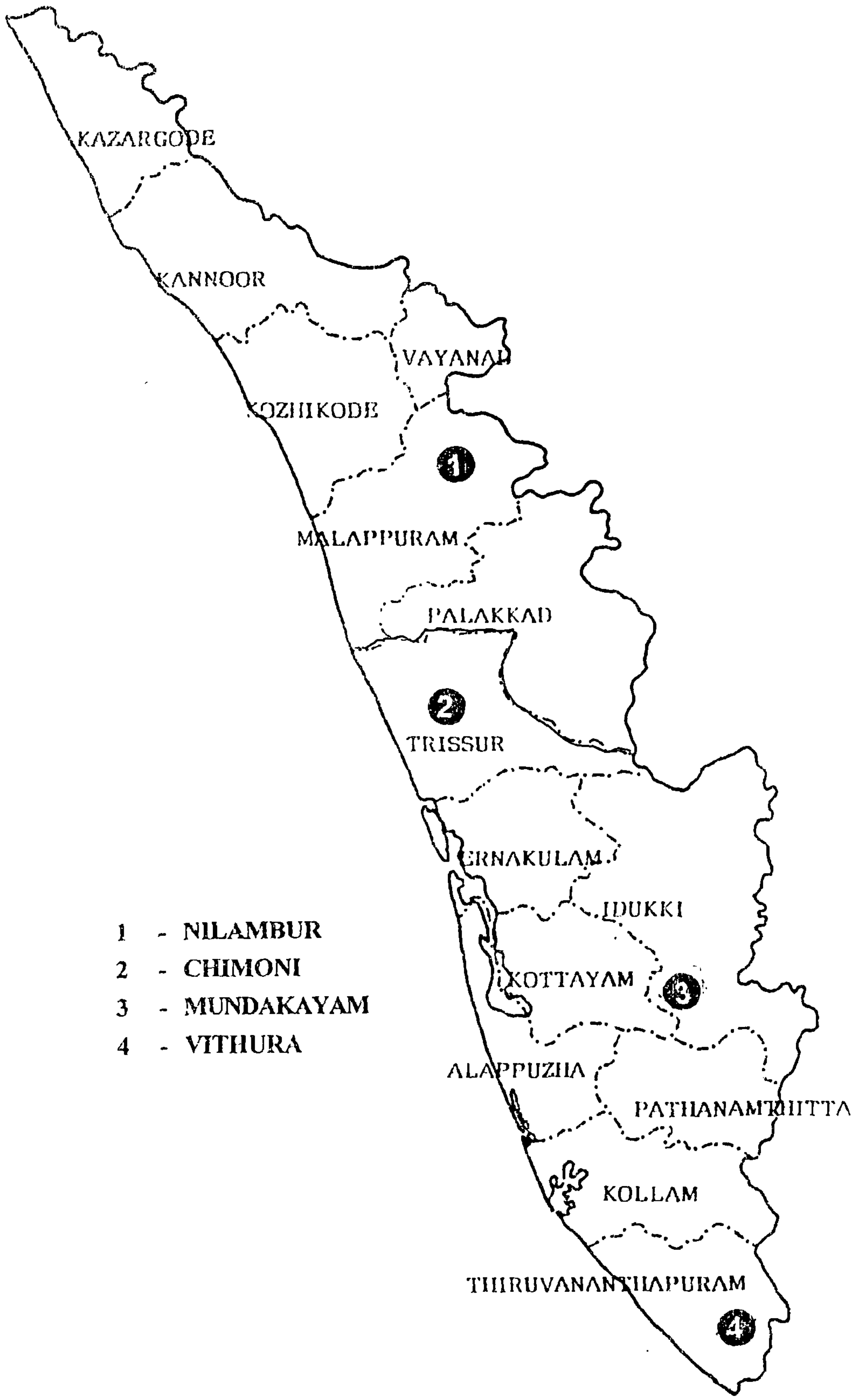

Fig. 1 Map of Kerala showing the location of sites from where profiles were taken

Plate 1. General view of a rubber plantation

Plate 2. Forest of Kerala

Profiles from such rubber plantation and adjoining forest lands of same physiography were taken from each of the locations. The details of the sites selected are given in Table 1 and the locations are illustrated in Fig. 1. A general view of rubber plantation and forests of Kerala is depicted in plate 1 and plate 2.

The profiles were excavated to 180 cm or more wherever possible or upto the parent material. The samples were collected from the pedogenic horizon after examination of the profiles for morphological features as per the criteria established by Soil Survey Staff (1975). Undisturbed standard core samples were collected from each horizon in duplicate for the estimation of bulk density. The samples collected horizonwise were dried and seived throguh 2 mm seive and were stored for physical and chemical analysis. Composite samples 0-30 and 30-60 cm were collected and analysed for chemical properties. The data was analysed stastically.

3.1 Morphological features

The profiles were described for their macro morphology on the basis of the criteria established by the Soil Survey Staff (1975). Colour of field moist samples were recorded following the colour chart (Munsell 1975). A classification upto the series level was done as per the soil taxonomy (Soil Survey Staff 1975).

3.2 Physical, physicochemical and chemical properties of the soils

These properties were estimated in air dried soils (2mm size) as shown in the following table.

Table 1. Details of methods followed in soil chemical analysis

	Parameter	Method adopted	Reference
Physical properties	1. Particle size	Pipette method	Piper, (1950)
	2. Bulk density	Core sampling	Black, 1965 (a)
	3. Soil moisture retention	Pressure plate method	Richards, (1949)
Physico chemical properties	1. pH	Electrometric method (1:2.5 ratio)	Jackson, (1973)
	2. Cation exchange capacity (CEC)	1 Normal neutral ammonium acetate extraction method	Black, (1965 b)
	3. Exchangeable Na, K, Ca, Mg	Ammonium acetate extraction method	Black, (1965 b)

Contd.

Chemical properties	1. Organic carbon	Wet digestion method	Jackson, (1973)
	2. Total nitrogen	Kjeldahl method	Black, (1965 b)
	3. Available nitrogen	Alkaline permanganate	Subbiah and Asija, (1956)
	4. Total phosphorus	Vanadomolyb-date method	Jackson, (1973)
	5. Available Phosphorus	Stannous chloride method	Bray and Kurtz, (1945)
	6. Total potassium calcium, magnesium, iron and aluminium	HCl extraction	Piper, (1950)
	7. Oxalate extrac-table iron	Atomic absorption	Mc keague and Dey, (1966)
	8. Dithionate Citrate Bicarbonate extractable iron		Mehra and Jackson, (1960)

B. Cyclic changes due to cultivation of rubber

Rubber plantations are economically viable for a period of 30-32 years and plantations are generally replanted in every 30-32 years. The aboveground parts excluding foliage is removed from the plantation for timber and firewood. This causes considerable biomass loss at the end of each plantation cycle whereas during plantation establishment substantial quantities of nutrients are added through the legume cover established during the initial years in a cycle of plantation. To evaluate the nutrient status in each of the repeated cycles of plantation, three locations Nilambur, Mundakayam and Vithura were selected and soil samples were collected at three depths 0-15, 15-30 and 30-60 cm from rubber plantations of first, second and third cycle and adjoining natural forests. These samples were analysed for pH, organic carbon, available phosphorous and available potassium and the results analysed statistically by analysis of variance technique (Snedecor and Cochran, 1967).

(b) Whole tree analysis

In order to study the biomass accumulation by mature rubber trees, a 20 year old tree was uprooted from the Central experiment station, Chethakal, Ranni, Kerala State during June 1993. Weight of each plant part viz. leaf, twig and branches, trunk, tap root and lateral root was determined separately using a plat form balance. Sub samples were taken from each part, brought to the laboratory and oven dry weight determined. From the weight of subsamples dry weight of the tree was computed. Percentage of Nitrogen, Phosphorous, Potassium, Calcium and Magnesium in the various parts of the plant was estimated as per standard proceedures (Karthikakuttyamma,1977).

Table 2. Site characteristics of locations

1.	Location	Nilambur	Chimoni	Vithura	Mundakayam
2.	Rubber	76° 20' 24" E 11° 9' 45" N	76° 20' 16" E 10° 26' 15" N	76° 6' 5" E 8° 39' 44" N	76° 55' 0" E 9° 33' 47" N
3.	Forest	76° 20' 55" E 11° 10' 0" N	76° 20' 32" E 10° 26' 26" N	77° 6' 28" E 8° 39' 35" N	76° 55' 19" E 9° 34' 16" N
4.	Type of forest	Moist decidious	Moist decidious	Wet evergreen	Wet evergreen
5.	Elevation	100 m MSL	100 m MSL	150 m MSL	300 m MSL
6.	Geology	Schistoze rocks of Sargur group with ultramaphytes and layered complexes	Main rock types are hyperstheln bearing gneisses and granulites belonging to charnokite group	Charnokite group includes hyperstheln bearing gneisses and granulities belonging to charnokite group	Biotic gneisses hornblend biotite gneiss and graphite bearing gneiss, and corderite gneiss
7.	District	Malappuram	Trichur	Trivandrum	Idukki
8.	Taluk	Nilambur	Mukundapuram	Nedumangad	Mundakayam
9.	Village	Kalikavu	Varandarapally	Vithura	Peruvanthanam

contd...

10.	Topography	Low ridge	Low ridge	Very steep	Very steep
11.	Land form	Summit	Summit	Summit	Concave slope
12.	Slope	8 - 15°	8 - 15°	8 - 25°	30 - 35°
13.	Erosion	Moderate	Moderate	Very severe	Moderate
14.	Run off	Medium	Moderate	Very rapid	Rapid
15.	Drainage	Well drained	Well drained	Well drained	Somewhat excessively drained
16.	Groundwater	> 10 meters	< 10 Meters	5-100 meter	> 50 meter
17.	Stone size (dia)	2.5 - 7.5 cm	2.5 - 8 cm	7.5-25cm dia	7.5-10mm dia
18.	Rainfall	3000-3500 mm	2500-3500 mm	2000-3000 mm	3000-3500 mm
19.	Temperature	24.5 - 26°C	26-28°C	26-27°C	26-27°C
20.	SMR	Ustic	Ustic	Ustic	Udic
21.	STR	Isohyperthermic	Isohyperthermic	Isohyper-thermic	Isohyperther-mic

Items 5 to 21 of physiography and climatic conditions are applicable to both the rubber soil profiles and adjoining forest soil profiles of each of the 4 locations.

SMR = Soil moisture regime; STR = Soil temperature regime

RESULTS

4. RESULTS

Sustainable land management has become an issue of major global importance, since the degradation of land is accelerating rapidly in many countries of the world. As land suitable for cultivation is only of limited extent further increase in production to meet the ever increasing demand for natural rubber can be met only by the more intensive cultivation of existing plantations in their present situation as well as in subsequent cycles. To combat with the deleterious effects of intensification,in the case of rubber, using the same land repeatedly requires the development and implementation of technologies which will result in sustainable land management.

A knowledge of the soil resource is central to sound land management. Understanding the nature and properties of soil is vital in this regard. It is more important in tropical regions where soil degradation is an increasingly serious problem. The variation in chemical properties and fertility in the tropical soils is quite evident for the last two decades (Greenland, 1994). The present investigation was taken up to understand the extent of changes in morphological, physical and chemical properties soil, when rubber is cultivated for three consecutive cycles. A series level classification is also attempted. Efforts are made to monitor the changes in the first, second and third planting cycles of rubber plantation and the study is limited only to the chemical properties of soil.

The level of production in any cropping system ultimately depends on the capacity to replace essential resources lost from one cycle with inputs during the next cycle (Swift et al 1994). Rubber cultivation is also no exception to this. Sustainability in rubber production can be ensured only with proper nutrient budgetting. For this purpose removal from the system was estimated by destructing a tree and calculating the nutrients in various parts of the tree. From this, nutrient removed from one hectare of plantation was worked out. Inputs were calculated from the quantity of fertilizer added (external source) and nitrogen fixed by cover crop (internal source). The loss occuring in the plantation system was compared with the nutrient status in the 60 cm soil which supports the main feeder roots of the system.

The results of the investigations mentioned above are presented in the ensuing sections.

Table 2.1. Morphological description of Profile R_1 – Rubber plantation – Nilambur

Horizon depth (cm)		Ap 0 - 19	A_2 19 - 35	BW_1 35 - 57	BW_2 57 - 100	BW_3 100 - 129	BC 129 - 164
Colour		Very dusky greyish brown 10YR 3/2	Dark yellowish brown 10 YR 3/4	Strong brown 7.5 YR 5/8	Strong brown 7.5 YR 5/8	Yellowish red 5 YR 4/8	Red 2.5 YR 4/8
Texture		Sandy clay	Sandy clay	Sandy clay	Sandy Clay	Sandy Clay loam	Sandy clay loam
Structure :	Size	Medium	Medium	Fine	Medium	Medium	Fine
	Grade	Moderate	Moderate	Moderate	Moderate	Moderate	Weak
	Type	Sbk	Sbk	Sbk	Sbk	Sbk	Sbk
Consistence :	Moist	Friable	Friable	Friable	Friable	Friable	Friable
	Wet	Slightly sticky Slightly plastic	Slightly sticky and plastic	Sticky and and plastic	Sticky and plastic	Sticky and plastic	Sticky and plastic
Porosity		Common and very fine	Few and very fine	Few fine	Few fine	---	---
Roots		Common and very fine	Few fine	Few fine	Few fine	---	---
Boundary		Clear wavy	Clear wavy	Clear wavy	Gradual wavy	Gradual irregular boundary	Diffuse irregular boundary

* Sbk Subangular blocky

Tentative classification : Fine loamy mixed isohyperthermic family of Humitropepts

Table 2.2. Morphological description of Profile F_1 - Virgin Forest - Nilambur

Horizon depth (cm)		Ap 0 - 18	Bt_1 18 - 34	Bt_2 34 - 57	Bt_3 57 - 100	BT_4 100 - 132	F 132 - 160
Colour		Dark brown 7.5 YR 3/2	Brown 7.5 YR 5/2	Reddish brown 5 YR 4/4	Yellowish red 5 YR 4/6	Yellowish red 5 YR 5/8	Red 2.5 YR 4/8
Texture		Sandy clay loam	Sandy clay	Sandy clay	Sandy clay	Sandy clay	Sandy clay
Structure	: Size	Medium	Medium	Medium	Fine	Fine	Structureless
	Grade	Moderate	Moderate	Moderate	Moderate	Moderate	
	Type	Sbk	Sbk	Sbk	Sbk	Sbk	
Consistence	: Moist	Friable	Friable	Friable	Friable	Friable	No consistence
	Wet	Slightly sticky	Sticky,plastic	Sticky, plastic	Sticky, plastic	Sticky, plastic	Sticky, plastic
Porosity		Few and fine	Few and fine	Few fine	Few fine	Few fine	
Roots		Few and fine	Common and medium	Few medium	Few medium	Few fine	
Boundary		Gradual wavy	Clear wavy	Clear wavy	Clear wavy	Gradual irregular	

Tentative classification : Fine loamy mixed isohyperthermic family Paleustalfs.

Site characteristics of Profiles 1 and 2

Location	:	Nilambur NWN of Kalikavu - Karuvarakundu road.
Rubber (R_1)	:	76°, 20' 24" E Longitude 11°, 9', 45" N Latitude
Forest (F_1)	:	76° 20' 55" E Longitude 11° 9' 0" N Latitude
Type of forest	:	Moist deciduous
Elevation	:	90 Meters
Gradient	:	8 - 15° Sloping
Water table	:	> 10 meters
Geology	:	Schistoze rocks of Sargar group is prevalent with ultramafytes and layered complexes.
Rainfall	:	3000-3500 mm
Temperature	:	24.5 - 26°C
SMR	:	Ustic
STR	:	Isohyperthermic

Table 3.1. Morphological description of Profile R_2 - Rubber Plantation - Chimoni

Horizon depth (cm)		Ap 0 - 14	A_2 14 - 24	BW_1 24 - 38	BW_2 38 - 52	BW_3 52 - 76	BC_1 76 - 100	BC_2 100-132
Colour		Very dusky red 2.5 YR 2/2	Dusky red 2.5 YR 3/2	Dark reddish brown 2.5YR 3/4	Reddish brown 2.5 YR 4/4	Yellowish red 5 YR 4/6	Yellowish red 5 YR 5/8	Yellowish red 5 YR 5/6
Texture		Sandy clay loam	Sandy clay	Sandy clay	Clay	Sandy clay loam	Sandy clay loam	Sandy clay loam
Structure	: Size	Medium	Medium	Fine	Medium	Medium	Medium	Medium
	Grade	Moderate	Weak	Moderate	Moderate	Moderate	Moderate	Moderate
	Type	Sbk	Sbk	Sbk	Sbk	Sbk	Sbk	Sbk
Consistence	: Moist	Friable	Friable	Friable	Friable	Friable	Friable	Friable
	Wet	Slightly sticky Slightly plastic	Slightly sticky and plastic	Sticky and plastic	Sticky and plastic	Sticky and Plastic	Sticky and Plastic	Sticky and plastic
Porosity		Many very fine	Common fine	Few fine	Very few fine	Very few fine	Very few fine	Very few fine
Roots		Common very fine	Common fine	Few fine	Very few fine	---	---	---
Boundary		Clear wavy	Abrupt wavy	Clear irregular	Clear wavy	Clear wavy	Gradual wavy	

Tentative classification : Fine loamy mixed isohyperthermic family of Humitropepts

Table 3.2. Morphological description of Profile F Virgin Forest - Chimoni

Horizon depth (cm)		Ap 0 - 11	A_2 11 - 33	BW_1 33 - 64	BW_2 64 - 100	BC 100 - 130
Colour		Reddish black 10R 2/1	Dark reddish grey 10R 3/1	Dark reddish brown 2.5YR 2/4	Dark red 2.5 R 3/2	Very dausky red 2.5 YR2/2
Texture		Sandy clay loam	Sandy clay	Sandy clay	Sandy clay loam	Sandy clay loam
Structure	: Size	Medium	Medium	Fine	Fine	Fine
	Grade	Moderate	Moderate	Weak	Weak	Weak
	Type	Sbk	Sbk	Sbk	Sbk	Sbk
Consistence	: Moist	Friable	Friable	Friable	Friable	Friable sticky
	Wet	Slightly sticky Slightly plastic	Slightly sticky and plastic	Sticky and plastic	Sticky and plastic	Sticky and plastic
Porosity		Common fine	Common fine	Few fine	Few fine	Few fine
Roots		Common fine	Common fine	Few very fine	Few fine	Few fine
Boundary		Clear wavy	Gradual wavy	Clear wavy	Gradual irregular	

Tentative classification : Fine loamy mixed isohyperthermic family Ustic Humitropepts.

Site characteristics of Profile 3 and 4

Location	:	Chimoni NWN of Varandarapilli Junction on Ambal lur Palapilli road
Rubber (R_2)	:	76^o 20'16" E Longitude 10^o 26',15" N Latitude
Forest (F_2)	:	76^o 20' 32" E Longitude 10^o 26' 26" N Latitude
Type of forest	:	Moist deciduous
Elevation	:	100 meters
Gradient	:	$8-15^o$
Water table	:	< 10 meters
Geology	:	Hypersthene bearing gneisses and granulites belonging to Charnockite group. Young doleritic and gabbroic dykes traverse the country rock.
Rainfall	:	2500-3500 mm
Temperature	:	$26 - 28^o$
SMR	:	Ustic
STR	:	Isohyperthermic

Table 4.1 Morphological description of Profile R_3 - Rubber Plantation - Vithura

Horizon depth (cm)		Ap 0 - 26	Bt_1 26 - 51	Bt_2 51 - 76	Bt_3 76 - 124
Colour		Very dark brown 10 YR 2/2	Dark brown 7.5 YR 3/2	Dark brown 7.5 YR 4/4	Strong brown 7.5 YR 5/8
Texture		Sandy clay	Sandy clay	Sandy clay	Sandy clay
Structure	: Size	Medium	Medium	Medium	Medium
	Grade	Weak	Moderate	Moderate	Moderate
	Type	Sbk	Sbk	Sbk	Sbk
Consistence	: Moist	Friable	Friable	Friable	Friable
	Wet	Slightly sticky Slightly plastic	Slightly sticky Slightly plastic	Slightly sticky Slightly plastic	Very sticky Plastic
Porosity		Many fine	Common fine	Common very fine	Common very fine
Roots		Many fine	Few fine	Common fine	Few fine
Boundary		Clear wavy	Gradual wavy	Diffused smooth	

Tentative classification : Clayey Kaolinitic - isohyperthermic family of Ustic Kamhaplohumult

Table 4.2. **Morphological description of Profile F_3 - Virgin forest - Vithura**

Horizon depth (cm)		A 0 - 22	BW_1 20 - 40	BW_2 40 - 69	BC 59 - 100
Colour		Very dark brown 10 YR 2/2	Dark reddish 5 YR 3/4	Strong brown 7.5 YR 5/6	Yellowish brown 10 YR 5/8
Texture		Sandy clay loam	Sandy clay		Sandy clay
Structure	: Size	Fine	Medium	Medium	Medium
	Grade	Weak	Weak	Moderate	Moderate
	Type	Granular	Sbk	Sbk	Sbk
Consistency	: Moist	Friable	Friable	Friable	Friable
	Wet	Sticky Slightly plastic	Sticky plastic	Sticky Plastic	Sticky Plastic
Porosity		Common fine	Common fine	Common fine	Common fine
Roots		Many fine	Common fine	Common medium	Very few
Boundary		Clear smooth	Clear wavy	Gradual smooth	
	Boulders			About 60%	Boulders 80%

Tentative classification : Clayey skeletal kaolinitic Isohyperthermic family of Humitropepts

Site characteristics of Profile 5 and 6

Location	:	Vithura NEN of Vithura-Mankala road, from Vithura junction
Rubber (R_3)	:	77^o 6' 5" E Longitude 8^o 39', 44" N Latitude
Forest (F_3)	:	77^o 6' 28" E Longitude 8^o 39' 35" N Latitude
Type of forest	:	Wet evergreen
Elevation	:	140 meters
Gradient	:	20^o
Water table	:	5 - 10 meters
Geology	:	Charnokite group includes hypersthene bearing gneisses and granulites. Khondalite group includes garnet biotite gneises, biotitic gneiss, etc.
Rainfall	:	2000-3000 mm
Temperature	:	26 - 27^oC
SMR	:	Ustic
STR	:	Isohyperthermic

Table 5.1. Morphological description of Profile R_4 - Rubber Plantation - Mundakayam

