PHYSICO - CHEMICAL CHARACTERISTICS, GENESIS AND CLASSIFICATION OF SOILS FROM FOREST ECOSYSTEMS IN KERALA

By

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THESIS

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requirement for the degree

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DECLARATION

I hereby declare that this thesis entitled "Physico-chemical characteristics, genesis and classification of soils from forest ecosystems in Kerala" is a bonafide record of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled "Physico-chemical characteristics, genesis and classification of soils from forest ecosystems in Kerala" is a record of research work done independently by Smt.P.A.Elsy, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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We, the undersigned, members of the Advisory Committee of Smt.P.A.Elsy, a candidate for the degree of Master of Science in Agriculture with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled "Physico-chemical characteristics, genesis and classification of soils from forest ecosystems in Kerala" may be submitted by Smt.P.A.Elsy in partial fulfilment of the requirement for the degree.

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INTRODUCTION

Soil is the most important nonrenewable natural resource which forms the main stay of livelihood and economy of a country. In recent years there has been an increasing concern of the widespread misuse and degradation of soils due to over exploitation for agriculture, industry and other activities. The seriousness of the problem has prompted the Food and Agriculture Organisation, the International Soil Science Society and the United Nations Environmental Programme to conceive the idea of a World Soils Policy giving priority to issues like degradation, conservation and judicious use of soil resources, without impairing its productivity.

Kerala is endowed with an abundance of forest wealth, rich in its variety of floristic composition. Variation in rainfall, temperature and elevation has been responsible for the extra ordinary diversity in the forest resources of the state. Chandrasekharan (1962) has identified six major types of forest ecosystems in Kerala viz. tropical evergreen, semi-evergreen, moist deciduous, grasslands, Shola forest and dry deciduous types.

According to the estimates of the Food and Agriculture Organisation (1984) the forest cover in Kerala is only 24% of the geographic area of the State. The dwindling forest cover as a result of indiscriminate felling and intensive cultivation has given rise to large scale degradation and loss of soil by erosion. The heavy rainfall and high temperature conditions existing in Kerala are conducive to the laterisation process which is hastened on removal of the forest cover causing rapid deterioration in the productive capacity of the soil.

A perusal of the literature would reveal considerable work on soils of forest ecosystems of the world. Special mention may be made of the work carried out by Cunningham (1963), Jaiyebo and Moore (1964), Reynolds and Wood (1977), Singhal and Sharma (1985) and Banerjee et al. (1986). In Kerala, studies on various aspects of forest soil have been taken up earlier by Chaly and Koshy (1967), Jose and Koshy (1972), Alexander and Balagopalan (1980), Balagopalan and Joss (1986) and Sankar et al. (1987).

The recent decade has shown a tremendous increase in the awareness on forestry and forestry management practices. The understanding of the nature and properties of forest soils is of utmost importance in their proper management and efficient utilisation. Hence comprehensive inventories on soil resources are prerequisites to serve as basic information for efficient management.

With this objective in view the present investigation covering soils of six major forest ecosystem located in Trichur and Palghat districts of Kerala was undertaken with emphasis on morphology, physico-chemical characteristics, genesis and classification. This has been achieved by a systematic study of the following aspects:

(1) Morphological features of the soil profile

(2) Physio-chemical characteristics of soils

(3) Extractable iron in relation to genesis of soils

(4) Phosphorus fraction and genesis of soils

(5) Chemical composition of clay fraction and molar ratios and

(6) Classification of soils under soil taxonomy

It is hoped that the present investigation will form the data base for improved forest land management practices for enhancing forest productivity and sustained use of these soils.

Review of Literature

REVIEW OF LITERATURE

Attempts have beem made by many earlier workers to examine the inter-relationships between the two basic natural resources namely soil and vegetation (Jenny, 1941; Gupta, 1956; Bryson et al., 1965; Daniels et al., 1983). The dynamic relationship between soil and vegetation has been receiving greater attention in the recent past.

In a study of forest succession and soil development near the Chena River in interior Alaska, Viereck (1970) found that soil temperature, soil moisture and depth of thawing varied directly in a 15 year old willow stand succeeded by a 20 year old white spruce forest and followed by a climax black spruce-sphagnum moss stand. In the early willow and poplar successions, the soil was colder and frozen rapidly to a greater depth than in the more advanced stages of succession. Soil-moisture regimes in the willow-white spruce forest, ranged from xeric to mesic, but were replaced by hydric regimes in the black spruce sphagnum stage.

Studies on the changes in soil properties brought by pure plantations and mixed plantations of long rotation crops have been carried out by Jose and Koshy, 1972.

Interaction of biotic factors like forest-prairie ecotones and soil formation has been reported by Severnson and Arneman, 1973.

The effect of vegetation cover on soil properties is not limited to the impact of different plant communities. Individual plants especially trees, can spatially influence the soil. These spatial variations occurring in the proximity of a single tree were more intense near the tree stem and decreased towards the edge of the canopy (Lodhi, 1977).

Alexander and Balagopalan (1980) had carried out vegetational and soil studies in areas representing the evergreen, semi evergreen, moist deciduous and dry deciduous types of forests. One among the conclusions was that soils under dry deciduous and to some extent moist deciduous forests were more resilient and can be developed for forestry or agricultural purposes through scientific soil management practices while soils under evergreen and semi evergreen forests were fragile and the vegetational cover needed protection. Balagopalan and Jose (1982) reported that soils under teak vegetation were more acidic than those under mahogany.

Doescher *et al.* (1984) observed that surface concentration of nutrients was greatest under shrubs in comparison to interspace and grass influenced soils. Differences in soil chemical levels between sites with a high proportion of perennial grasses to shrubs and sites with a low proportion of perennial grasses to shrubs were noted. However, no consistent pattern was evident.

Banerjee *et al.* (1985) in a study on chemical properties of soils under different old stands on upper forest hill of (Darjeeling) West Bengal have reported that soil differences related to vegetation were most pronounced in the surface layer (0-15 cm) and the effect decreased with depth.

Study of the soil properties at three sites under different vegetations, overlying almost similar parent material in the Tarai region of Kurseong Forest Division, West Bengal by Banerjee *et al.* (1986) revealed considerable difference among the pedons. This was primarily due to rooting and litterfall characteristics of the perennial vegetations they support. All the soils were acidic. The values of exchangeable H^+ were highest under mixed species, intermediate under sal and lowest under teak.

1. Morphological characteristics of the soil profiles

The most classical work on vegetation soil relationship relates to the studies in the forest prairie transition areas in the United States which have been described by numerous workers (White, 1941; Jenny, 1941; Kilburn, 1959; Al-Barrak and Lewis, 1978; Buol *et al*., 1973, 1980 and Birkeland, 1974). The morphological properties of these soils revealed thinner organic horizons in prairie soil than the adjacent forest soils. The B horizons were more developed and redder in the latter than the former. In respect of the clay distribution, the surface soils of prairie areas had higher clay content while in the forest soils, clay accumulation was observed in the subsurface horizons.

Singh and Ramam (1979) have reported that the soils under *Pinus patula* in Eastern Himalayas were brown in colour, and the upper two horizons were dark brown due to the relatively greater humification.

Banerjee and Badola (1980) in a study of the forest soils of Chakrata Forest Division, Uttar Pradesh, have reported that the colour of soils varied from 10 YR (greyish brown) to 7.5 YR and 5 YR (reddish brown).

Surface soils were granular, with subangular blocky at lower depths. Clay translocation could be observed in the form of cutans, which were patchy, broken and continuous. Organic cutans were also observed on some ped surfaces.

Based on the study of several pedons in two dominant soils of the warm temperate and humid region of the central Himalayas, Jawahar et al. (1985) have reported that the mountain soils on slopes formed on chlorite-schist under deciduous forest had a mollic epipedon followed by a cambic horizon. The soils in the valleys developed on colluvium (derived mainly from gneisses) showed a clay-enriched Bt-horizon and an ochric epipedon and were classified as Typic Hapludolls and Mollic Hapludalfs respectively.

Gangopadhyay et al. (1986) have observed intense movement of clay in the soil profiles of some high altitude soils of Sikkim Forest Division, within an altitudinal range of 1970 m and 2425 m.

Sankar et al. (1987) working on the soils of the Trichur Forest Division reported differences in their level of erosion, presence of mottled horizon and concretions, which were attributed to the impact of forest degradation (felling, grazing, fires etc.). Most of the soil profiles showed the presence of iron concretions indicating the onset of the laterization, which have become pronounced, with the removal of the forest cover.

The morphological studies of five representative soil profiles developed under Pine forest in East Khasi Hill district of Meghalaya by Nair and Chamuah (1988) revealed that all the soils were very deep except the profile on steep slopes with severe erosion. They have variable colours both at surface and subsoils depending upon the degree of oxidation of Fe - Mn bearing minerals. Surface layers were granular, while subsurface layers were subangular blocky. The clay distribution down the profile did not follow any regular pattern.

2. Physical properties

Bulk density, mechanical composition and moisture retention characteristics

Jose and Koshy (1972) in their studies on the forest soils of Nilambur Division, Kerala have observed that the surface soils of the young teak plantations exhibited remarkably higher values for apparent density and absolute specific gravity and relatively lower values for pore space, water holding capacity and volume expansion indicating that physical conditions of the soils have been markedly altered as a result of deforestation and planting of teak.

In a study on the influence of altitude on the physicochemical characters of forest soils in Western Ghats in South India, Rajamannar and Krishnamoorthy (1978) reported that bulk density was reduced slightly at higher elevation principally due to the higher organic matter content. The maximum water holding capacity, total pore space and moisture equivalent showed an increasing trend with increasing elevation.

Sharma <u>et</u> <u>al</u>. (1980) reported bulk density values ranging from 1.06 to 1.41 g/cc with mean value of 1.20 g/cc in the acidic soils of Kangra district in Himachal Pradesh.

✓In a study on the properties of soils in the natural forests and plantations of Trivandrum forest division Balagopal (1987) has reported efficient nutrient cycling in moist deciduous forests. In the plantations, monocultures have relatively low organic carbon and high exchange acidity in the surface as well as deeper layers.

Moreover monocultures have stronger acidifying effect on the soils than mixed stands. Relatively higher values of pH, organic carbon and exchangeable bases have been observed in the mixed stands of teak and bombax.

Nair and Koshy (1970) reported a textural range between clay and clay loam in respect of soils from the High Ranges of Kerala, situated in Devicolam taluk of Kottayam district. The surface horizon generally contained the maximum amount of clay which decreased with depth down the profile. The translocation of clay was maximum in the soils at an elevation of 1200 m where the highest amount of rainfall was received. At 1200 m, the clay content showed a sudden decrease in the intermediate layers with the trend continuing to the lower depths.

In a study on the influence of altitude on the physicochemical characters of forest soils in Western Ghats areas in South India, Rajamannar and Krishnamoorthy (1978) observed that the clay content of the soil decreased with depth and varied from 5.8 to 8.1 per cent for 1010 m and 16.0 to 29.2 per cent for 2237 m elevations.

Banerjee and Badola (1980) in a study of the nature and properties of some Deodar (Cendrus deodara) forest soils of Chakrata Forest Division in Uttar Pradesh, observed that the soil horizons were fine textured. No definite trends were however observed in the distribution of the mechanical separates in any of the profiles.

Prasad *et al.* (1985) in the study of soil properties under different vegetations, observed that percentage of sand was highest in the soil of natural forest followed by mixed and teak plantation. Highest percentage of clay was noticed in teak plantation and lowest in the natural forest. It was also observed that translocation of clay with depth was highest in teak plantation followed by mixed plantation and natural forest. Highest percentage of clay and lowest percentage of sand on two different sites indicated the effect of deforestation activities on the sites.

Sankar *et al.* (1987) observed in the case of soils in natural forests of Trichur Forest Division, high content of gravel with sandy loam texture, indicative of intense erosional activity.

Ali (1965) observed a beneficial effect of soil organic carbon in improving soil moisture retention characters irrespective of the texture and mineralogical composition of clays. Organic carbon and available moisture were found to be positively correlated.

In the Deodar Forest soils of Chakrata Forest Division in Uttar Pradesh, Banerjee and Badola (1980) reported high water holding capacity (42.1% to 69.9%) and attributed this to the higher organic matter and finer soil fractions. The deeper horizons had in general, lower water holding capacity.

In a study on the moisture retention characteristics of red and Forest soils of Kerala, Mathew (1985) revealed that 53% of the available water was removed as the tension increased from 0.3 to one bar. When the tension reached three bars more than 80% of water was depleted.

The fine fractions of soil, clay and silt, showed significant positive correlation with moisture retention at all the tensions. An increasing influence of clay at increasing tensions was observed. The relation with sand franction was, as expected, negative. The organic carbon content was not found important in deciding moisture retention in these soils.

3. Total Chemical Composition

In the case of Forest soils of Western Ghats in South India, Rajamannar and Krishnamoorthy (1978) reported that the iron content of soil from lower altitude was very low (4.37 per cent) when compared to soils of the higher altitude (14.26 per cent).

In the study on the pedological characteristics of some soils of the Darjeeling Himalayan region, Pal *et al.* (1984) reported that next to silica, sesquioxides was the dominant fraction, with alumina contributing the greater proportion, than iron oxides. The Al_2O_3 content of these soils varied from 7.83 to 32.0 per cent.

In the Forest soils of Darjeeling Himalayan region under *Pinus patula*, Pal *et al.* (1985) observed that the mobile form of iron and particularly aluminium increased down the profile upto certain depth indicating their interaction with organic constituents. They also reported that both silica and sesquioxide contents more or less uniformly increased with depth. The relative accumulation of sesquioxides in the lower horizons appeared to be resulting partly from the breakdown of the silicate minerals and partly from downward translocation of mobile sesquioxides which were otherwise profusely present in Himalayan soils.

Alexander and Balagopalan (1980) reported a decrease in the organic carbon content with depth in the profiles in the case of reserved and vested forests in Attappady area of Kerala. Most of the surface samples of the evergreen, semi evergreen and moist deciduous soils were rich in organic carbon.

The organic carbon content decreased from evergreen to moist deciduous soil, further there was considerable reduction (about 50%) in dry deciduous. This has been mainly attributed to the differences in the canopy cover.

A close correlation between the organic carbon content and that of bases was reported in the soils in natural forests of Trichur Forest Division by Sankar et al. (1987). They also observed that these constituents were concentrated only in the upper horizon.

Singh et al. (1983) found the level of total N, of Bundelkhand forests that were tropical dry deciduous type to vary from 0.09 to 1.03% and also observed wide variation in C/N ratio in these soils (8.0 to 22.1).

Venkataraman *et al.* (1983) compared the nutrient status at different soil depths in the natural forests and man made protected plantations of Nilgiris in Tamilnadu and observed that the total N status was very high in 0-15 cm soil layer as compared to 30-60 cm soil layer.

In a study on the forms of P in some Vidarbha soils (Maharashtra) Bapat *et al.* (1965) found that the surface layer of all the profiles were rich in total P. Singh and Ramam (1980) found the level of total P in different immature soil profiles in Eastern Himalayas was more or less uniformly distributed and ranged from 0.04% to 0.084%.

Pal *et al.* (1984) reported that the P_2O_5 in the soils of Darjeeling Himalayan region ranged from 0.13 to 0.60%, while the total K_2O varied from 0.32 to 2.1%.

Ghabru and Ghosh (1979) found that the total CaO and MgO content in a soil profile from Kangra district of Himachal Pradesh varied from 0.20-0.24 and 0.65-0.96 per cent respectively while Banerjee and Badola (1980) observed Ca as the preponderant cation in all the horizons of the forest soils of Chakrata forest Division in Uttar Pradesh.

Menon and Shah (1982) studied the vegetation soil relationships in 35 localities of four major forest divisions in Saurashtra and observed that there were not much variations in the contents of Ca and Mg to that of typical dry deciduous and moist deciduous forests.

3.1. pH and Cation exchange properties

Alexander and Balagopalan (1980) in a case study of the reserved and vested forests in Attappady, Kerala reported that most of the surface horizons were slightly acid to neutral in reaction. In the profiles, pH increased with depth. Evergreen soil was the most acid followed by the slightly acid semi evergreen and near neutral moist deciduous and dry deciduous soils. CEC values were highest for moist deciduous forests and lowest for dry deciduous type. In the profiles CEC generally decreased with depth and varied from 18-25 me/100 g for semi evergreen, 14-26 me/100 g for moist deciduous and 10-26 me/100 g for dry diciduous type of forest.

Banerjee and Badola (1980) reported that the soils of Chakrata Forest Division in Uttar Pradesh were acidic and even though developed on limestone were non-calcareous. Surface horizons had pH ranging from 6.1 to 6.5 and subsoil horizons between 5.3 to 6.7. The CEC was medium to somewhat low and manifested no regular pattern in the profiles.

Singh et al. (1983) observed wide variation in CEC in the forest soils of Bundelkhand division (tropical dry deciduous type) (5.2 to 19.2 me/100 g soil). The exchangeable Ca varied from 2.7 to 10.00 me/100 g soil. Exchangeable Ca content of the soils of high CEC was found to be relatively higher than the soils of low CEC which might ~~be~~ possibly be due to formation of some of these soils from mica, limestone and slate minerals.

Dhar et al. (1984) in the study of clay mineralogy of some teak bearing soils of Maharashtra observed that illite and kaolinite were the dominant minerals and quarts occurred as an accessory mineral in the clay fraction. It was inferred that the loss of bases due to kaolinization might not get adequately replenished by the nutrient cycling through inorganic and organic substances, if the balanced ecosystem was disturbed.

Pal et al. (1985) observed that in the Forest soils of Darjeeling Himalayan region, the total exchangeable bases were highest in the surface layers. CEC ranged between 11.5 and 46.5 me/100 g soil and decreased uniformly down the profile. The base saturation in the surface horizon was greater in comparison to the subsurface and more so in the lowland profile. Exchangeable Ca and Mg were high in the surface layers.

For the subalpine eucalyptus forest of Australia, Khanna et al. (1986) observed that most of the exchange sites in the red and yellow earths were occupied by Al and were associated with soil organic matter.

Balagopalan (1987) in a study on the properties of soils in the natural forests and plantations of Trivandrum forest division reported that in the natural forest sequence, exchangeable bases, exchange acidity, cation exchange capacity and base saturation were high in moist deciduous forests. As regards plantations, exchangeable bases, cation exchange capacity and base saturation were high in teak + bombax. In the plantations, organic carbon was relatively low, while exchange acidity values were high in monoculture. Also monocultures had a stronger acidifying effect on the soils than mixed stands.

Sankar et al. (1987) found a close correlation between the organic carbon content and bases in the case of soils in natural forests of Trichur Forest Division. The exchangeable bases were seen concentrated in the humus rich surface horizon.

3.2. Iron fractions and active iron ratio of soils

Mc Keague (1965) reported that the brownish Bfg horizons of the soils of upland catena ie. podzols, uplands and Rubicon were high in free iron oxide but low in organic matter and free aluminium. Oxidation of ferrous iron from the underlying reduced zone apparently contributed towards the development of this horizon.

Mc Keague and Day (1966) showed an overall decline of active iron with depth for some Canadian soils, but "Bt" horizons tended to show an accumulation of active iron. They concluded that oxalate, as well as dithionite were useful as extractants in identifying horizons of accumulation of secondary sequioxides.

Blume and Schwertmann (1969) have observed the efficacy of acid ammonium oxalate in extracting "amorphous" iron fractions in soils. The ratio of oxalate-soluble iron to dithionite soluble iron (activity ratio) has been made use of to provide a relative measure of the degree of aging or crystallinity of iron oxides. They also indicated that an estimate of the iron that existed as a structural component of silicate minerals was provided by that portion of the total iron not extracted by dithionite, $(Fe_t - Fe_d)$ unless significant amount of magnetite was present. According to them the constancy of the Fe_d/total clay ratio with depth could be considered indicative of the co-migration of clay and iron oxides. They also reported that the iron, aluminium and manganese were greatly affected by the processes of soil profile genesis.

Mc Keague et al. (1971) reported that haematite occurred in some reddish brown parent materials having a high ratio of dithionite to oxalate extractable iron, but mottles formed in these soils contained secondary goethite.