Horizon depth (cm)		Ap 0 -9	A_2 9 - 32	A_3 32 - 51	Bt_1 51 - 73	Bt_2 73 - 91	Bt_2 94 - 124	Bt_4 124-200
Colour		Dark reddish brown 5YR 3/4	Reddish brown 5 YR 4/4	Yellowish red 5 YR 4/4	Reddish brown 5 YR 5/4	Yellowish red 5 YR 5/8	Yellowish red 5 YR 5/6	Yellowish red 5 YR 5/7
Texture		Sandy clay	Sandy clay	Sandy clay	Sandy clay	Clay	Clay	Clay
Structure	: Size	Medium	Medium	Medium	Medium	Medium	Medium	Medium
	Grade	Weak	Weak	Weak	Moderate	Moderate	Moderate	Moderate
	Type	Sbk	Sbk	Sbk	Sbk	Sbk	Sbk	Sbk
Consistence	: Moist	Friable	Friable	Friable	Friable	Friable	Friable	
	Wet	Slightly sticky Slightly plastic	Sticky plastic	Sticky Plastic	Sticky Plastic	Sticky Plastic	Sticky Plastic	
Porosity		Common fine	Common fine	Common fine	Common fine	Common fine	Common fine	
Roots		Common fine	Common very fine	Common very fine	Few very fine	Few very fine		
Boundary		Clear wavy	Clear wavy	Diffused irregular	Diffused irregular	Diffused irregulr	Diffused irregular	

Tentative classification : Clayey Kaolinitic Isohyperthermic family of ustic Kandihumults

Table 5.2. Morphological description of Profile F_4 Virgin Forest - Mundakayam

Horizon depth (cm)	Ap 0 - 11	A_2 11 - 24	Bt_1 24 - 45	Bt_2 45 - 69	BC 69 - 72
Colour	Very dusky red 10 R 2/2	Dusky red 10 R 3/2	Dusky red 10 YR 3/3	Reddish brown 2.5 YR 4/4	Reddish brown 2.5 YR 4/5
Texture	Sandy clay loam	Sandy clay loam	Clay	Clay loam	
Texture : Size	Fine	Medium	Medium	Medium	Medium
Grade	Moderate	Moderate	Moderate	Moderate	Moderate
Type	Sbk	Sbk	Sbk	Sbk	Sbk
Consistence : Moist wet	Friable Slightly sticky Plastic	Friable Sticky Plastic	Friable Sticky Plastic	Very firm Sticky Plastic	Friable Sticky Plastic
Porosity	Common medium	Common medium	Few fine	Few fine	Few fine
Roots	Common very fine	Many fine	Many fine	Many fine	Few fine
Boundary	Clear wavy	Clear wavy	Clear wavy	Diffused irregular	

Tentative classification : Clayey Kaolinitic Isohyperthermic family of Ustic Kanheplohumults

Site characteristics of profile 7 and 8

Location	:	Mundakayam
Rubber (R_4)	:	76^o 55' 0" E Longitude 9^o 33', 47" N Latitude
Forest (F_4)	:	76^o 55' 19" E Longitude 9^o 34' 16" N Latitude
Type of forest	:	Wet evergreen
Elevation	:	250 Meters
Gradient	:	8 - 20^o
Water table	:	> 10 meters
Geology	:	Prevalence of biotite gneiss, graphite bearing gneisses and corderite gneiss.
Rainfall	:	3000-3500 mm
Temperature	:	26^o - 27^o
SMR	:	Udic
STR	:	Isohyperthermic

4.1. Morphological features

Colour

The colour of the profiles 1 and 2 representing rubber and forest soils of Nilambur had brownish surface soils to red coloured sub soils. The redder hues increased with depth in both the soils. The red colour was a feature of the surface horizon of the rubber growing soils of Chimoni (Profile 3) with hue of 2.5 YR and yellowish red (5YR) in the sub soils. The adjacent forest soil (Profile 4) in the same area had characteristic reddish black 10R with reddish dusk red in the deeper layer of the profile. Brownish colour dominated the entire depth of both the profiles of Vithura (Profile 5 and 6). 5YR was the dominant hue throughout the profile 7 of Mundakayam while the forest soils (Profile 8) had dusky red surface soils to reddish brown subsoils.

Texture

The textural class recorded little variation between the rubber and forest areas from different locations. The Nilambur profile had dominant sandy clay loam texture with little variation in clay content with depth. This observation holds good for profiles 3 & 4 from Chimoni. Sandy clay texture was observed throughout the profile in the rubber areas of Vithura, while sandy clay and clay was observed in the sub soils of forest areas. Increased clay in the lower layers was a feature of Mundakayam profile (Profile 7). However, sandy texture were observed in the lower layers of forest profiles (Profile 8). Erratic trends in the distribution of the size fractions has been reflected in the textural class of the different layers of the profile.

Structure

Subangular blocky structure was observed as the major structural form in the profile from all locations.

4.2. Organic Carbon

The organic carbon content in the various horizons of rubber plantation at third planting cycle and adjoining forest profiles is presented in Table 6. In forest as well as in rubber maximum content of organic carbon was observed in the upper most horizons. In all the horizons, organic carbon content decreased towards the lower horizons. In rubber, the values ranged from 0.50 per cent to 2.33 per cent. The maximum content of 2.33 per cent was observed in Chimoni estate in the surface horizon and minimum in the lowest horizon of Nilambur. In Vithura, Mundakayam and Nilambur, the values in surface horizons were 2.22, 1.83, and 1.68 per cent respectively. The total soil organic carbon content in one meter depth were 144, 168, 163 and 130 Megagram/hectare (Mg/ha) in rubber plantations in Nilambur, Chimoni, Vithura and Mundakayam respectively (Table 6.1). In forest profiles, organic carbon ranged from 0.49 per cent in the 132 - 160 cm horizon of Nilambur to 3.96 per cent in the surface horizon of Chimoni. The organic carbon content in the surface horizons of Vithura, Mundakayam and Nilambur were 2.93, 2.61 and 1.99 per cent respectively. The forest profile (1 meter) in Nilambur, Chimoni, Vithura, and Mundakayam contained 192, 312, 245 and 144 Mg/ha (Table 6.1) of organic carbon respectively. The distribution of organic carbon content in forest and rubber profiles in the four locations are presented in Fig. 2.

The organic carbon content in the various horizon in forest and rubber profiles upto 100 cm depth has been worked out mainly to bring uniformity in the presentation of data on organic carbon of the profiles having horizon with varying depth and varying bulk densities. This table (Table 6.1) also indicates the varying bulk density as well. In general all the profiles, both rubber and forest, have an increasing trend in bulk density towards the lower horizons. The horizonwise quantities in (Mg/ha) varies with depth since the horizons are not of uniform distance. However, there is considerable reduction in organic carbon content between rubber and forest profiles. On per cent basis the reduction is 25, 46, 33 and 9 in Nilambur, Chimoni, Vithura and Mundakayam respectively. The reduction is maximum in Chimoni and minimum in Mundakayam. Statistically also the reduction was significant for 0-30 and 30-60 cm soil (Appendix 1).

Table 6. Organic carbon in various horizons of the profiles from rubber plantations and corresponding virgin forests

Rubber			Forest		
Location	Depth (cm)	Organic carbon %	Location	Depth (cm)	Organic carbon %
Nilambur	0-19	1.68	Nilambur	0-18	1.99
	19-35	1.13		18-34	1.26
	35-57	0.73		34-57	0.89
	57-100	0.67		57-100	0.87
	100-129	0.52		100-132	0.73
	129-164	0.50		132-160	0.49
Chimoni	0-14	2.33	Chimoni	0-11	3.96
	14-24	1.33		11-33	2.26
	24-38	1.06		33-64	1.62
	38-52	0.99		64-100	1.56
	52-76	0.67		100-130	1.42
	76-100	0.55			
	100-132	0.55			
Vithura	0-26	2.22	Vithura	0-22	2.93
	26-51	1.15		22-40	1.68
	51-76	0.97		40-59	1.19
	76-100	0.89		59-80	0.78
	100-124	0.81		80-100	0.87
Mundakayam	0-9	1.83	Mundakayam	0-11	2.61
	9-32	1.36		11-24	1.60
	32-51	1.07		24-45	1.28
	51-73	0.96		45-69	0.95
	73-100	0.67		69-100	0.69
	100-124	0.75		100-120	0.69

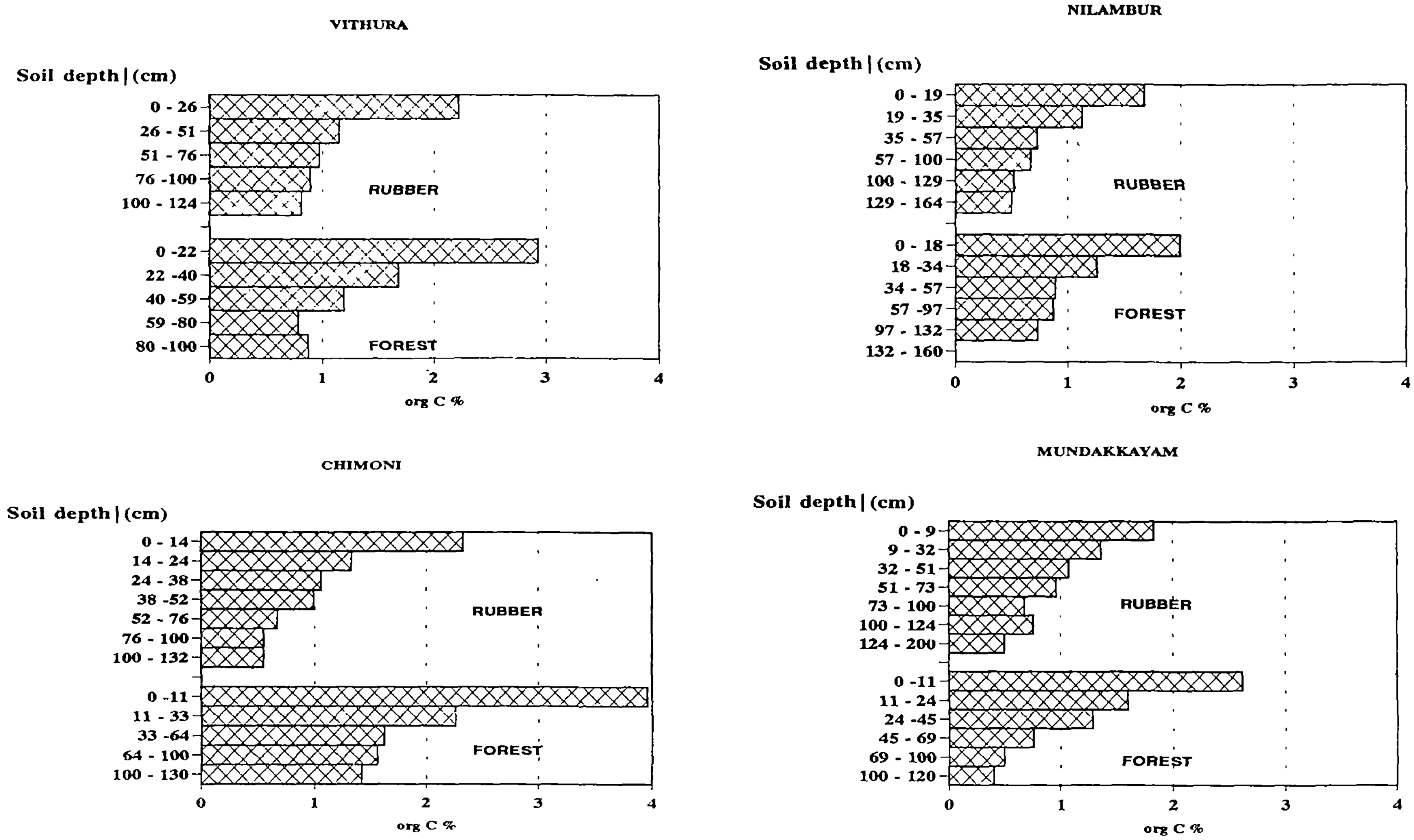

Fig. 2. Organic carbon content in rubber and forest profiles

Table 6.1. Organic carbon content in 100 cm profile of four rubber plantations and corresponding virgin forests

NILAMBUR - Rubber

Depth (cm)	OC %	BD (Mgm^{-3})	OC (Mg/ha)
0 - 19	1.68	1.24	40.0
19-35	1.13	1.26	22.0
35-57	0.73	1.88	29.0
57-100	0.67	1.88	53.0
Total			144.00

NILAMBUR - Forest

Depth (cm)	OC %	BD (Mgm^{-3})	OC (Mg/ha)
0 - 18	1.99	1.50	53.00
18 - 34	1.26	1.65	33.00
34 - 57	0.89	1.91	39.00
57 - 100	0.87	1.79	66.00
Total			192.00

CHIMONI - Rubber

0 -14	2.33	1.27	41.50
14-24	1.33	1.86	24.80
24-38	1.06	1.68	25.00
38-52	0.99	1.75	24.30
52-76	0.67	1.80	29.00
76-100	0.55	1.75	23.00
Total			168.00

CHIMONI - Forest

0-11	3.96	1.37	46.70
11-33	2.26	1.76	87.70
33-64	1.62	1.66	83.60
64-100	1.56	1.68	94.00
Total			312.00

Contd.....

Table 6.1. (Contd...)

VITHURA - Rubber

Depth (cm)	OC %	BD (Mgm^{-3})	OC (Mg/ha)
0- 26	2.22	1.08	62.50
26- 51	1.15	1.29	37.00
51- 76	0.97	1.31	31.80
76-100	0.89	1.45	31.00
Total			163.00

VITHURA - Forest

Depth (cm)	OC %	BD (Mgm^{-3})	OC (Mg/ha)
0 - 22	2.93	1.35	74.00
22- 40	1.68	1.20	36.00
40- 59	1.19	1.48	83.00
59- 80	0.78	1.53	26.00
80-100	0.87	1.50	26.00
Total			245.00

MUNDAKAYAM - Rubber

0 - 9	1.83	1.00	16.50
9 -32	1.36	1.10	34.50
32 -51	1.02	1.20	24.40
51 -73	0.96	1.40	30.00
73-100	0.67	1.40	25.00
Total			130.40

MUNDAKAYAM - Forest

0-11	2.61	1.10	31.50
11-24	1.60	1.20	25.00
24-45	1.28	1.10	30.00
45-69	0.95	1.20	27.50
69-100	0.69	1.40	30.00
Total			144.00

4.3. Total Nitrogen, Available Nitrogen, C:N ratio

In the rubber soils, the total nitrogen content varied from 0.06 per cent in the lowest horizon of Mundakayam and Chimoni to 0.26 per cent in the surface horizon of Chimoni (Table 7.). The surface horizon of Vithura contained 0.26 per cent while in Nilambur and Mundakayam, quantity of nitrogen was the same viz. 0.18 per cent. Total nitrogen content in one meter depth in the four location were 19, 18, 16 and 13 Mg/ha (Table 7.1.). In the forest soils the total nitrogen content varied from 0.06 per cent in the lowest horizon of Mundakayam and Nilambur to 0.30 per cent in the surface horizon of Chimoni. The surface horizon of Vithura contained 0.24 per cent while those of Mundakayam and Nilambur contained 0.22 per cent total nitrogen. Total nitrogen content in one meter depth in the four location were 27, 31, 19, 15 Mg/ha respectively (Table 7.1.). As in the case of organic carbon, total nitrogen also was found to be maximum in the surface horizons which decreased down the profile in both rubber and forest. The distribution of total nitrogen in rubber and forest profiles are as shown in Fig. 3. In 100 cm profile there was a decrease in total nitrogen content of rubber plantations by 29, 41, 15 and 13 per cent as compared to adjacent forest. In 0-30 and 30-60 cm soil also the reduction in rubber growing soil was significant (Appendix 2).

Available nitrogen

Available nitrogen in rubber soils varied from 70 ppm in 100-129 cm horizon of Nilambur and 52-76cm horizon of Chimoni, to 323 ppm in the surface horizon of Mundakayam (Table 7). The surface horizons of Nilambur, Chimoni and Vithura contained 239, 244 and 265 ppm available nitrogen respectively. In forest profiles the available nitrogen content varied from 75 ppm in the lowest horizon of Nilambur to 365 ppm in the surface horizon of Chimoni. The surface horizons of Vithura, Mundakayam and Nilambur recorded 274, 352 and 294 ppm available nitrogen respectively. Available nitrogen was also found to be maximum in surface horizons which declined down the profile in forest and rubber plantations. A general reduction in available nitrogen content can be observed in surface horizons of rubber plantations as compared to forest soils. Statistically also the reduction in available nitrogen content in rubber growing soils was significant (Appendix 3).

C/N ratio (Table 7)

The C/N ratio in rubber plantations varied from 4.9 in the 35-57cm horizon of Nilambur to 12.5 in the 100 - 124 cm horizon of Mundakayam. In forest the ratio varied from 6.2 in 57-100 cm horizon of Mundakayam to 13.2 in the surface horizon of Chimoni. In general no pattern in the distribution of C/N ratio in the various horizons can be noticed in the soil profiles of forest and rubber.

4.4. Total phosphorus, available phosphorous and pH

Total phosphorus in profiles of rubber varied from 300 ppm in the 100-124 cm layer of Vithura to 1080 ppm in the 0-9 cm layer in Mundakayam (Table 8). In forest profiles the minimum phosphorus content of 310 ppm was obtained in the 80-100 cm layer in Vithura and maximum 830 ppm was recorded in the surface horizon of Mundakayam. 100 cm profile of rubber contained 7, 13, 7 and 10 Mg/ha while in forest the quantities were 7, 8, 5 and 10 Mg/ha in Nilambur, Chimoni, Vithura and Mundakayam respectively (Table 8.1). In general a higher content of total phosphorous was observable in profiles of rubber plantations as compared to natural forest. Distribution of total phosphorous is given in Fig. 4. The increase in total phosphorous content in rubber growing areas was significant also (Appendix 4).

Table 7. Total N, Available N, Organic carbon, C/N ratio in various horizons of the profiles from rubber plantations and corresponding virgin forest locations

Nilambur

Rubber					Forest				
Depth (cm)	Total N (%)	Available N ppm	Organic Carbon %	C/N ratio	Depth (cm)	Total N (%)	Available N ppm	Organic Carbon %	C/N ratio
0 - 19	0.18	239	1.68	9.3	0 - 18	0.22	294	1.99	9.0
19 - 35	0.14	190	1.13	8.1	18 - 34	0.16	268	1.26	7.9
35 - 57	0.15	166	0.73	4.9	34 - 57	0.14	200	0.89	6.4
57 -100	0.07	100	0.67	9.5	57 -100	0.14	130	0.87	6.2
100- 129	0.07	70	0.52	9.4	100-132	0.09	100	0.73	8.1
					132-160	0.06	75	0.49	8.2

Chimoni

Rubber					Forest				
Depth (cm)	Total N (%)	Available N ppm	Organic Carbon %	C/N ratio	Depth (cm)	Total N (%)	Available N ppm	Organic Carbon %	C/N ratio
0-14	0.26	244	2.33	8.9	0-11	0.30	365	3.96	13.2
14-24	0.17	209	1.33	7.8	11-33	0.21	300	2.26	10.8
24-38	0.13	182	1.06	8.1	33-64	0.17	225	1.62	9.5
38-52	0.10	130	0.99	9.9	64-100	0.15	200	1.56	10.4
52-76	0.06	70	0.67	11.1	100-130	0.11	100	1.42	12.9
76-100	0.07	75	0.55	7.8					
100-132	0.06	90	0.55	9.1					

Contd....

Table 7. (Contd...)

Vithura

Rubber					Forest				
Depth (cm)	Total N (%)	Available N ppm	Organic Carbon %	C/N ratio	Depth (cm)	Total N (%)	Available N ppm	Organic Carbon %	C/N ratio
0 - 26	0.21	265	2.22	10.5	0 - 22	0.24	274	2.93	12.2
26 - 51	0.13	200	1.15	8.8	22 - 40	0.18	239	1.68	9.3
51 - 76	0.10	125	0.97	9.7	40 - 59	0.10	177	1.19	11.9
76 -100	0.09	100	0.89	9.8	59 - 80	0.09	150	0.78	8.7
100-124	0.09	80	0.89	9.0	80 - 100	0.07	160	0.77	11.1

Mundakayam

Rubber					Forest				
Depth (cm)	Total N (%)	Available N ppm	Organic Carbon %	C/N ratio	Depth (cm)	Total N (%)	Available N ppm	Organic Carbon %	C/N ratio
0-9	0.18	323	1.83	10.2	0-11	0.22	352	2.61	11.9
9-32	0.16	280	1.36	8.5	11-24	0.18	253	1.60	8.9
32-51	0.09	180	1.07	11.8	24-45	0.15	207	1.28	8.5
51-73	0.08	150	0.96	12.0	45-69	0.09	186	0.75	8.3
73-100	0.07	100	0.67	9.6	69-100	0.08	170	0.49	8.2
100-124	0.06	180	0.75	12.5	100-120	0.06	100	0.40	6.6

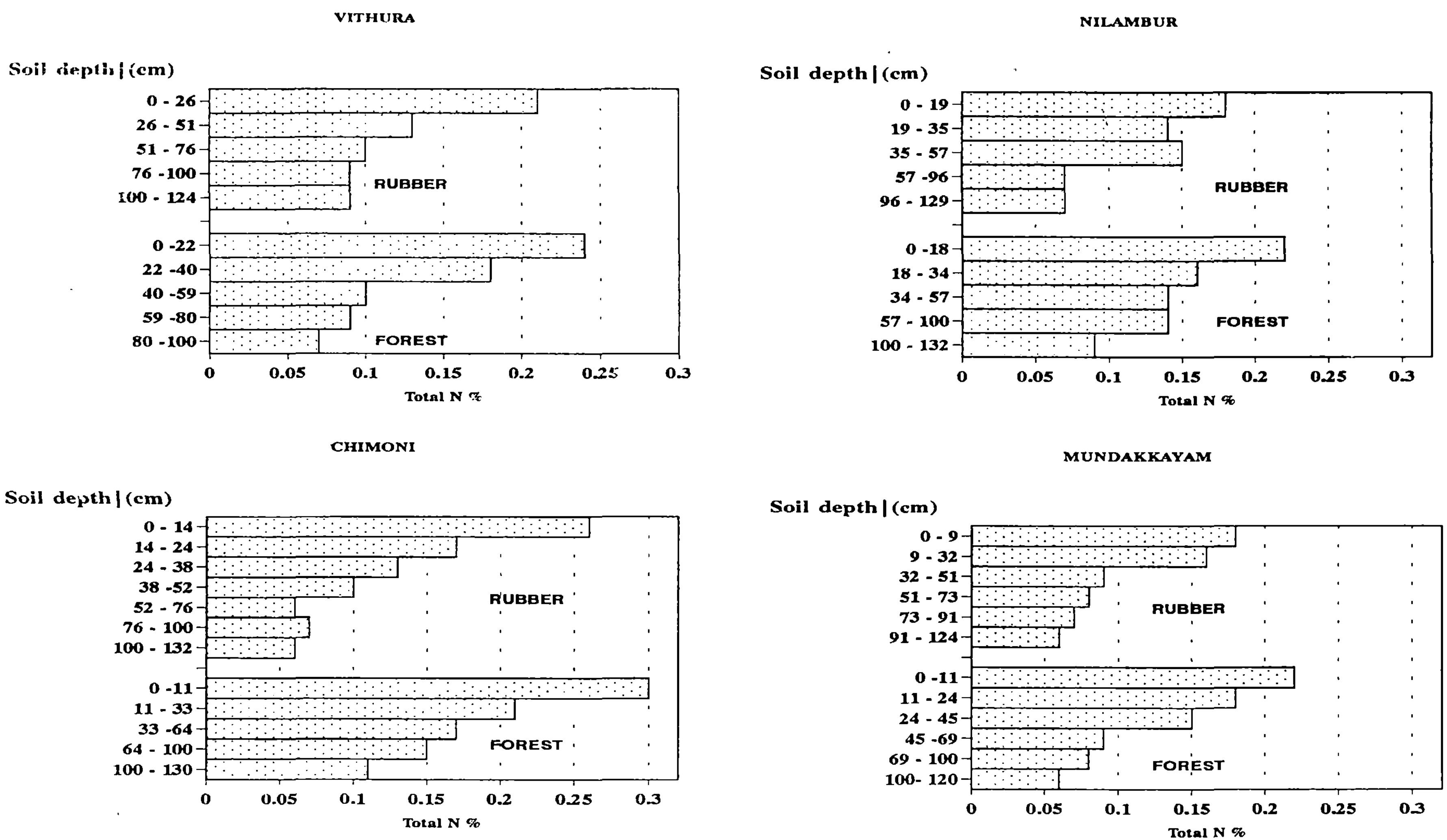

Fig. 3. Total N content in rubber and forest profiles

Table 7.1 Total N content in 100 cm profile of four rubber plantations and corresponding virgin forests

Nilambur

Rubber				Forest			
Depth (cm)	BD Mgm^{-3}	Total N(%)	Total N Mg/ha	Depth cm	BD Mgm^{-3}	Total N (%)	Total N Mg/ha
0 - 19	1.24	0.18	4.24	0-19	1.50	0.22	6.27
19 - 35	1.26	0.14	2.82	19-35	1.65	0.16	4.22
35 - 57	1.88	0.15	6.20	35-57	1.91	0.14	5.88
57 - 100	1.88	0.07	5.66	57-100	1.77	0.14	10.78
Total			18.92				27.15

Chimoni

Rubber				Forest			
0 - 14	1.27	0.26	4.62	0-11	1.37	0.30	4.52
14 - 24	1.86	0.17	3.16	11-33	1.76	0.21	8.13
24 - 38	1.68	0.13	2.35	33-64	1.66	0.17	8.75
38 - 52	1.75	0.10	2.45	64-100	1.68	0.15	9.07
52 - 76	1.80	0.06	2.59				
76 - 100	1.75	0.07	2.94				
Total			18.11				30.47

Contd..

Table 7.1 (Contd...)

Vithura

Rubber				Forest			
0 - 26	1.08	0.21	5.90	0-22	1.35	0.24	7.13
26 - 51	1.29	0.13	4.12	22-40	1.20	0.18	3.89
26 - 51	1.29	0.13	4.12	22-40	1.20	0.18	3.89
51 - 76	1.31	0.10	3.28	40-59	1.48	0.10	2.81
76 -100	1.45	0.09	3.13	59-80	1.53	0.09	2.89
				80-100	1.50	0.07	2.10
Total			16.43				18.82

Mundakayam

Rubber				Forest			
0 - 9	1.00	0.18	1.62	0-11	1.10	0.22	2.66
9 - 32	1.10	0.16	4.05	11-24	1.20	0.18	2.81
32 - 51	1.20	0.09	2.05	24-45	1.10	0.15	3.47
51 - 73	1.40	0.08	2.46	45-69	1.20	0.09	2.59
73 - 100	1.40	0.07	2.65	69-100	1.40	0.08	3.47
Total			12.83				15.00

Available phosphorous

Available phosphorous in rubber profiles varied from 0.1 ppm to 6 ppm the minimum being recorded in 35-57 cm horizon of Nilambur and maximum in surface horizon of Chimoni (Table 8). In forest the values ranged from 1 ppm to 5 ppm. Much difference is not observable in available phosphorous status between rubber and forest situation.

4.5. Soil reaction

pH in rubber profiles ranged from 4.1 in the middle horizon of Chimoni estate to 4.9 in the lower horizons of Mundakayam (Table 8.). In forest the pH values ranged from 4.6 to 6.0, lowest value being recorded in 100 cm horizon of Nilambur and highest value in 11-24 cm horizon of Mundakayam. In general, pH is found to be low in rubber cultivated areas as compared to adjacent natural forest. This reduction was found to be significant also (Appendix 5).

Table 8. Total P, available P and pH from rubber plantations and corresponding virgin forests

Nilambur

Rubber				Forest			
Depth (cm)	Total P (ppm)	Available P (ppm)	pH	Depth (cm)	Total P (ppm)	Available P (ppm)	pH
0 - 19	430	2.0	4.4	0 - 18	430	2.7	4.6
19 - 35	430	1.0	4.5	18 - 34	430	1.0	4.7
35 - 57	420	0.1	4.4	34 - 57	420	1.0	4.7
57 - 100	380	1.0	4.3	57 - 100	390	1.0	4.6
100 - 129	380	1.0	4.2	100 - 132	330	1.0	4.9

4.1 5.7

Chimoni

Rubber				Forest			
Depth (cm)	Total P (ppm)	Available P (ppm)	pH	Depth (cm)	Total P (ppm)	Available P (ppm)	pH
0 - 14	1060	6.0	4.9	0 - 11	690	2.0	5.0
14 - 24	810	2.0	4.9	11 - 33	630	2.0	5.0
24 - 38	760	1.0	4.1	33 - 64	440	1.0	5.0
38 - 52	730	2.0	4.5	64 - 100	390	2.0	4.8
52 - 76	740	3.0	4.5	100 - 130	360	2.0	5.1
76 - 100	730	1.0	4.5				
100 - 132	740	1.0	4.5				

15.0 9.0

Vithura

Rubber				Forest			
Depth (cm)	Total P (ppm)	Available P (ppm)	pH	Depth (cm)	Total P (ppm)	Available P (ppm)	pH
0 - 26	940	4.4	4.9	0 - 22	460	3.0	5.0
26 - 51	480	2.0	4.8	22 - 40	410	3.0	5.0
51 - 76	460	1.0	4.7	40 - 59	380	2.0	4.8
76 - 100	400	3.0	4.6	59 - 80	350	2.0	4.6
100 - 124	300	1.0	4.7	80 - 100	310	2.0	4.7

10.4 12.0

Mundakayam

Rubber				Forest			
Depth (cm)	Total P (ppm)	Available P (ppm)	pH	Depth (cm)	Total P (ppm)	Available P (ppm)	pH
0 - 9	1080	1.0	4.7	0 - 11	830	5.0	5.2
9 - 32	880	3.0	4.7	11 - 24	830	3.0	6.0
32 - 51	790	2.0	4.8	24 - 45	810	2.0	5.6
51 - 73	760	2.0	4.9	45 - 69	810	2.0	5.2
73 - 100	680	2.0	4.9	69 - 100	810	2.0	5.0
100 - 124	600	1.0	4.9	100 - 120	800	3.0	5.0

10.0 14.0

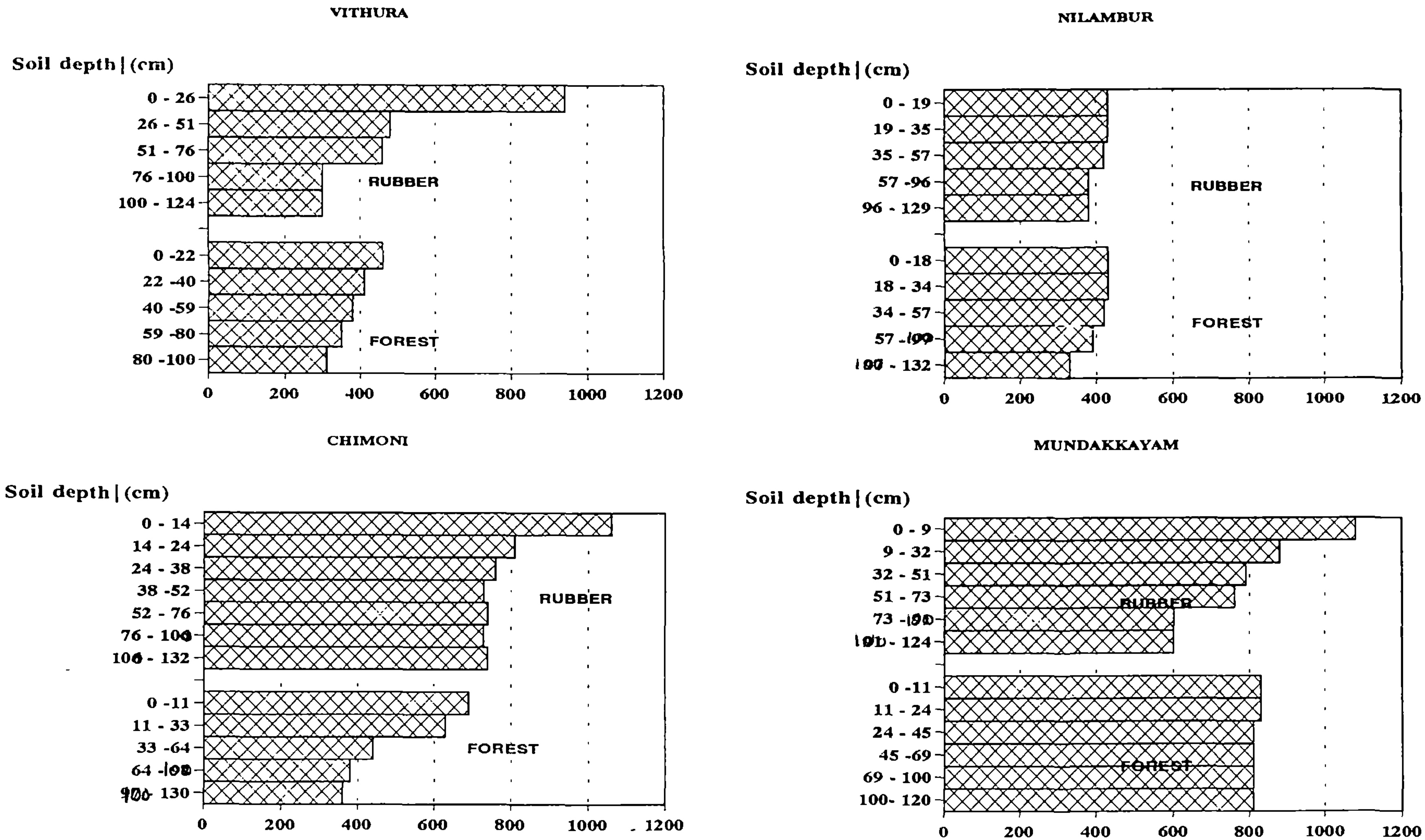

Fig. 4. Total P content in rubber and forest profiles

Table 8.1. Total P content in 100 cm profile of four rubber plantations and corresponding virgin forests

NILAMBUR

Rubber				Forest			
Depth (cm)	BD Mg m^{-3}	Total P (%)	Total P Mg/ha	Depth (cm)	BD Mg m^{-3}	Total P (%)	Total P Mg/ha
0 - 19	1.24	0.043	1.01	0 - 18	1.50	0.043	1.22
19 - 35	1.26	0.043	0.87	19 - 34	1.65	0.043	1.13
35 - 57	1.88	0.042	1.74	34 - 57	1.91	0.042	1.76
57 - 100	1.88	3.038	3.07	57 - 100	1.79	0.039	3.00
Total			6.69				7.11

CHIMONI

Rubber				Forest			
0 - 14	1.27	0.1	1.77	0 - 11	1.37	0.069	1.04
14 - 24	1.86	0.08	1.49	11 - 33	1.76	0.063	2.44
24 - 38	1.68	0.076	1.79	33 - 64	1.66	0.044	2.26
38 - 52	1.75	0.073	1.79	64 - 100	1.68	0.038	2.30
52 - 76	1.80	0.074	3.20				
76 - 100	1.75	0.073	3.07				
Total			13.11				8.04

VITHURA

Rubber				Forest			
0 - 26	1.08	0.094	2.64	0 - 22	1.35	0.046	1.37
26 - 51	1.29	0.048	1.55	22 - 40	1.2	0.041	0.89
51 - 76	1.31	0.046	1.50	40 - 59	1.48	0.038	1.07
76 - 100	1.45	0.03	1.04	59 - 80	1.53	0.035	1.12
				80 - 100	1.5	0.031	0.93
Total			6.73				5.38

MUNDAKAYAM

Rubber				Forest			
0 - 9	1.00	0.1	0.9	0 - 11	1.1	0.083	1.00
9 - 32	1.1	0.088	2.23	11 - 24	1.2	0.083	1.30
32 - 51	1.2	0.079	2.03	24 - 45	1.1	0.081	1.87
51 - 73	1.4	0.076	2.34	45 - 69	1.2	0.081	2.33
73 - 100	1.4	0.068	2.57	69 - 100	1.4	0.081	3.51
Total			10.07				10.01

36.60 30.54

4.6. Total potassium

Total potassium in the rubber soils ranged from 0.05 per cent in the surface horizon of Nilambur to 0.30 per cent in 9-32 cm horizon in Mundakayam (Table 9.). In general, surface layers contained lesser quantities of potassium compared to lower horizons. In forest total potassium content ranged from 0.12 per cent in the lower horizons of Vithura to 0.39 per cent in 25-45 cm horizon in Mundakayam. In forest also surface layers contained lesser quantities of total potassium compared to the lower layers. No definite pattern in the distribution of total potassium was observable in rubber or forest profiles. The distribution of this element in rubber and forest profiles is shwon in Fig. 5. Total potassium content in 100 cm profile in rubber and forest profiles in Nilambur, Chimoni, Vithura and Mundakayam were 12, 21, 12 and 30 Mg/ha and 31, 28, 17 and 38 Mg/ha respectively (Table 9.1.). Reduction in total potassium content in 100cm rubber profiles were 61,25,28 & 21 per cent in the four locations, reduction being maximum in Nilambur and minimum in Mundakayam, the reduction was significant in 0-30 and 30-60 cm soil (Appendix 6.).

4.7. Total Calcium

Data on total calcium content of rubber and forest profiles are presented in Table 9. Total calcium in rubber ranged from 0.06% in 26-51 cm in Vithura to 0.25% in 124-200 cm horizon in Mundakayam. In forest profiles, the total calcium content varied from 0.08% in 100-132 cm horizon in Nilambur and 59-100 cm horizon in Vithura to 0.33% in 18-34 cm horizon in Nilambur. No definite pattern in the distribution of this element down the profile can be observed in rubber or in forest Fig 6. Total calcium content in rubber and forest profiles (100 cm depth) in the four locations (Nilambur, Chimoni, Vithura and Mundakayam) are given in Table 9.2. In rubber, the values were 17, 15, 11 and 10 Mg/ha respectively. In forest the corresponding values were 36, 26,17 and 18 Mg/ha.

The data on total calcium content in 100 cm profile indicate that rubber profiles contain lesser quantities of calcium than natural forest, the percentage decline being of the order 55, 42, 35, 44 in Nilambur, Chimoni, Vithura and Mundakayam respectively. Maximum reduction has occurred in Nilambur and minimum in Vithura. In 0-30 and 30-60 soil the reduction was statistically significant also (Appendix 7).

4.8. Total Magnesium

In the soil profiles from rubber plantations the total magnesium values ranged form 0.01 per cent to 0.05 per cent. Maximum quantity was observed in the surface horizon of Mundakayam (Table 9). In forest the minimum quantity of 0.01 was obtained in several horizons as in the case of plantation profiles. In forest also the maximum total magnesium content was 0.05 per cent, obtained in the 92-123 cm horizon of Mundakayam. There was no definite pattern in the depth-wise distribution of magnesium. Total magnesium content in 100 cm profiles of rubber plantations in the four locations Nilambur, Chimoni, Vithura and Mundakayam were 2.47, 2.30, 1.89 and 2.92 Mg/ha. while in forest the values were 2.29, 3.31, 1.45, 1.23 Mg/ha respectively. Between rubber and forest soil profiles, no appreciable difference could be observed in the magnesium content except in Chimoni where 30 per cent reduction has occurred due to cultivation of rubber.

Table 9. Total Ca, Mg and K in various horizons of the profiles from rubber plantations and corresponding virgin forest

Nilambur

Rubber				Forest			
Depth (cm)	% Ca	% Mg	% K	Depth (cm)	% Ca	% Mg	% K
0 - 19	0.08	0.01	0.05	0 - 18	0.21	0.02	0.14
19 - 35	0.21	0.01	0.05	18 - 34	0.33	0.02	0.17
35 - 57	0.08	0.01	0.07	34 - 57	0.17	0.01	0.16
57 - 100	0.09	0.02	0.08	57 - 100	0.18	0.01	0.24
100- 129	0.09	0.03	0.13	100 - 132	0.08	0.01	0.24
				132 - 160	0.25	0.01	0.22

Chimoni

Rubber				Forest			
Depth (cm)	% Ca	% Mg	% K	Depth (cm)	% Ca	% Mg	% K
0 - 14	0.11	0.02	0.07	0 - 11	0.13	0.02	0.14
14 - 24	0.07	0.02	0.06	11 - 33	0.16	0.02	0.12
24 - 38	0.08	0.02	0.07	33 - 64	0.14	0.02	0.20
38 - 52	0.14	0.01	0.12	64 - 100	0.18	0.02	0.18
52 - 76	0.08	0.01	0.16	100 - 130	0.15	0.01	0.16
76 - 100	0.08	0.01	0.18				
100- 132	0.20	0.02	0.17				

Table 9. (Contd...)

Vithura

Rubber				Forest			
Depth (cm)	% Ca	% Mg	% K	Depth (cm)	% Ca	% Mg	% K
0 - 26	0.13	0.02	0.10	0 - 22	0.18	0.01	0.14
26 - 51	0.06	0.01	0.09	22 - 40	0.16	0.01	0.17
51 - 76	0.06	0.02	0.12	40 - 59	0.10	0.01	0.18
76 - 100	0.10	0.01	0.08	59 - 80	0.08	0.01	0.12
				80 - 100	0.08	0.01	0.12

Mubdakayam

Rubber				Forest			
Depth (cm)	% Ca	% Mg	% K	Depth (cm)	% Ca	% Mg	% K
0 - 9	0.08	0.05	0.20	0 - 11	0.18	0.01	0.29
9 - 32	0.09	0.04	0.30	11 - 25	0.10	0.01	0.35
32 - 51	0.08	0.02	0.24	25 - 45	0.12	0.01	0.39
51 - 73	0.08	0.02	0.23	45 - 69	0.12	0.01	0.30
73 - 100	0.09	0.01	0.29	69 - 92	0.20	0.01	0.25
100- 124	0.07	0.01	0.23	92 - 100	0.20	0.05	0.25
124- 200	0.25	0.01	0.22	100 - 120	0.18	0.04	0.24