Juo et al. (1974) observed a decline in active iron with depth for some well drained Nigerian soils. They reported that the amount of amorphous iron oxides of Alfisols and Ultisols derived from acidic parent rocks of West Africa was relatively small. The content of oxalate extractable iron oxides in these soils ranged from 0.05 to 0.20%, which comprised less than 10% of the total free iron oxides.

Richardson and Hole (1979) used the Fe_d/Fe_t ratio as an indicator of the degree of weathering in soils. It was evident that the Boralfs from Wisconsin studied by them with ratios nearer to 0.6 were more highly weathered than those from northern Saskatchewan.

Banerjee et al. (1981) in a study of free iron oxide in relation to aggregation in lateritic soils of East Midnapur Forest Division, West Bengal, summarized that these soils were low in the physico-chemical agents responsible for soil aggregation except total iron and free iron oxides. The state of aggregation in the five depths studied considered along with the vertical distribution pattern of free iron oxides and of clay in these soils indicated that free iron oxides had participated rather actively in the formation of the nondispersible aggregates stable to water action.

Ugolini and Edmonds (1983) observed that, out of the various forms of iron, Fe_d showed rapid decrease with depth in the forest soil and a gradual decrease in the prairie soil. Both Fe_o + Fe_p displayed an accumulation in the B horizon in the forest soil but not in prairie.

Bhattacharya et al. (1983) observed the level of citrate-bicarbonate-dithionite extractable iron content in red soils of Karnataka derived from granite gneiss ranged from 0.88 to 4.3% and constituted 20.6 to 73.7% of the total iron content.

Arduino et al. (1984) reported that the relative age of soil could be estimated from the amount of iron, extracted by dithionite and oxalate. The larger the proportion of total iron extracted by these reagents especially by dithionite, the older the terrace was the proportions of total iron extracted by dithionite over and above those removed by oxalate offered the best basis for discriminating the age.

Mineralogy of the clay from soils of northern Italy showed dominance of 2:1 minerals in the younger profile and abundance of kaolinite in soils from older terraces (Arduino et al., 1986). They also observed an increase in the Fe_d/Fe_t and $Fe_d - Fe_o/Fe_t$ ratios with age of the terrace.

Santos et al. (1986) studied the transformation and translocation of iron in three Boralfs (Gray Luvisols) of Saskatchewan, in relation to the iron contained within silicate minerals and that existed in oxide forms, and concluded that losses of iron from E horizons and gains in B_t horizons were largely accounted by the translocation of iron rich fine clays that were relatively unaffected by chemical weathering during transport. Coarse clay was found to be weathering to fine clay in the sola, particularly in the E horizons.

3.3. Phosphorus fractions

Chang and Jackson (1958) postulated that in the case of chemical weathering and soil development, Ca-P would decrease considerably followed by Al-P resulting in an increase of Fe-P, occluded P and reductant soluble P. They found that inorganic P increased in the order Ca-P (1%), Al-P (0-3%), Fe-P (10-13%) and occluded and reductant soluble P (66-78%) in two latosols.

Gupta and Khanna (1964) reported that eroded soils were poor in organic and Ca bound P and had greater proportions of iron and Al bound P.

Bapat et al. (1965) in a study on forms of P in some Vidarbha soils (Maharashtra) found that the surface layers of all the profiles were rich in total P. Inorganic fraction constituted a significantly high proportion of the total. Aluminium occluded P was found to be in traces. The organic P content was low and generally decreased with depth. Three profiles which contained sufficiently high amounts of free $CaCo_3$ and total CaO were rich in Ca-PO_4 form. Profiles having less of $CaCO_3$ or CaO were rich in iron and aluminium phosphates. The reductant soluble P was observed to exceed 25% of the total P. It was found to be related with sesquioxides or iron content. All the soil profiles were poor in available P. Significant correlations of available P with Ca-P had been observed in soils containing more $CaCo_3$ and with iron and Al-P in other soils.

The concept that Calcium phosphate in soils was of primary origin and that iron and aluminium phosphate in contrast were largely of secondary origin formed in the course of geological and pedological weathering was supported by Juo and Ellis (1968).

Singh and Gangwar (1968) reported that in the Vindhyan soils of Mirzapur, calcium bound P was found to be maximum representing on an average 58.5 and 70.1% of the inorganic P in upland and lowland soils respectively.

Syers et al. (1969) and Smeck (1973) reported that reductant soluble P reflected the age of the soils.

Smeck (1973) also reported that as chemical weathering and soil development advanced, the occluded P would increase at the expense of Ca-P and Al-P. As pH and other ionic concentrations changed with soil profile development, form of P also changed. Generally pH dropped with development, relatively soluble form of P decreased and occluded form increased. Consequently, relative quantities of P forms could serve as a measure of soil development.

Pathak *et al.* (1977) estimated different fractions of soil P in four alluvial soil profiles of Hardoi district in Uttar Pradesh and were correlated with various physical and chemical characteristics. Ca-P was found to be maximum followed by Fe-P, Al-P, organic-P and available P respectively. The normal alkaline soil contained greater proportion of Ca-P. Significant negative relationships of available P with Al-P, Fe-P, Al_2O_3, Fe_2O_3 and clay content were observed between organic carbon and organic P, Al_2O_3 and Al-P, Al_2O_3 and Fe-P, Fe_2O_3 and Fe-P, $CaCo_3$ and Ca-P, Fe_2O_3 and Al-P and pH and available P. Organic carbon, $CaCo_3$ and pH were also found negatively and significantly associated with Ca-P, organic-P and organic P respectively.

Singh and Ram (1977) reported that the total amount of P recovered as saloid P, Al-P, Fe-P and Ca-P in different soils accounted for 55 to 98% of the added amount. The unrecovered P to the extent of 45% of the added P might have transformed into reductant soluble Fe and or occluded Al-Phosphates.

In the case of Tamil Nadu soils, Kothandaraman and Krishnamoorthy (1979) found that fractions of P viz. Al-P, Fe-P, reductant soluble P and occluded P were relatively more in high altitude laterite soils, whereas Ca-P dominated in black and alluvial soils.

Tiessen et al. (1984) reported that correlation and regression analysis of P distribution and chemical analysis confirmed the partial dependence of organic matter accumulation on available forms of P.

Sah and Mikkelson (1986) observed that when soils were flooded, typically the Fe-P fractions increased and Al-P fractions decreased. He also reported that the P fractions occurred in all soils, but differed in proportion according to soil characteristics. Strongly acid soils which are usually highly weathered, were dominant in Al-P, Fe-P and reductant soluble P. Neutral and slightly acid soils usually contained all four P fractions Ca-P, Fe-P, Al-P and RS-P in comparable amounts. Alkaline and calcareous soils were often dominant in Ca-P. The most stable Al-P, Fe-P and Ca-P minerals were variscite, strengite and flourapatite respectively. The most common Ca-P mineral in soil however was Ca-apatite.

4. Chemical characteristics of clay fraction

Lissonite (1960) observed the ratio of silica sesquioxides ranging from 1.60 to 2.09 in red earths of Italy. He used the silica/sesquioxide ratios for characterising the clays.

Satyanarayana (1968) reported that the silica content of clay fraction of red soils of Andhra Pradesh ranged from 30.20 to 41.90%.

Bouma and Schuylenbergh (1969) observed that the SiO_2/R_2O_3 and SiO_2/Al_2O_3 ratios of clays appeared to be more relevant as a index of pedogenic processes. Decreasing SiO_2/R_2O_3 and SiO_2/Al_2O_3 with depth in the pedon were believed to be indicative of movement of aluminium and iron or clay migration where as increasing ratios were interpreted as movement of silica to lower depth in the pedon.

Ameer (1970) found the ratio of SiO_2/R_2O_3 of red soils of Tamil Nadu as 1.97 and that for laterites as 1.23. Significant positive correlation was obtained between clay content and SiO_2/R_2O_3.

Gupta *et al.* (1977) in a study of 27 surface soils from Jammu and Kashmir observed that the CEC of the clays was mostly in the range of 20 to 40 me/100 g though a few had somewhat higher values of 40 to 50 me/100 g.

Manickam (1977) reported a silica/alumina ratio of 1.57 to 3.96, silica/iron oxide ratio of 3.96 to 12.43 and silica/sesquioxide ratio of 1.12 to 2.71, in respect of the lateritic soils of Tamil Nadu.

Greenland (1981) reported that the free iron oxide of the clay fractions of humid tropics acted as cementing agents, stabilizing their porosity and these soils possessed free drainage characteristics.

Studies on tropical soils by Eswaran (1983) revealed that, these soils were dominated by low activity clays and had effective CEC of less than 12 me/100 g soil, when soil pH was less than 6.5 and had CEC less than 16 me/100 g clay in 1 N NH_4OAc pH 7. Some of this low activity soils were Oxisols while others were Ultisols and Alfisols and even Inceptisols and Mollisols.

5. Taxonomy of forest soils

Das et al. (1980) in a study on genesis of red and lateritic forest soils of West Bengal on catenary basis have classified all the ten soil profiles of the three catenas, under Alfisol except in the case of upland and midland profiles of one catena and the upland profile of another catena which was placed under Entisol.

Banerjee and Singhal (1983) arranged the soils representing four types of Bijnor forest division, Uttar Pradesh from Entisol at the dry end of a moisture and soil development gradient to Mollisol on the other end with better moisture and organic matter status and also soil development.

Sarma et al. (1985) classified some soil biosequences occurring in a nearly similar topography with special reference to the role of natural vegetation on their genesis, in the Bijnor plantation division. Sandy hyperthermic Typic Haplumbrept and Ustochrepts were the major silvicult- urally important soils of this areas. From the organic carbon content, and its relative distribution along depth, comparison of base status in different horizons and clay migration, it appeared that marks of grassy woodland ecotones on the genesis of Argiustolls were quite evident. Thick B horizons, migration of clay, lower base saturation gradual decrease in organic carbon and redistribution of exchangeable Ca and Mg possibly due to phytocycling among various horizons indicated the dominant role played by tree species in the comparatively more weathered habitats of Haplustalfs.

Jalalian and Southard (1986) reported that the underlying sequum of all three soils in northernUtah studied by them had the morphology of Alfisols - thick E horizons and thick red and reddish brown B_t horizons with mineralogy dominated by kaolinite, quartz and chlorite and a base saturation greater than 60% through out. The fine clay in the upper sequum of all three soils was dominated by amorphous material suggesting an early stage of weathering. Results of these studies suggested that the older series (lower sequum) were Alfisols. Recent additions of eolian material from lake Bonneville sediments and Snake River plain have covered the Alfisols and mollic epipedons have developed in the eolian material and these soils were classified as Paleborolls.

Sankar *et al.* (1987) reported that the soils of the Trichur forest division belong to the group of red soils or Oxisols or red ferralitic soils.

Biswas (1988) classified the forest soils and associated typifying pedons of Mahanadi Catchment district Raigarh, Madhya Pradesh, India, as Entisol, Inceptisol and Alfisols upto subgroup level.

Materials and Methods

MATERIALS AND METHODS

The investigations carried out in this study relate mainly to six soil profiles located from different forest ecosystems in the central region of Kerala. The areas selected for the study are indicated in the map (Fig. 1).

Field studies

The sampling areas were selected after initial identification of the forest type characterized by the State Forest Department. The profile pits were dug in typifying areas and morphological features were observed horizon wise and recorded as per Soil Survey Manual (AISLUSO, 1970). The salient features of the areas in respect of locations, physiography, drainage, vegetation and forest types were also recorded. The morphological descriptions of the profiles are presented in Appendix I. The abbreviated morphology of the profiles are given in Table 2.

1. Sample collection

After morphological examination of the profile, soil samples representing the different horizons in the profile were collected for laboratory characterization. The particulars of samples collected are presented in Table 1.

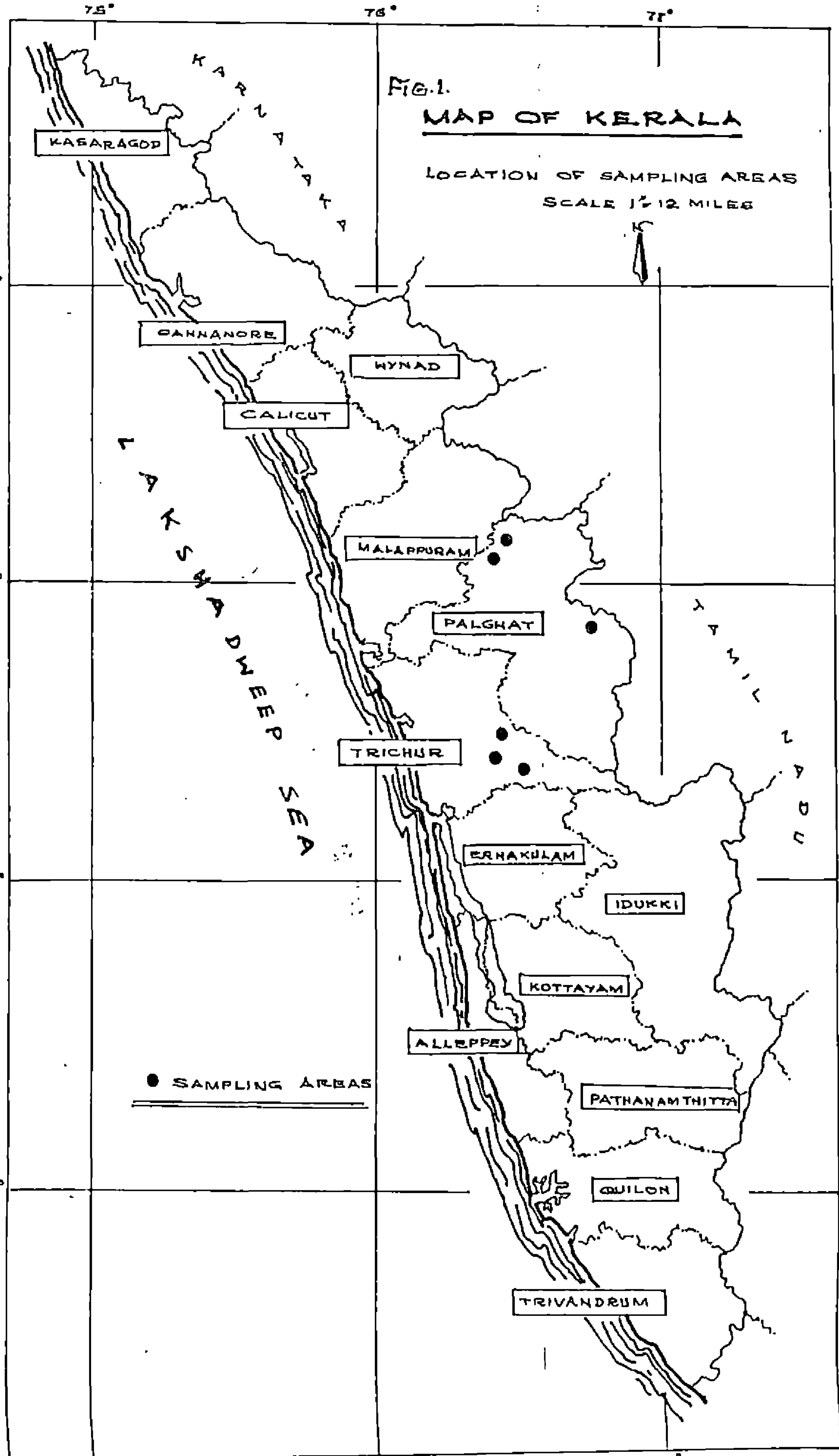

FIG.1.

MAP OF KERALA

LOCATION OF SAMPLING AREAS

SCALE 1" = 12 MILES

Table 1. Details of profile samples collected

Profile No.	Vegetation type	Location (district)	Sample No.	Horizon	Depth (cm)
I	Tropical evergreen	Sholayar (Trichur)	1	A_p	0-10
			2	A_2	10-20
			3	A_3	20-40
			4	B_1	40-70
			5	B_{12}	70-150+
II	Semi evergreen	Kummatti (Trichur)	6	A_1	0-10
			7	A_2	10-27
			8	B_1	27-46
			9	B_{21}	46-88
			10	B_{22}	88-150+
III	Moist deciduous	Athirapalli (Trichur)	11	A_1	0-13
			12	A_3	13-32
			13	B_1	32-66
			14	B_{21}	66-95
			15	B_{22}	95-165+
IV	Grasslands	Siruvani (Palghat)	16	A_1	0-10
			17	A_2	10-25
			18	B_{21}	25-60
			19	B_{22}	60-110+
V	Hill-top evergreen (Shola forest)	Siruvani (Palghat)	20	A_p	0-13
			21	A_1	13-29
			22	A_2	29-52
			23	B_1	52-83
			24	B_{21}	83-120
			25	B_{22}	120-150+
VI	Dry deciduous	Walayar (Palghat)	26	A_1	0-13
			27	B_{21}	13-33
			28	B_{22}	33-70
			29	B_3	70-150+

2. Laboratory studies

2.1. Preparation of samples

The soil samples collected were air dried, ground with a wooden mallet and passed through 2 mm sieve. The sieved samples were utilized for the study of various physico-chemical properties.

2.2. Physical properties

The particle size distribution was carried out by the International Pipette Method (Piper, 1942).

Moisture retention studies were conducted in a pressure plate apparatus using ceramic plates (Richards, 1954). Physical constants were determined using Keen-Raczkowski boxes by the method suggested by Sankaram (1966).

3. Chemical properties

The chemical properties of samples were determined by standard analytical procedure and expressed on moisture free basis.

3.1. Analysis of profile samples

Soil reaction was determined in 1:1 soil water suspension using a Systronic pH meter. Determination of organic carbon was done by Walkley and Black method and total nitrogen by semi-micro-kjeldahl method (Soil Survey Staff, 1967).

Analyses for total SiO_2, ~~R_2O_3~~, Al_2O_3, Fe_2O_3, K_2O, CaO, MgO and Na_2O were done using the HCl extract (Piper, 1942). Total SiO_2 and R_2O_3 were determined gravimetrically. Total iron was determined using volumetric potassium permanganate method and total Al_2O_3 by difference from sesquioxides (Sankaram, 1966). EDTA method as outlined by Hesse (1971) was used for the determination of total CaO and MgO, while P_2O_5 was estimated by vanadomolybdo-phosphoric yellow colour method (Jackson, 1958). Total potassium and sodium were estimated using an EEL flame photometer.

Cation exchange capacity was determined by the NH_4OAc method and exchange acidity, by $BaCl_2$-TEA method (Soil Survey Staff, 1967). Exchangeable potassium and sodium in the NH_4OAc extract were read using EEL flame photometer (Jackson, 1958).

Exchangeable calcium and magnesium in the neutral N NH_4OAc extract were estimated by EDTA titration method (Hesse, 1971).

Amorphous iron oxides were estimated using ammonium oxalate (Mc Keague and Day, 1966) and free iron oxide by dithionite-citrate-bicarbonate method (Mehra and Jackson, 1960). Iron was determined in the extracts by the ortho-phenanthroline method (Hesse, 1971).

Fractionation of P was carried out using the modified procedure of Chang and Jackson as described by Hesse (1971).

3.2. Separation and analysis of clay fraction

The clay fraction of samples was separated by the method outlined by Jackson (1975). Total SiO_2 and R_2O_3 were determined gravimetrically from sodium carbonate fusion extract and total iron by volumetric potassium permanganate method (Sankaram, 1966). Total Al_2O_3 was determined by difference from sesquioxides and the molar ratios of the clay were calculated.

3.3. Statistical analysis

Simple correlation coefficients between the various physico-chemical characteristics of soils were calculated as suggested by Snedecor and Cochran (1967). The significance of the correlation coefficients was tested by using students 't' test.

Results

RESULTS

1. Profile morphology

The abbreviated morphological descriptions of the soil profiles are presented in Table 2 and the detailed morphological descriptions in Appendix I.

The colour of the surface soil was mostly in the hue of 10 YR, the colour ranging from greyish brown to brown. The surface horizons under tropical evergreen forests and the dry deciduous forests had hues of 5 YR with reddish colours predominating. In respect of the subsurface layers, dark brown colours dominated with hues of 5 YR, 7.5 YR and 10 YR. The profiles of semi evergreen and Shola forest had yellowish red colours in the lower layers, while conspicuous red colour was observed in the lower horizons of the soil profile under dry deciduous forests. Increase in intensity of red colour with depth was a feature observed in this soil.