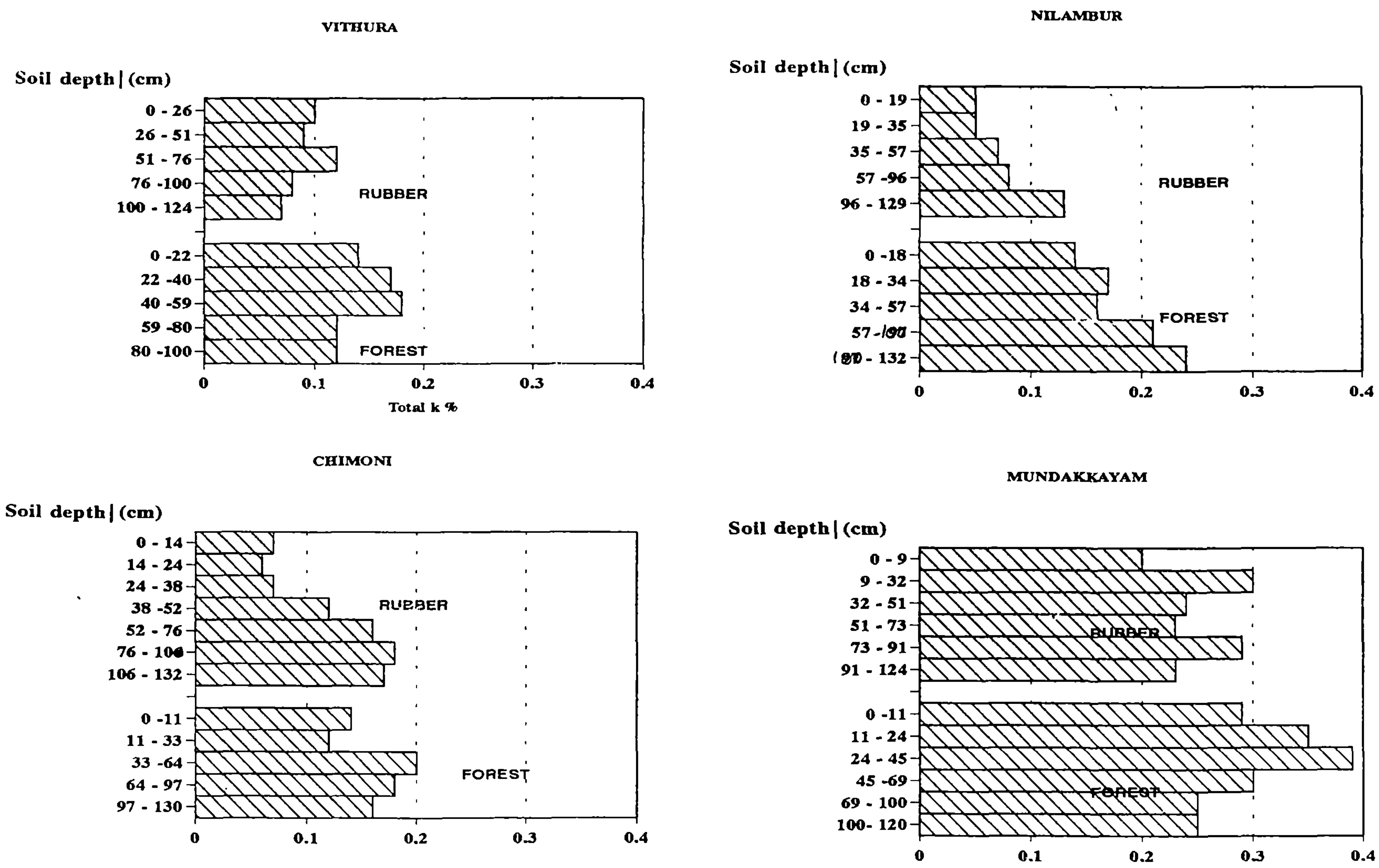

Fig. 5. Total K content in rubber and forest profiles

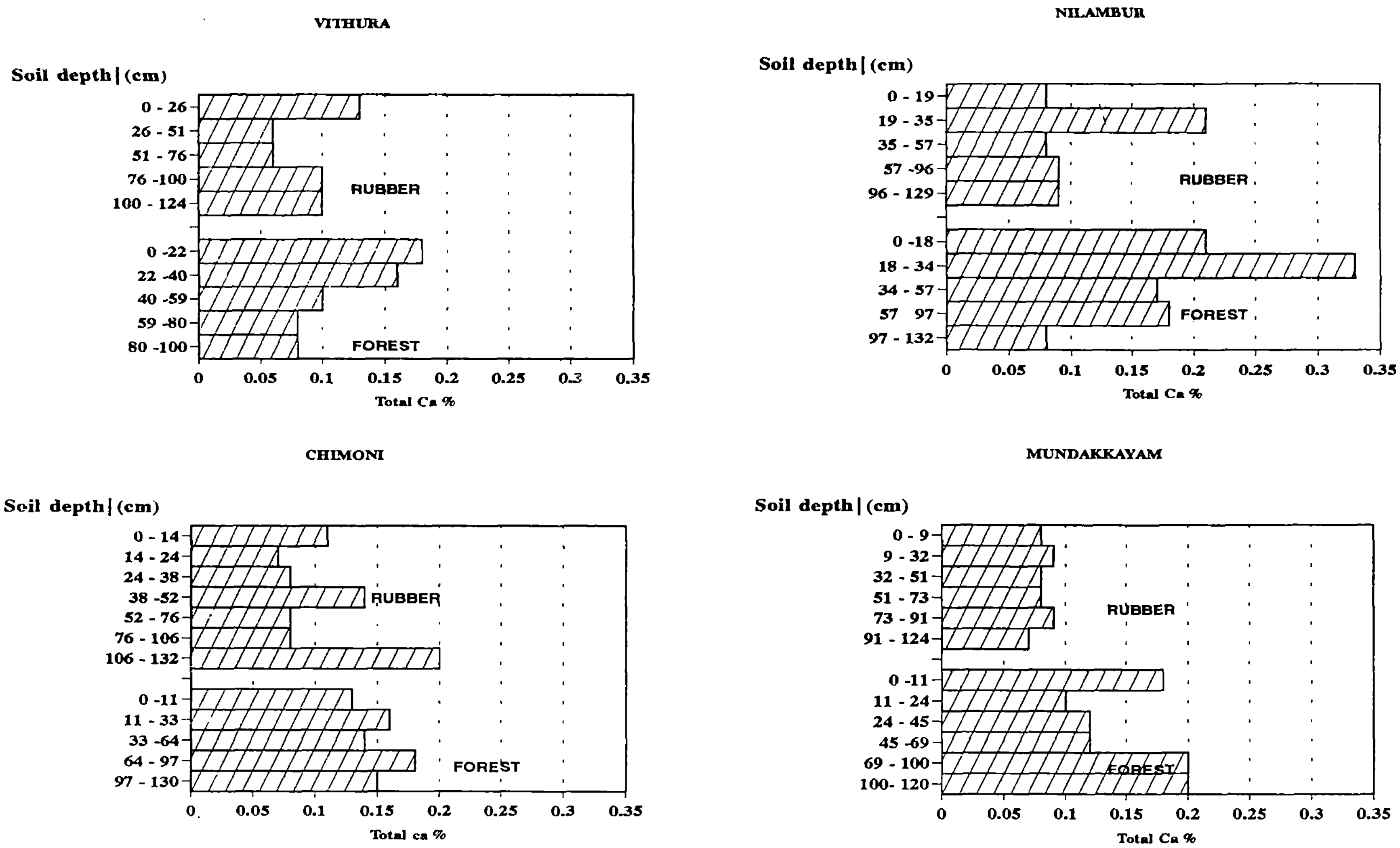

Fig. 6. Total Ca content in rubber and forest profiles

Table 9.1. Total potassium in 100 cm profile of four rubber plantations and corresponding virgin forests

Nilambur

Rubber				Forest			
Depth (cm)	BD Mg m^{-3}	Total K (%)	Total K (Mg/ha)	Depth (cm)	BD Mg m^{-3}	Total K (%)	Total K (Mg/ha)
0 - 19	1.24	0.05	1.18	0-19	1.50	0.14	3.99
19 - 35	1.26	0.05	1.01	19-35	1.65	0.17	4.49
35 - 57	1.88	0.07	2.90	35-57	1.91	0.16	6.72
57 - 100	1.88	0.08	6.69	57-100	1.79	0.21	16.16
			11.78				31.36

Chimoni

Rubber				Forest			
Depth (cm)	BD Mg m^{-3}	Total K (%)	Total (Mg/ha)	Depth (cm)	BD Mg m^{-3}	Total K (%)	Total K (Mg/ha)
0 - 14	1.27	0.07	1.25	0-11	1.37	0.14	2.11
14 - 24	1.86	0.06	1.12	11-33	1.76	0.12	4.65
24 - 38	1.68	0.07	1.65	33-64	1.66	0.20	10.29
38 - 52	1.75	0.12	2.94	64-100	1.68	0.18	10.89
52 - 76	1.80	0.16	6.91				
76 - 100	1.75	0.18	7.56				
			21.43				27.94

Table 9.1 Contd...

Vithura

Rubber				Forest			
Depth	BD	Total K (%)	Total K (Mg/ha)	Depth	BD gm/cc	Total K (%)	Total K Mg/ha
0 - 26	1.08	0.10	2.81	0-22	1.35	0.14	4.16
26 - 51	1.29	0.09	2.90	22-40	1.20	0.17	3.67
51 - 76	1.31	0.12	3.93	40-59	1.48	0.18	5.06
76 - 100	1.45	0.08	2.78	59-80	1.53	0.12	3.86
			12				16.75

Mundakayam

Rubber				Forest			
Depth	BD gm/cc	Total K (%)	Total K (Mg/ha)	Depth	BD gm/cc	Total K (%)	Total K Mg/ha
0 - 09	1.00	0.20	1.80	0-11	1.10	0.29	3.51
9 - 32	1.10	0.30	7.39	11-24	1.20	0.35	5.46
35 - 51	1.20	0.24	5.47	24-45	1.10	0.39	9.01
51 - 73	1.40	0.23	7.08	45-69	1.20	0.30	8.64
73 - 100	1.40	0.29	7.94	69-100	1.40	0.25	10.85
			30				37.47

Table 9.2. Total calcium content in 100 cm profile of four rubber plantations and corresponding virgin forest

Nilambur

Rubber				Forest			
Depth (cm)	BD Mg m^{-3}	Total Ca	Total Ca Mg/ha	Depth (cm)	BD Mg m^{-3}	Total Ca (%)	Total Ca (Mg/ha)
0 - 19	1.24	0.08	1.88	0-19	1.50	0.21	5.98
19 - 35	1.26	0.21	4.23	19-35	1.65	0.33	8.71
35 - 57	1.88	0.08	3.30	35-57	1.91	0.17	7.14
57 - 100	1.88	0.09	7.27	57-100	1.79	0.18	13.85
Total			16.68				35.68

Chimoni

Rubber				Forest			
Depth (cm)	BD Mg m^{-3}	Total Ca (%)	Total Ca (Mg/ha)	Depth (cm)	BD Mg m^{-3}	Total Ca (%)	Total Ca (Mg/ha)
0 - 14	1.27	0.11	1.88	0-19	1.50	0.21	1.95
14 - 24	1.86	0.07	1.30	11-33	1.76	0.16	6.19
38 - 52	1.68	0.08	1.88	33-64	1.66	0.14	7.20
52 - 76	1.80	0.14	3.43	64-100	1.68	0.18	10.88
76 - 100	1.75	0.08	3.36				
Total			15.38				26.22

Table 9.2. Contd....

Vithura

Rubber				Forest			
Depth (cm)	BD Mg m^{-3}	Total Ca (%)	Total Ca (Mg/ha)	Depth (cm)	BD Mg m^{-3}	Total Ca (%)	Total Ca (Mg/ha)
0 - 26	1.05	0.13	3.65	0-22	1.35	0.18	5.35
26 - 51	1.29	0.06	1.93	22-40	1.20	0.16	3.46
51 - 76	1.31	0.06	1.96	40-59	1.48	0.10	2.81
76 - 100	1.45	0.10	3.48	59-80	1.53	0.08	2.57
Total			11.02				16.5

Mundakayam

Rubber				Forest			
Depth (cm)	BD Mg m^{-3}	Total Ca (%)	Total Ca (Mg/ha)	Depth (cm)	BD Mg m^{-3}	Total Ca (%)	Total Ca (Mg/ha)
0 - 09	1.00	0.08	0.72	0-11	1.10	1.18	2.17
9 - 32	1.10	0.09	2.27	11-24	1.20	0.10	1.56
35 - 51	1.20	0.08	1.82	24-45	1.10	0.12	2.77
51 - 73	1.40	0.08	2.46	45-69	1.20	0.10	2.88
73 - 100	1.40	0.08	3.02	69-100	1.40	0.20	8.68
Total			10.29				18.06

Table 9.3. Total Magnesium content in 100 cm profile of rubber plantations and corresponding virgin forest

Nilambur

Rubber				Forest			
Depth (cm)	BD Mg m^{-3}	Total Mg (%)	Total Mg (Mg/ha)	Depth (cm)	BD Mg m^{-3}	Total Mg (%)	Total Mg (Mg/ha)
0 - 19	1.24	0.01	0.24	0-19	1.50	0.02	0.57
19 - 35	1.26	0.01	0.20	19-35	1.65	0.02	0.53
35 - 57	1.88	0.01	0.41	35-57	1.91	0.01	0.42
57 - 100	1.88	0.02	1.62	57-100	1.79	0.01	0.77
Total			2.47	Total			2.29

Chimoni

Rubber				Forest			
Depth (cm)	BD Mg m^{-3}	Total Mg (%)	Total Mg (Mg/ha)	Depth (cm)	BD Mg m^{-3}	Total Mg (%)	Total Mg (Mg/ha)
0 - 14	1.27	0.02	0.36	0-19	1.37	0.02	0.30
14 - 24	1.86	0.02	1.37	11-33	1.76	0.02	0.77
34 - 38	1.68	0.02	0.47				
38 - 52	1.75	0.01	0.25	33-64	1.66	0.02	1.03
52 - 76	1.80	0.01	0.43	64-100	1.68	0.02	1.21
76 - 100	1.75	0.01	0.42				
Total			2.30	Total			3.31

Table 9.3 Contd....

Vithura

Rubber				Forest			
Depth (Cm)	BD Mg m^{-3}	Total Mg (%)	Total Mg (Mg/ha)	Depth	BD Mg m^{-3}	Total Mg (%)	Total Mg (Mg/ha)
0 - 26	1.08	0.02	0.56	0-22	1.35	0.01	0.30
26 - 51	1.29	0.01	0.32	22-40	1.20	0.01	0.22
51 - 76	1.31	0.02	0.66	40-59	1.48	0.01	0.28
76 - 100	1.45	0.01	0.35	59-80	1.53	0.01	0.32
				80-100	1.50	0.01	0.33
Total			1.89				1.45

Mundakayam

Rubber				Forest			
Depth (cm)	BD Mg m^{-3}	Total Mg (%)	Total Mg (Mg/ha)	Depth (cm)	BD Mg m^{-3}	Total Mg (%)	Total Mg (Mg/ha)
0 - 9	1.00	0.05	0.45	0-11	1.10	0.01	0.12
9 - 32	1.10	0.04	1.01	11-24	1.20	0.01	0.16
32 - 51	1.20	0.02	0.46	24-45	1.10	0.01	0.23
51 - 73	1.40	0.02	0.62	45-69	1.20	0.01	0.29
73 - 100	1.40	0.01	0.38	69-100	1.40	0.01	0.43
Total			2.92	Total			1.23

4.9. Exchangeable Potassium

Exchangeable Potassium in rubber soil profiles varied from 0.11 Cmol/kg in the lower horizons of Nilambur to 0.63 Cmol/kg in the upper most horizon of Mundakayam (Table 10). The surface horizons of Nilambur, Chimoni and Vithura contained 0.27, 0.59, 0.25 Cmol/kg respectively. In forest soil profiles, the exchangeable potassium content varied from 0.08 in the lowest horizon of Vithura to 1.05 Cmol/kg in the surface horizon of Mundakayam. In rubber and in forest maximum exchangeable potassium was obtained in Mundakayam. In forest soil profiles, the surface horizons of Nilambur, Chimoni and Vithura had exahangeable potassium content of 0.69, 0.62 and 0.27 Cmol/kg respectively. Exchangeable potassium was found to be significantly lowered as a result of rubber cultivation (Appendix 10). In general a reduction in exchangeable potassium can be noticed from surface to lower horizon in rubber as well as in forest.

4.10. Exchangeable calcium

The exchangeable calcium content in plantation profiles ranged from 0.17 Cmol/kg in lowest horizon of Vithura to 2.19 Cmol/kg in 38-52 cm horizon in Chimoni (Table 10). The values for surface horizons in Nilambur, Vithura and Mundakayam were 1.23, 0.44,and 0.97 Cmol/kg respectively. In forest the values ranged from 0.22 Cmol/kg in 59-80 cm layer in Vithura to 4.91 C mol/kg in the uppermost horizon in Chimoni. The values in surface horizons of Nilambur, Vithura and Mundakayam were 2.54, 1.50, and 2.75 Cmol/kg respectively. Exchangeable calcium in rubber as well as in forest soil was found to be maximum in the same location viz Chimoni. It is evident from table 10 that exchangeable calcium is high in forest areas as compared to rubber cultivated areas. Except in Vithura rubber profiles, a lower level of exahangeable calcium can be noticed in the middle horizon compared to upper and lower horizons. Reduction in exchangeable calcium content in rubber cultivated areas were statistically significant also (Appendix 8).

4.11. Exchangeable Magnesium

Exchangeable magnesium in rubber varied from 0.12 Cmol/kg in 35.57 cm layer in Nilambur to 0.98 C mol/kg in 38-52 cm layer in Chimoni (Table 10). In Nilambur and Vithura, a decreasing trend in exchageable magnesium can be noticed down the profile. In Chimoni and Mundakayam the lower three horizons contained more exchangeable magnesium. In forest the values ranged from 0.03 Cmol/kg in the 80-100 cm horizon in Vithura to 1.10 Cmol/kg in the 0-11 cm horizon in Chimoni. No definite pattern in the distribution of exchangeable magnesium is obtained in forest. Exchangeable magnesium is also found to be low in profiles in rubber estates as compared to profiles in forests. Statistically also the lowering in exchangeable magnesium in rubber cultivated areas was significant.

4.12. Cation exchange capacity (CEC)

CEC values in rubber varied from 2.71 Cmol/kg in 57-100 cm horizon of Nilambur to 12.5 Cmol/kg in the 0-14 cm horizon of Chimoni. In the other three location also CEC was found to be maximum in surface horizons. In forest, the CEC varied from 2.54 in the 80-100 cm horizon of Vithura to 18.57 Cmol/kg in 11-33 cm horizons of Chimoni, (Table 10) indcates that CEC values are low in rubber cultivated areas when compared to natural forest. Appendix 11 also indicates CEC was significantly low in rubber estates as compared to adjucent natural forest.

4.13. Base saturation

In rubber plantations the base saturation (BS)values ranged from 10.10 per cent in 0-26 cm horizon of Vithura to 60.46 per cent in the 38-52 cm horizon of Chimoni (Table 10). In forest, base saturation varied from 13.55 per cent in 33-64 cm horizon of Chimoni to 60.78 per cent in 57-100 cm horizon of Nilambur.

Table 10. Exchangeable K, Ca, Mg, CEC and Base saturation in percentage in rubber and forest profiles

NILAMBUR Rubber

Depth (cm)	Ex.K	Ex.Ca	Ex. Mg.	BS %	CEC Cmol/kg
	(Cmol/kg)				
0-19	0.27	1.23	0.48	36.08	6.07
19-35	0.23	0.51	0.18	20.90	5.36
35-57	0.13	0.28	0.12	19.08	3.93
57-100	0.11	0.38	0.17	32.10	2.71
100-129	0.11	0.28	0.43	21.84	4.99

NILAMBUR Forest

Depth (cm)	Ex.K	Ex.Ca	Ex. Mg.	BS %	CEC Cmol/kg
	(Cmol/kg)				
0-18	0.69	2.54	0.62	40.80	10.70
18-34	0.69	1.31	0.52	31.39	8.57
34-57	0.57	0.62	0.64	20.90	10.00
57-100	0.25	0.96	0.73	60.78	3.57
100-132	0.20	0.91	0.76	58.52	3.93

CHIMONI Rubber

Depth (cm)	Ex.K	Ex.Ca	Ex. Mg.	BS %	CEC Cmol/kg
	(Cmol/kg)				
0-14	0.59	1.08	0.31	18.80	12.5
14-24	0.19	0.86	0.12	12.71	10.7
24-38	0.19	0.74	0.30	14.39	9.8
38-52	0.21	2.19	0.98	60.46	6.07
52-76	0.29	2.00	0.64	56.89	5.36
76-100	0.29	1.11	0.40	53.63	5.36

Table 10 contd..

CHIMONI Forest

Depth (cm)	Ex.K	Ex.Ca	Ex. Mg.	BS %	CEC Cmol/kg
	------- (Cmol/kg)-----				
0-11	0.62	4.91	1.10	53.15	12.85
11-33	0.26	2.64	0.92	16.32	18.57
33-64	0.23	0.84	0.19	13.55	11.07
64-100	0.24	0.72	0.31	19.45	6.98
100-130	0.34	0.78	0.43	22.66	7.68

VITHURA Rubber

Depth (cm)	Ex.K	Ex.Ca	Ex. Mg.	BS %	CEC Cmol/kg
	------- (Cmol/kg)-----				
0-26	0.25	0.44	0.37	10.10	11.78
26-51	0.17	0.85	0.21	12.47	11.07
51-76	0.13	0.69	0.18	12.43	8.93
76-100	0.15	0.30	0.19	15.03	4.39
100-124	0.13	0.17	0.20	13.13	3.81

VITHURA Forest

Depth (cm)	Ex.K	Ex.Ca	Ex. Mg.	BS %	CEC Cmol/kg
	------- (Cmol/kg)-----				
0-22	0.27	1.50	0.57	20.88	12.50
22-40	0.27	0.62	0.20	16.83	8.20
40-59	0.09	0.51	0.13	15.87	8.57
59-80	0.19	0.22	0.04	19.69	3.81
80-100	0.08	0.26	0.03	25.59	2.54

Table 10 contd..

MUNDAKAYAM Rubber

Depth (cm)	Ex.K	Ex.Ca	Ex. Mg.	BS %	CEC Cmol/kg
	(Cmol/kg)				
0-9	0.63	0.97	0.28	24.87	7.72
9-32	0.32	0.35	0.14	11.67	6.77
32-51	0.34	0.72	0.16	23.79	5.80
51-73	0.29	0.73	0.33	26.67	5.90
73-100	0.42	0.71	0.45	41.52	4.72
100-124	0.29	0.70	0.41	35.24	5.25

MUNDAKAYAM Forest

Depth (cm)	Ex.K	Ex.Ca	Ex. Mg.	BS %	CEC Cmol/kg
	(Cmol/kg)				
0-11	1.05	2.75	0.45	55.12	9.09
11-25	0.59	1.38	0.45	30.14	7.83
25-45	0.76	1.11	0.45	33.69	7.51
45-69	0.59	0.84	0.45	42.70	4.66
69-100	0.42	0.49	0.28	19.63	6.52

4.14. Total iron, aluminium and sesquioxides

The distribution of sesquioxides, total iron and aluminium (Table 11) shows that the contents are high both in rubber and forest. A higher content of Aluminium is noticed in all the profiles as compared to iron. It was also noticed that total iron and aluminium are higher in rubber as compared to forest. The percentage of iron in rubber profile varied from 7.0 per cent in the surface horizon of Vithura to 12 per cent in the bottom most horizon of Mundakayam. In forest iron content varied from 5.6 per cent in the surface horizon of Nilambur to 9.4 per cent in the middle horizon of Mundakayam. Iron content was found to be significantly high in rubber plantations (Appendix 12). The Aluminium content in rubber soil profiles varied from 14.2 per cent in the 0-19 cm of Nilambur to 27 per cent in the 52.76 cm horizon of Chimoni. In forest soil profiles the variation was from 12.4 per cent in 34-57 cm horizon of Nilambur to 23 per cent in the 22-40 cm horizon of Vithura.

The sesquioxide content in rubber varied from 23 per cent in the 0 - 19 cm horizon of Nilambur to 36 per cent

Table 11. **Sesquioxide, Iron and Aluminium oxide in various horizons of the profile from rubber plantations and corresponding virgin forest locations (%)**

Nilambur

Rubber				Forest			
Depth cm.	Sesqui oxide	Iron oxide	Aluminium oxide	Depth cm.	Sesqui oxide	Iron oxide	Aluminium oxide
0-19	23	8.8	14.2	0-18	14	5.6	18.4
19-35	26	8.8	17.2	18-34	20	6.4	13.6
35-57	28	8.0	20.0	34-57	20	7.6	12.4
57-100	30	9.8	20.2	57-97	22	8.2	13.8
100-129	29	9.4	19.6	97-132	24	8.8	15.2

Chimoni

Rubber				Forest			
0-14	26	9.4	16.6	0-11	21	6.2	17.8
14-24	28	9.4	18.6	11-33	22	6.4	15.6
24-38	31	9.0	22.0	33-64	21	6.6	14.4
38-52	33	9.2	23.8	64-100	24	7.0	17.0
52-76	36	9.0	27.0	100-130	25	6.0	19.0
76-100	33	9.0	24.0				
100-132	31	9.5	24.5				

Table 11 (Contd....)

Vithura

Rubber				Forest			
Depth cm.	Sesqui oxide	Iron oxide	Aluminium oxide	Depth cm.	Sesqui oxide	Iron oxide	Aluminium oxide
				0-22	25	7.4	17.6
0-26	24	7.0	17.0	22-40	31	8.0	23.0
26-51	24	7.6	19.6	40-59	30	8.0	22.0
51-76	27	8.0	19.0	59-80	26	6.2	19.8
76-100	23	7.0	16.0	80-100	24	5.8	18.2

Mundakayam

Rubber				Forest			
0-9	29	10.0	19.0	0-11	27	7.6	19.4
9-32	27	9.0	18.0	11-24	28	9.2	18.8
32-51	28	9.2	18.8	24-45	26	9.4	16.8
51-73	30	10.2	19.8	45-69	29	9.4	19.6
73-100	30	11.0	22.0	69-100	26	5.6	20.4
100-124	33	11.0	22.5	100-120	25	6.0	17.0
124-200	36	12.0	21.5				

in the 124 - 200 cm horizon of Mundakayam and 52-76 cm of Chimoni. In forest soil profiles the quantity varied from 14 per cent in 0-18 cm horizon of Nilambur to 31 per cent in 22-40 cm horizon of Vithura. Sesquioxide can be found to be high in rubber cultivated area as compared to forest areas (Appendix 14). In general, higher quantities of sesquioxide, iron and aluminium contents were observable in rubber as compared to forest which is an indication of the tendency of laterisation in monoculture plantation as compared to natural forest.

4.15. Oxalate extractable iron (Fe-Ox)

Oxalate extractable iron, which is an indication of the active iron content, in rubber soil profiles, varied from 1.0 per cent in the 52-76 cm horizon of Chimoni and 100 -124 cm horizon of Vithura to 2.5 per cent in the 9 - 32 cm horizon of Mundakayam (Table 12). In forest soil profiles the oxalate iron content varied from 1.0 per cent in the lower most horizons of Chimoni, Mundakayam and Vithura to 2.5 per cent in the top horizon of Mundakayam and Vithura. It was observed that there is a decrease in Fe-Ox in the lower horizons of rubber and forest profiles.

4.16. The Dithionate citrate buffer extractable iron (Fe-DCB)

The dithionate citrate buffer extractable iron in rubber varied from 1.6 per cent in the top most horizon of Chimoni to 9.9 per cent in the 73-91 cm horizon of Mundakayam (Table 12). In forest, Fe-DCB values varied from 0.8 per cent in the lower most horizons of Mundakayam and Vithura to 5.3 per cent in the top most horizons of Mundakayam and Vithura.

In general, a higher quantity of Fe-DCB as compared to Fe-OX can be observed in rubber as well as in forest profiles. Comparing rubber and forest profiles, Fe-DCB can be found to be high in rubber plantations (Appendix 13).

Table 12. Total Fe, Oxalate extractable Fe, Dithionate citrate bicarbonate extractable Fe and in various horizons of the profiles from rubber plantations and virgin forests (%)

Nilambur

Rubber				Forest			
Depth (cm)	Total Fe %	Fe-ox %	Fe DCB %	Depth (cm)	Total Fe %	Fe-ox %	Fe DCB %
0 - 19	8.8	2.2	3.2	0 - 18	5.6	1.6	3.7
19 - 35	8.8	2.4	3.3	18 - 34	6.4	1.9	2.5
35 - 57	8.0	2.6	4.7	34 - 57	7.6	1.6	2.7
57 - 96	9.8	1.9	2.2	57 - 100	12.4	1.5	3.0
100 - 129	9.4	1.9	2.5	100 - 132	12.5	1.6	2.3

Chimoni

Rubber				Forest			
Depth (cm)	Total Fe %	Fe ox %	Fe DCB %	Depth (cm)	Total Fe %	Fe ox %	Fe DCB %
0 - 14	9.4	2.0	1.6	0 - 11	6.2	1.9	2.3
14 - 24	9.4	2.0	3.7	11 - 33	6.4	1.9	2.3
24 - 38	9.0	1.5	4.7	33 - 64	6.6	2.2	3.0
38 - 52	9.2	1.3	2.5	64 - 100	7.0	1.6	1.9
52 - 76	9.0	1.0	5.6	100 - 130	6.0	1.0	1.5

Table 12 (Contd....)

Vithura

Rubber Depth (cm)	Total Fe %	Fe ox %	Fe DCB %	Forest Depth (cm)	Total Fe %	Fe ox %	Fe DCB %
0 - 26	7.0	1.1	1.9	0 - 22	7.4	2.5	5.3
26 - 51	7.6	1.4	4.7	22 - 40	8.0	2.5	2.3
57 - 76	8.0	1.3	2.7	40 - 59	8.0	2.5	2.0
76 - 100	7.0	1.5	2.2	59 - 80	6.2	2.5	1.9
100 - 124	7.1	1.0	2.5	80 - 100	5.8	1.0	0.8

Mundakayam

Rubber Depth (cm)	Total Fe %	Fe ox %	Fe DCB %	Forest Depth (cm)	Total Fe %	Fe ox %	Fe DCB %
0 - 9	10.0	2.4	5.0	0 - 11	7.6	2.5	5.3
9 - 32	9.0	2.5	1.9	11 - 24	9.2	2.5	2.3
32 - 51	9.2	2.3	10.0	24 - 45	9.4	2.5	1.9
51 - 73	11.4	1.7	7.4	45 - 69	9.4	2.5	1.9
73 - 100	12.0	2.1	9.9	69 - 100	5.7	1.0	0.8

4.18. Sequential changes in nutrient status in different cycles of rubber

Cultivation of *Hevea* was initiated in Kerala as early as 1903, and in the traditional rubber growing tracts, rubber plantations are now in the third cycle of cultivation. Each cycle takes about 30-32 years. In some of the traditional areas the third cycle will be over in another 4 or 5 years. In order to study the nutritional changes appearing in the soil due to the repeated cultivation of rubber in consecutive replanting cycles, after continous field visits and study, sites were located in a compact area where forest, and rubber in three stages namely 1st cycle, 2nd cycle and 3rd cycle existed in Nilambur, Mundakayam and Vithura. Samples were collected at 0-15, 15-30 and 30-60 interval in all the rubber plantations selected and the forest area. The soil fertility parameters were investigated

4.19. Sequential changes in pH, organic carbon and available nutrients

pH

Mean Table 13.1 presents the data on pH of soil horizons from rubber plantations cycle 1, Cycle 2 and Cycle 3 as compared to forest.

Table 13.1. pH of three horizons of soil from 1st, 2nd and 3rd cycle of rubber plantations and corresponding virgin forest

Depth (cm)	Virgin Forest	Soil pH: Rubber plantation			
		Cycle 1	Cycle 2	Cycle 3	Mean of rubber (3 cycles)
0 - 15	5.09	5.06	5.03	4.67	4.92
15 - 30	5.01	5.00	4.90	4.77	4.89
30 - 60	5.08	5.20	4.90	4.76	4.96
Mean	5.06	5.09	4.94	4.73	4.92

CD for comparison of rubber and forest 0.13

CD for comparison of forest and 2 cycles of rubber - 0.22

The data revealed that when three horizons up to a depth of 60 cm is considered, continuous cultivation of rubber for three cycles brought about a significant reduction in pH of the three horizons. The average pH values were 5.06 for forests and 4.92 for rubber plantations. When the pattern of pH of each of the cycle was compared with forest, it was seen that values of the third cycle only (4.73) were significantly lower that of the forest. The first and the second cycles were not significantly lower than that of the forest. This indicates that a gradual decrease in pH from the first to the third cycle had occured. The magnitude of changes, though not significant was, almost uniform in all layers. In the first cycle, the 1st layer had a higher pH than the lower layer. In the third cycle, it had a lower pH than the lower layers. In the second cycle, the top layers had a pH nearly the same as the lower layers.

Organic carbon

Results on changes in organic carbon content due to cultivation of rubber in the first, second and third cycle as compared to adjacent virgin forest are presented in Table 13.2.

Table 13.2. Organic carbon of three horizons of soil from 1st, 2nd and 3rd cycle of Rubber plantations and corresponding virgin forest (%)

	Organic carbon as percentage				
Depth (cm)	Virgin Forest	Rubber plantations			
		Cycle 1	Cycle 2	Cycle 3	Mean
0 - 15	2.494	1.707	1.800	2.040	1.806
15 - 30	1.893	1.310	1.450	1.340	1.340
30 - 60	1.538	0.748	0.728	0.961	0.913
Mean	1.975	1.288	1.326	1.447	1.353

CD for comparison of rubber and forest 0.30
CD for comparison of forests and cycles of rubber 0.43

When each cycle was compared seperately with forest, it was seen that organic carbon content in all the three layers were significantly lower than that in the forest. However, the general trend followed was one of a slight increase in organic carbon content in the second and third cycles in the 0 - 15 cm layer, compared to first cycle. However the differences were not significant. In the lowest layer (30-60 cm) slight significant variation in organic carbon content was noticed. When the average organic carbon content in the 0-60 cm layer was considered, it was revealed that from first cycle to third cycle, there is a gradual increase in the organic carbon status, though not significant. The average organic carbon content of the soils (0-60cm) in each cycle was significantly lower than that of the virgin forests. However, there was no significant difference in the C content of the soils collected from the plantations of 1st, 2nd and 3rd cycle.

Available phosphorus

Table 13.3 presents the results on the available phosphorous status in the first, second and third cycles of rubber plantation as compared to adjacent virgin forests.

Table 13.3. **Available P of three horizons of soil from first second and third cycle of rubber plantations and corresponding virgin forest**

Depth (cm)	Available phosphorous (ppm)				
	Virgin forest	Rubber plantations			
		Cycle 1	Cycle 2	Cycle 3	Means of rubber cycles
0 - 15	3.6	4.2	4.7	12.0	7.0
15 - 30	1.7	2.7	1.1	2.0	1.9
30- 60	1.3	1.7	2.8	0.7	1.7
Mean	2.2	2.8	2.9	4.9	3.5

SE for rubber and forest - 0.78

SE for cycles of rubber and forest - 1.1

The data on mean available P content of the soil from the forests are not significantly different from that of rubber plantations in 1st and 2nd cycle. However, the rubber plantations in 3rd cycle contained significantly higher available phosphorous content than the forests and the 1st and 2nd cycles of plantations. After each cycle of rubber, the available phosphorous content in soils increased significantly. The build up of available phosphorous in the surface horizon (0-15cm) progressively increased after each cycle reaching greater than that of virgin forests by the second and third cycle. However, in the 2nd and 3rd horizons progressive cultivation of rubber led to decrease in available phosphorous content.

Available K

Available potassium status in the three cycles of rubber as compared to adjoining forest are given in Table 13.4.

Table 13.4. Available K of three horizons of soil from first, second and third cycle of rubber plantations and corresponding virgin forests

	Available K ppm				
	Virgin forest	Rubber plantations			
Depth		Cycle 1	Cycle 2	Cycle 3	Mean
0 - 15	79.9	69.6	78.0	88.0	84.6
15 - 30	65.0	77.7	44.0	63.0	50.3
30 - 60	69.1	32.0	33.0	45.0	36.8
Mean	71.2	48.3	51.8	72.0	57.2

The mean available potassium content of the virgin forests, 1st cycle, 2nd cycle and 3rd cycle are not significantly different from one another. However, the trend indicated that with planting of rubber, a decrease in available potassium content ensues after which a gradual build up of potassium is accomplished by the third cycle. In the third cycle of the plantation the available potassium status was nearly that of the virgin forest.

4.20. Mechanical composition

The mechanical composition of the profile samples of the third cycle are summarised and presented in Table 14.

Coarse sand

The coarse sand fraction in rubber soils varied from 24 per cent in the 38-52 cm horizon in Chimoni estate to 50 per cent in the 100-132 cm horizon of the same profile. In forest coarse sand varied from 28 per cent in 24-45 cm horizon in Mundakayam to 55 per cent in 69-100 cm of the same profile.

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Fine sand

The fine sand fraction in rubber estate varied from 7 per cent in the 51-73 cm layer of Mundakayam and in the 76-100 and 100-124 cm horizon of Vithura to 20 per cent in the 14-24 cm layer in Chimoni estate. In forest, fine sand varied from 9 per cent in 22-40 and 40-59 cm in Vithura to 23 per cent in the topmost horizon of Nilambur.

Silt and Clay

The silt per cent in rubber varied from 3 per cent in the top horizons of Vithura to 18 per cent in the 52-76 cm layer in Chimoni. In forest silt content varied from 5 per cent in 22-40 cm horizon in Vithura and lower horizons of nilambur to 24 per cent in 45-69 cm horizon of Mundakayam. Clay content varied from 18 per cent in the bottom most horizon of Chimoni to 51 per cent in 51-73 and 100-124cm horizon in Mundakayam. In forest, the values ranged from 14 per cent in 69-92 cm horizon in Mundakayam to 51 per cent in 24-45 cm of the same profile.

Table 14. **Mechanical composition of profile from rubber plantations and corresponding forest locations**

Location	Depth	Organic Carbon %	Coarse sand %	Fine sand %	Silt %	Clay %	Textural Class
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Nilambur Rubber							
	0 - 19	1.68	30	18	10	42	Sandy clay
	19 - 35	1.13	45	8	6	41	Sandy clay
	35 - 57	0.73	35	15	11	39	Sandy clay
	57 - 100	0.52	28	14	14	34	Sandy clay loam
	100 - 129	0.50	31	19	7	33	Sandy clay loam
Nilambur Forest							
	0 - 18	1.99	43	23	7	27	Sandy clay loam
	18 - 34	1.26	40	13	7	40	Sandy clay
	34 - 57	0.89	36	12	6	46	Sandy clay
	57 - 100	0.87	33	16	10	41	Sandy clay
	100 - 132	0.73	33	17	5	45	Sandy clay
	132 - 160	0.49	34	16	5	44	Sandy clay
Chmoni Rubber							
	0 - 14	2.33	42	17	13	28	Sandy clay loam
	14 - 24	1.33	33	20	12	35	Sandy clay
	24 - 38	1.06	30	17	9	44	Sandy clay
	38 - 52	0.99	24	18	17	41	Clay
	52 - 76	0.67	30	19	18	33	Sandy clay loam
	76 - 100	0.55	35	19	17	29	Sandy Clay loam
	100 - 132	0.55	50	18	14	18	Sandy clay laom
Chimoni Forest							
	0 - 11	3.96	42	17	9	32	Sandy clay loam
	11 - 33	2.26	36	20	9	35	Sandy clay
	33 - 64	1.62	35	20	7	38	Sandy clay
	64 - 100	1.56	40	18	10	32	Sandy clay loam
	100 - 130	1.42	41	19	10	30	Sandy clay loam
Vithura Rubber							
	0 - 26	2.22	46	18	3	37	Sandy clay
	21 - 51	1.15	36	13	3	48	Sandy clay
	51 - 76	0.97	37	11	5	48	Sandy clay
	76 - 100	0.89	48	7	6	42	Sandy clay
	100 - 124	0.81	40	7	5	48	Sandy clay

Table 14 (Contd....)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Vithura Forest							
	0 - 22	2.93	48	11	7	34	Sandy clay loam
	22 - 40	1.68	40	9	5	47	Sandy clay
	40 - 59	1.19	43	9	6	42	Sandy clay
	59 - 80	0.78	37	11	9	43	Sandy clay
	80 - 100	0.77	32	10	13	40	Clay
Mundakayam Rubber							
	0 - 9	1.83	37	15	9	39	Sandy clay
	9 - 32	1.36	33	13	15	39	Sandy clay
	32 - 51	1.07	40	12	9	39	Sandy clay
	51 - 73	0.96	30	7	12	51	Clay
	73 - 100	0.67	30	11	15	44	Clay
	100 - 124	0.75	29	9	11	51	Clay
	124 - 200	0.49	31	12	14	43	Sandy clay laom
Mundakayam Forest							
	0 - 11	2.61	52	15	8	25	Sandy clay loam
	11 - 24	1.60	41	13	17	29	Sandy clay loam
	24 - 45	1.28	28	14	7	51	Clay
	45 - 69	0.75	31	12	24	33	Clay loam
	69 - 100	0.49	55	18	13	14	Sandy loam
	100 -120	0.40	54	17	14	15	Sandy loam

4.21. Available moisture (Table 15)

The available moisture percentage, obtained as the difference between moisture percentage at field capacity and that at wilting point, is presented in the Table 15. In rubber soils, available moisture percentage values ranged from 1.68 in Vithura horizon to 8.88 per cent Chimoni. In forest soils the quantity varied from 4.35 to 13.16 per cent. Available moisture in rubber and forest profiles are shown in Fig 7. Moisture content in one meter profiles in the four locations were worked out by adding the volume of water retained in each horizon. In rubber, the water storage (1 meter depth) in litres was 39, 40, 74, and 105 in Mundakayam, Vithura, Nilambur and Chimoni respectively. In forest the profile water storage was 62, 73, 110 and 144 litres in Mundakayam, Vithura, Nilambur and Chimoni respectively. The results in Table 15 clearly indicate that there is significant difference in available moisture content and water storage capacity between rubber and forest, forest soils having higher moisture retention compared to those under rubber. Forest trees with deeper and strong root system might be extracting water from deeper layers more efficiently than rubber trees with fibrous root system Plate - 6.

BD x 100 x 100 x depth x Moist %
100 X 1000

Table 15. Moisture characteristics in various horizons of the profiles from rubber plantations and correspondings virgi forest

Nilambur Rubber						Chimoni Rubber					
Depth cm	Bulk Density	Soil water potential -0.033Mpa	-1.5Mpa	Available moisture%	Available moisture in 1m^2 (litres)	Depth cm	Bulk density	Soil water potential -0.033Mpa	-1.5Mpa	Available Moisture%	Available Moisture i in 1m^2 (litres)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
0 - 19	1.24	25.76	21.87	3.89	9.1	0 - 14	1.27	21.25	12.35	8.88	17.78
						14 - 24	1.86	14.14	6.26	7.88	11.64
19 - 35	1.26	23.94	19.15	4.79	9.6	24 - 38	1.68	16.39	13.03	3.36	7.90
						38 - 52	1.75	17.00	13.72	4.72	11.56
35 - 57	1.88	24.15	17.56	6.59	27.2	52 - 76	1.80	24.55	17.83	6.72	29.03
57 - 100	1.88	28.31	24.41	3.90	31.5	76 - 100	1.75	24.50	18.00	6.50	27.30
Total					77.4						105.21

Nilambur Forest						Chimoni Forest					
0 - 18	1.50	18.76	13.49	5.27	14.2	0 - 11	1.37	30.74	17.58	13.16	19.83
18 - 34	1.65	22.30	16.93	5.37	14.1	11 - 33	1.57	23.78	15.98	7.80	24.49
34 - 57	1.91	24.46	17.61	6.85	30.0	33 - 64	1.66	24.42	14.26	10.16	52.88
57 - 100	1.91	23.74	17.39	6.35	52.1	64 - 100	1.68	21.85	11.86	9.99	48.50
Total					110.4						144.60

Table 15 (Contd..)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Vithura Rubber						Mundakayam Rubber					
0 - 26	1.08	24.61	20.73	3.88	10.90	0 - 9	1.00	19.00	16.05	2.95	2.92
						9 - 32	1.10	19.98	17.1	2.88	7.29
26 - 51	1.29	24.48	21.72	2.76	8.90	32 - 51	1.20	20.32	16.05	4.27	9.74
51 - 76	1.31	25.57	23.89	1.68	5.50	51 - 73	1.40	23.57	19.05	4.52	1.93
76 - 100	1.45	36.54	32.17	4.37	15.21	73 - 100	1.40	24.50	20.60	3.90	8.42
Total					40.51						30.30
Vithura Forest						Mundakayam Forest					
0 -22	1.15	23.29	18.98	4.31	9.96	0 - 11	0.90	21.90	16.90	5.00	4.95
22 - 40	1.00	24.63	19.37	5.26	9.47	11 - 24	1.00	22.13	16.53	5.60	7.28
40 - 59	1.28	75.07	20.40	4.67	13.13	24 - 45	1.10	28.44	21.54	6.90	15.94
59 - 80	1.23	26.06	19.40	6.66	17.20	45 - 69	1.20	23.66	16.66	7.00	20.16
80 - 100	1.20	26.31	21.14	5.17	12.41	69 - 100	1.20	28.44	21.54	6.90	25.30
Total					62.17						73.63

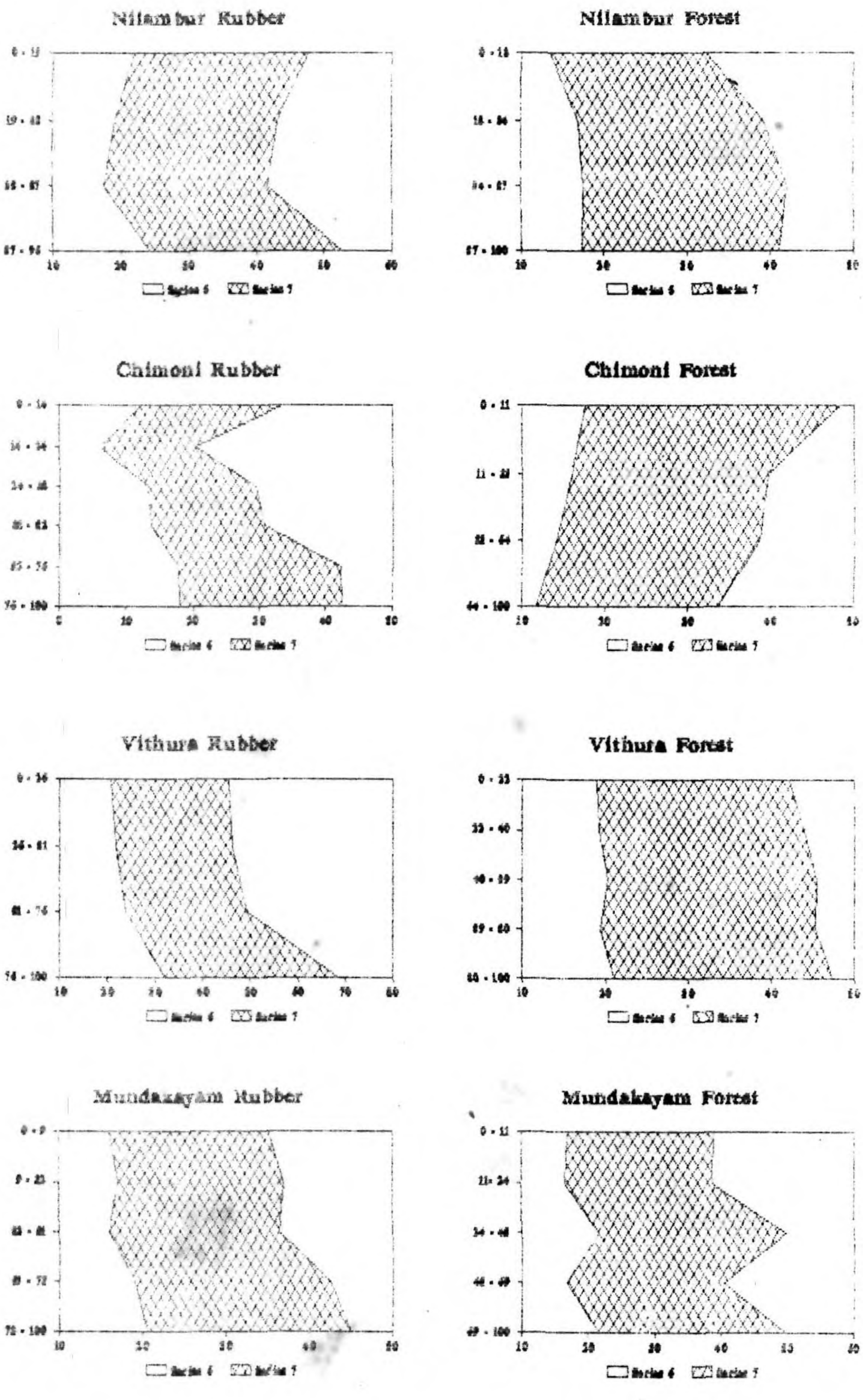

Fig. – Available moisture in Rubber and Forest profiles

4.22. Biomass Accumulation

In the commercial cultivation of *Hevea*, repeated cycles of planting the rubber trees (afforestation) and felling the trees (deforestration) are encountered during every 30-32 years. During plantation clearing, massive amounts of biomass are removed through timber and the area will be replanted by fresh planting materials; whereas as in natural forests, though there is a practice of selective felling of trees for timber, the quantum of such biomass removal is insignificant. In rubber plantations the plants take 4-5 years for canopy closure and attain good tree size in 15-20 years time. In order to quantify the amount of biomass and nutrients removed at the end of each plantation cycle and to know the pattern of biomass accumulation by rubber trees, attempts were made to study the relative distribution of biomass and nutrients in the different plant parts of *Hevea*. A mature plantation of 20 years age was selected. From this two trees having same girth were selected for this study. This two trees were destructively sampled for the study. A 20 year old plant represents a fully mature tree and its dry matter and nutrient partitioning into various plant parts are presented below.