The surface horizons had the characteristic granular structure, but were only weakly developed. The subsurface horizons revealed good structural development as evident from the moderate subangular blocky structure. This was

Table 2. Abbreviated morphological description (**) of the soil profiles

Profile No. & vegetation type	Horizon and depth (cm)	Munsell notation: Dry	Munsell notation: Moist	Texture	Structure	Consistence	Boundary	Remarks
1	2	3	4	5	6	7	8	9
I Tropical evergreen	A_p 0-10		5YR 3/4	gls	$m_1$gr	mvfr, wcs, wpo	cs	
	A_2 10-20		7.5YR 5/6	gls	$m_2$gr	mvfr, ws, wps	dw	
	A_3 20-40		7YR 5/8	gsl	$m_2$sbk	mfr, ws, wp	dw	
	B_1 40-70		5YR 4/8	gl	$m_2$sbk	mfi, ws, wp	dw	
	B_{12} 70-150		5YR 4/8	gsl	$m_2$sbk	mfi, ws, wp, ps	-	
II Semi ever-green	A_1 0-10		10YR 3/3	gsl	$m_2$gr	mvfr, wss, wps	cs	
	A_2 10-27		10YR 3/2	gsl	$m_2$sbk	mfr, wss, wps	dw	
	B_1 27-46		10YR 4/4	gscl	$m_2$sbk	mfr, ws, wps	dw	
	B_{21} 46-88		10YR 4/4	gscl	$m_2$sbk	mfr, ws, wps	dw	
	B_{22} 88-150		10YR 5/6	gscl	m	- ws, wps		faint to distinct 10YR 5/3 and 10YR 7/8 mottles plenty

(**) Soil Survey Staff, 1951

Contd.

Table 2. Continued

1	2		3	4	5	6	7	8	9
III Moist deciduous	A_1	0-13	10YR 4/2	10YR 3/2	gl	$m_1$gr	dl, mvfr, wso, wpo	-	Very loose layer with fluffy fine decomposed organic material
	A_3	13-32		7.5YR 8/2	l	$m_1$gr	dl, mvfr, wso, wpo	cw	
	B_1	32-66		5YR 3/3	cl	$m_1$sbk	mfi, wss, wps	dw	
	B_{21}	66-95		5YR 4/4	gscl	$m_1$sbk	mfi, wss, wps	dw	
	B_{22}	95-165		2.5YR 4/4	c	$m_2$sbk	mfi, ws, wp	-	
IV Grasslands	A_1	0-10	10YR 5/3	10YR 3/3	gsc	$m_4$gr	dsh, mfr, wss, wpo	cs	
	A_2	10-25		10YR 4/4	gcl	$m_1$gr	mfi, wss, wps	dw	
	B_{21}	25-60		7.5YR 5/6	gc	$m_1$sbk	mfi, ws, wp	dw	
	B_{22}	60-110		7.5YR 5/8	gc	$c_2$sbk	mfi, ws, wp	-	
V Hill top evergreen	A_p	0-13		10YR 3/2	gcl	$m_2$gr	mfr, wss, wps	cs	
	A_1	13-29		7.5YR 5/6	gsl	$m_2$sbk	mfi, ws, wp	cw	
	A_2	29-52		7.5YR 4/4	gcl	$c_2$sbk	mfi, ws, wp	dw	
	B_1	52-83		7.5YR 4/4	gl	$c_2$sbk	mfi, ws, wp	dw	
	B_{21}	83-120		5YR 4/6	gcl	$c_2$sk	mfi, ws, wp	dg	
	B_{22}	120-150		5YR 5/8	gcl	$m_2$sbk	mfr, wss, wps	-	A very compact layer

Contd.

Table 2. Continued

1	2	3	4	5	6	7	8	9
VI Dry deciduous	A_1 0-13		5YR 3/3	gl	$m_2$gr	mvfr, wss, wps	cs	The entire profile was very hard and layers compact
	B_{21} 13-33		2.5YR 2.5/4	gcl	$m_2$sbk	mfi, ws, wp	dw	
	B_{22} 33-70		2.5YR 2.5/4	gc	$c_2$sbk	mvfi, ws, wvp	dw	
	B_3 70-150		10YR 3/4	gc	$c_2$sbk	mvfi, wvs, wvp	-	

true for all the soils under investigation. In the dry deciduous profile, the structural aggregates were very firm in the subsurface horizon.

The coarse fragments formed the predominant part of the soil ranging from 15.4 to 87.3 per cent. All the horizons in the soil profile had gravel content more than 20% and qualified to be termed gravelly, with the exception of subsurface layers in moist deciduous forests.

Sandy textures were observed in the profiles from tropical evergreen and semi evergreen forests while loamy texture was a feature observed in moist deciduous and hill top evergreen forests. Clay loam and clayey texture were observed in grasslands and dry deciduous forests. Increase in clay content with depth was observed in all the soil profiles with marked accumulation noticed in the last layer of moist deciduous, grasslands and dry deciduous forests. In the dry deciduous soil profile, marked increase in clay was observed even from the second layer with marginal increase downwards.

The soils from all the locations under investigation were well drained both internally and externally being located in upland physiographic condition. However, the soils from semi evergreen profile were located in a valley bottom and developed mainly from colluvial deposits. The absence of internal drainage was evident from the mottles observed in the B_2 horizons.

2. Physical properties

Mechanical composition, moisture retention characteristics, physical constants, mean and range values for profiles are given in Table 3 to 6. The depth wise distribution of clay in soil profiles is given in Fig. 2.

2.1. Mechanical composition

Coarse sand formed the predominant size fraction ranging from 25.63 per cent in dry deciduous (No.29) to 58.32 per cent in semi evergreen (No.7). The fine sand fraction ranged from 10.76 per cent in grasslands (No.16) to 41.58 per cent in tropical evergreen (No.2). In the grasslands and dry deciduous forest types, the content of sand (coarse sand + fine sand) showed a decreasing trend with depth. In respect of the other profiles, no definite pattern could be observed, in the distribution of the sand fraction with depth in the profile. Silt was the lowest among the size fractions and its content ranged from 1.85 per cent in grasslands (No.16) to 24.01 per cent in moist

FIG. 2. DISTRIBUTION OF CLAY AND ORGANIC CARBON IN SOIL PROFILES

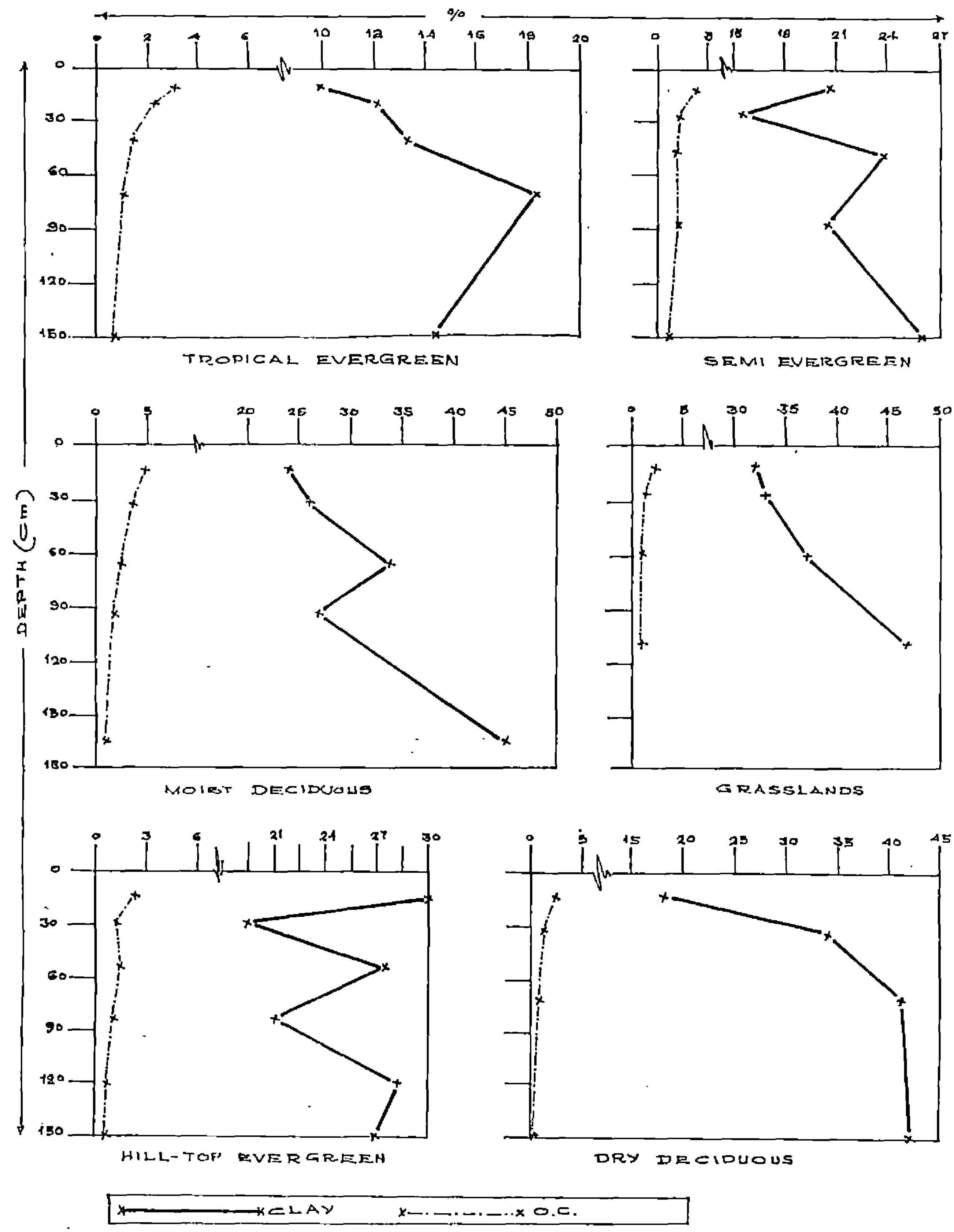

Table 3. Mechanical composition of soils

Vegetation type sample No. and depth (cm)		Coarse fragments (> 2 mm) %	Size class and particle diameter (mm) Coarse sand 2-0.2 %	Fine sand 0.2-0.02 %	Silt 0.02-0.002 %	Clay <0.002 %	Textural class	Coarse sand/ fine sand	Silt/ clay
1		2	3	4	5	6	7	8	9
Tropical evergreen									
1	0-10	29.95	48.21	31.67	10.28	9.85	Gravelly loamy sand	1.52	1.04
2	10-20	41.67	41.37	41.58	4.93	12.11	Gravelly loamy sand	1.00	0.41
3	20-40	34.82	46.99	32.26	7.45	13.30	Gravelly sandy loam	1.46	0.56
4	40-70	27.80	44.59	24.37	12.72	18.32	Gravelly loam	1.83	0.69
5	70-150	30.99	44.26	34.70	6.70	14.34	Gravelly sandy loam	1.28	0.47
Semi evergreen									
6	0-10	24.90	56.45	15.06	7.95	20.54	Gravelly sandy loam	3.75	0.39
7	10-27	28.35	58.32	15.10	11.36	15.22	Gravelly sandy loam	3.86	0.75
8	27-46	34.93	54.04	16.02	6.12	23.82	Gravelly sandy clay loam	3.37	0.26
9	46-88	44.20	55.87	14.14	9.66	20.33	Gravelly sandy clay loam	3.95	0.48
10	88-150	35.76	53.74	15.18	5.22	25.86	Gravelly sandy clay loam	3.54	0.20
Moist deciduous									
11	0-13	28.57	43.83	17.14	15.36	23.67	Gravelly loam	2.55	0.65
12	13-32	15.42	37.74	15.95	19.85	26.46	Gravelly loam	2.37	0.75
13	32-66	16.29	38.29	16.46	11.31	33.94	Gravelly clay loam	2.33	0.33
14	66-95	23.73	35.99	12.88	24.01	27.12	Gravelly sandy clay loam	2.79	0.89
15	95-165	17.75	30.62	12.76	11.32	45.30	Gravelly clay	2.40	0.25

Contd.

Table 3. Continued

1		2	3	4	5	6	7	8	9
Grasslands									
16	0-10	87.39	55.74	10.76	1.85	31.65	Gravelly sandy clay	5.18	0.06
17	10-25	21.78	48.31	12.57	6.13	32.99	Gravelly clay loam	3.84	0.19
18	25-60	28.64	36.07	15.12	11.80	37.01	Gravelly clay	2.39	0.32
19	60-110	34.63	28.74	14.29	9.89	47.08	Gravelly clay	2.01	0.21
Hill top evergreen									
20	0-13	54.90	45.38	18.19	6.86	29.57	Gravelly clay loam	2.49	0.23
21	13-29	50.10	39.26	34.49	6.84	19.41	Gravelly sandy loam	1.14	0.35
22	29-52	56.06	34.32	15.24	22.88	27.56	Gravelly clay loam	2.25	0.83
23	52-83	52.71	36.08	19.24	23.62	21.06	Gravelly loam	1.88	1.12
24	83-120	58.23	35.86	14.37	21.48	28.29	Gravelly clay loam	2.50	0.76
25	120-150	40.24	48.96	19.42	4.67	26.95	Gravelly clay loam	2.52	0.17
Dry deciduous									
26	0-13	27.49	40.00	27.42	14.19	18.39	Gravelly loam	1.46	0.77
27	13-33	33.11	34.76	19.63	11.60	34.01	Gravelly clay loam	1.77	0.34
28	33-70	44.47	34.92	19.54	3.84	41.70	Gravelly clay	1.79	0.09
29	70-150	45.29	25.63	10.80	21.51	42.06	Gravelly clay	2.37	0.51

Table 4. Moisture retention characteristics of soils (per cent by weight)

Vegetation type sample No. and depth (cm)		Soil moisture tension(bars) 0.3	15	Available water 0.3-15 bar	Ratio of 15 bar moisture to clay
Tropical evergreen					
1	0-10	14.63	9.46	5.17	0.96
2	10-20	18.32	10.25	8.07	0.85
3	20-40	19.76	9.21	10.55	0.69
4	40-70	16.23	6.94	9.29	0.38
5	70-150	13.13	4.79	8.34	0.33
Semi evergreen					
6	0-10	11.06	7.54	3.52	0.37
7	10-27	10.37	5.07	5.30	0.33
8	27-46	11.53	5.85	5.68	0.25
9	46-88	13.12	6.70	6.42	0.33
10	88-150	7.20	6.03	1.17	0.23
Moist deciduous					
11	0-13	36.72	12.42	24.30	0.52
12	13-32	37.02	18.40	18.62	0.70
13	32-66	32.99	14.55	18.44	0.43
14	66-95	28.08	15.20	12.88	0.56
15	95-165	29.39	16.73	12.66	0.37
Grasslands					
16	0-10	16.41	13.26	3.15	0.42
17	10-25	16.13	10.07	6.06	0.31
18	25-60	20.36	13.75	6.61	0.37
19	60-110	23.08	16.95	6.13	0.36
Hill top evergreen					
20	0-13	18.63	12.23	6.40	0.41
21	13-29	17.54	11.53	6.01	0.59
22	29-52	18.18	12.28	5.90	0.45
23	52-83	19.71	12.59	7.12	0.60
24	83-120	22.31	14.09	8.22	0.50
25	120-150	16.98	9.90	7.08	0.37
Dry deciduous					
26	0-13	18.88	8.18	10.70	0.44
27	13-33	18.95	10.63	8.32	0.31
28	33-70	21.63	11.81	9.82	0.28
29	70-150	24.93	12.98	11.95	0.31

Table 5. Physical constants of soils

Vegetation type sample No. and depth (cm)		Apparent density g/cm^3	Absolute specific gravity	Maximum water holding capacity (%)	Pore space (%)	Volume expansion (%)
Tropical evergreen						
1	0-10	1.07	2.00	51.84	45.82	5.13
2	10-20	1.21	1.95	31.55	48.57	7.09
3	20-40	1.09	2.02	43.43	49.35	3.59
4	40-70	1.14	2.00	40.24	46.86	4.42
5	70-150	1.24	2.04	35.63	43.60	5.93
Semi evergreen						
6	0-10	1.23	2.07	36.93	44.50	5.49
7	10-27	1.20	2.06	34.60	42.93	0.70
8	27-46	1.22	2.15	37.07	45.72	2.34
9	46-88	1.21	2.14	37.36	45.97	2.57
10	88-150	1.19	2.09	36.31	44.54	0.85
Moist deciduous						
11	0-13	1.00	1.85	51.38	52.36	8.01
12	13-32	1.04	2.00	52.84	55.76	6.57
13	32-66	0.90	1.73	69.67	52.58	5.64
14	66-95	0.99	1.93	53.22	53.19	6.59
15	95-165	1.00	2.01	53.12	54.05	6.93
Grasslands						
16	0-10	0.99	1.90	50.93	50.46	5.81
17	10-25	1.01	1.93	47.69	49.81	3.02
18	25-60	1.01	2.04	49.50	53.31	2.31
19	60-110	0.94	1.86	51.46	52.72	2.14
Hill top evergreen						
20	0-13	1.02	2.00	50.37	52.66	3.40
21	13-29	1.06	2.84	46.82	51.45	5.40
22	29-52	1.03	1.97	47.71	51.42	3.99
23	52-83	1.11	2.06	43.01	49.68	5.38
24	83-120	1.10	2.06	45.25	51.12	1.12
25	120-150	1.18	2.18	40.36	49.29	6.17
Dry deciduous						
26	0-13	1.23	1.98	38.58	45.47	14.32
27	13-33	1.22	2.09	36.91	46.63	8.98
28	33-70	1.23	2.19	51.23	49.42	10.64
29	70-150	1.13	1.99	80.62	49.73	10.20

Table 6. Physical properties of soils, mean and range values for profiles

Constituents	Tropical evergreen	Semi ever-green	Moist deciduous	Grass lands	Hill top evergreen	Dry deciduous
Coarse fragments (2 mm)	27.80-41.67 (33.05)	24.90-44.20 (33.63)	15.42-28.57 (20.35)	21.78-87.39 (43.11)	40.24-58.23 (52.04)	27.49-45.29 (37.59)
Coarse sand % (2.0-0.2 mm)	41.37-48.21 (45.08)	53.74-58.32 (55.68)	30.62-43.83 (37.29)	28.74-55.74 (42.22)	34.32-48.96 (39.98)	25.63-40.00 (33.83)
Fine sand % (0.2-0.02 mm)	24.37-41.58 (32.92)	14.14-16.02 (15.10)	12.76-17.14 (15.04)	10.76-15.12 (13.19)	14.37-34.49 (20.16)	10.80-27.42 (19.35)
Silt % (0.02-0.002 mm)	4.93-12.72 (8.42)	5.22-11.36 (8.06)	11.31-24.01 (16.37)	1.85-11.80 (7.42)	4.67-23.62 (14.39)	3.84-21.51 (12.79)
Clay % (< 0.002 mm)	9.85-18.32 (13.58)	15.22-25.86 (21.15)	23.67-45.30 (31.30)	31.65-47.08 (37.18)	19.41-29.57 (25.47)	18.39-42.06 (34.04)
Coarse sand/fine sand	1.00-1.83 (1.42)	3.37-3.95 (3.69)	2.33-2.79 (2.49)	2.01-5.18 (3.36)	1.14-2.52 (2.13)	1.46-2.37 (1.85)
Silt/clay	0.41-1.04 (0.63)	0.20-0.75 (0.42)	0.25-0.89 (0.57)	0.06-0.32 (0.20)	0.17-1.12 (0.58)	0.09-0.77 (0.43)
Apparent density g/cm3)	1.07-1.24 (1.15)	1.19-1.23 (1.21)	0.90-1.04 (0.99)	0.94-1.01 (0.99)	1.02-1.18 (1.08)	1.13-1.23 (1.20)
Absolute sp. gravity	1.95-2.04 (2.00)	2.06-2.15 (2.10)	1.73-2.01 (1.90)	1.86-2.04 (1.93)	1.97-2.18 (2.05)	1.98-2.19 (2.06)
Maximum water holding capacity %	31.55-51.84 (40.54)	34.6-37.36 (36.45)	51.38-69.67 (56.05)	47.69-51.46 (49.90)	40.36-50.37 (45.59)	36.91-80.62 (51.84)
Percentage of pore space	43.60-49.35 (46.84)	42.93-45.97 (44.73)	52.36-55.76 (53.59)	49.81-53.31 (51.58)	49.29-52.66 (50.94)	45.77-49.73 (47.81)

Contd.