Dry matter

Table 16 shows the fresh weight, dry weight and dry matter percentage of the various plant parts of the 20 year old tree. The tree had a total fresh weight of 2.6 tonnes of which branches had the highest share of 1.3 tonnes followed by 0.75 tonne of the trunk. The highest percentage of dry matter was noticed in trunk (59.5 per cent) and the lowest for green twigs which was lower to the weight noticed for leaves. In the shoot portion of the plant, branches had 45.6 per cent while in leaves it was 39 per cent. The relative distribution of total dry matter in the various plant parts were also expressed as the percentages of total dry matter. Branches and trunk accounted for nearly 80 per cent of the total dry matter of the tree and the share of the tap root was only 14.5 per cent.

Major elements were estimated and the elemental concentration in various parts of the tree is furnished in Table 17. For comparitive purpose samples were taken from as many parts as possible. For estimation of accumulation of nutrients, values of leaves, twigs, branch, trunk and root only were taken.

Nitrogen

Leaves contained maximum concentration 3.65 per cent nitrogen followed by bark of the main trunk containing 3.38 per cent. Next in order was green twigs with 2.09 per cent. Bark of tap root and lateral roots contained 1.12 and 1.08 per cent nitrogen respectively. Of the above ground parts main trunk had the least concentration of 0.42 per cent. In roots also smaller groups contained more concentration. Small roots contained 0.97 per cent and side roots contained 0.74 per cent.

Phosphorus

Of the various parts, maximum concentration of 0.27 per cent phosphorous was observed in leaves. Minimum concentration of 0.04 per cent was noticed in petioles. The concentration of phosphorous in twigs, main trunk and branches were 0.30, 0.06 and 0.06 per cent respectively. In root system, tap root contained 0.11 per cent and smaller roots contained 0.09 per cent. Considering the composition of bark from different, parts bark of the main trunk contained maximum phosphorous concentration of 0.10 per cent.

Potassium

In the above ground parts potassium also registered maximum concentration in leaves viz. 1.40 per cent. Concentration in petioles, twigs, branches and main trunk were 0.88, 0.72, 0.64 and 0.22 per cent respectively. Of the above ground parts main trunk contained the lowest concentration of 0.22 per cent while the concentration in leaves was seven times higher to this. Of the various roots, tap root contained 0.94 per cent. Comparatively higher concentration of potassium was present in the bark.

Calcium

Considering the whole plant, bark of main trunk contained the maximum concentration of 4 per cent calcium. Bark of branches also contained high concentration of 3.2 per cent. Bark of lateral roots contained 2.22 per cent of calcium. In the above ground parts petiole contained 2.18 per cent and all other parts contained only lesser concentration.

Magnesium

In the case of Mg, maximum concentration of 0.49 per cent was recorded in the bark of tap root. Bark of the main trunk also contained almost the same quantity of 0.48 per cent. Leaf contained 0.41 per cent and stem recorded the least concentration of 0.08 per cent.

Table 18 indicates that major share of nitrogen, phosphorus, potassium, calcium and magnesium is in branches.

From Table 19 it is evident that when the plant attained maturity, the share of nitrogen is next only to calcium. The accumulation of calcium was 20 kg while that of nitrogen 16 kg only. Accumulation of K was only 11 kg and that of Mg was 7 kg. The concentration were 1.5, 1.2, 0.8, 0.5 and 0.2 per cent for calcium, nitrogen, potassium, magnesium and phosphorous respectively.

Table 16. Fresh weight, dry weight and percentage dry matter of different parts of twenty year old rubber trees (kg)

Plant part	Fresh weight	Dry weight	% dry matter	% dry matter whole plant basis
Leaves	135	52	39	4
Twigs	104	24	23	2
Branches	1301	593	45	46
Trunk	747	444	59	34
Roots	353	188	53	15
Total	2647	1303	49	

Table 17. Nutrient concentration in 20 year old trees

Plant part	Percentage				
	N	P	K	Ca	Mg
Leaves	3.65	0.27	1.40	1.04	0.41
Petioles	0.83	0.04	0.88	2.18	0.29
Twigs	2.09	0.30	0.72	0.28	0.11
Branches	0.60	0.06	0.64	1.45	0.14
Main trunk	0.42	0.06	0.22	0.84	0.15
Tap root	0.81	0.11	0.94	1.29	0.31
Side roots	0.74	0.09	0.44	0.89	0.21
Small roots	0.97	0.09	0.86	1.83	0.38
Bark (tap root)	1.12	0.09	1.06	1.87	0.49
Bark (laternal roots)	1.08	0.09	1.72	2.22	0.46
Bark branch	0.83	0.05	0.96	3.22	0.27
Bark (main trunk)	3.38	0.10	1.16	4.00	0.48

Table 18. Accumulation of nutrient (g/tree) of various parts of the rubber

Plant part	N	P	K	Ca	Mg
Leaves	1927.2	142.6	731.0	501.6	216.00
Twigs	507.9	72.9	175.0	68.04	26.73
Branches	3558.0	355.8	3795.0	5159.00	2905.70
Trunk	1876.2	268.0	982.5	3751.44	670.00
Roots	848.38	113.10	490.0	2733.25	263.20

Table 19. Major elemental concentration as per cent of the whole tree

Element	Total accumulation (kg)	% of nutrient
Nitrogen	16	1.2
Phosphorus	2	0.2
Potassium	11	0.8
Calcium	20	1.5
Magnesium	7	0.5
Total dry weight	1303 kg	4.2

4.23. Nutrient loss due to felling of trees

In order to get a clear picture of the nutritional balance of each plantation cycle, the quantities of different nutrients removed by way of clear felling of plants has to be quantified besides working out the impacts. Table 20 shows the quantities of various nutrients removed through timber of rubber trees. Here the quantities removed through twigs, branches and trunk only are accounted for since it is assumed that leaves and roots of the plants are not removed from the site and are thus recycled. On an average one hectare of land at the later stages of plantation contain approximately 300 trees per hectare and thus the quantitites of nutrients are expressed per hectare of land.

From the Table 20, it can be noticed that calcium is the nutrient which has been removed in the largest quantity followed by nitrogen and potassium. The removal of phosphorous was only 210 kg. while for Mg it was 5 times that of phosphorus.

Tapping of the trees from the sixth or seventh year to 30th year also results in the removal of nutrients through latex. The outflow of nutrients over a period of 20-25 years is also significant though it is only less than the outflow through timber.

In order to work out the balance sheet of nutrients of one plantation cycle, the quantities applied through fertilizers are also to be accounted. The amount of nitrogen fixed by the leguminous cover crops raised in the plantation as a part of the management practices is also to be taken into account. A well growing leguminous cover fixes up nearly 275 kgN/ha every year. Through the process wintering (plate - 5) large quantities of nutrients are added to rubber plantation, but it is not included in the present computation, as this is a cyclic proces. The schedule of fertilizer recommended by the Rubber Board and widely adopted by farmers are as follows.

Fertilizer schedule for rubber

Year of planting	Nutrients applied/ha			
	N	P_2O_5	K_2O	MgO
1	10	10	4	1.5
2	40	40	16	6
3	50	50	20	7.5
4	40	40	16	6
5	30	30	30	-

The dose of fertilizer applied in the fifth year is continued every year till slaughter tapping and felling. Thus during a period of 32-34 years the quantities of various nutrients added to one hectare approximately works out to

N - 1070 kg

P - 467 kg P (P_2O_5 has been converted and expressed as P)

K - 797 kg K (K_2O has been converted to K)

Mg - 12.5 kg,Mg (MgO has been converted to Mg)

Ca - 1530 kg, Ca (CaO has been converted to Ca)

Since the popularly applied P fertilizer, Mussourie rock phosphate, contains CaO and MgO its indirect contribution to the two nutrients are also accounted for.

4.24. Balance sheet of nutrients

The quantities of major nutrients added through fertilizers and the quantities removed through biomass during replantating were worked out.

Table 21 shows the balance sheet of the major nutrients viz., nitrogen, phosphorous, calcium and magnesium at the end of one cultivation cycle of *Hevea*. From the table it can be noticed that the plantation brings forth a depletion of all the nutrients in the soil except P. The highest depletion was noticed for Ca. (1260 kg Ca/ha) followed by Mg, K and N.

Comparison of total nutrient reserve

In order to relate the depletion of major nutrients observed on the basis of the balance sheet, a comparison was made between rubber (three cycles) and forest with respect to the total quantities of nutrients contained up to 60 cm depth in one hectare of the soil. Rubber roots are believed to proliferate in the surface soil layers and go up to 60 cm, plate - 6. Therefore this depth of the soil is taken for comparison. The results are presented in Table 22. With respect to all the nutrients except phosphorous there is a depletion, the highest being noticed for potassium and lowest for magnesium. The depletion of calcium is also observed to be significant compared to the other nutrients. Rubber plantation in its 3rd planting cycle is taken for this comparison and such changes have taken place over a period of approximately 90 - 100 years.

Table 20. **Nutrient loss per tree (g) and per ha(kg) during felling and removal of rubber trees**

Parts removed from field	N	P	K	Ca	Mg
Twig	507.9	72.9	175.0	68.04	26.73
Branch	3558.0	355.8	3795.0	5159.00	2905.70
Trunk	1876.2	268.0	982.5	3751.44	670.00
Total	5942.1	696.7	4952.5	8978.48	3602.43
For 300 trees (kg)	1800.0	210.0	1500.0	2700.00	1050.00

* It is assumed that leaves and root are left in the field and one hectare area will be having 300 trees.

Table 21. Balance sheet for addition and removal of nutrients in rubber plantation (kg/ha)

Nutrient	Addition (fertilizer)	Removal		Total removal	Deficit kg/ha	Surplus kg/ha
		Latex	Timber			
N	1345	300	1800	2100	755	-
P	467	90	210	300	-	167
K	797	180	1500	1680	883	-
Ca	1530	90	2700	2790	1260	-
Mg	195	90	1050	1140	945	-

Table 22. Total quantity of nutrients contained in 60 cm depth of soil in forest and rubber after 3 cycles of rubber (kg/ha)

		Nilambur	Chimoni	Vithura	Mundakayam	Mean	Difference
Nitrogen	Rubber	12520	15090	13600	10920	13020	
	Forest	15840	26000	18000	15480	18830	-5810
Phosphorus	Rubber	3304	7224	5656	7648	5958	
	Forest	2800	4204	3224	6304	4133	+1825
Potassium	Rubber	4400	5600	7600	22400	10000	
	Forest	10800	12800	12000	25200	12160	-2160
Calcium	Rubber	8400	7200	7200	6800	9200	
	Forest	16000	11200	11600	9600	12100	-2900
Magnesium	Rubber	800	800	800	1200	900	
	Forest	1200	1600	800	1200	1200	-300

5. DISCUSSION

Morphological features

One of the characteristic field morphological feature of well drained tropical soil is the dominant dark reddish colour mainly contributed by the free iron oxides. The increasing redness observed in the subsoil layers of the profiles is closely related to the changes in the Fe-DCB content. The brownish colour of the soils from the forest areas especially in the surface horizons is the melanisation due to decomposed organic residues and living roots. The red colour in the surface horizons of Chimoni and Mundakayam can possibly be due to erosion and exposure of subsoil layers due to the absence of effective cover cropping.

The soil texture is an intrinsic property which is seldom altered by management. The soil profiles both in the rubber and forest areas located in adjacent sites have been derived from more or less the same parent material. The similarities in the textural class between these two sites observed is only reasonable.

Ferrallitic soils of the tropics have characteristic well developed structure. The high sesquioxide content and the well drained nature of subsoils are conducive to the development of a stable structure. The soils from rubber growing areas of different locations do not reveal structural degradation as compared to forest soils. The cover cropping practice, a routine cultural operation in rubber plantations, further aids in the development and stabilisation of soil structure. Studies on changes in physical, chemical and morphological features due to deforestation and raising of monocultural plantations have shown that morphological features are least affected. (Prasad et al. 1985, Sivadasan 1989).

Organic carbon (Table 6)

A persual of the results of organic carbon (Table 6) indicate that the surface layers of the profiles had the highest organic carbon content in rubber plantations as well in forest areas (Fig. 2). From the data as well as from the figures it is evident that organic carbon content decreases with depth in both situations. This may be attributed to a lesser rate of incorporation of organic matter in these soils. The absence of a grass cover, which normally adds appreciable amounts of organic matter through the sloughing off of old roots may be one reason for this observation. Also it is evident from tables 6 and Appendix 1 that organic carbon content is significantly lower in rubber plantation as compared to natural forest. In 100 cm profile also there is appreciable decrease in organic carbon status in rubber plantation as compared to forest, the reduction varied from 45% in Chimoni to 9% in Mundakayam. The less reduction in Mundakayam can be attributed to the lesser organic carbon content in the wet ever green forests of Mundakayam. Ever green forest contain lesser quantities of organic carbon as compared to decidious forests in Chimoni which experiences leaf shedding every year (Sivadasan, 1989).

Several reasons can be attributed to the reduction in organic carbon content in rubber plantations. In natural forests because of specious multiplicity (Lal, 1986) with practically no disturbances and peculiar micro climate conditions, the pace of oxidation will be minimum thus contributing to higher organic carbon content in forest soil.

The role of vegetation in the accumulation of organic carbon in forests has been reported by Singh et al., 1987.

The results of the present investigation also indicate that their is a sharp decline in organic carbon content with depth, and the trend was similar in the two situation, though the organic carbon content in all the layers in forest soil was higher than that of rubber plantations. However, this suggests that in spite of continuous cropping for about ninety years, rubber plantations maintain similar character as that of forest in terms of the nature of organic carbon distribution. The organic carbon content in the profiles from rubber plantations encountered in the study though are low compared to the adjoining natural forest, are still high when compared to most tropical soils which are laterite and lateritic in nature with poor nutrient status. While working out the fertility index of organic carbon in rubber plantations in Kerala it has been reported that the range of organic carbon content was medium to high in all rubber growing districts (Karthikakuttyamma et al. 1991). In the grading of rubber soils from the point of view of fertility status, 0.75 to 1.5 per cent is considered as medium range (Pushpadas and

Karthikakuttyamma, 1980). The comparatively high values registered in rubber growing soils can be attributed to the specific agromanagement practices adopted in the rubber plantation such as minimum disturbance to soil, growing of leguminous cover crop and significant litter addition. (Krishnakumar, 1989). During the economic life-cycle, rubber plantation presents almost a closed eco-system. The only disturbance compared to forest is the prevention of an understorey vegetation to come up, which possibly contributed to the higher organic carbon content in the forest than rubber plantation soils. Even after about 90 years of cropping (3 replanting cycles), the mean extent of reduction of organic carbon content in the surface layer is only around 24 per cent and 25 per cent in the sub-surface layer compared to forest. The slow pace of oxidation inside the closed canopy of rubber plantation helps to maintain the high organic carbon status. Since most soils under rubber have an abundance of aluminium, the organic matter is complexed with this element, thereby leading to a reduction in decomposition. Interactions of oxides with organic matter in the tropical soils again render the organic matter relatively resistant to mineralisation. Extreme phosphorous deficiency consequent to the presence of higher soluble aluminium

Plate 3. Rubber plantation with cover crop-
Pueraria phaseoloides

Plate 4. Rubber plantation with cover crop-
Mucuna bracteata

inhibits microbial growth and these factors also result in low mineralisation of organic mater (Munevar and Wollum 1977). In rubber plantations because of luxuriant ground cover crop (adopted widely as a management practice) addition of biomass to the tune of around 3 tons per hectare take place when the cover crop established is Pueraria phaseoloides (Plate 3) (Kothandaraman et al., 1990). Another cover crop Mucuna bracteata (Plate 4) introduced to Kerala at a later stage add about 5 tons of biomass as compared to 3 tons for Pueraria. This compensates to some extent the lack of under-story vegetation and soil exposure during the immature phase. The cover crop also conserves soil by reducing erosion. The rubber plantation also is having a closed canopy which regulates the micro-climate more or less similar to that of the forest. The deciduous nature of the tree (Plate 5) adds around 5 to 6 tonnes of leaf litter annually (Krishnakumar and Potty, 1992). The surface root of rubber also contributes to the enrichment of the organic matter in the topmost layer. All these attributes of the rubber plantation help to maintain a higher organic carbon status compared to other agricultural soils in the same region. The decline in organic carbon content noticed in the rubber plantation as compared to forest can mainly be present investigation indicate that considerable reduction in nitrogen has occurred due to the conversion of natural forest to rubber plantation.

The percentage reduction in total nitrogen content in 100 cm. profiles in the four locations Nilambur, Chimoni, Vithura and Mundakayam is 29,41,15 and 13 per cent respectively. As in the case of organic carbon, reduction in total nitrogen was also maximum in Chimoni and minimum in Mundakayam. Distribution of total nitrogen closely follows the organic carbon distribution both showing a decreasing trend with depth (Fig 3.). As compared to forest soils, the available nitrogen content also are lower in rubber plantation. Total as well as available nitrogen were found to show a declining trend down the profile.

Aweto (1987) has reported the effect of converting a natural forest to a plantation of rubber on the nitrogen status of the soils. He observed a gradual increase in total nitrogen content in rubber plantations of age group 1 to 18 years. The nitrogen status in an 18 year old plantation was the same as natural forest. But the total nitrogen levels in soil were low upto 14 years which corresponds to the active growth phase of the tree. Shorrocks (1965b) has indicated that the growth rate of rubber tree is fastest during the first 10 years of planting and thereafter a stable equilibrium is maintained in the uptake of nitrogen. Report on the effect of deforestation and subsequent planting of rubber in Malaysia (Sivanadyan and Norhayati, 1992) indicated that 50 months of rubber cultivation resulted in a drop in total nitrogen, during the initial years but the values tended to increase subsequently presumably due to the release of nutrients from the legume cover. Reduction in total nitrogen content when forest was converted for crops like oil palm, coconut, cocoa etc. have been reported by Sanchez et al., (1985), Koyamu and Nambiar (1978), Aborisade and Aweto (1990), Adejuwon and Ekanade (1987), Balagopalan and Jose (1984) and Maro et al.(1994).

The C/N ratio of about 10 in rubber and forest soils suggest that organic matter in them has come to a state of decomposition nearer to humus. In general, a decrease in C/N ratio with depth is observable in the upper horizon. Decrease in C/N ratio with depth was reported by Krishnakumar (1989) for rubber growing soils in India. The variation in

C/N ratio may be due to the difference in the state of decomposition of organic matter in different horizons and the preferential eluviation of mineralised nitrogen over carbon.

Studies on biomass removal from rubber plantation in India has shown that at the end of each plantation cycle, a total removal of 400 tons of dry matter is taking place during the felling of trees (Table 19). In terms of nitrogen, the removal works out to be 1800 kg/ha (taking 300 trees as stand/hectare). This may be responsible for the reduction in total nitrogen observed in rubber plantations.

Leong (1977) based on a study on rubber pointed that on a spread out basis (over 33 years) of the life span, the amounts of nutrients locked up each year in the trunk, branches and roots is still about 2-3 times greater than that drained through latex. This may come as a surprise for those who are trying to estimate the nutrient requirements of rubber tree through yield data. Even during the immature period when the tree is not yielding rubber, the nutrient requirement is much greater than the input because of locking up of nutrients. Total nitrogen locked up during the immature period averages to 120 kg/ha/year while the input of nitrogen is only 30 to 40 kg/ha/year. The soil will have to provide the balance and this leads to the depletion of the nutrients in soil later on (Table 22). The immature trees may thus be able to respond to a greater dose of nitrogen fertilizer.

Total Phosphorus

Phosphorus is considered as the master key to agriculture. All Indian soils with the exception of certain parts of Punjab, United Province and Bengal and certain small specific tracts, are deficient in phosphorus. In rubber cultivation phosphorus demand is met by the application rock phosphate which is comparatively cheaper and efficient in the acidic soil conditions prevailing in the rubber growing tracts.

Phosphorus status of soils in continuously rubber cultivated area is given in Table 8. In contrast to nitrogen a build up in total phosphorus can be observed in rubber plantations compared to adjacent natural forest. Depth wise decrease can be noticed down the profile both in forest and in rubber. This can be attributed to the low mobility of this element. The high total phosphorous observed in 100 cm profile in rubber cultivated soil can also be attributed to the high iron and aluminium contents which fix the applied phosphorus and convert it into unavailable forms (Karthikakuttyamma et al. 1991). The low requirement for phosphorus by rubber trees may also be another reason for maintaining a higher level of phosphorus in rubber cultivated areas. Data on nutrient immobilisation averaged for the whole period of 33 years indicate phosphorous nutrient locked up by rubber trees from one hectare of plantation is only 8.4 kg as against 54 kg of nitrogen 37 kg of potassium and 13 kg of magnesium, (Leong, 1977). The requirement for phosphorous is only 10 kg/ha as against 120 kg/ha for nitrogen during the immaturity period extending to six years. At present the accepted level of phosphorus application is far above this and hence the soil reserves are not being exploited to meet the crop demand. The data shown in Table 21 on balance sheet of nutrients is in agreement with this view.

Along with other nutrient the effect of phosphorus on deforestation and raising of rubber plantations has been investigated by Norhayati and Lau (1990) in Malaysia for a period of 50 months and they could not notice any definite trend in phosphorus status during this short span of time. However an increase in total phosphorus content in plantation profiles as compared to natural forest has been reported by Sivadasan during 1989. Adams and Boyle (1980) has attributed mineralisation of organic matter as the reason for the high total phosphorus in man-made plantations.

Prasad et al (1985) has observed a decline in total phosphorous content in mixed and tea plantation as compared to moist deciduous natural forest in the Bolampatti range of Coimbatore forest division. Chijicke (1980) reported the effects of forest clearing and planting Gmelina arborea on a fertile alfisol in Omo Ajebandele, Nigera. An increased available phosphorous status was noticed in plantation area as compared to natural forest.

Available P

Available phosphorous status was found to be low in most of the horizons in rubber as well as forest soils.

Similar observation of poor available status in forest and plantations were recorded by Sivadasan (1989). Even though available phosphorous status is low, no visible phosphorous deficiency is observable in rubber plantation indicating that phosphorous requirement of the crop may be met from organic sources which is not accounted in the available phosphorous extracted by the usual soil testing method.