Table 6. Continued

1	2	3	4	5	6	7
Volume expansion %	3.59-7.09 (5.23)	0.70-5.49 (2.39)	5.64-8.01 (6.75)	2.14-5.81 (3.32)	1.12-6.17 (4.24)	8.98-14.32 (11.04)
Soil moisture tension (bars) 0.3	13.13-19.76 (16.41)	7.20-13.12 (10.66)	28.08-37.02 (32.84)	16.13-23.08 (19.00)	16.98-22.31 (18.89)	18.88-24.93 (21.10)
15	4.79-10.25 (8.13)	5.07-7.54 (6.24)	12.42-18.40 (15.46)	10.07-16.95 (13.51)	9.90-14.09 (12.10)	8.18-12.98 (10.90)
Available water 0.3-15 bar)	5.17-10.55 (8.28)	1.17-6.42 (4.42)	12.66-24.30 (17.38)	3.15-6.61 (5.49)	5.90-8.22 (6.79)	8.32-11.95 (10.20)
Ratio of 15 bar moisture to clay	0.33-0.96 (0.64)	0.23-0.37 (0.30)	0.37-0.70 (0.52)	0.31-0.42 (0.37)	0.37-0.60 (0.49)	0.28-0.44 (0.34)

deciduous (No.14). The pattern of distribution of silt along the profile followed no definite trend. The clay content varied from 9.85 per cent in tropical evergreen (No.1) to 47.08 per cent in grasslands (No.19). Translocation of clay was noticed in all the soils except in hill top evergreen, in which the highest content of clay was noticed in the surface layer. Tropical evergreen soils showed maximum accumulation of clay in the intermediate layers, whereas in all the other cases, clay accumulation was observed in the lowest layer.

The highest value (5.18) for coarse sand/fine sand ratio was obtained in the case of grasslands (No.16), while the tropical evergreen soils had the lowest value of one (No.2). In the case of grasslands, this ratio was found to decrease with depth, whereas the reverse pattern was observed in the soil from dry deciduous type. The silt/clay ratios of the soil varied from 0.06 in the case of grasslands (No.16) to 1.12 in the case of hill top evergreen (No.23). No definite pattern of variation could be discerned with depth, in all the soils investigated.

Highly significant positive correlation was obtained between fine sand and clay (0.556**).

2.2. Moisture retention characteristics

The amount of water held at 0.3 bar and 15 bar is presented in Table 4.

The amount of water held at 0.3 bar often taken as field capacity of soil, varied from 13.13 to 19.76, 7.2 to 13.12, 28.08 to 37.02, 16.13 to 23.08, 16.98 to 22.31 and 18.88 to 24.93 per cent for tropical evergreen, semi evergreen, moist deciduous, grasslands, hill top evergreen and dry deciduous type of soils, respectively. The highest value (37.02) was obtained for moist deciduous (No.12) and the lowest value (7.20 per cent) for semi evergreen (No.10). An increase in field capacity with depth was observed in the case of soil profiles representing grasslands and dry deciduous type of vegetations.

The moisture held at 15 bar, designated as wilting point, ranged from 4.79 to 10.25, 5.07 to 7.54, 12.42 to 18.40, 10.07 to 16.95, 9.90 to 14.09 and 8.18 and 12.98 per cent in the case of soil profiles representing tropical evergreen, semi evergreen, moist deciduous, grasslands, hill top evergreen and dry deciduous type of vegetations, respectively. The maximum content of 18.40

per cent was observed in the profile from moist deciduous vegetation (No.12) and the minimum content of 4.79 per cent, in the profile representing tropical evergreen type of vegetations (No.5).

An increase in water retention at 15 bar with depth was observed in the dry deciduous, whereas no definite pattern of variation with depth was noticed in other cases.

Clay content and moisture retention at 1/3 and 15 bar showed a positive and highly significant correlation (r = 0.568**, r = 0.755**).

The difference between water held at 0.3 bar and 15 bar, often considered as the available water content, was highest (24.30%) in moist deciduous (No.11) and was lowest (1.17%) in semi evergreen (No.10). The range observed were 5.17 to 10.55, 1.17 to 6.42, 12.66 to 24.30, 3.15 to 6.61, 5.90 to 8.22, 8.32 to 11.95 per cent, in the case of soil profiles representing tropical evergreen, semi evergreen, moist deciduous, grasslands, hill top evergreen and dry deciduous type of vegetations respectively. The available water content showed a decrease with depth in the case of profile representing moist deciduous, while no definite pattern of variation with depth was noticed in the other soil profiles investigated.

Ratios of 15 bar moisture to clay varied from 0.23 in semi evergreen (No.10) to 0.96 in tropical evergreen (No.1). This ratio was found to decrease with depth in the case of soils representing tropical evergreen vegetations, while the other soils did not reveal any definite pattern of variation with depth.

2.3. Physical constants

Physical constants of soils are given in Table 5 and the mean and range values in Table 6.

The apparent density varied from 0.90 g/cm^3 in moist deciduous (No.13) to 1.24 g/cm^3 in tropical evergreen (No.5). The values followed no definite trend with depth along the profiles. The highest value (2.19) for absolute specific gravity was obtained in dry deciduous (No.28) and lowest value (1.73) for moist deciduous (No.13). The absolute specific gravity also did not reveal any definite pattern of variation with depth, in the profile.

Maximum water holding capacity was highest (80.62%) for dry deciduous (No.29) and lowest (31.55%) for tropical evergreen (No.2). A decrease in the maximum water holding capacity with depth was observed in tropical evergreen and hill top evergreen and a reverse trend was observed in the case of dry deciduous. No definite pattern of variation was noticed in other soils.

Percentage of pore space varied from 42.93 in semi evergreen (No.7) to 55.76 in moist deciduous (No.12). The values showed a decreasing trend with depth in the case of hill top evergreen while a reverse trend was observed in dry deciduous. The other soils did not show any definite pattern of variation with depth. Highly significant and positive correlation was obtained between percentage of pore space and clay ($r = 0.595^{**}$).

The percentage volume expansion was maximum (14.32) in the case of dry deciduous (No.26) and it was minimum (0.70) in the case of semi evergreen (No.7). A definite decreasing trend with depth was observed in percentage volume expansion in the case of grasslands. The highest value was obtained for the surface horizons in the case of semi evergreen, moist deciduous, grasslands and dry deciduous whereas maximum volume expansion was observed in the subsurface horizons in tropical evergreen and hill top evergreen.

3. Chemical characteristics

3.1. Soil reaction and organic constituents

The values for soil reaction and organic constituents are given in Table 7(a). Mean and range values are presented in Table 7(b). The depthwise distribution of organic carbon in soil profiles is given in Fig. 2.

The soils were in general acidic with pH (1:1 soil water) ranging from 4.00 in tropical evergreen (No.2) to 6.95 in dry deciduous (No.26). The pH showed a decreasing trend with depth in moist deciduous, hill top evergreen and dry deciduous. In the other soils, no definite trend was observed with depth.

The organic carbon content of soils ranged from 0.58 per cent in semi evergreen (No.10) to 5.36 per cent in moist deciduous (No.11). The surface horizons invariably had greater organic matter content. A steady decrease with depth was observed in all the soils except in the soils from the hill top evergreen forests.

The total nitrogen content varied from 0.09 per cent in hill top evergreen (No.25) to 0.56 per cent in moist deciduous (No.11). As in the case of organic carbon, the

Table 7(a). Soil reaction and organic constituents

Vegetation type sample No. and depth (cm)		Soil reaction (1:1 H_2O)	Organic carbon (%)	Total nitrogen (%)	Carbon / nitrogen ratio
Tropical evergreen					
1	0-10	5.75	3.04	0.34	8.94
2	10-20	4.00	2.34	0.28	8.36
3	20-40	4.60	1.59	0.22	7.23
4	40-70	5.00	1.10	0.14	7.86
5	70-150	4.45	0.72	0.11	6.55
Semi evergreen					
6	0-10	4.50	2.31	0.22	10.50
7	10-27	5.00	1.27	0.17	7.47
8	27-46	5.00	1.16	0.16	7.25
9	46-88	4.95	1.04	0.13	8.00
10	88-150	4.90	0.58	0.10	5.80
Moist deciduous					
11	0-13	5.60	5.36	0.56	9.57
12	13-32	5.50	3.95	0.42	9.40
13	32-66	5.55	3.19	0.33	9.67
14	66-95	5.40	1.99	0.28	7.11
15	95-165	5.10	1.13	0.18	6.28
Grasslands					
16	0-10	5.40	2.46	0.27	9.11
17	10-25	5.15	1.68	0.15	11.20
18	25-60	5.20	1.13	0.13	8.69
19	60-110	5.55	0.99	0.10	9.90
Hill top evergreen					
20	0-13	6.20	2.51	0.27	9.30
21	13-29	5.55	1.43	0.19	7.53
22	29-52	5.55	1.60	0.16	10.00
23	52-83	5.45	1.26	0.16	7.88
24	83-120	5.45	0.74	0.14	5.29
25	120-150	5.45	0.60	0.09	6.67
Dry deciduous					
26	0-13	6.95	2.45	0.21	11.67
27	13-33	6.20	1.40	0.16	8.75
28	33-70	6.05	1.05	0.15	7.00
29	70-150	6.00	0.82	0.14	5.86

Table 7(b). Soil reaction and organic constituents, mean and range values for profiles

Constituents	Vegetation type					
	Tropical evergreen	Semi ever-green	Moist deciduous	Grass lands	Hill top evergreen	Dry deciduous
Soil reaction 1:1 H_2O	4.00-5.75 (4.76)	4.50-5.00 (4.87)	5.10-5.60 (5.43)	5.15-5.55 (5.33)	5.45-6.20 (5.61)	6.00-6.95 (6.30)
Organic carbon (%)	0.72-3.04 (1.76)	0.58-2.31 (1.27)	1.13-5.36 (3.12)	0.99-2.46 (1.57)	0.60-2.51 (1.36)	0.82-2.45 (1.43)
Total nitrogen (%)	0.11-0.34 (0.22)	0.10-0.22 (0.16)	0.18-0.56 (0.35)	0.10-0.27 (0.16)	0.09-0.27 (0.17)	0.14-0.21 (0.17)
Carbon/nitrogen ratio	6.55-8.94 (7.79)	5.80-10.50 (7.80)	6.28-9.67 (8.41)	8.69-11.20 (9.73)	5.29-10.00 (7.78)	5.86-11.67 (8.32)

distribution of nitrogen along the profile showed a steady decrease with depth in the soils from all the locations investigated. Highly significant positive correlation between organic carbon and nitrogen was observed ($r=0.971^{**}$). Significant positive correlation was obtained for organic carbon with available water ($r=0.636^{**}$) field capacity ($r=0.571^{**}$) and a negative significant correlation was obtained between organic carbon and bulk density ($r=-0.388^{*}$).

The C/N ratio was highest (11.67) in the case of dry deciduous forest (No.26) and lowest (5.29) in hill top evergreen (No.24). The C/N ratio showed a steady decrease with depth only in dry deciduous forests.

3.2.. Total chemical analysis of soils

The total elemental composition of soils and the mean and range values for profiles are given in Table 8(a) and 8(b) respectively.

SiO_2 formed the predominant constituent in all the soils with contents ranging from 56.4 per cent in tropical evergreen (No.3) to 78.62 per cent in dry deciduous (No.26). In semi evergreen, an increasing trend with depth, in the distribution of silica was observed while in all the other

Table 8(a). Total chemical analysis of soil

Vegetation type sample No. and depth (cm)		Per cent whole soil							
		SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5
1		2	3	4	5	6	7	8	9
Tropical evergreen									
1	0-10	61.24	14.87	6.06	0.156	0.15	0.009	0.16	0.14
2	10-20	62.38	19.89	7.34	0.137	0.09	0.021	0.15	0.15
3	20-40	56.40	26.08	8.08	0.116	0.19	0.020	0.23	0.18
4	40-70	59.60	22.73	8.53	0.034	0.18	0.023	0.34	0.17
5	70-150	62.40	29.64	9.09	0.094	0.23	0.020	0.16	0.23
Semi evergreen									
6	0-10	74.62	6.82	3.43	0.109	0.16	0.018	0.10	0.08
7	10-27	74.32	10.66	4.04	0.150	0.27	0.048	0.12	0.10
8	27-46	76.44	9.24	4.04	0.109	0.30	0.053	0.14	0.12
9	46-88	78.32	9.29	4.24	0.054	0.23	0.044	0.11	0.11
10	88-150	78.40	7.63	4.44	0.298	0.16	0.043	0.11	0.09
Moist deciduous									
11	0-13	59.44	13.02	5.25	0.298	0.43	0.058	0.21	0.13
12	13-32	64.63	15.96	5.46	0.298	0.28	0.053	0.22	0.17
13	32-66	62.72	15.80	6.30	0.311	0.14	0.043	0.20	0.15
14	66-95	63.65	16.43	8.11	0.281	0.26	0.050	0.26	0.14
15	95-165	58.63	23.61	9.57	0.295	0.16	0.051	0.28	0.15

Contd.

Table 8(a). Continued

1		2	3	4	5	6	7	8	9
Grasslands									
16	0-10	76.54	6.43	4.28	0.083	0.16	0.040	0.16	0.16
17	10-25	78.22	8.44	4.74	0.083	0.26	0.038	0.16	0.08
18	25-60	72.42	13.62	7.28	0.084	0.26	0.040	0.10	0.22
19	60-110	68.52	18.59	7.35	0.128	0.12	0.038	0.10	0.15
Hill top evergreen									
20	0-13	76.43	12.61	5.36	0.167	0.30	0.045	0.20	0.16
21	13-29	69.68	15.63	7.00	0.172	0.22	0.033	0.18	0.17
22	29-52	75.86	9.22	5.97	0.111	0.23	0.040	0.16	0.16
23	52-83	74.47	9.89	7.34	0.110	0.23	0.048	0.15	0.10
24	83-120	68.64	15.86	9.68	0.209	0.30	0.048	0.22	0.22
25	120-150	68.43	10.04	6.86	0.197	0.31	0.045	0.19	0.12
Dry deciduous									
26	0-13	78.62	5.36	5.56	0.195	0.44	0.043	0.88	0.21
27	13-33	76.43	6.03	6.45	0.253	0.31	0.044	0.88	0.17
28	33-70	76.86	10.53	6.91	0.365	0.37	0.044	0.43	0.13
29	70-150	77.67	13.41	9.54	0.473	0.33	0.036	0.81	0.07

Table 8(b). Total chemical analysis of soils, mean and range values for profiles

Constituents	Vegetation type					
	Tropical evergreen	Semi evergreen	Moist deciduous	Grasslands	Hill top evergreen	Dry deciduous
SiO_2	56.40-62.40 (60.4)	74.32-78.40 (76.42)	58.63-64.63 (60.61)	68.52-78.22 (73.93)	68.43-76.43 (72.25)	76.43-78.62 (77.40)
Al_2O_3	14.87-29.64 (22.64)	6.82-10.66 (8.73)	13.02-23.61 (16.96)	6.43-18.59 (11.77)	9.22-15.86 (12.21)	5.36-13.41 (8.83)
Fe_2O_3	6.06-9.09 (7.82)	3.43-4.44 (4.04)	5.25-9.57 (6.94)	4.28-7.35 (5.91)	5.36-9.68 (7.04)	5.56-9.54 (7.12)
MgO	0.034-0.156 (0.107)	0.054-0.298 (0.144)	0.281-0.311 (0.297)	0.083-0.128 (0.095)	0.111-0.209 (0.161)	0.195-0.473 (0.322)
CaO	0.09-0.50 (0.23)	0.16-0.30 (0.22)	0.14-0.43 (0.25)	0.12-0.26 (0.20)	0.22-0.31 (0.27)	0.31-0.44 (0.36)
Na_2O	0.009-0.023 (0.019)	0.018-0.053 (0.041)	0.043-0.058 (0.051)	0.038-0.040 (0.039)	0.033-0.048 (0.043)	0.036-0.044 (0.042)
K_2O	0.15-0.34 (0.21)	0.10-0.14 (0.14)	0.20-0.28 (0.23)	0.10-0.16 (0.13)	0.15-0.22 (0.18)	0.43-0.88 (0.75)
P_2O_5	0.14-0.23 (0.17)	0.08-0.12 (0.10)	0.13-0.17 (0.15)	0.08-0.22 (0.12)	0.10-0.22 (0.16)	0.07-0.21 (0.15)

soils under investigation, no definite pattern of variation could be noticed.

The content of Al_2O_3 in the soils varied from 5.36 per cent in dry deciduous (No.26) to 29.64 per cent in tropical evergreen (No.5). The Al_2O_3 content followed a definite increasing trend with depth in the case of moist deciduous, grasslands and dry deciduous forests, while others showed no definite trend in variation with depth.

The Fe_2O_3 content varied from 3.43 per cent in semi evergreen (No.6) to 9.68 per cent in hill top evergreen (No.24). A steady increase in the Fe_2O_3 content with depth was a feature exhibited by all the soils except soils from hill top evergreen forests, where irregular distribution with depth was observed. Clay content and total Fe_2O_3 showed a positive correlation, but was not significant.

The content of MgO ranged from 0.034 per cent in tropical evergreen (No.4) to 0.473 per cent in dry deciduous (No.29). The MgO content showed an increasing trend with depth in the case of grasslands and dry deciduous while no definite variation with depth was noted in all the other soils investigated.

Both the lowest and highest values of the CaO content was observed in the tropical evergreen, lowest value of 0.09 was observed in the A_2 horizon, while the highest value of 0.5 per cent in the B_1 horizon. The distribution of CaO content within the profile did not reveal any definite pattern of variation with depth.

The content of Na_2O varied from 0.009 per cent, in tropical evergreen (No.1) to 0.058 per cent in moist deciduous (No.11). The Na_2O content showed no definite depth wise variation in the profile.

The highest value for K_2O (0.88% was obtained in dry deciduous (No.26 and 27). The lowest value (0.10% was observed in semi evergreen, (No.6) and also in grasslands, (No.18 and 19). The K_2O content showed a decreasing trend with depth in the case of grasslands, while no definite pattern of variation with depth was observed in all other profiles.

The total P_2O_5 content in soils varied from 0.07 per cent, in dry deciduous (No.29) to 0.23 per cent in tropical evergreen (No.5). The distribution pattern of P_2O_5 within the profile was irregular.

4. Cation exchange properties

Cation exchange properties of soils are given in Table 9(a). Mean and range values are presented in Table 9(b).

4.1. Cation exchange capacity

The CEC determined by sum of cations was highest (36.43) me/100 g in moist deciduous (No.11) and lowest (21.62) me/100 g in hill top evergreen (No.25). In all the profiles studied, the CEC_s values did not show any regular pattern of variation with depth.

The CEC found out by NH_4OAc method ranged from 3.80 me/100 g in semi evergreen (No.10) to 17.50 me/100 g soil in moist deciduous (No.11). Within the profiles, the surface layer showed the highest CEC value in all the soils except in dry deciduous where the highest CEC was obtained in the lower most layer. Clay was positively correlated with CEC, but was not significant.

4.2. Exchange acidity

The exchange acidity was maximum (30.86) me/100 g in moist deciduous (No.12) and minimum (17.73) me/100 g soil in

Table 9(a). Cation exchange properties of soils

Vegetation type sample No. and depth (cm)		Exchangeable cations me/100 g soil				Sum of bases	Exchange acidity me/100g	CEC		CEC (NH_4OAc) me/100g clay	Base saturation (%)	
		Ca	Mg	K	Na			*CEC_s	NH_4OAc pH7		Sum of cations	NH_4OAc pH7
1		2	3	4	5	6	7	8	9	10	11	12
Tropical evergreen												
1	0-10	3.92	0.17	0.13	0.08	4.30	25.35	29.65	8.60	87.31	14.50	50.00
2	10-20	1.12	0.08	0.05	0.07	1.32	26.92	28.24	5.40	44.59	4.67	24.44
3	20-40	0.70	0.08	0.03	0.04	0.85	27.45	28.30	5.30	39.85	3.00	16.04
4	40-70	0.56	0.08	0.03	0.04	0.71	26.81	27.52	4.20	22.93	2.58	16.90
5	70-150	0.98	0.17	0.03	0.05	1.23	26.79	28.02	4.40	30.68	4.38	27.95
Semi evergreen												
6	0-10	1.40	0.17	0.06	0.06	1.69	27.58	29.27	13.90	67.67	5.77	12.20
7	10-27	1.12	0.08	0.08	0.05	1.33	26.79	28.12	5.30	34.82	4.73	25.10
8	27-46	1.40	0.08	0.04	0.05	1.57	26.79	28.36	6.80	28.55	5.54	23.10
9	46-88	1.40	0.08	0.03	0.04	1.55	27.58	29.13	5.90	29.02	5.32	26.30
10	88-150	1.12	0.08	0.13	0.07	1.40	27.58	28.98	3.80	14.69	4.83	36.80
Moist deciduous												
11	0-13	7.00	1.00	0.21	0.12	8.33	28.10	36.43	17.50	73.93	22.87	47.60
12	13-32	1.96	0.08	0.08	0.04	2.16	30.86	33.02	13.10	49.51	6.54	16.50
13	32-66	1.12	0.17	0.09	0.05	1.43	28.76	30.19	11.60	34.18	4.74	12.30
14	66-95	1.40	0.34	0.08	0.05	1.87	29.34	31.21	10.60	39.09	5.99	17.60
15	95-165	1.82	0.50	0.10	0.09	2.51	28.76	31.27	12.00	26.49	8.03	20.90

*CEC_s (Sum of bases + Exchange acidity)

Contd.

Table 9(a). Continued

1		2	3	4	5	6	7	8	9	10	11	12
Grasslands												
16	0-10	2.10	0.84	0.07	0.06	3.07	21.28	24.35	8.20	25.91	12.61	37.40
17	10-25	1.82	0.34	0.03	0.06	2.25	21.67	23.92	6.80	20.61	9.41	33.10
18	25-60	1.54	0.25	0.04	0.10	1.93	22.85	24.78	5.70	15.40	7.79	33.90
19	60-110	1.68	0.25	0.03	0.07	2.03	22.85	24.88	8.20	17.42	8.16	24.80
Hill top evergreen												
20	0-13	7.42	0.76	0.15	0.11	8.44	18.52	26.96	10.60	35.85	31.31	79.60
21	13-29	2.94	0.42	0.07	0.07	3.50	18.52	22.02	5.10	26.28	15.89	68.60
22	29-52	2.80	0.34	0.05	0.08	3.27	22.46	25.73	7.40	26.85	12.71	44.20
23	52-83	3.22	0.34	0.03	0.06	3.65	21.67	25.32	7.20	34.19	14.42	50.70
24	83-120	3.08	0.25	0.06	0.07	3.46	21.28	24.74	7.00	24.74	13.99	49.40
25	120-150	2.25	0.34	0.06	0.06	2.71	18.91	21.62	5.10	18.92	12.53	53.10
Dry deciduous												
26	0-13	8.10	0.76	0.22	0.14	9.22	19.70	28.92	11.20	60.90	31.88	82.10
27	13-33	8.04	0.17	0.18	0.10	8.49	17.73	26.22	10.60	31.17	32.38	80.10
28	33-70	6.82	1.09	0.14	0.12	8.17	19.70	27.87	10.30	24.70	29.31	79.30
29	70-150	8.08	1.34	0.17	0.13	9.72	19.70	29.42	11.80	28.06	33.04	82.40

Table 9(b). Cation exchange properties of soils, mean and range values for profiles

Constituents		Vegetation type					
		Tropical evergreen	Semi ever-green	Moist deciduous	Grasslands	Hill top evergreen	Dry deciduous
Exchangeable cations me/100 g soil	Ca	0.56-3.92 (1.46)	1.12-1.40 (1.29)	1.12-7.00 (2.66)	1.54-2.10 (1.79)	2.25-7.42 (3.62)	6.82-8.10 (7.76)
	Mg	0.08-0.17 (0.12)	0.08-0.17 (0.10)	0.08-1.00 (0.42)	0.25-0.84 (0.42)	0.25-0.76 (0.41)	0.17-1.34 (0.84)
	K	0.03-0.13 (0.05)	0.03-0.13 (0.07)	0.08-0.21 (0.11)	0.03-0.07 (0.04)	0.03-0.15 (0.07)	0.14-0.22 (0.18)
	Na	0.04-0.08 (0.06)	0.04-0.07 (0.05)	0.04-0.12 (0.07)	0.06-0.10 (0.07)	0.06-0.11 (0.08)	0.10-0.14 (0.12)
Sum of bases		0.71-4.30 (1.68)	1.33-1.69 (1.51)	1.43-8.33 (3.26)	1.93-3.07 (2.32)	2.71-8.44 (4.17)	8.17-9.72 (8.90)
Exchange acidity me/100 g soil		25.35-27.45 (26.66)	26.79-27.58 (27.26)	28.10-30.86 (29.16)	21.28-22.85 (22.16)	18.52-22.46 (20.23)	17.73-19.70 (19.21)
CEC (me/100 g soil)							
CECs (sum of cations)		27.52-29.65 (28.35)	28.12-29.27 (28.77)	30.19-36.43 (32.42)	23.92-24.88 (24.48)	21.62-26.96 (24.40)	26.22-29.42 (28.11)
NH_4OAc pH7		4.20-8.60 (5.58)	3.80-13.90 (7.14)	10.60-17.50 (13.00)	5.70-8.20 (7.20)	5.10-10.60 (7.10)	10.30-11.80 (11.00)
CEC (NH_4OAc) me/100 g clay		22.93-87.31 (45.07)	14.69-67.67 (34.95)	26.49-73.93 (44.64)	15.40-25.91 (19.84)	18.92-35.85 (27.81)	24.70-60.90 (36.21)
Base saturation %							
Sum of cations		2.58-14.50 (5.83)	4.73-5.77 (5.24)	4.74-22.87 (9.63)	7.79-12.61 (9.49)	12.53-31.31 (16.81)	29.31-33.04 (31.65)
NH_4OAc pH7		16.04-50.00 (27.07)	12.20-36.80 (24.70)	12.30-47.60 (23.00)	24.80-37.40 (32.30)	44.20-79.60 (57.60)	79.30-82.40 (81.00)

dry deciduous (No.27). The highest profile mean was also obtained in the case of moist deciduous (29.16) me/100g and lowest for dry deciduous (19.21) me/100g

CEC (NH_4OAc)/100 g clay varied from 14.69 me/100g in semi evergreen (No.10) to 87.31 me/100g in tropical evergreen (No.1). Within the profiles this value was found to be maximum in the surface horizons, in all the profiles.

4.3. Exchangeable cations

Ca formed the major element under the exchangeable cations and it varied from 0.56 me/100 g soil, in tropical evergreen (No.4) to 8.10 me/100g in dry deciduous (No.26).

The exchangeable Ca was concentrated in the uppermost horizon in all the six profiles studied. The distribution with depth in the profile was irregular for all the pedons studied. The exchangeable calcium showed positive and significant correlation with CEC and percentage base saturation ($r = 0.541^{**}$, $r = 0.888^{**}$).

Mg formed the second major element among the exchangeable cations. The content of Mg ranged from 0.08 me/100g in tropical evergreen, semi evergreen and moist deciduous to 1.34 me/100 g soil in dry deciduous (No.29). Here also the highest content within the profile was observed in the uppermost horizon in all the soils, except in dry deciduous in which case, the highest content was in the lower most horizon. The exchangeable magnesium showed positive and significant correlation with CEC and percentage base saturation ($r = 0.514^{**}$, $r = 0.660^{**}$).

Exchangeable potassium content of the soils ranged from 0.03 to 0.22 me/100 g soil. The lowest value of 0.03 me/100 g was obtained in tropical evergreen, semi evergreen, grasslands and hill top evergreen and the highest value was observed in dry deciduous (No.26). Its distribution throughout the profile was irregular in all the soils. The exchangeable potassium showed positive and significant correlation with CEC and percentage base saturation ($r = 0.625^{**}$, $r = 0.665^{**}$).

Exchangeable sodium content ranged from 0.04 me/100 g in tropical evergreen, semi evergreen and moist deciduous to 0.14 me/100 g in dry deciduous (No.26). Positive and significant correlation was also obtained for the exchangeable sodium with CEC and percentage base saturation ($r = 0.479^{**}$, $r = 0.783^{**}$).

Sum of bases recorded highest value (9.72) me/100g in dry deciduous and lowest value (0.71) me/100g in tropical evergreen (No.4). In all the soils except in dry deciduous, the highest value for sum of bases was obtained in the surface horizon. In the dry deciduous base saturation was highest for the lower most horizon.

Percentage base saturation was calculated by sum of cations, as well as NH_4OAc method. The base saturation calculated by sum of cations method recorded lower values in all the soil samples. The values varying from 2.58 % in tropical evergreen (No.4) to 33.04% in dry deciduous (No.29). All the soils recorded higher values for base saturation in the surface horizons excepting dry deciduous, where the highest value was obtained for the lower most horizon.

Percentage base saturation calculated by ammonium acetate method varied from 12.20 in semi evergreen (No.6) to 82.4 in dry deciduous (No.29). Within the profiles, the highest value was obtained in the surface horizons in tropical evergreen, moist deciduous, grasslands and hill top evergreen, while the lowermost horizon recorded the highest value in the case of semi evergreen and dry deciduous forests.

5. Extractable iron and active iron ratio

The iron oxide fractions and active iron ratio are presented in Table 10(a) and mean and range values for profiles are given in Table 10(b). The depthwise variations in free iron oxides and total iron are shown in Fig. 3.

The Fe_d ranged from 1.37 per cent in semi evergreen (No.8) to 4.69 % in tropical evergreen (No.5). The lower most layer showed maximum accumulation of Fe_d in the case of tropical evergreen and dry deciducus. The Fe_d also showed a steady increase with depth in these two profiles. No definite trend was observed in the distribution pattern of Fe_d in the other soils. This fraction was found to be the highest among the three fractions of iron seperated, in all the samples. Correlation of Fe_d with the sand fraction was negative and significant (r =-0.946**).

The Fe_o% varied from 0.47 in tropical evergreen (No.5) to 3.64 in dry deciduous (No.29). Only in the case of dry deciduous forests, a steady increase of Fe_o%, with depth was observed. Negative and significant correlation was obtained for Fe_o with sand fraction (r = -0.457*).

FIG. 3. DISTRIBUTION OF TOTAL IRON AND ITS FRACTIONS IN SOIL PROFILES

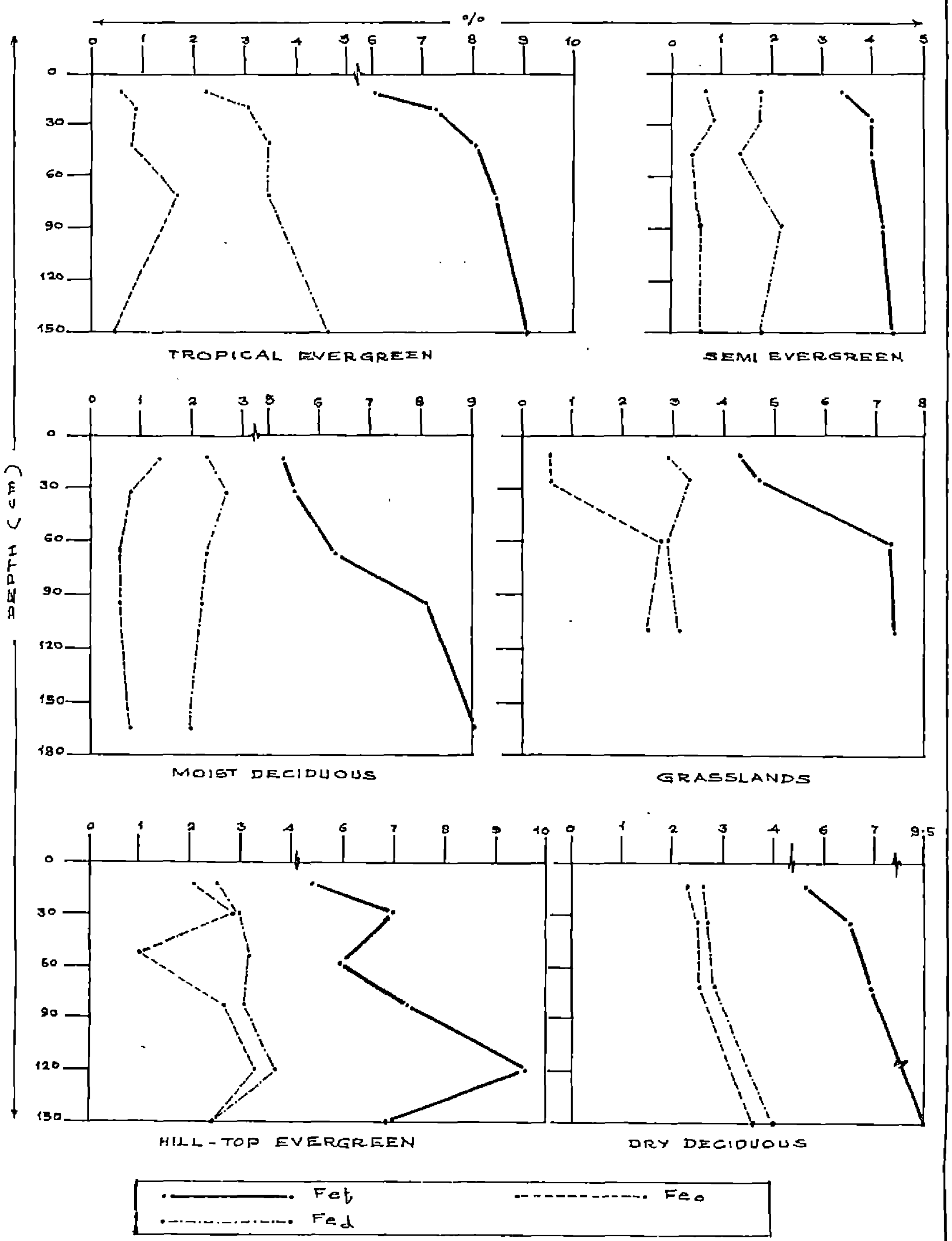

Table 10(a). Iron oxide fractions in soils

Vegetation type sample No. and depth (cm)		% Fe_2O_3 *Fe_t	*Fe_d	*Fe_o	$\frac{Fe_d \times 100}{Fe_t}$	Active iron ratio Fe_o/Fe_d	Fe_d/clay	Fe_d/silt+sand
1		2	3	4	5	6	7	8
Tropical evergreen								
1	0-10	6.06	2.34	0.55	38.61	0.24	0.24	0.026
2	10-20	7.34	3.13	0.86	42.64	0.27	0.26	0.036
3	20-40	8.08	3.52	0.80	43.56	0.23	0.26	0.041
4	40-70	8.53	3.52	1.72	41.27	0.49	0.19	0.043
5	70-150	9.09	4.69	0.47	51.60	0.10	0.33	0.055
Semi evergreen								
6	0-10	3.43	1.76	0.72	51.31	0.41	0.09	0.022
7	10-27	4.04	1.76	0.91	43.56	0.52	0.12	0.021
8	27-46	4.04	1.37	0.50	33.91	0.36	0.06	0.018
9	46-88	4.24	2.15	0.59	50.71	0.27	0.11	0.027
10	88-150	4.44	1.76	0.62	39.64	0.35	0.07	0.024
Moist deciduous								
11	0-13	5.25	2.34	1.41	44.57	0.60	0.10	0.031
12	13-32	5.46	2.69	0.78	49.26	0.29	0.10	0.037
13	32-66	6.30	2.34	0.63	37.14	0.27	0.07	0.035
14	66-95	8.11	2.15	0.63	26.51	0.29	0.08	0.030
15	95-165	9.57	1.95	0.78	20.38	0.40	0.04	0.036

*Fe_t - Total iron

*Fe_d - Dithionite citrate bicarbonate extractable iron

*Fe_o - Oxalate extractable iron

Contd.

Table 10(a). Continued

1		2	3	4	5	6	7	8
Grasslands								
16	0-10	4.28	2.92	0.64	68.22	0.22	0.09	0.043
17	10-25	4.74	3.30	0.64	69.62	0.19	0.10	0.049
18	25-60	7.28	2.93	2.81	40.25	0.96	0.08	0.047
19	60-110	7.35	3.13	2.50	42.59	0.80	0.07	0.059
Hill top evergreen								
20	0-13	5.36	2.53	2.06	47.20	0.81	0.09	0.036
21	13-29	7.00	3.02	2.85	43.14	0.94	0.16	0.037
22	29-52	5.97	3.16	1.02	52.93	0.33	0.11	0.044
23	52-83	7.34	3.13	2.66	42.64	0.85	0.15	0.040
24	83-120	9.68	3.73	3.34	38.53	0.89	0.13	0.052
25	120-150	6.86	2.53	2.50	36.88	0.99	0.09	0.035
Dry deciduous								
26	0-13	5.56	2.63	2.26	47.30	0.86	0.14	0.032
27	13-33	6.45	2.73	2.50	42.33	0.92	0.08	0.041
28	33-70	6.91	2.91	2.50	42.11	0.86	0.07	0.050
29	70-150	9.54	3.96	3.64	41.51	0.92	0.09	0.068

Table 10(b). Iron oxide fractions in soils, mean and range values for profiles

Constituents	Vegetation type					
	Tropical evergreen	Semi ever-green	Moist deciduous	Grasslands	Hill top evergreen	Dry deciduous
Fe_t %	6.06-9.09 (7.82)	3.43-4.44 (4.04)	5.25-9.57 (6.94)	4.28-7.35 (5.91)	5.36-9.68 (7.04)	5.56-9.54 (7.12)
Fe_d	2.34-4.69 (3.44)	1.37-2.15 (1.76)	1.95-2.69 (2.29)	2.92-3.30 (3.07)	2.53-3.73 (3.02)	2.63-3.96 (3.06)
Fe_o	0.47-1.72 (0.88)	0.50-0.91 (0.67)	0.63-1.41 (0.85)	0.64-2.81 (1.65)	1.02-3.34 (2.41)	2.50-3.64 (2.73)
$\frac{Fe_d \times 100}{Fe_t}$	38.61-51.60 (43.54)	33.91-51.31 (43.83)	20.38-49.26 (35.57)	40.25-69.62 (55.17)	36.88-52.93 (43.55)	41.51-47.30 (43.31)
$\frac{Fe_o}{Fe_d}$	0.10-0.49 (0.27)	0.27-0.52 (0.38)	0.29-0.60 (0.37)	0.19-0.96 (0.54)	0.33-0.99 (0.80)	0.86-0.92 (0.89)
$\frac{Fe_d}{clay}$	0.19-0.33 (0.25)	0.06-0.12 (0.09)	0.04-0.10 (0.08)	0.07-0.10 (0.09)	0.09-0.16 (0.12)	0.07-0.14 (0.095)
$\frac{Fe_d}{Silt + sand}$	0.026-0.055 (0.040)	0.018-0.027 (0.022)	0.030-0.037 (0.034)	0.043-0.059 (0.050)	0.035-0.052 (0.041)	0.032-0.068 (0.048)

Fe_d expressed as a percentage of total iron, referred to as "degree of freeness of iron oxide" was highest (69.62) in grasslands (No.17) and lowest (20.38) in moist deciduous (No.15). The values showed a steady decrease with depth in dry deciduous while no definite trend in the ratio with depth was observed in the other profiles investigated.

The ratio of Fe_o/Fe_d, designated as active iron ratio ranged from 0.10 in tropical evergreen (No.5) to 0.99 in hill top evergreen (No.25). The active iron ratio showed no definite trend of variation with depth in any of the profiles studied.