Maro et al (1993) noticed no significant difference in available phosphorous status between natural forest and Cupressus lusanica plantations at West Kilimanjaro, northern Tanzania. But lower levels of available phosphorous in monoculture plantations as compared to natural forests were reported by Robinson (1967), Adejuwon and Ekanade (1988). Aweto (1987) has attributed the difference in the intrinsic soil nutrient status for this differential observations. When cashew was planted after clearing rain forest in Nigeria, Aweto and Ishola (1994) did not notice any decrease in available phosphorous status.

Soil reaction

A decrease in pH of the soils was observed in rubber cultivated areas as compared to forest areas in the present study. In surface soils 0-60 cm the reduction was significant also. Several reasons can be attributed to this phenomenon. As the canopy is not as thick as in adjacent forest areas, leaching of cation will be more in rubber plantations with a concomitant increase in the concentration of ions like H^{+} and Al^{3+} which are held on firmly to the soil colloidal complex. Continuous application of nitrogenous fertilizers also increases the soil acidity in rubber plantation. Asawalam et al. (1991) noticed decrease in pH values due to cultivation of rubber in Iyanomo, Nigeria. He has attributed this for the removal of basic cation from the exchange sites of the soil and subsequent removal by aluminium ions. Mongia and Bandhopadhyay (1994) have reported significant reduction in pH under plantation crops in South Andaman Islands. A decrease in pH in surface and subsoil was reported by Adejuwon and Ekanade (1988) due to the replacement of rain forest and cultivation of cocoa, in South West Nigeria.

Total Potassium

Total potassium in forest and rubber plantations profiles are shown in Table 9. Total potassium was less in rubber cultivated areas as compared to forest areas. The percentage reduction in the surface horizon in the four locations were 64, 50, 28 and 31 in Nilambur, Chimoni, Vithura and Mundakayam respectively. In 100 cm profile also marked reduction was noticeable, the reduction in this case being 61, 25, 40 and 21 per cent respectively in the four locations mentioned above. In rubber estate the top horizon contained lesser quantities compared to lower horizon. In forest also same trend was observable. The reduction in total potassium as compared to forest may be due to the high leaching occuring in rubber estates where canopy is less dense as compared to that in the forests. The high requirement of potassium by rubber trees may also be another reason for the low potassium content in rubber plantation. The low content of potassium in rubber growing soils suggests that the soils need frequent potassium fertilization. To achieve a sustained high level of production, higher doses of potassium fertilization is inevitable in these soils.

Sanchez et al (1985) while reviewing the effect of deliberately planted tree crops on the properties of soils of the humid tropics, have remarked that significant losses of potassium occur when rain forests are replaced by tree plantations. Potassium content decreased to about 32 per cent of that in the forest after land clearing.

Koyamu and Nambiar (1978) has reported reduction in potassium content in coconut gardens after conversion of virgin forest. They observed that reduction was more in high yielding varieties and attributed this reduction as due to the variation in the uptake of crops grown and leaching and depletion of potassium content. Russel (1983) measured losses in potassium in Jari, Brazil due to planting of trees after deforestation. Prasad et al (1985) studied the effect of converting natural forest into mixed plantations and teak and found that total potassium was always higher in natural forest as compared to mixed plantations and teak. Balagopalan and Jose (1993) reported decreased potassium content in teak, eucalyptus and rubber plantations in Kerala as compared to adjacent natural forest. They have attributed this reduction as due to the disturbance caused in the forest ecosystem when natural forests were converted to monoculture plantation.

In the present study on nutrient uptake and biomass removal, table 21 it has been observed that by the completion of one cycle of plantation, loss in potassium to the tune of 1500 kg/ha and 180 kg/ha occur through timber and latex. In soil (0-60 cm) this has caused a reduction of 2160 kg/ha of potassium. Table 22. Anyhow considering the long period for which rubber is cultivated this loss was not as serious as it would appear. However, there is a strong case for increasing the application of potassium by about 20 Kg/ha/year during the life cycle of a plantation of rubber. This will enhance the sustainable yield as suggested by Lundgren (1978) and ensure greater biomass incorporation in the soil through the recycled leaf of the rubber trees annually.

Total Magnesium

A persual of the data on total magnesium in rubber and forest profiles Table 9. indicate that higher quantities are observable in forest in most cases. In Nilambur forest the surface layers contained 0.02 per cent while it was only 0.01 per cent in the surface layers of rubber estates. In Chimoni, there was no difference between forest and rubber profiles in the top three horizons the quantity present being attributed to removal of timber at the end of each replanting cycle estimated to be around 445 tonnes per hectare (Shorrocks 1965b). Studies conducted on biomass removal (Table 16) indicated removal of around 400 tonnes of biomass at the end of each replanting cycle.

The reduction in organic carbon content when forests are converted to plantation and short duration crops have been reported by Sivanadyan and Norhayati, (1992), Pushparajah, (1984), Koyamu and Nambiar, (1978), Veldkamp (1994), Balagopalan, (1991), Mongia and Bandhopadhyay (1994), Prasad et al. (1985), Mongia et al. (1991), Adejuwon and Ekanade, 1987, Arrouays and Pelisser, 1994. Concern on this aspect has been highlighted by Greenland 1994 and Syers and Rimmer 1994. Juo and Lal (1977), Johnston (1986), Thampan (1993) and Swift et al. (1994) have pointed out the importance of organic matter in crop production.

Total and available nitrogen (Table 7)

Nitrogen is an important major nutrient required for all phases of rubber growth. Results obtained in the

0.02 per cent. In Vithura and Mundakayam the surface soils in rubber estates registered higher values 0.02 and 0.05 per cent compared to 0.01 per cent in the surface of forest soils. In forest soils in all location the pattern of distribution in total Mg was uniform where as no such trend was observable in rubber profiles.

Eventhough considerable decline in total magnesium content was not noticed in the present study, evidence from other monoculture plantations indicate that reduction occurs due to forest clearing causing disturbance in forest equilibrium. Increase as well as decrease in total magnesium content has been reported from similar studies. Sivadasan (1989) has reported an increase in magnesium content in acacia, tea and cashew plantations as compared to forest plantations.

Data on total quantity of nutrients in 0-60 cm (Table 22) indicate a deficit of 300 kg/ha of magnesium as a result of rubber cultivation. The data on nutrient budget (Table 21) show that 945 kg/ha of magnesium is removed from each plantation cycle. This removal is fairly higher than nitrogen and potassium and points to the necessity of a revision in the present fertilizer schedule. A total withdrawal of magnesium containing fertilisers from fifth year onwards may not be worthwhile considering the loss of magnesium taking place at the end of each plantation cycle, through biomass removal.

Total Calcium (Table 9)

Total calcium was found to be less in profiles of the rubber plantation as compared to the adjoining forest. In surface samples also significant reduction can be noticed (Appendix 7). The per cent reduction in 100 cm profile were of the order 56, 42, 35, 44 in Nilambur, Chimoni, Vithura and Mundakayam respectively. In surface soil the decline was in the order 62, 57, 27, 55 in the four locations respectively. In subsoil an increase in calcium content of 62 and 36 per cent is observed in rubber and forest of Nilambur. In subsequent layers again there was decline. In Chimoni also an increase in total calcium content has occurred in middle horizon but this was not observable in the other two locations. In forest also no definite pattern in the distribution of total calcium was observable. This differential distribution in nutrients may be due to difference in the degree of leaching and the absorption pattern by roots in different strata of soil.

Sanchez (1985) has recorded a loss of 56 per cent calcium in rain forest upon planting of Pinus. They attributed this that to the differential uptake by the trees and also the variations in the degree of leaching.

Rubber trees appear to have a fair degree of adaptability to low calcium environment. The influence of calcium in plant nutrition is vital mainly because of its role in alleviating Al toxicity thereby increasing the availability of phosphorous and potassium. The ratio of calcium to total cations should be around 0.15 for the roots to grow uninhibited. Al/Ca molar activity ratio also influence root development and growth in acid soils. A ratio of 0.02 is considered to be the upper limit beyond which growth will be affected. (Marschner, 1986).

The investigations conducted (Table 22) has shown that as a result of continuous cultivation of rubber for over 70-80 years, calcium to the tune of 2900 kg/ha is lost from 0-60 cm layer of the soil. The balance sheet worked out (Table 21) indicate a deficit 1260 Kg/ha of calcium at the end of each plantation cycle by removal through biomass and latex. Eventhough these losses are not at a hazardous rate, these facts should be considered in planning future agromanagement practices in rubber plantations.

Cation exchange properties

Data on exchangeable calcium (Table 10) indicate that it has been considerably decreased in rubber cultivated areas as compared to forest areas. The observed decrease on percentage basis in surface horizon in four locations were 52, 78, 71 and 65 in Nilambur, Chimoni, Vithura and Mundakayam respectively. In Nilambur throughout the whole profile there was decrease, the observed decrease in lower layers were 61, 55, 60 and 69 per cent. In Chimoni reduction was noticed only in the top three layers the percentage reduction being 78, 67 and 12 per cent down the profile. In lower horizons no reduction was noticed. In Vithura a decrease of 71 per cent was noticed only in top most horizon. There was no reduction in lower layers. In Mundakayam the pattern of reduction was more or less similar to that of Nilambur, an increased reduction in the second horizon and a lesser reduction in the third horizon. In lower horizons the reduction was less or nil at all. Many reasons can be attributed for this variation in the distribution of exchangeable calcium. The difference in the distribution and quantity of rainfall obtained in these four locations may be attributed as the main reason to this observation.

For exchangeable magnesium, the reduction in surface horizons varied much. In surface horizons the per cent reduction was 23, 72, 35 and 38 in Nilambur, Chimoni, Vithura and Mundakayam respectively. In Nilambur the per cent reduction increased for the upper three horizons which again declined in the lower two horizons. In Mundakayam also reduction was evident in the top three horizons. In Chimoni too major reduction occurred only in the upper layers. Just like calcium, for magnesium also there was no reduction in Vithura. For exchangeable potassium, the trend was more or less similar to that of calcium and magnesium, Nilambur showing a decline in the top three layers which again increased and decreased in the two horizons below. In Chimoni, reduction was minimum 4 per cent in the surface layer and maximum decrease of 26 per cent was observed in sub surface horizon. In Vithura also maximum reduction was observed in sub surface horizon. In Mundakayam, the pattern of decrease was more or less the same as that of Nilambur. In general exchangeable calcium, magnesium and potassium recorded lower values which is characteristic of laterite soils formed under conditions of high rainfall, temperature and intense leaching. The predominant cation was calcium followed by magnesium and potassium. Low values of exchangeable cations was reported by Krishnakumar (1989) for rubber growing soils of Kerala.

The CEC values for rubber plantations varied from 2.71 to 12.5 Cmol/kg which for forest, the range was 2.54 to 18.57 Cmol/kg. For CEC also reduction occurred in rubber cultivated areas but the extent of reduction varied among places. In the surface horizons the per cent reduction was 43, 3, 5 and 15 in Nilambur, Chimoni, Vithura and Mundakayam respectively. The distribution in lower layers were almost similar in both cases. The CEC registered higher values in the surface horizon evidently due to the effect of organic fraction. This is also expressed in the decline of CEC with depth as organic carbon also declines towards lower horizons. The kaolinitic nature of the clay minerals can be attributed as the major reason for the lower CEC in lower layers in rubber and forest profiles. The low CEC values observed in forest and rubber plantations is due to the predominance of kaolinitic and sesquioxide clays, the CEC of pure kaolinitic is reported to be between 3 and 15 Cmol/kg. Only in 11-33 cm horizon of Chimoni forest a value higher from 15 Cmol/kg was obtained. The low CEC values observed are also characteristic of laterite soils and indicate that, the CEC is dependent not only on the quantity of clay but also on lattice structure and electro chemical nature. The comparatively higher CEC observed in forest soils in definitely due to the higher organic carbon content, as variation is parent material cannot be expected between forest and plantation profiles.

Two soils orders viz. inceptisol and ultisol have been identified in the rubber areas while forest pedon were alfisol, inceptisol and ultisol. The soils in general were not base rich as in characteristic of the high rainfall areas. The base rich soils of Nilambur forest is evidently due to the higher litter fall shown by the moist decidous forest. The degraded values in the wet evergreen forest of Mundakayam has been responsible for the lower litter addition and consequent base unsaturated natures of soil.

The results of the present study indicates that cultivation of rubber in general cause decline in pH. The litter from rubber plantations do not contribute much to enrich the base status of the soils.

Sesquioxide, total iron and aluminium (Table 11)

Sesquioxide are found to be high in rubber as well as adjacent forest soils. Comparing the two situations rubber growing soils were having significantly higher quantities of these elements appendix 12 & 14. Comparing total iron and aluminium, total aluminium was always higher than total iron. The distribution of iron and aluminium showed an increasing trend with depth. The lower content of iron and aluminium in the surface soil as compared to subsurface soil is due to intense leaching and passive movement of the oxides along with clay. The better structural properties as evidenced from morphological features can be attributed to the higher sesquioxide content present in profiles in rubber estate and adjoining forests. Though the clay content in rubber growing soils of India has been reported to be relatively high, it is moderated by the presence of high amounts of sesquioxides, thus reducing the adverse effect of high clay content.

Fe DCB (Table 12)

Fe DCB or crystalline form of Fe was found to be higher in rubber growing soils than forest soils appendix 13. In rubber profiles the values ranged from 1.9 to 5.9 per cent and in forest 0.8 to 5.2 per cent. Eshett (1991)reported mean value of 0.20 per cent of Fe DCB for soils of south western Nigeria. He has mentioned that the quantity of iron oxide varies depending on the nature of parent material. As the crystalline form are less weatherable, higher Fe DCB in rubber indicates that the rubber soils are more weathered than forest soils. Sivadasan (1989) has also observed higher Fe-DCB value in plantation soils as compared to adjacent forest soils. A close examination of the data reveals that in forest and rubber plantations iron is mostly in crystalline form.

Fe-Ox (Table 12)

Fe-Ox represents the amorphous form of iron which ranged from 1.0 to 2.6 per cent in rubber cultivated areas. In forest soils the quantity ranged from 1.0 to 2.5 per cent. In comparing the oxalate extractable iron in rubber and forest, it can be seen that in Nilambur and Chimoni, the profile in rubber estate contained more Fe-Ox whereas in Vithura and Mundakayam Fe-Ox was high in forest profiles. Fe-Ox is present in relatively smaller quantities when compared to Fe DCB which also indicates that in well drained soils Fe remains mostly in crystalline form.

Comparison of sequential changes in nutrient status of soil

The result of the present study to monitor the nutritional status of soil for rubber in first, second and third cycle reveal that not much variation in nutritional status has occured due to the continuous cultivation of rubber. The changes in pH, organic carbon content and available nutrients are discussed here.

pH of the (Table 13.1) soils decreased in rubber plantations but significant decrease was noticed only in the third planting cycle. Since the same area will be utilised for subsequent cycles also, this reduction in pH should be viewed seriously. One possible explanation for this phenomenon may be the removal of bases like calcium and magnesium at the end of each plantation cycle by way of cutting and removal of trees. Since this process will continue, measures should be taken to improve the base status of soil. This can be achieved by the application of lime at a minimum level. By this a microheterogeneous soil situation can be created which is a very important aspect in soil pH. The practice of growing cover crops also contribute to the removal of bases from the lower layers and recycle to the surface layers, from where it will be taken up by the rubber trees. Investigations on changes in organic carbon content in first, second and third cycles (Table 13.2) revealed that the organic carbon content was significantly lower than the forest values. But compared to first cycle there was an increasing trend in second and third cycles. This point to the possibility of reaching equilibrium with forest conditions in subsequent cycles of rubber cultivation. Abandoning rubber cultivation and raising some other crops will not be a wise proposition, as is evident from the present investigation. Raising of leguminous cover crop along with planting of rubber can be attributed as the sole reason for the increase in organic carbon, in spite of the removal of large quantities of biomass at the end of each plantation cycle. Broughton (1977) has pointed out that the beneficial effect of growing cover crops is not by nitrogen fixation alone but the effect of a large and deep system of roots contributing more for the improvement of soil. He attributed that 96 per cent of the beneficial effect is through root proliferation and only 4 per cent through nitrogen fixation. In spite of these, forest maintained higher organic carbon status. Improved management techniques now being resorted, will definetly improve the organic matter status of the soil by the fourth cycle and stabilise it, no doubt, at a level only lower than the forest but difinetly much higher than the status at the end of the first cycle. This confirms that rubber is the most ecological alternative to forest ecosystem. The less erosion in forest only at the rate of 100 kg/ha (Megahan 1972) may also be another reason for maintenance of higher organic carbon status in forest soil.

The available phosphorous status (Table 13.3) in forest and rubber plantations were found to be high in 0-15 cm layer as compared to lower layers. This may be due to the maintenance of organic debris in surface layers and also due to the lesser movement of phosphorous to lower layers. Eventhough numerically higher values are obtained for available phosphorous in rubber estates, the difference was not significant.

For available potassium, (Table 13.4) also the surface 0-15 cm registered higher available potassium values in forest in second and third replanting cycles. The available potassium content in the two surface layers were in medium range in forest and rubber. In 30-60 cm layer available potassium content was low in rubber estates, possibly due to the pumping of nutrients to upper layers.

Mechanical composition (Table 14)

The results of the present investigation indicate that significant change has not occurred in texture as a result of conversion of natural forest to rubber plantation. Adoption of zero tillage practice and cultivation of cover crop in rubber plantation may be responsible for this. In the coarse or finer fractions an increasing or decreasing trend is not observable in plantation or forest profiles. Differential leaching of finer fractions may be the reason for this observation. In all the profiles the silt content was low compared to clay fraction, which is characteristic of latosols.

The data in table 14 indicates that clay content is slightly higher in plantation profiles. A comparatively higher clay content has been reported for the rubber growing soils of India, but it is moderated by the presence of high sesquioxide (Krishnakumar and Potty, 1992). Soils of loamy texture has been reported to be best suited for the cultivation of rubber (Pushpadas and Karthikakuttyamma, 1980). Within loams, higher clay content was found beneficial in promoting growth as well as yield of *Hevea*. Soong (1971) observed a positive correlation of root development with sand content and a negative correlation with clay content. He observed that feeder root development has been affected by soil texture. Aweto and Ishola (1994) reported the results of twenty year cultivation of cashew (Anacardium occidentale) in Nigeria. No significant difference in sand, silt or clay were obtained in 10-20 cm soil layer, but in 0-10 cm soil, silt and clay contents were higher. The study was limited to 20 cm depth only and generalisation cannot be made from this study. Balagopalan and Jose (1993) reported a lower clay content in monoculture plantations like, teak, eucalyptus and rubber as compared to evergreen and semi ever green forests of Kerala. Aweto (1987) observed a higher clay and silt content in rubber plantations of 18 years age as compared to natural forest in Nigeria. In earlier years the clay content was less in rubber plantations. The study was confined to 0-10 and 10-30 cm only. The higher clay content in 10-30 cm soil was attributed to the downward eluviation of clay from 0-10 cm layer. His study also indicated that rubber does not significantly modify textural composition over time, as no significant difference could be observed among 1, 7, 11, 14 and 18 year age groups. Adejuvon and Ekanade (1987) worked out indices of deterioration in physical properties due to conversion of natural forest to cocoa plantations in Nigeria. Deterioration in clay was observed especially in top soil as compared to subsoil.

Ekanade (1985) conducted detailed studies on this aspect and reported that degeneration caused in soil physical properties may be responsible for the failure of the various efforts to rehabilitate old cocoa plots in parts of western Nigeria. The increase in sand content and decline in clay content has been observed in cocoa cultivated areas both in topsoil and subsoil which is an indication of mechanical elluviation. Erosion by surface run off could also have occurred when during the first few years, the plots used to cultivate cocoa were also used simultaneously to cultivate arable crops. When the land was later covered by cocoa, it could have failed to completely recover from the earlier erosional processes. In the present investigation as no decrease in clay content was observed in rubber plantation, it can be assumed that rubber cultivation does not result in degeneration of soil.

Available moisture (Table 15)

Table 15 indicates the moisture at field capacity and wilting point, available moisture percentage and the moisture content in one meter profile. Available moisture percent obtained by subtracting the moisture per cent at wilting point (-1.5 MPa) from that at field capacity (-0.033 MPa) always showed higher values in forest profiles as compared to profiles in rubber estate Fig 7. In surface horizons the per cent reduction was in the order 36,33,10,41 in Nilambur, Chimoni, Vithura and Mundakayam respectively, maximum reduction is shown in Mundakayam and minimum in Vithura. The moisture content in one meter profile (in litres) were 30,40,77 and 105 in Mundakayam, Vithura, Nilambur and Chimoni respectively. In forest the quantities were 62,73,110 and 144 litres in Vithura, Mundakayam, Nilambur and Chimoni respectively. In can be seen that rubber profiles contained only less quantity of water compared to adjoining forest. The per cent reduction in one meter profile were of the order 58,35,30,27 in Mundakayam, Vithura, Nilambur and Chimoni respectively. Difference in organic carbon content itself can be attributed as the main reason for the lower quantity of available water in rubber as compared to forest. Another view is the lower dependence of certain species of forest plants on the soil for water requirements. Thus epiphytes, such as orchids and spanish moss, absorb water and nutrients from the air (also some nutrients from decaying organic materials in tree forks and the like). In rubber plantation the whole water requirement should be met from the soil itself. Also the peculiar root system of rubber plants (plate 6) with 70 per cent in the upper 0-20 cm, extracts water only from surface soil, whereas forest plants can remove appreciable water from great distances laterally and from sub soils.

The effect of monoculture plantation on soil moisture storage has been reported by Balagopalan and Jose (1993). They observed higher water holding capacity for soils under natural forest as compared to teak, eucalyptus and rubber. Mongia et al. (1991) investigated the changes in moisture characteristics after the conversion of forest plantations with red oil palm in Andaman islands. They observed changes in profile moisture storage which was caused by a decrease in retention time of water, intake rate of soil and greater withdrawal of soil water from the active root zone of oil palm plants. Mongia and Bandyopadhyay (1994) in another study compared natural forest with monoculture plantations such as teak, oil palm and rubber and observed changes in profile water storage. Water content upto 175 cm was minimum under teak plantation and maximum under natural forest. Among plantations, soil under rubber showed maximum water content whereas those under red oil palm and padauk were intermediate.

The cumulative water intake rates for three hours were 5,13,16 and 14 for padauk, teak, rubber and red oil palm respectively when compared to 27 cm under virgin forest. It is thus evident that the variation in the water content of soil profile is caused due to the variations in the vegetative cover, differences in their evaporative demands and differences in bulk density under different crops.