The ratio of Fe_d/clay was highest (0.33) in tropical evergreen (No.5) and lowest (0.04) in moist deciduous (No.15). This ratio showed no definite pattern of variation with depth in all the profiles studied.

Fe_d/silt + sand varied from 0.018 in semi evergreen (No.8) to 0.068 in dry deciduous (No.29). A steady increase with depth was observed for this ratio, in tropical evergreen and dry deciduous, whereas the distribution did not follow any definite pattern with depth in the other soils.

6. Phosphorus fractions

Data on phosphorus fractions are presented in Table 11(a) and mean and range values for profiles are given in Table 11(b). The depthwise distribution is shown in Fig. 4.

Fe-P

Fe-P formed the major part of active inorganic P-fractions and ranged from 60 ppm in hill top evergreen (No.20) to 183 ppm in semi evergreen (No.8). Significant positive correlation was obtained for Fe-P with sand ($r = 0.551^{**}$) and significant negative correlation was obtained for Fe-P with clay ($r = -0.509^{**}$) and pH ($r = -0.591^{**}$).

Al-P

The Al-P ranged from 16.5 ppm in moist deciduous (No.11) to 87 ppm in tropical evergreen (No.3).

No regular pattern in the distribution of Fe-P and Al-P was observed with depth in all the profiles.

Positive and significant correlation was obtained for Al-P with sand ($r = 0.640^{**}$) and significant negative

FIG. 4. DISTRIBUTION OF INORGANIC PHOSPHORUS FRACTIONS IN SOIL PROFILES

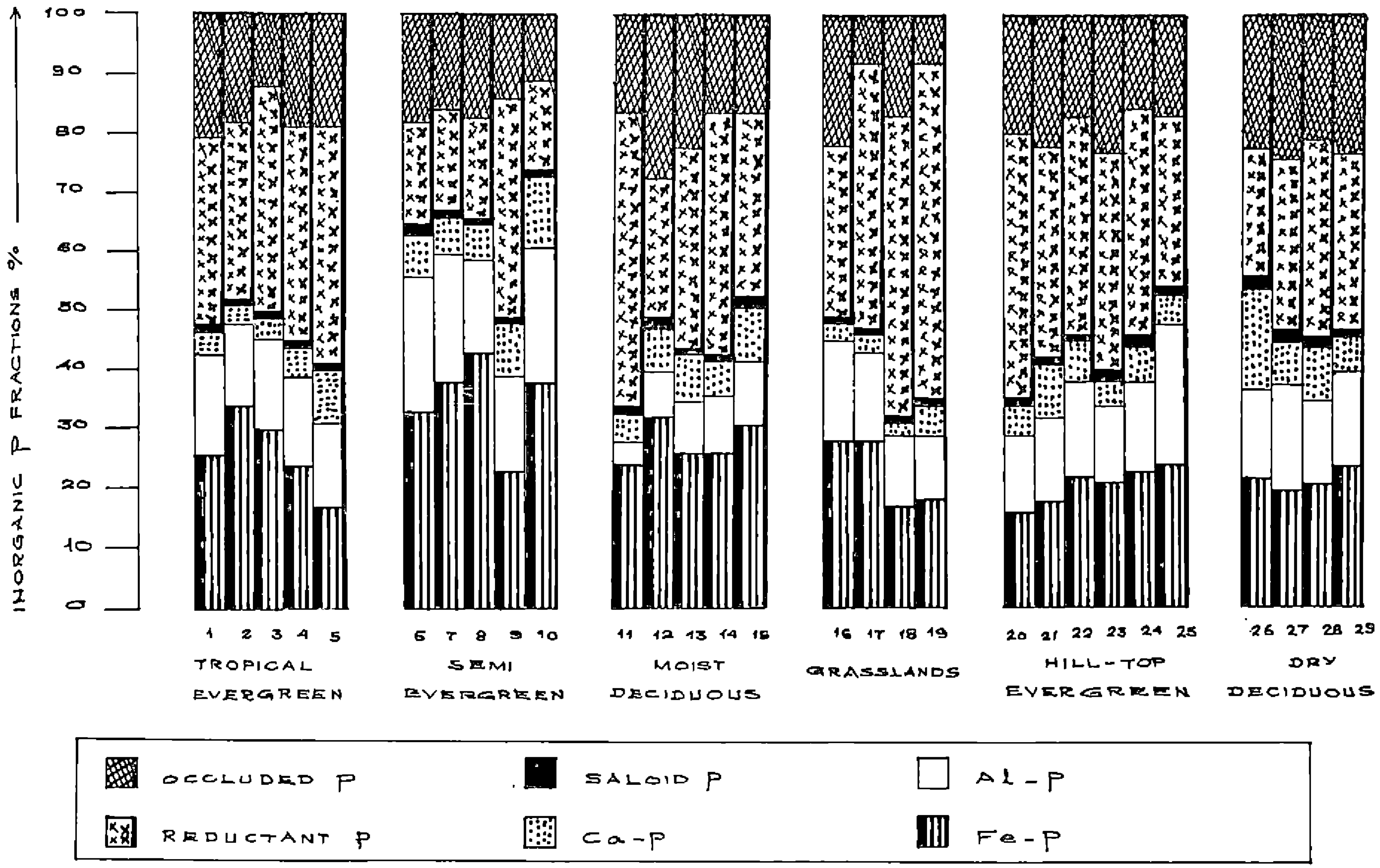

Table 11(a). Phosphorus fractions in soil (ppm)

Vegetation type, sample No. & depth (cm)		Total P	Active inorganic P			Sum	Saloid P	Reductant P	Occluded P	Active fraction %			$\frac{Al\text{-}P + Fe\text{-}P}{Ca\text{-}P}$
			Fe-P	Al-P	Ca-P					Fe-P	Al-P	Ca-P	
Tropical evergreen													
1	0-10	611.00	105	66	17	188	4.0	125	78	55.9	35.1	9.0	10.06
2	10-20	654.6	147	60	14	221	2.3	130	75	66.5	27.2	6.3	14.79
3	20-40	785.6	177	87	22	286	3.8	225	75	61.9	30.4	7.7	12.00
4	40-70	741.9	105	66	23	194	2.8	155	81	54.1	34.0	11.9	7.43
5	70-150	1003.8	96	81	54	231	3.5	240	102	41.5	35.1	23.4	3.28
Semi evergreen													
6	0-10	349.1	96	66	21	183	4.5	50	54	52.5	36.1	11.4	7.71
7	10-27	436.4	141	81	23	245	5.3	65	60	57.5	33.1	9.4	9.65
8	27-46	523.7	183	66	25	274	4.8	70	72	66.8	24.1	9.1	9.96
9	46-88	480.1	99	66	36	201	3.8	155	60	49.3	32.8	17.9	4.58
10	88-150	392.8	126	78	41	245	2.8	50	36	51.4	31.8	16.8	4.98
Moist deciduous													
11	0-13	567.3	96	16.5	20	132.5	3.3	205	66	72.5	12.4	15.1	5.63
12	13-32	741.9	120	30	26	176.0	6.0	90	102	68.2	17.0	14.8	5.77
13	32-66	654.6	84	27	26	137.0	3.0	110	72	61.3	19.7	19.0	4.27
14	66-95	611.0	87	33	21	141.0	4.3	140	54	61.7	23.4	14.9	5.71
15	95-165	654.6	75	27	23	125.0	5.0	75	39	60.0	21.6	18.4	4.43

Contd.

Table 11(a). Continued

1		2	3	4	5	6	7	8	9	10	11	12	13
Grasslands													
16	0-10	698.3	90	54	11	155	3.3	95	72	58.1	34.8	7.1	13.09
17	10-25	349.1	93	48	9	150	2.5	150	27	62.0	32.0	6.0	15.67
18	25-60	960.1	75	54	9	138	4.0	230	75	54.3	39.1	6.6	14.33
19	60-110	654.6	69	45	21	135	4.0	225	33	51.1	33.3	15.6	5.43
Hill top evergreen													
20	0-13	698.3	60	48	21	129	4.0	170	75	46.5	37.2	16.3	5.14
21	13-29	741.9	66	51	30	147	4.8	130	78	44.9	34.7	20.4	3.90
22	29-52	698.3	63	45	20	128	4.3	105	48	49.2	35.2	15.6	5.40
23	52-83	436.4	75	48	15	138	5.8	130	81	54.3	34.8	10.9	8.20
24	83-120	960.1	81	54	20	155	4.8	135	57	52.3	34.8	12.9	6.75
25	120-150	523.7	75	75	14	164	4.5	90	54	45.7	45.7	8.6	10.71
Dry deciduous													
26	0-13	916.5	75	51	57	183	5.5	75	72	41.0	27.9	31.1	2.21
27	13-23	741.9	63	57	22	142	6.0	90	75	44.4	40.1	15.5	5.45
28	33-70	567.3	78	51	34	163	4.8	120	78	47.9	31.3	20.8	3.79
29	70-150	305.5	81	54	22	157	3.8	100	78	51.6	34.4	14.0	6.14

Table 11(b). Phosphorus fractions in soil (ppm) mean and range values for profiles

Constituents	Vegetation type					
	Tropical evergreen	Semi ever-green	Moist deciduous	Grasslands	Hill top evergreen	Dry deciduous
Total P (ppm)	611.0-1003.8 (759.4)	349.1-523.7 (436.4)	611.0-741.9 (645.9)	349.1-960.1 (665.5)	436.4-960.1 (676.5)	305.5-916.5 (643.7)
Active inorganic P						
Fe-P	96-177 (126.0)	96-183 (129)	75-120 (92.4)	69-93 (81.8)	60-81 (70)	63-81 (74.3)
Al-P	60-87 (72.0)	66-81 (71.4)	16.5-33.0 (26.7)	45-54 (50.3)	45-75 (53.5)	51-57 (53.3)
Ca-P	14-54 (26.0)	21-41 (29.2)	20-26 (23.2)	9-21 (12.5)	14-30 (20)	22-57 (33.8)
Sum	188-286 (224)	183-274 (229.6)	125-176 (142.3)	135-155 (144.5)	128-164 (143.5)	142-183 (161.3)
Saloid-P	2.3-4.0 (3.30)	2.8-5.3 (4.2)	3-6 (4.3)	2.5-4.0 (3.5)	4.0-5.8 (4.7)	3.8-6.0 (5.0)
Reductant-P	125-240 (175)	50-155 (78)	75-205 (124)	95-230 (175)	90-170 (126.7)	75-120 (96.3)
Occluded-P	75-102 (82.2)	36-72 (56.4)	39-102 (66.6)	27-75 (51.8)	48-81 (65.5)	72-78 (75.8)
Percentage of active fraction						
Fe-P	41.5-66.5 (56.0)	49.3-66.8 (55.5)	60.0-72.5 (64.7)	51.1-62.0 (56.4)	44.9-54.3 (48.8)	41.0-51.6 (46.2)
Al-P	27.2-35.1 (32.4)	24.1-36.1 (31.6)	12.4-23.4 (18.8)	32.0-39.1 (34.8)	34.7-45.7 (37.1)	27.9-40.1 (33.4)
Ca-P	6.3-23.4 (11.7)	9.1-17.9 (12.9)	14.8-19.0 (16.4)	6.0-15.6 (8.8)	8.6-20.4 (14.1)	14.0-31.1 (20.4)
$\frac{Fe-P + Al-P}{Ca-P}$	3.28-14.79 (9.51)	4.58-9.96 (7.38)	4.27-5.77 (5.16)	5.43-15.67 (12.13)	3.90-10.71 (6.68)	2.21-6.14 (4.40)

correlation was obtained for Al-P with silt (r = -0.444*), clay (r = -0.502**), CEC (r = -0.717**) and pH (r = -0.409*).

Ca-P

Ca-P ranged from 9 ppm in grasslands (Nos.17 & 18) to 57 ppm in dry deciduous (No.26). The Ca-P showed a steady increase with depth in semi evergreen while no regular pattern in the distribution was observed with depth in all the other soils.

Saloid-P

Saloid-P was found to be the maximum (6 ppm) in moist deciduous (No.12) and dry deciduous (No.27) and minimum (2.3) in tropical evergreen (No.2) and this constituted the lowest among the various fractions of total P. Its distribution throughout the profile was irregular in all the soil profiles investigated. Significant positive correlation was obtained for Saloid-P with silt (r = 0.380*), pH (r = 0.453*).

Reductant-soluble P

This fraction constituted a fairly large proportion of inorganic-P and ranged from 50 ppm in semi evergreen (No.6 & 10) to 240 ppm in tropical evergreen (No.5).

There was no definite pattern in the distribution of reductant-P with depth in the profiles. Significant positive correlation was obtained for reductant-P with total Al_2O_3 (r = 0.576*), total Fe_2O_3 (r = 0.387*).

Occluded-P

In the case of occluded-P, its content varied from 27 ppm in grasslands (No.17) to 102 ppm in tropical evergreen (No.5) and moist deciduous (No.12). Its distribution within the profile showed a steady increase with depth in dry deciduous but no definite pattern of variation with depth was observed in other soils.

Among the active fractions, Fe-P formed the predominant portion, in all the soils. This was followed by Al-P and Ca-P respectively in all the soils.

The ratio of $\frac{\text{Al-P + Fe-P}}{\text{Ca-P}}$ was highest (15.67) in grasslands (No.17) and lowest (2.21) in dry deciduous (No.26). Significant negative correlation was obtained between occluded-P and clay (r = -0.373*).

7. Chemical composition of clay fraction and molar ratios

The data on chemical composition and molar ratios of clay fraction are presented in Table 12(a) and its mean and range values are given in Table 12(b).

Table 12(a). Chemical composition and molar ratio of clay fraction

Vegetation type, sample number and depth (cm)		SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	SiO_2/R_2O_3
Tropical evergreen							
1	0-10	34.0	23.2	26.0	2.48	3.56	1.46
2	10-20	33.7	27.0	23.5	2.15	3.73	1.37
3	20-40	26.5	34.2	18.4	1.29	3.67	0.96
4	40-70	33.0	28.2	21.0	1.96	4.23	1.34
5	70-150	40.0	28.0	12.0	2.48	8.38	1.91
Semi evergreen							
6	0-10	26.3	34.0	18.0	1.33	4.00	1.00
7	10-27	30.0	28.0	20.0	1.85	3.85	1.25
8	27-46	30.8	30.5	21.9	1.70	3.64	1.12
9	46-88	36.8	25.9	21.6	2.44	4.34	1.56
10	88-150	35.6	35.0	14.4	1.74	6.56	1.37
Moist deciduous							
11	0-13	33.0	27.5	20.0	2.12	4.23	1.41
12	13-32	32.1	34.5	18.0	1.59	4.90	1.20
13	32-66	36.7	27.0	20.0	2.35	4.69	1.56
14	66-95	36.0	34.5	18.0	1.76	5.45	1.33
15	95-165	34.4	30.7	21.8	1.90	4.07	1.30
Grasslands							
16	0-10	34.8	28.0	21.0	2.15	4.46	1.45
17	10-25	38.2	27.1	23.0	2.37	4.57	1.56
18	25-60	38.8	27.2	18.4	2.41	5.42	1.67
19	60-110	39.6	26.0	23.1	2.64	4.71	1.69
Hill top evergreen							
20	0-13	38.9	23.4	19.6	2.83	5.42	1.86
21	13-29	40.00	26.5	14.5	2.58	7.44	1.91
22	29-52	42.2	25.1	20.4	2.80	5.38	1.84
23	52-83	43.0	24.4	18.0	3.00	6.55	2.05
24	83-120	39.9	23.1	18.2	2.91	6.09	1.97
25	120-150	40.1	23.4	19.0	2.91	5.58	1.91
Dry deciduous							
26	0-13	39.1	22.0	29.0	2.95	3.61	1.63
27	13-33	41.0	18.4	30.1	3.78	3.56	1.84
28	33-70	41.2	16.2	29.5	4.31	3.83	2.03
29	70-150	38.9	19.5	30.2	3.42	3.42	1.71

Table 12(b). Chemical composition and molar ratio of clay fraction mean and range values for profiles

Constituents	Vegetation type					
	Tropical evergreen	Semi evergreen	Moist deciduous	Grasslands	Hill top evergreen	Dry deciduous
SiO_2 %	26.5–40.0 (33.4)	26.3–36.8 (31.9)	32.1–36.7 (34.4)	34.8–39.6 (37.9)	38.9–43.0 (40.7)	38.9–41.2 (40.1)
Al_2O_3 %	23.2–34.2 (28.1)	25.9–35.0 (30.7)	27.0–34.5 (30.8)	26.0–28.0 (27.1)	23.1–26.5 (24.3)	16.2–22.0 (19.0)
Fe_2O_3 %	12.0–26.0 (20.2)	14.4–21.9 (19.2)	18.0–21.8 (19.6)	18.4–23.1 (21.4)	14.5–20.4 (18.3)	29.0–30.2 (29.7)
Molar ratios						
SiO_2/Al_2O_3	1.29–2.48 (2.07)	1.33–2.44 (1.81)	1.59–2.35 (1.94)	2.15–2.64 (2.39)	2.58–3.00 (2.84)	2.95–4.31 (3.62)
SiO_2/Fe_2O_3	3.56–8.38 (4.71)	3.64–6.56 (4.48)	4.07–5.45 (4.67)	4.46–5.42 (4.79)	5.38–7.44 (6.08)	3.42–3.83 (3.61)
SiO_2/R_2O_3	0.96–1.91 (1.41)	1.00–1.56 (1.26)	1.20–1.56 (1.36)	1.45–1.69 (1.59)	1.84–2.05 (1.92)	1.63–2.03 (1.80)

Silica constituted the major part of clay and it varied from 26.3 per cent in semi evergreen (No.6) to 43 per cent in hill top evergreen (No.23). The silica content showed an increase with depth in grasslands, while no regular pattern of distribution with depth was obtained in all the other soils.

The Al_2O_3 content ranged from 16.20 per cent in dry deciduous (No.28) to 35 per cent in semi evergreen (No.10). The Al_2O_3 content decreased with depth in grasslands while no definite variation in the distribution pattern was observed in all other profiles.

The highest content of Fe_2O_3 (30.2%) was obtained in dry deciduous (No.29) and the lowest content (12.0)% in tropical evergreen (No.5). The distribution pattern of Fe_2O_3 along the profiles did not reveal any regular variation with depth.

The SiO_2/Al_2O_3 ratio varied from 1.29 in tropical evergreen (No.3) to 4.31 in dry deciduous (No.28). This ratio showed a steady increase with depth in grasslands whereas all other soils showed no definite pattern of variation, with depth.

The SiO_2/Fe_2O_3 ratio ranged from 3.42 ~~per cent~~ in dry deciduous (No.29) to 8.38 ~~per cent~~ in tropical evergreen (No.5). This ratio showed a definite increase with depth in the case of tropical evergreen, but no definite trend in variation was observed with depth in all the other soils.

The ratio of SiO_2/R_2O_3 was found to be highest (2.05) in hill top evergreen (No.23) and lowest (0.96) in tropical evergreen (No.3). This ratio did not follow any definite trend with depth, in the soils investigated.

8. Soil classification

The classification of soils according to Soil Taxonomy (1975) was attempted based on the morphological and analytical characters of the pedons. The classification has been done upto the subgroup level.

Pedons II and V under semi evergreen and hill top evergreen have been classified under Inceptisols. Pedons I, III, IV and VI from tropical evergreen, moist deciduous, grasslands and dry deciduous forests come under Ultisols. The taxonomic names of the soils are given in Table 15.

Table 13. Coefficients of simple linear correlation (r) between soil characteristics (number of pairs = 29)

Sl. No.	x Soil characteristics	y	r
1	Clay	Moisture retension at 1/3 bar	0.568**
2	Clay	Moisture retension at 15 bar	0.755**
3	Clay	Available water	0.267
4	Clay	Apparent density	0.112
5	Clay	Absolute specific gravity	0.363
6	Clay	Percentage pore space	0.595**
7	Clay	Volume expansion percentage	0.205
8	Clay	Coarse sand	-0.098
9	Clay	Fine sand	0.556**
10	Clay	Total Al_2O_3	-0.132
11	Clay	Total Fe_2O_3	0.247
12	Clay	Total P_2O_5	-0.141
13	Clay	Total K_2O	0.211
14	Clay	Cation exchange capacity	0.184
15	Clay	Fe_d	0.020
16	Clay	Fe_o	0.406*
17	Clay	Organic carbon	-0.196

Contd.