Biomass production and Nutrient accumulation

Data on table 17 indicate that next to nitrogen, potassium and calcium has the highest leaf mineral concentration. Calcium being a constituent of cell wall and

Plate 5. Rubber plantation after wintering and leaf fall

Plate 6. Root system of a rubber tree

potassium a nutrient with regular function in the plant metabollic activities, their concentration is generally higher than that of the other nutrients. Accumulation of calcium is found to be highest considering the whole plant (Table 19). Shorrocks (1965a) had also mentioned about the large scale deposition of calcium in the trunk and branch bark, which probably is not needed fully for essential growth of the plant. It appears that the role of this nutrient has to be studied in greater detail not only because of its large uptake, but also on account of soil fertility considerations. In general, all the cationic and anionic nutrients except nitrogen are locked up in the trunk and do not contribute much to the soil pool through the annual litter recycling.

A perusal on the balance sheet of nutrients for one cycle of plantation (Table 21) reveals that the cultivation of *Hevea* encountered a deficiency with respect to nitrogen, potassium, calcium and magnesium whereas with regard to phosphorous it was excess. A reason for the accumulation of phosphorous may be due to the less leaching loss of this element added to soil through regular application of phosphate fertilizers. This has been corroborated by the finding that in all the zones, soils of rubber plantation in the 3rd cycle contained, higher quantities of total phosphorous when compared with nearby forest lands.

With respect to nitrogen, calcium, potassium and magnesium a prominent difference was noticed in the total nutrient reserve upto 60 cm layer in the rubber plantations. Table 22. This difference has occurred in 80 to 90 year period. From the observed depletion it has to be assumed that the removal is not at an alarming rate as compared to a situation where annual crops are raised. All the same the importance of the observation is that such decrease has to be overcome by careful management techniques so that the ecosystem is not considerably altered. Aweto and Obe (1993) had mentioned about the lower extent of soil degradation by planting cocoa in Nigeria while the degradation was more where cassava and maize were raised in a shifting cultivation.

Rubber as an agro-forestry crop

Soil Science has a potential role in identifying the various management practices for the maintenance of soil fertility, quality and productivity. Among the various management practices, fallowing and rest period technique, agroforestry, etc. are worth mentioning.

One of the most useful ways for linking production with soil conditions in tropical areas is through the 'R' factor suggested by Young and Wright (1979) and Young (1989). R factor is the per cent of cultivation within the total cycle of fallowing and cropping.

$$\text{Therefore R (per cent)} = \frac{\text{Years under cultivation}}{\text{Years of cultivation + Fallow}} \times 100$$

ie., an R value of 5 per cent indicate, cultivation allowable only once in 20 years. R value per cent means 100 per cent cultivation. Young and Wright (1979) had given the rest period required for various levels of inputs (low, intermediate and high) for various soil types. Thus in ferralsols in a rain forest for low level input R = 15 per cent, under intermediate level of input, for the same soil and a rain forest R value will be 35 per cent, while at a high level of input for the same soil type and ecosystem R value will be 70 per cent.

In the case of rubber, in one cycle of nearly 32 years, we have initially one year for clearing the land and planting, later 5 years for canopy establishment. During the second year when a leguminous cover crop is introduced, its establishment takes about 3 years. So out of the initial period of six years for planting, three years can be considered to be under cultivation and three years under fallow. Once the canopy is established, the rubber trees act as a fallow system for nearly 25 years after which one year may be devoted for slaughter tapping, logging and replanting of the second cycle. Thus during the first cycle of 32 years, there will be 4 years of cultivation and 28 years of fallow period. In such a situation

$$\text{R value} = \frac{4}{28 + 4} \times 100 = 12.5 \text{ per cent}$$

Taking a similar argument, for the second and third cycles the R value will continue to be around 14 per cent. Considering rubber as a tree crop under agroforestry situations with intermediate range of management, we can have an R value up to 35 per cent. However, its R value under the cultivation situation in Kerala is only 14 per cent which makes it an agroforestry tree crop with an ecosystem very near to that of rain forest.

Based on the findings of the present investigation, it can be concluded that organic carbon status in rubber plantation can be brought to the level of nearly forest ecosystem by continuously cultivating rubber in fourth and fifth replanting cycles by the adoption of intense covercrop management and by reducing the time lag between logging and raising of cover crops. In the first, second and third cycles we have seen an improvement in the level of organic carbon status eventhough the values were lower than the levels in virgin forest.

In subsequent cycles viz. the fourth and fifth cycle these values may attain the level very near to the values of forest soils. We cannot improve the soil conditions by abandoning rubber cultivation and leaving the soil bare for regeneration of natural forest. Regeneration of forest will not be effective and this has to be realised by environmental protagonists who advocate abandoning tree crop plantations. Going for cultivation of tree crops like oil palm for more economic return also will not be a wise proposition as this will only degrade the soil further, due to the higher uptake of nutrients by oil palm and also due to lesser canopy cover leading to greater exposure of the soil.

Similarly nitrogen management in rubber plantations can be achieved much easier than organic carbon because of the addition of large quantities leaf litter both of rubber and of cover crops. In order to cope with the demand of high yielding clones mostly to be cultivated in future, high dosages of nitrogenous fertilizer application will be necessary, to raise the nitrogen levels of soil. With regards to phosphorus a reduction in the current rate of application can be seriously thought of as a significant build up of phosphorus in rubber plantations has been observed after 3 cycles. Once the yield levels are stabilised (ie. after 15 years growth) application of phosphatic fertilizer can be limited to once in three or four years. However all the cationic nutrients are considerably reduced in rubber plantations though we are adding potassium as muriate of potash in the fertilizer programme and calcium and magnesium through the added rock phosphate. This depletion happens due to the storage of these cationic nutrients in the trunk and their complete loss from the rubber ecosystem during the logging operations. So, in order to maintain the pH of the soil and to meet the trunk storage requirements of calcium and magnesium we may recommend fairly low doses of dolomitic limestone as a treatment for rubber. Under such circumstances application of higher levels of potassium will be necessary for maintaining the equilibrium among these three nutrients. As there is a declining trend for potassium in rubber cultivated areas this level of potassic fertilisers also should be raised to cope with the potassium depletion in soil. Planting of high yielding varieties in future plantation cycles also necessitates the application of higher doses of potassic fertilizers.

Thus for ensuring sustainable yield from rubber plantation and for making the rubber ecosystem as close to the forest ecosystem, intense cover crop management, and application of higher doses of nitrogenous and potassic fertilisers should be adopted. Liming in lower dosages can also be adopted to ward off the lowering of pH and compensate for the loss of calcium and magnesium during felling and removal of trees. The findings of the study aids in formulating suitable nutrient management approach and to adopt a modified package of practices to prevent the degradation of soil resource base.

6. SUMMARY AND CONCLUSION

In Kerala rubber was introduced as a tree crop about 100 years back and has become a monocrop plantation in degraded forests and deforested areas. Thus the third cycle of rubber plantation is in existence in the traditional areas. No systematic study has so far been done in India to assess the soil properties and nutrient status of soils of this monocropped plantation in comparison with that of virgin forest of the same location. With this aim the present study was undertaken with soil profiles from rubber plantations in the third cycle representing the major traditional rubber growing region and the corresponding virgin forest profiles of Kerala. This study enabled to have a clear idea about the changes of soil properties of rubber plantations in the third planting cycle as compared to that of adjacent forest areas of the same location. Further it was envisaged that the study would enable to make prediction for the management of future cycles of rubber in order to make the soil component of the rubber plantation ecosystem as near to that of the forest ecosystem.

The sequential changes brought about in nutrient status of soils of monocropped plantations in each planting cycle were observed and monitored and nutrient removal in each cycle of plantation was also quantified.

The results of these studies are enumerated below

1. Morphological examination of the profiles revealed that there is not much difference in morphological features between profiles taken in rubber plantation and that of the adjacent virgin forest. The prominence of red colour indicated that these soils are well drained.

2. The texture of the various horizon of the profiles in rubber plantations and those of virgin forest were sandy clay and sandy clay loam. The soil profiles located in adjacent sites have been derived from more or less the same parent material and hence the similarities in textural class between these two sites are only reasonable.

3. Soils of rubber plantations did not show any structural degradation as compared to forest soils. The high sesquioxide content and the well drained nature of subsoil are conducive to the development of a stable

structure. Subangular blocky structure was observed as the major structural form in the profiles from all locations.

4. Organic carbon content in the surface horizons of the rubber estates and virgin forests were in the high range accoring to the current fertility standards. The higher organic carbon status in rubber plantations is due to the high amount of litter addition (of rubber as well as cover crops), surface feeder roots of rubber and comparatively low pace of oxidation due to the prevailing microclimate inside the rubber plantation. The minimum tillage operations also helps further enrichment. But the organic carbon status are found to be significantly low in rubber estates in all the three cycles as compared to adjacent natural forests. The species multiplicity with practically no disturbance, the higher quantities of litter addition and the cooler climate prevailing inside forest helps to maintain the organic carbon status at a higher level than man made plantations.

5. Total nitrogen content tended to be lower in rubber plantations as compared to virgin forest. In one meter

depth the quantities were 19, 18, 16 and 13 Mg/ha in rubber plantations while the corresponding quantities in virgin forests were 27, 31, 19, 15 Mg/ha in Nilambur, Chimoni, Vithura and Mundakayam respectively. During felling and removal of trees at the end of each plantation cycle, loss of nitrogen to the tune of 755 kg/ha takes place inspite of the application of inorganic nitrogeneous fertilizers and addition through cover crops. This biomass removal may be attributed as the reason for the lower levels of nitrogen in rubber cultivated areas.

6. Total phosphorus showed an enrichment in rubber plantations. The 100 cm profile in rubber plantation contained 7, 13, 7 and 10 Mg/ha while in natural forest the quantities were 7, 8, 5, 10 Mg/ha in Nilambur, Chimoni, Vithura and Mundakayam respectively. The surface horizons of rubber plantation contained 430, 1060, 940 and 1080 ppm in Nilambur, Chimoni, Vithura and Mundakayam respectively, while in forest the corresponding quantities were 430, 690, 460 and 830 ppm. The low requirement of phosphorus by rubber plants and the addition of rock phosphate may be the contributing

factors for the high phosphorus status in rubber plantations. Available phosphorus was low in rubber plantation as well as virgin forests. But as no phophorous deficiency symptoms were observable it may be assumed that plants are meeting phophorous requirements from some other source.

7. Total potassium in rubber plantations were always lower than that in virgin forests. The 100 cm profile in rubber plantations contained 12, 21, 12 and 30 Mg/ha while the corresponding quantities were 31, 28, 20 and 38 kg/ha in NIlambur, Chimoni, Vithura and Mundakayam respectively. Exchangeable potassium was also found to be lower in rubber plantations in spite of the regular application of potassic fertilizers. Removal of 883 kg/ha of potassium at the end of each plantation cycle by felling and removal of trees can be cited as the reason for this observation.

8. Total and exchangeable calcium is also found to be low in rubber plantation than the corresponding virgin forest profiles. Removal at the rate of 1260 kg/ha, during clear felling at the end of each plantation cycle may be reason for a lower level of calcium in rubber plantations.

9. For exchangeable magnesium also the quantities were low in rubber cultivated areas as compared to natural forest. The higher leaching loss and biomass removal at the end of each plantation cycle contribute to the reduction of magnesium in rubber plantations. Significant reduction was noticed in the case of exchangeable magnesium. Cation exchange capacity and per cent base saturation were also found to be lower in rubber plantations.

10. Sequioxide content were found to be significantly high in rubber plantations as compared to natural forest. These impart good physical properties for rubber growing soils. Similarly crystalline forms of iron viz. Fe.DCB was found to be higher in all the profiles than amorphous form (Fe-ox). Fe-DCB was high in rubber plantations than adjacent natural forest which is an indication of advanced weathering process in rubber plantations.

11. Studies on changes in nutritional status in the first, second and third cycles as compared to forest situation indicated that major changes are happening in the

organic carbon status of soil. By continuous cultivation of rubber, organic carbon content lowered in all the three cycles of rubber cultivation. The total carbon content in the third cycle of rubber plantation was 144, 168, 163 and 130 Mg/ha and 192, 312, 245 and 144 Mg/ha in corresponding virgin forest in Nilambur, Chimoni, Vithura and Mundakayam respectively. Change in organic carbon content between the cycles were not significant.

12. For pH, significant reduction was notiiced in the third replanting cycle only. Removal of base through leaching and at the time of felling and removal of trees contributes to the reduction in base status and consequent increase in acidity. However the reduction in first and second cycles were not significant.

13. There was no significant difference in textural classes between rubber plantations and adjacent natural forest. Texture varied from sandy clay loam to sandy clay. No pattern in the distribution of textural components were observable in the profiles.

14. Moisture holding capacities at two tension -0.033 MPa and -1.5 MPa indicated that the profiles in rubber plantation have only lesser quantities of water than profiles in virgin forests.

15. In order to quantify the amount of biomass and nutrients removed at the end of each plantation cycle, for twenty year old tree were totally destructed. The nutrient accumulated in each part of the trees was estimated from the dry weight and concentration of nutrients in each part assessed. From this biomass rmeoval from one hectare of plantation was computed. Removal through latex throughout the whole yielding phase was also taken into account. These figures and the data on nutrient addition through fertilizer application were used for working out a balance sheet of nutrients from rubber plantation. This was compared with loss occuring in 0-60 cms depth of soil where rubber was being cultivated for three consecutive cycles.

16. An R value of ~~14~~ 12.5 was computed for rubber plantations which makes it an agroforestry tree crop with an ecosystem very near to that of rain forest.

Thus for ensuring sustainable yield from rubber plantation and for conserving the same as close to forest ecosystem, we should adopt intense cover crop management, application of higher doses of nitrogen and potassic fertilisers to safeguard the declining trend noticed in these nutrients. Liming in lower dosages can also be adopted to ward off lowering of pH and compensate for the loss of calcium and magnesium during felling and removal of trees.

As a consequence the soil component of the rubber plantations in the fourth and fifth cycles in future will be made as near to that of the forest ecosystem. This alone will be able to raise the rubber plantations to be an economically advantageous and near ecologic alternative to the forest ecosystem in as far as the already rubber planted areas are concerned.

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8. APPENDICES

Appendix 1. Organic Carbon Content in 0-30 and 30-60 cm (%)

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	1.56	1.10	1.33	2,10	1.40	1.75
Chimony	2.33	1.80	2.07	3.52	2.97	3.24
Vithura	2.16	1.87	2.02	2.95	1.85	2.40
Mundakayam	2.45	1.00	2.03	2.61	2.28	2.45
Mean	2.13	1.59	1.86	2.80	2.13	2.46

C.D for comparison between Rubber and Forest 0.062

Appendix 2. Total Nitrogen %

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	0.170	0.143	0.157	0.223	0.173	0.197
Chimony	0.203	0.173	0.188	0.350	0.300	0.325
Vithura	0.190	0.150	0.170	0.240	0.210	0.225
Mundakayam	0.150	0.123	0.137	0.207	0.180	0.193
Mean	0.178	0.147	0.163	0.225	0.215	0.235

C.D for comparison between Rubber and Forest = 0.013

Appendix 3. Available Nitrogen (ppm)

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	230	158	194	290	193	242
Chimony	238	135	187	353	230	292
Vithura	260	197	228	323	308	316
Mundakayam	300	183	242	355	203	279
Mean	257	168	213	330	234	283

C.D for comparison between Rubber and Forest = 6.2

Appendix 4. Total Phosphorus (ppm)

Location	Rubber 0-30 cm	Rubber 30-60 cm	Rubber Mean	Forest 0-30 cm	Forest 30-60 cm	Forest Mean
Nilambur	423	403	413	380	320	350
Chimony	1046	760	903	600	451	525
Vithura	926	488	707	423	383	403
Mundakayam	1056	856	956	810	766	788
Mean	863	627	745	553	480	516

C.D for comparison between Rubber and Forest = 20.5

Appendix 5. pH in Surface and Subsoil (1:2.5 ratio)

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	4.1	4.3	4.2	4.6	4.6	4.6
Chimony	4.5	4.4	4.5	5.1	5.1	5.1
Vithura	4.6	4.4	4.5	5.2	5.0	5.1
Mundakayam	4.6	4.5	4.5	5.3	5.5	5.4
Mean	4.4	4.4	4.4	5.1	5.1	5.1

C.D for comparison between Rubber and Forest = 0.12

Appendix 6. Total Potassium %

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	0.05	0.06	0.06	0,15	0.12	0.13
Chimony	0.07	0.07	0.07	0.13	0.19	0.16
Vithura	0.10	0.09	0.09	0.14	0.16	0.14
Mundakayam	0.24	0.32	0.28	0.29	0.34	0.32
Mean	0.12	0.14	0.13	0.18	0.20	0.19

C.D for comparison between Rubber and Forest = 0.01

Appendix 7. Total Calcium %

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	0.13	0.08	0.11	0,25	0.15	0.21
Chimony	0.09	0.09	0.09	0.15	0.13	0.14
Vithura	0.12	0.06	0.09	0.18	0.11	0.14
Mundakayam	0.09	0.08	0.09	0.14	0.10	0.12
Mean	0.11	0.08	0.09	0.18	0.12	0.15

C.D for comparison between Rubber and Forest = 0.007

Appendix 8. Exchageable Calcium (Cmol/Kg)

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	0.91	0.32	0.61	1.57	0.62	1.10
Chimony	0.96	0.85	0.90	3.10	1.10	2.10
Vithura	0.45	0.55	0.50	1.40	0.52	0.96
Mundakayam	0.60	0.33	0.47	1.32	0.83	1.08
Mean	0.73	0.51	0.62	1.85	0.80	1.31

C.D for comparison between Rubber and Forest = 0.092

Appendix 9. Exchageable Magnesium (Cmol/kg)

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	0.32	0.12	0.22	0.57	0.60	0.59
Chimony	0.32	0.38	0.35	0.60	0.24	0.42
Vithura	0.35	0.22	0.29	0.54	0.24	0.39
Mundakayam	0.22	0.14	0.18	0.40	0.34	0.37
Mean	0.30	0.22	0.26	0.53	0.36	0.44

C.D for comparison between Rubber and Forest = 0.020

Appendix 10. Exchangable Polassium (Cmol/Kg)

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	0.28	0.24	0.25	0.69	0.62	0.66
Chimony	0.58	0.19	0.39	0.63	0.30	0.47
Vithura	0.25	0.17	0.21	0.29	0.28	0.29
Mundakayam	0.62	0.31	0.47	1.04	0.66	0.86
Mean	0.43	0.22	0.33	0.67	0.46	0.57

C.D for comparison between Rubber and Forest = 0.023

Appendix 11. Cation Excahnge Capacity (Cmol/Kg)

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	6.67	5.83	6.25	10.40	8.50	9.45
Chimony	11.67	10.17	10.92	12.70	10.97	11.83
Vithura	11.37	10.50	10.93	12.67	9.30	10.98
Mundakayam	7.20	5.50	6.35	9.33	8.50	8.92
Mean	9.23	8.00	8.61	11.27	9.28	10.29

C.D for comparison between Rubber and Forest = 0.452

Appendix 12. Total $Fc_2 O_3$ %

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	9	8	8	6	7	7
Chimony	11	9	10	6	6	6
Vithura	8	8	8	6	7	7
Mundakayam	11	9	10	6	7	7
Mean	10	8	9	6	7	7

C.D for comparison between Rubber and Forest = 0.505

Appendix 13. Fe - DCB (%)

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	3.2	4.7	4.0	3.8	2.7	3.3
Chimony	3.5	3.1	3.3	2.3	2.2	2.3
Vithura	5.6	4.1	4.9	5.2	2.7	4.0
Mundakayam	5.0	2.7	3.8	4.2	2.7	3.4
Mean	4.4	3.7	4.0	3.8	2.5	3.2

C.D for comparison between Rubber and Forest = 0.158

Appendix 14. Sesquioxide %

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	23	29	26	14	16	15
Chimony	28	28	28	18	20	19
Vithura	28	26	27	22	22	22
Mundakayam	30	33	32	25	27	26
Mean	27	29	28	20	21	21

C.D for comparison between Rubber and Forest = 1.055

Appendix 15. Silt %

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	9	9	9	6	5	5
Chimony	14	16	15	8	7	7
Vithura	4	3	4	4	3	3
Mundakayam	12	10	11	10	8	9
Mean	10	10	9	7	5	6

C.D for comparison between Rubber and Forest = 0.6

Appendix 16. Clay %

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	42	39	41	35	37	36
Chimony	32	39	36	31	35	33
Vithura	37	47	42	36	41	39
Mundakayam	40	43	42	30	35	33
Mean	38	42	40	33	37	35

C.D for comparison between Rubber and Forest = 0.97

Appendix 17. Available Water %

	Rubber			Forest		
Location	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Nilambur	4.5	6.4	5.5	5.4	6.7	6.1
Chimony	7.3	4.4	5.8	10.2	11.0	10.6
Vithura	3.4	2.8	3.1	4.6	5.2	4.9
Mundakayam	2.7	3.5	3.1	5.8	6.3	6.1
Mean	4.48	4.30	4.39	6.51	7.30	6.90

C.D for comparison between Rubber and Forest = 0.245

ABSTRACT

The present investigation aims to assess the change in soil properties of monocropped rubber plantations in the third cycle of planting and to have an appraisal of nutrient status of soil in each planting cycle. The objective is thus to make predictions for the management of the future cycles of rubber in order to make the soil component of the rubber plantation ecosystem as near to that of the forest ecosystem. The study has been conducted using four soil profiles from rubber plantations of Nilambur, Chimmoni, Vithura and Mundakayam currently in the third cycle of planting, which represents the major traditional tract of rubber growing areas of Kerala State. To have a comparison with forest soils, vergin forest profiles were taken from the corresponding four locations. Soil samples were collected horizon wise and analysed for physical and chemical properties.

The morphological studies revealed that there is not much difference in morphological features between rubber and forest profile. Soils from rubber plantation did not show any structural degradation as compared to forest soils. Textural changes were also not noticed. Moisture holding capacity of forest soil was observed to be higher than that

of rubber plantations. Significant reduction in organic carbon content was noticed in all cycles of planting of the crop compared to adjacent natural forest, though the plantations maintained high range of organic carbon according to current fertility standards. For total nitrogen the same trend was noticed. An enrichment of phosphorus was observed in these cropped areas. A reduction in cationic nutrients like potassium, calcium and magnesium was obtained in plantation soils than that of virgin forest. pH was decreased significantly in the third planting cycle. With regard to total iron, aluminium and sesquixides an increase was noticed in rubber planted areas. The total nutrient removal from one hectare of rubber plantation was estimated and these estimates revealed that a deficit of 755, 883, 1260 and 945 kg/ha is taking place for nitrogen, potassium, calcium and magnesium respectively. These figures highlights the necessity for intense management of nutrients in subsequent cycles of rubber planting. All these findings emphasise the need for modifying the current trends of nutrient management and rescheduling the package of practices for sustainable rubber production where in the soil component of the rubber plantation will be made as near to that of the forest ecosystem. This alone will be able to raise the rubber plantations to be an economically advantageous and near alternative to the forest ecosystem in as far as the already rubber planted areas are concerned.

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