Table 13. Continued

1	2	3	4
18	Silt	Fe_d	0.156
19	Silt	Fe_o	0.278
20	Silt	Apparent density	-0.247
21	Silt	Absolute specific gravity	-0.202
22	Silt	Maximum water holding capacity	0.353
23	Silt	Percentage pore space	0.344
24	Silt	Volume expansion percentage	0.121
25	Sand (coarse sand + fine sand)	Fe_d	-0.946**
26	Sand	Fe_o	-0.457*
27	Sand	Apparent density	0.476**
28	Sand	Absolute specific gravity	0.226
29	Sand	Maximum water holding capacity	-0.656**
30	Sand	Percentage pore space	-0.630**
31	Sand	Volume expansion percentage	-0.148
32	Sand	Total Fe_2O_3	-0.367*
33	Sand	Total Al_2O_3	-0.098
34	Total iron	Fe_d	0.648**
35	Total iron	Fe_o	0.450*
36	Organic carbon	Fe_d	-0.236
37	Organic carbon	Fe_o	-0.309
38	Organic carbon	Total nitrogen	0.971**

Table 13. Continued

1	2	3	4
39	Organic carbon	Cation exchange capacity	0.690**
40	Exchangeable calcium	Cation exchange capacity	0.541**
41	Exchangeable magnesium	Cation exchange capacity	0.514**
42	Exchangeable potassium	Cation exchange capacity	0.625**
43	Exchangeable sodium	Cation exchange capacity	0.479**
44	Exchangeable calcium	Percentage base saturation	0.888**
45	Exchangeable magnesium	Percentage base saturation	0.660**
46	Exchangeable potassium	Percentage base saturation	0.665**
47	Exchangeable sodium	Percentage base saturation	0.783**
48	pH	Percentage base saturation	0.764**
49	Bulk density	Organic carbon	-0.388*
50	Water holding capacity	Organic carbon	0.229
51	Field capacity	Organic carbon	0.571**
52	Wilting coefficient	Organic carbon	0.293
53	Available water	Organic carbon	0.636**

** Significant at 1 per cent level
* Significant at 5 per cent level

Table 14. Correlation coefficient between soil properties and P fractions (n = 29)

Sl. No.	Soil property	Fe-P	Al-P	Ca-P	Saloid-P	Reductant-P	Occluded-P
1	Clay	-0.509**	-0.502**	-0.216	0.084	-0.017	-0.373*
2	Silt	-0.264	-0.444*	-0.080	0.380*	-0.013	0.068
3	Sand	0.551**	0.640**	0.217	-0.267	0.021	0.230
4	Total Al_2O_3	0.208	0.052	0.099	-0.256	0.576**	0.274
5	Total Fe_2O_3	-0.240	-0.097	0.003	0.004	0.387*	0.179
6	Total CaO	-0.144	-0.098	0.219	0.213	0.027	0.261
7	Cation exchange capacity	-0.284	-0.717**	-0.037	0.253	-0.165	0.045
8	pH	-0.591**	-0.409*	0.166	0.453*	-0.157	0.086

* Significant at 5% level
** Significant at 1% level

Table 15. Classification of soils according to soil Taxonomy (1975)

Profile No.	Vegetation type	Location	Taxonomic name (subgroup level)
I	Tropical evergreen	Sholayar (Trichur)	Typic Haplohumults
II	Semi evergreen	Kummatti (Trichur)	Typic Humitropepts
III	Moist deciduous	Athirapalli (Trichur)	Typic Haplohumults
IV	Grasslands	Siruvani (Palghat)	Typic Haplohumults
V	Hill top evergreen (Shola forests)	Siruvani (Palghat)	Oxic Humitropepts
VI	Dry deciduous	Walayar (Palghat)	Typic Haplchumults

Discussion

DISCUSSION

The results of the study pertaining to profile morphology, physico-chemical characteristics, behaviour of iron and phosphorus fractions, chemical composition of clay and classification of soils are discussed.

1. Profile morphology

The surface soils from all the profiles had darker colours ranging from greyish brown to brown indicating the influence of organic matter accumulation. Increasing redness in the subsurface horizon was a feature common to soils from tropical evergreen, moist deciduous, hill top evergreen and dry deciduous. The total iron content and free iron oxides (Table 10(a) showed a definite increase in the subsurface horizons. Intense red colours according to Webster (1985) have been associated with free iron oxide content and hence reddish colours of the subsurface layers can be attributed to the influence of iron oxides. Sankar *et al*. (1987) have reported the occurrence of red ferrallitic soil in Trichur forest division and attributed this to the presence of crystallized iron in sizeable proportions.

Weak granular structure in the surface horizon followed by subangular blocky structure in the subsurface layers was observed in the soils from all the locations. The granular structure is characteristic of the vigorous forest cover which favours maintenance of good soil structure. Good structural development was mainly the result of conducive drainage conditions, temperature, binding action of microbes, sesquioxides and products of microbial synthesis that were features of forest floor. The product of microbial decomposition formed complexes with sesquioxides and clays due to the cementing action of resistant humus, which gave highest stability to the aggregates. The structural development observed in the profiles under investigation was mainly the effect of these processes.

The soils from all the profiles under investigation showed an abundance of coarse fragments. Coarse fragments normally occupy a considerable fraction of forest soil mostly in the form of rock fragments. But in the present investigation, the coarse fragments were mostly secondary gravels. Another striking feature was the increase in the coarse fragments in the subsurface layers in the profiles from all the locations, except in grasslands, where the highest gravel content (87.3%) was observed in the surface horizon. Rangaswamy *et al.* (1978) postulated that the granular iron component and subsequent induration after the kaolinite has been saturated with iron oxides was the possible process for the pedogenesis of these coarse fragments, in iron rich soils. Hence the formation of gravel in these soils under investigation can be as a result of the operation of this process. In the case of grasslands, as part of afforestation programme, tree species have been planted by pitting along contours, however, intense erosion with the pits as focus points has been responsible for the removal of surface layers exposing the gravel rich subsurface horizons and this may be the probable reason for the high accumulation of gravel in these layers.

Texture of a forest soil influences its productivity. But this influence may be indirect through its effect on the air and water movement. Sandy texture was dominant in the soil profile from the tropical evergreen and semi evergreen forests. No appreciable difference in the clay content with depth was noticed in both these profiles. Wide variations in texture were observed between the soils from the various ecosystems. Another feature was the increase in the content of clay with depth. Balagopalan (1987) working on forest in Trivandrum and Trichur has reported the predominance of sand fraction in the tropical evergreen and semi evergreen forests of these areas. On the other hand soils from moist deciduous forests of grasslands and dry deciduous forests revealed clayey textures with more pronounced clay illuviation to the lower depth. The maximum accumulation of clay being observed in the last layer of the profile from grasslands. High rainfall conditions in the study area (1988 mm) have been responsible for clay migration to the lower layers. The absence of canopy in the grasslands has been further responsible for the intense leaching and washing down of the clay to the lower layers.

Among the various size fractions, silt was the lowest, ranging from 7.4 (grasslands) to 16.4% (moist deciduous). Intense weathering conditions in all the locations under study have been responsible for the complete transformation of the primary minerals especially feldspars to clays with insufficient proportion of silt (Radwanski and Olier, 1959).

Among the textural ratios, the silt/clay ratio was taken as an index of weathering in soils. Van (1967) has reported silt/clay ratios less than 0.15 and weatherable minerals less than 3% as indicative of highly weathered conditions. Judged from the above, all the soils registered values above the stipulated limit and hence considered as less mature. The mean value for the profiles decreased in the order 0.63, 0.58, 0.57, 0.43, 0.42 and 0.20 for tropical evergreen, hill top evergreen, moist deciduous, dry deciduous, semi evergreen and grasslands respectively. The maturity sequence also followed the above order. The most mature soils being those from the grasslands, this again points to the intense weathering conditions in the absence of canopy as compared to other forest ecosystems.

2. Moisture retention characteristics

Variations in moisture retained at 0.3 bar, field capacity and 15 bar, wilting coefficient (Table 4) were observed in most of the soils under investigation. These differences have been reflected in the available water content of the soils. The means of the profile (Table 6) showed the highest available water content for moist deciduous followed by dry deciduous, tropical evergreen, hill top evergreen, grasslands and semi evergreen. Correlations of moisture at 0.3 and 15 bar with clay were positive and significant (0.568**, 0.755** respectively) while that between available water content and clay was positive but not significant. The dominating influence of clay fraction in deciding the moisture retention characteristics at various tensions was evident from the positive correlations obtained. Hence the differences obtained in the soils under investigation were mainly due to the variations in content of clay. This was further strengthened with the increasing trends in field capacity moisture observed in grasslands and dry deciduous concomitant with the definite increase in clay. Another important observation was the presence of coarse fragments in soils from all the location which reduced the total soil volume exposed to roots, thus further reducing the available water capacity of the soils.

3. Physical constants of soils

The apparent density did not reveal appreciable differences within the soil profile from different locations. The mean value for the profile varied from

0.99 to 1.21. The surface horizons invariably recorded a lower value evidently due to the effect of organic matter which was characteristic of forest floor accumulation. Positive significant correlations were obtained for the coarse fractions with apparent density (0.476**). The dominating effect of the coarse fractions on the bulk density has been reported by Ushakumari (1983) for laterite soils of Kerala.

The absolute specific gravity did not reveal appreciable differences between the profiles from various locations indicating the more or less similar range in the occurrence of primary minerals in the soils. All the soils were rich in sesquioxides and this contributed to the high absolute specific gravity which agreed with the observation of Antony (1982) in the laterite soils of Kerala.

Porosity was calculated from particle density and bulk density and therefore factors which influence these parameters affect the porosity too. One such factor was the clay content. There was an indication that the pore space increased with clay content as was evident from the positive correlations with clay which agreed with the findings of Ushakumari (1983). Wilde *et al.* (1972) had observed that reasonable pore volume of soils varied from 30-70% which implied that the soils under study did not offer any resistance to root penetration and infiltration of rain water. This was further strengthened by the reports on higher infiltration rates for the upland laterites of Kerala by Ushakumari (1983). All the soils under investigation came under ferrallitic group and the results obtained were consistent with the observations made by earlier workers.

The maximum water holding capacity and volume expansion were closely related to the nature and content of clay and organic matter. The data revealed erratic profile trends. The predominant clay minerals in all the soils under investigation were a mixture of kaolinite and hydrous oxides and hence the negative correlation observed with clay can be attributed to the predominance of 1 : 1 type of clay minerals, which have a low capacity to hold water and are nonexpansive. The combined effect of organic matter and clay was clearly evident in the upper horizons of all the profiles which registered higher values. However, the soils under dry deciduous forests registered the highest volume expansion and water holding capacity and may be attributed to the presence of an admixture of 1 : 1 and 2 : 1 minerals in the clay fraction. The higher silica sesquioxide ratio (Table 17) also adds strength to this contention.

4. Chemical characteristics

4.1. Soil reaction and organic constituents (Table 7(a)

The soils were all acidic in reaction and most of the soils were expected as developed under intense humid conditions, where leaching has depleted the bases from the surface and subsurface layers of the soil profiles. The lower pH values of tropical evergreen and semi evergreen observed were again reflected in the higher rainfall (1988 mm) and consequent low percentage base saturation (Table 11) observed. The profile under the dry deciduous forests recorded the highest pH of 6.3 and had a very high percentage base saturation of 87% among the different soils under investigation. These soils were developed under lower rainfall areas (745 mm) as compared to other location and hence the accumulation of bases and consequent higher pH values. Balagopal (1987) has reported least variation between pH values in moist deciduous and semi evergreen forest divisions in Trichur district and has attributed this to the higher buffer capacity of the soils.

Organic carbon, nitrogen and C/N ratios were high in the surface horizons with decreasing profile trends from all the locations except in hill top evergreen. The organic carbon content and its distribution in the profile are features of forest ecosystems with its characteristic forest floor litter, Wooi-Khoon and Jin-Econg (1983). Thus the upper horizons showed higher organic carbon content which decreased with depth. The organic matter mineralization under tropical conditions according to Sanchez (1976) was very high and hence its depletion, inspite of very high litterfall. The nitrogen content of the soils and the variations observed in the profile followed the pattern of organic matter distribution and this was strengthened by the positive significant correlation (0.971**).

4.2. Total chemical analysis

SiO_2 formed the predominant constituent. The primary mineral assemblage was dominated by quartz, which was highly resistant to weathering and insoluble in the normal pH range of weathering. The movement of SiO_2 within the profile was seldom observed except under conditions of intense laterisation. This pointed to the absence of definite patterns of movement within the profile.

Al_2O_3 was the next predominant constituent and formed a major portion of the hydrous oxide rich clays which dominated the soils under investigation. The hydrous oxide also occured as coatings around the clay and sand grains as free oxides. This also contributed to its content in soils. However, the major fraction was held by clays and its movement in the profile could bring about significant changes in the Al_2O_3 content also, as was clearly evident from the pattern of Al_2O_3 distribution down the profile in the soils from moist deciduous, grasslands and dry deciduous types which parallels the clay content.

The Fe_2O_3 content though less, compared to Al_2O_3 was also held both in the clay fraction and sand particles as free iron oxides. The correlation with clay was positive. The profile trend also revealed steady increase with depth. The clay fraction of these soils being rich in sesquioxides, has the capacity to retain the oxides on the clay fraction (Jacob, 1987).

The total reserves of MgO, CaO, K_2O and P_2O_5 were low as is expected of humid tropical soils, where intense weathering conditions leave very little of the primary minerals except quartz. The soils of the study area were derived mainly from acid crystalline rocks which were again poor in bases. Thus the low total nutrient content of the soils was a reflection of the parent geology as revealed from the results of the present investigation.

4.3. Cation exchange properties (Table 11)

The cation exchange capacity was low as is expected of highly weathered tropical soils rich in 1:1 and hydrous oxide clays. The profile trends in CEC indicated that the surface horizons invariably recorded higher values clearly indicating the role of the organic fractions. The fact that the low activity clays dominated the mineralogy of the clay fraction of all the soils under study was clearly brought out by the narrow range in variation observed in the CEC values between soils from various locations. Appreciable differences in clay content (Table 3) between the tropical evergreen and grasslands have not registered a significant change in the CEC of the soils, highlighting the importance of nature of the clay fraction. This is further strengthened by the correlation between CEC and clay which is nonsignificant. Coleman and Thomas (1967) have observed that soils rich in kaolinite, halloysite, hydrated oxides of iron and aluminium and other low activity clays usually have low CEC, lending credence to the observations made in the present investigation.

Organic matter of the soils has a very high CEC and a small increase in the organic matter levels can bring about a significant change in the CEC values. The dominating influence of organic fraction on CEC is clearly brought out by the variations in the profile with depth observed. The calculated CEC per 100 g clay showed that the upper horizons of the soils from all the locations had higher CEC while in the lower horizons with lesser organic matter, greater clay content and the inert oxides, the CEC was less. Thus the variations observed in the CEC in the soils under study can mainly be attributed to the difference in organic matter content and its distribution.

The CEC determined by the sum of cations method observed higher values as compared to NH_4OAc method in all soils under investigation and is in agreement with the observations made by earlier workers, in soils with higher proportion of 1:1 clay. Jacob (1987) had made similar observations on laterite soils of Kerala. According to Coleman and Thomas (1967), the higher values of CECs suggested that the higher proportion of the exchange sites in the soil is pH dependent and probably blocked by iron and aluminium hydroxides.

4.4. Exchange acidity

The exchange acidity values did not reveal much variation within the soil profile and also between locations. The values recorded were evidently higher than the earlier reports by Jacob (1987) on laterite soils of Kerala. According to Sanchez (1976) the acidity extracted by $BaCl_2$-TEA method includes the non-exchangeable hydrogen associated with COOH groups and also the iron and aluminium hydrated oxides. The organic carbon data (Table 7(a) revealed that the moist deciduous soils with the highest organic carbon content (profile mean 3.12) evidently had the highest exchange acidity of 29.2 me/100 g soil. Hence the higher values obtained in the present investigation can be attributed to dominating influence of organic colloids. It is also interesting to note that the soils from the dry deciduous forests recorded lower values for exchange acidity, which is possibly due to the influence of free calcium carbonates present. The percentage base saturation recorded (31.65%) for these soils was also the highest among the soils investigated.

5. Exchangeable bases and percentage base saturation

The exchangeable Ca and Mg were the predominant cations in the exchange complex. The mean values of the profiles showed that the exchangeable cations were in the order Ca > Mg > K > Na for soils from semi evergreen, moist deciduous and dry deciduous forests while in the case of tropical evergreen, grasslands and hill top evergreen the exchangeable sodium showed a slight increase over exchangeable potassium. Another feature observed was the greater accumulation of bases in the upper horizon of all the profiles, clearly highlighting the influence of organic matter. This feature of the forest floor hae been reported by many workers (Golley et al., 1975, Stark and Jordan, 1978). The broad leaf species according to these workers have higher requirement of bases and have a more intense cycling, where by more bases are returned to the soil. Another observation was the greater accumulation of bases in the dry deciduous forests evidently due to the influence of lower rainfall conditions as compared to the other regions.

The percentage base saturation was calculated by using CECs and NH_4OAc. The former recorded lower values. The percentage base saturation showed higher values in the surface in tropical evergreen, moist deciduous, grasslands and hill top evergreen, indicating the less intense leaching of bases. Increase in base content in subsurface horizons was observed in semi evergreen only, while in dry deciduous, though the base saturation was high, the variation in the profile was not appreciable.

6. Extractable iron and active iron ratios (Table 10(a)

The dithionite extractable iron, Fe_d gives a reasonable estimate of the pedogenic free iron oxides in soils, while those extracted by ammonium oxalate, Fe_o represent the more or less amorphous form (Mehra and Jackson, 1960; Mc Keague and Day, 1966).

The Fe_d constituted the major portion of the total iron in all the soils under investigation. It varied from 35.57% in the soils from moist deciduous to 55.17% in grasslands. The correlation between Fe_t and Fe_d was positive and significant (0.648**). The accumulation of Fe_d was in the subsurface horizon of the profiles. No definite profile trends was observed. The accumulation in the subsurface layers followed the pattern of total clay content suggesting a passive movement of these oxides into the lower layers by absorption (Blume and Schwertmann, 1969). The positive correlation with silt and clay also lend support to the observation that, there is passive movement of Fe_d with finer fractions, during the illuviation process.

The Fe_d expressed as percentage of the total, referred to as degree of freeness of iron is often taken as an indicator of the age of soils (Alexander, 1974). Judged by this, the grasslands were the most weathered followed by semi evergreen, hill top evergreen, tropical evergreen and dry deciduous and the least weathered was moist deciduous. The grasslands with its absence of canopy were exposed to the elements of weathering to a greater extent and thus reflected in their more weathered nature. The soils from other forest ecosystems with good canopy cover were less mature evidently due to the lesser impact of the weathering forces. Jacob (1987) observed in the case of upland cultivated laterite soils of Kerala, that the crystalline oxides constituted 57-99% of the total iron. This clearly indicates the need for the higher temperature and other weathering conditions for crystallinity of iron oxides, a condition which sets into operation as soon as the forest cover is denuded.

Another interesting observation was the outstanding influence of iron oxides in soil colour which was clearly brought out by increasing redness down the profile following the distribution of iron oxides. The impact of free iron oxides on soil colour has been reported by earlier workers (Webster, 1985 and Sankar *et al.*, 1987).

The Fe_o recorded lower values of the soils from tropical evergreen, semi evergreen and moist deciduous while grasslands and hill top evergreen showed slightly higher values and the highest was observed in dry deciduous forests. Organic matter had an inhibiting effect in the crystallinity of iron oxides (Juo *et al.*, 1974). The lower value of Fe_o observed in the upper horizons of tropical evergreen and semi evergreen can be attributed to the influence of organic matter.

Consistent with the low values of Fe_o, the active iron ratio also registered low value. Alexander (1974) has reported strikingly low values approaching zero for all tropical soils. Judged from this, the tropical evergreen was the most mature followed by moist deciduous, semi evergreen, grasslands, hill top evergreen and dry deciduous. Very low values for active iron ratios have been reported by Jacob (1987) on laterite soils of Kerala. The slightly high values observed in the soils under investigation suggest the lesser maturity of the soils, because of the effect of the forest canopy.

The negative correlation of sand with Fe_d was significant (-946**) indicating that the oxides occupied mostly in the clay fractions. This is most evident from the distribution of Fe_d by silt + sand which did not reveal any characteristic profile trend. The silt being the lowest among the size fraction, the positive correlation (0.156) with Fe_d has been masked by the over riding influence of dominating sand fraction in all the soils under investigation. In respect of Fe_d/clay ratio, subsurface layers showed an increase in tropical evergreen, semi evergreen, grasslands and hill top evergreen, while slightly higher values near the surface were observed in moist deciduous and dry deciduous forests. In general, the movement of iron oxide by suspension with finer particles by adsorption and subsequent movement with clay have been postulated by Parks (1965). The variations observed in the present study suggest the operation of the above process.

7. Phosphorus fractions Table 11(a)

The transformation of inorganic P during weathering, followed a sequence of Ca-P, Al-P, Fe-P and occluded-P and is often taken as an index of pedogenesis (Chang and Jackson, 1958). Fe-P the dominant constituent in all the profiles under investigation, formed the major portion of the active fraction, represented by Ca-P, Al-P and Fe-P. The means of the percentage active fraction show the highest of 64.7% for moist deciduous followed by 56.4, 56.0, 55.5, 48.8 and 46.2% for grasslands, tropical evergreen, semi evergreen, hill top evergreen and dry deciduous respectively. Preponderance of Fe-P over the other fractions has been reported for laterite soils of Kerala by Jacob (1987). The Fe-P distribution did not have any relationship to the total iron, Fe_d and clay as revealed by the absence of correlation. These observations, reaffirm the earlier support by Chang and Chu (1961) that the distribution of Fe-P is governed to a little extent by the above facts, but is more influenced by the pedogenic process. The predominance of Fe-P in all the soil investigated also indicated the highly weathered nature of the soil consistent with observation of Chang and Jackson (1958).

Slightly higher amounts of Al-P were observed in tropical evergreen and semi evergreen. Al-P was negatively correlated with clay and silt (-0.502**, -0.444* respectively) but correlations were positive with sand and Al_2O_3 (0.640**, 0.052 respectively). The variations observed in Al-P fraction can be attributed to the difference in the content of free Al_2O_3, 1:1 clay and water movement (Smeck, 1973).

Low level of Ca-P is taken as an index of advanced stage of weathering in soils (Chang and Jackson, 1958). All the soils under investigation were acidic, had low CEC, low exchangeable Ca and these have contributed to the small levels of Ca-P. Judged from the above, grasslands were the most mature followed by hill top evergreen, moist deciduous, tropical evergreen, semi evergreen and dry deciduous. The absence of correlations with particle size fractions revealed that the content of Ca-P was more influenced by pedogenic processes. The relationship of total CaO and Ca-P was positive but not significant. The higher content of Ca-P observed in dry deciduous forests may be attributed to the higher content of exchangeable and total Ca observed in these soils.

The saloid bound P was the lowest among the P fractions studied. The profile means showed the lowest of 3.3 ppm for tropical evergreen followed by 3.5, 4.2, 4.3, 4.7 and 5 ppm for grasslands, semi evergreen, moist deciduous, hill top evergreen and dry deciduous. All the soils under investigation were rich in sesquioxides and 1:1 type of minerals and consequently very high P fixing capacity. Hence the low value of saloid bound P may be attributed to the above factor (Kothandaraman and Krishnamoorthy, 1979).

The reductant-P showed higher levels than occluded-P. Profile means showed highest value of 175 ppm for tropical evergreen and grasslands followed by 126.7, 124, 96.3 and 78 ppm for hill top evergreen, moist deciduous, dry deciduous and semi evergreen respectively. All soils had appreciable quantities of Fe_d and this account for the higher content of this fraction, Swindale (1966). Positive significant correlations of total iron and Fe_d (0.367* and 0.566**) with this fraction further supported the above view. Thus the tropical evergreen with the highest Fe_d had the highest reductant P, while the semi evergreen had also the lowest Fe_d. The results of the present investigation confirmed earlier report by Manickam (1977) on laterite soils of Tamil Nadu.

The occluded P was highest in tropical evergreens with a mean of 82.2 ppm followed by 75.8, 66.6, 66.5, 56.4 and 51.8 ppm in dry deciduous, moist deciduous, hill top evergreen, semi evergreen and grasslands. The correlations of this fraction with silt and sand were positive, but not significant, while with clay fraction, it was negative and significant (-0.373*). Kothandaraman and Krishnamoorthy (1979) have reported higher values for occluded P in laterite soils of Tamil Nadu. Fife (1963) concluded that the distribution of occluded P was more dependent on chemical reaction and age of the soil rather than texture and chemical composition as was observed in the present study.

7.1. P fractions and pedogenesis

The ratio of $\frac{Fe\text{-}P + Al\text{-}P}{Ca\text{-}P}$ gives an indication of the degree of weathering of the soils. As weathering proceeds Ca-P is transformed to Fe-P and Al-P. The ratios in the present study indicated erratic profile trends. The mean values for the profiles varied from 4.4 for the dry deciduous soils to 12.13 for grasslands. The ratio according to Mausbach (1969) increased with increasing soil development and corresponded to transformation of Ca-P to Fe-P and Al-P. Judged from this contention, the grasslands measured further along the soil development scale as compared to the dry deciduous soils. As explained earlier, the grasslands with less of canopy cover were better exposed to the weathering elements and hence more mature. The soils from the moist deciduous and dry deciduous forests had low values for this ratio viz., 5.16 and 4.4 respectively. The moist deciduous soils were located in the valley and formed mainly from colluvial debris. The high water table condition also impeded soil development process, as revealed by the macromorphology of the profiles. The distribution of the phosphorus fraction also lended support to the above conclusion. In the case of the dry deciduous forests, the lower ratios observed were mainly due to the higher exchangeable calcium content. The soils of this location had free calcium carbonate also. The lower rainfall conditions (745 mm) as compared to the other locations added to the greater exchangeable calcium content of the soils and hence the lower ratios. So based on the weathering theory put forward by Chang and Jackson (1958) and later confirmed by Mausbach (1969) the maturity sequence of soils under investigation were 12.1 > 9.5 > 7.4 > 6.7 5.2 > 4.4 for grasslands, tropical evergreen, semi evergreen, hill top evergreen, moist deciduous and dry deciduous respectively.

8. Chemical composition of clay fraction (Table 12(a)

Chemical composition of clay fraction and molar ratios served mainly pedogenic purpose and threw light on the mineralogy of clays. In all the soils under investigation, SiO_2 formed a very important constituent and its content does not revealed much variations in the profile and also between soils from various location, suggesting similarity in the clay mineral make up of soils.

The sesquioxide content of all soils also does not reveal any appreciable variation. However, the sub-surface layer in all the profile recorded greater accumulation. The behaviour of Fe_2O_3 and Al_2O_3, Mc Farlane (1976) were antipathetic in that increase in Fe_2O_3 was matched by a decrease in Al_2O_3 and vice versa. The results of the study brought out this trend.

The molar ratio SiO_2/Al_2O_3 is taken as a criterion in designating laterite soils. Buringh (1970) suggested a SiO_2/Al_2O_3 ratio of two for ferrallitic soils and a value of 1.33 for SiO_2/R_2O_3 was suggested by Martyn and Doyne (1927) for true laterites. Judged from the above, most of the soils under investigation could not be designated as true laterite, but conformed more to the ferrallitic group. High molar ratio for laterite soils of Kerala has been reported by Jacob (1987). The major processes affecting the composition of soils and clays in humid climate were differential leaching of SiO_2 and retention of highly immobile Fe and Al, (Crompton, 1960). The slightly higher molar ratios observed in the present study indicated the lesser impact of the high temperature and rainfall conditions which was masked by the forest canopy, thus retarding the intense weathering and differential leaching conditions characteristic of humid agricultural ecosystems. Removal of forest cover and subsequent exposure of soils to weathering element hastened the pedogenic process which finally lead to the development of true laterite, there by lowering the ratio. Thus the results of the present study pointed to the importance of maintenance of forest cover. Removal of virgin vegetation and change over to agricultural ecosystem would result in hastening the process of laterization and consequent deterioration in the productive capacity of the soil.

9. Soil classification

The classification of the pedons up to the subgroup level is indicated in Table 15. Pedons I, III, IV and VI had the characteristic argillic horizon and also satisfied the requirement of base saturation and hence classified under Ultisols. Pedons II and V have got both ochric epipedon and cambic horizon and hence classified under Inceptisols.

At the suborder level, pedons I, III, IV and VI satisfied the requirement of organic carbon content of the profiles and hence classified under Humults. Pedons II and V have been classified as Tropepts.

Pedons I, III, IV and VI have been classified under Haplohumults at the great group level, while pedons II and V satisfied the requirement of organic carbon content and base saturation in the profile and hence classified under Humitropepts.

At the subgroup level pedons I, II, III, IV and VI were typic while pedon V had an Oxic subgroup.

Summary

SUMMARY

A study was conducted to evaluate the morphological, physico-chemical characteristics and genesis of soils representing different forest ecosystems in Kerala. Soil profiles representing six vegetation types viz. tropical evergreen, semi evergreen, moist deciduous, grasslands, hill top evergreen (Shola forest) and dry deciduous types were selected for the study. Soil profiles were excavated in these locations and detailed morphological studies were carried out. Soil samples representing the different horizons were collected for laboratory studies. The physico-chemical characteristics of the soils and distribution of iron and phosphorus fractions were investigated with a view to study the inter-relationship between various soil properties and to relate them to the genesis of soils. Attempts have also been made to classify the soils according to Soil taxonomy.

The salient findings are summarized below.

1) The surface soils from all the profiles had darker colours ranging from greyish brown to brown, evidently due to higher organic matter content. Increasing redness in the subsurface horizon of the soil profile

though present in all the soils, was a feature conspicuously observed only in the soils from dry deciduous forests.

2) Weak granular structure in the surface horizons followed by subangular blocky in the subsurface layers was a feature characteristic of all the soils under investigation.

3) Coarse fragments in the form of secondary laterite gravel occupied a major portion of the soils under investigation.

4) Texture of the soils varied widely between the soils from the various ecosystems. However the clay content of the soil increased with depth in all the soil profiles.

5) Positive and significant correlation was obtained between moisture at 0.3 and 15 bar with clay, bringing out the dominating influence of clay fraction in deciding the moisture retention characteristics.

6) The apparent density and absolute specific gravity did not reveal appreciable differences within the soil profile and between different locations.

7) The maximum water holding capacity and volume expansion were closely related to the nature and content of clay and organic matter. The soils under dry deciduous forests registered the highest volume expansion and maximum water holding capacity

8) All the soils under investigation were found to be acidic in reaction, with little variation observed within the soil profile or between locations. Organic carbon, nitrogen and C/N ratios were high in the surface horisons with decreasing profile trends in all the soils except from hill top evergreen. Highly significant positive correlation between organic carbon and nitrogen was also obtained.

9) Silica constituted the predominant portion in all the soils followed by Al_2O_3.

10) Iron oxide content was less than Al_2O_3 and showed a positive correlation with clay.

11) The total reserves of MgO, CaO, K_2O and P_2O_5 were low as is expected of humid tropical soils, where intense weathering conditions leave very little of the primary minerals except quartz.

12) The CEC was low, a feature characteristic of highly weathered tropical soils rich in 1:1 and hydrous oxide clays. The CEC determined by sum of cations method recorded higher values as compared to ammonium acetate method.

13) The exchange acidity recorded higher values and did not reveal much variation within the soil profile and also between locations. The moist deciduous soils with the highest organic carbon content had the highest exchange acidity and the soils from the dry deciduous forests recorded lower values for exchange acidity. The percentage base saturation recorded for these soils was also the highest among the soils investigated.

14) The exchangeable Ca and Mg were the predominant cations in the exchange complex. The exchangeable cations were in the order Ca $>$ Mg $>$ K $>$ Na for soils from semi evergreen, moist deciduous and dry deciduous forests while in the case of tropical evergreen, grass-lands and hill top evergreen, the exchangeable sodium showed a slight increase over exchangeable potassium. The distribution of other cations however followed the same order. Greater accumulation of bases in the upper horizons was a characteristic feature observed in the soils from all locations.

15) The percentage base saturation was calculated by using CEC_s and NH_4OAc method. The former recorded lower values. The percentage base saturation was higher in the surface horizons in tropical evergreen, moist deciduous, grasslands and hill top evergreen.

16) The dithionite extractable iron (Fe_d) constituted the major portion of the total iron in all the soils. Positive and significant correlations were obtained between total Fe and Fe_d. Subsurface accumulation of Fe_d was observed in all the profiles.

17) The influence of free iron oxides on soil colour has been clearly brought out by the increasing redness down the profile, following the distribution of iron oxides.

18) The active iron ratio (Fe_o/Fe_d) was low for all the soils under investigation.

19) Among the active inorganic P fractions, Fe-P formed the dominant constituent in all the soils indicating their highly weathered nature. Based on the contents of Ca-P, grasslands with minimum Ca-P was the most mature, followed by hill top evergreen, moist deciduous, tropical evergreen, semi evergreen and dry deciduous.

20) Judged from the ratio of $\frac{Fe\text{-}P + Al\text{-}P}{Ca\text{-}P}$ which is an indicator of the degree of weathering, the grasslands were the most mature along the soil development scale and the soils from the dry deciduous forests were the least mature.

21) Analysis of clay fraction revealed that silica formed a very important constituent and its content did not vary in the profile and also between soils from various locations. Judged from the SiO_2/Al_2O_3 ratio of clay fraction, most of the soils under investigation belonged to ferrallitic group.

22) Based on the available data, the soils have been classified under soil taxonomy. Pedons I, III, IV and VI have been classified as Typic Haplohumults, Pedon II as Typic Humitropepts and pedon V as Oxic Humitropepts.

Based on the degree of freeness of iron which is an indicator of the age of soils, grasslands were the most weathered followed by semi evergreen, hill top evergreen, tropical evergreen, dry deciduous and the least weathered moist deciduous.

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Appendix

APPENDIX I

Description of Soil Profiles

Profile I

Location	Sholayar project area - Ambalappara
Topography	Rolling - Top of Hillock 20% in the west direction
Drainage	Well drained
Ground water table	50 m
Natural vegetation	Wet evergreen forests - trees and shrubs

Horizon	Depth (cm)	Description
A_1	0-10	Dark reddish brown (5 Y/R 3/4), gravelly loamy sand; medium weak granular structure; moist; very friable; wet slightly sticky and nonplastic; moderate permeability; fine roots plenty; clear smooth boundary.
A_2	10-20	Strong brown (7.5 YR 5/6), gravelly loamy sand; medium moderate granular structure; very friable; wet sticky and slightly plastic; medium roots plenty; diffuse wavy boundary; moderate rapid permeable.
A_3	20-40	Strong brown (7 YR 5/8), gravelly sandy loam; medium moderate sub-angular blocky structure; moist friable, sticky and plastic; big roots few; moderate rapid permeable; diffuse wavy boundary.
B_1	40-70	Yellowish red (5 YR 4/8), gravelly loam; medium moderate sub-angular blocky; firm, sticky and plastic; roots dominant; moderate permeability.

B_{12}	70-150+	Yellowish red (5 YR 4/8), gravelly sandy loam; medium moderate sub-angular blocky; firm sticky and plastic; roots absent; moderately slow permeability.

<u>Profile-II</u>

Location	Side of Chalakudy-Sholayar route, 10 KM from Athirapalli, Pariyaram Village, Mukundapuram Taluk, Trichur District.
Topography	Bottom of slope, level area
Slope	3% in the south direction
Drainage	Moderately drained
Ground water table	~~10'~~ 3m
Natural vegetation	Semi evergreen
Remarks	Profile is located in the valley bottom and mostly colluvial debris form side slopes

Horizon	Depth (cm)	Description
A_1	0-10	Dark brown (10 YR 3/3), gravelly sandy loam; medium weak granular structure; moist, very friable, slightly sticky and slightly plastic; medium roots plenty; moderate permeability; clear smooth boundary.
A_2	10-27	Dark brown (10 YR 3/2), gravelly sandy clay loam; medium weak sub-angular blocky structure; moist friable, wet slightly sticky and sticky and slightly plastic; medium roots few; moderate permeable; diffuse wavy boundary.
B_1	27-46	Dark yellowish brown (10 YR 4/4) brown (10 YR 5/3) mottles few, gravelly sandy clay loam; medium weak sub-angular blocky; moist friable; wet sticky and slightly plastic; medium sized roots few; moderately slow permeability; diffuse wavy boundary.

B_{21}	46-88	Dark yellowish brown (10 YR 4/4) yellow (10 YR 7/8) mottles plenty, gravelly sandy clay loam; medium moderate sub-angular blocky structure; moist firm, wet sticky and plastic; medium sized roots plenty; moderately low permeability; diffuse wavy boundary.
B_{22}	88-150+	Yellowish brown (10 YR 5/6), gravelly sandy clay loam; massive structure; 10 YR 5/3 (brown) 10 YR 7/8) mottles plenty; moderately low permeability.

<u>Profile-III</u>

Location	Left side of Chalakudy-Sholayar road, 1 KM from Athirapally Junction, Pariyaram Village, Mukundapuram Taluk, Trichur.
Topography	Gently sloping ridge, which breaks off to strongly sloping side slopes.
Slope	25% in south direction
Surface drainage	Well drained
Ground water table	~~150'~~ 45m
Natural vegetation	Moist deciduous forest
Remarks	The area is a side slope. The upper reaches are thick forest with rock out crops.

Horizon	Depth (cm)	Description
A_1	0-13	Dark greyish brown (10 YR 4/2) dry, very dark greyish brown (10 YR 3/2) gravelly loam; medium weak granular structure; dry loose, moist very friable, wet sticky and nonplastic; fine roots plenty; rapid permeability; clear smooth boundary.
A_3	13-32	Dark brown (7.5 YR 8/2) loam; medium weak granular structure; dry loose, moist very friable, wet nonsticky and nonplastic; fine roots plenty; moderately rapid permeability; clear wavy boundary.

B_1	32-66	Dark reddish brown (5 YR 3/3) clay loam, medium weak sub-angular blocky; moist firm, wet slightly sticky and slightly plastic; few medium roots; moderately rapid permeability; diffuse wavy boundary.
B_{21}	66-95	Reddish brown (5 YR 4/4), gravelly sandy cley loam; medium moderate sub-angular blocky structure; moist firm, wet slightly sticky and slightly plastic; few moderate roots; moderate permeability; diffuse wavy boundary.
B_{22}	95-165+	Reddish brown (2.5 YR 4/4) clay; medium moderate sub-angular blocky structure; moist firm, wet sticky and plastic; fine to medium roots few; moderate permeability.

Profile-IV.

Location and access	Profile IV - Siruvani dam site - Sholayar Village, Mannarghat Taluk, Palghat District.
Topography	Crest of Hillock - nearly level. Rolling upland, elevation 900 m.
Slope	20% in the east direction
Drainage	Well drained
Ground water table	~~150'~~ 45 m
Natural vegetation	Grass lands

Horizon	Depth (cm)	Description
A_1	0-10	Brown (10 YR 5/3) dark brown (10 YR 3/3) moist, gravelly sandy clay; weak medium granular structure; slightly hard, moist friable, wet slightly sticky and nonplastic; fine roots plenty; rapid permeability; clear smooth boundary.
A_2	10-25	Dark yellowish brown (10 YR 4/4), gravelly clay loam; medium weak granular; moist firm, wet slightly sticky and slightly plastic; moderately rapid permeability; diffuse wavy boundary.

B_{21}	25-60	Strong brown (7.5 YR 5/6), gravelly clay; medium weak sub-angular blocky structure; moist firm, wet sticky and plastic; moderately slow permeability; diffuse wavy boundary.
B_{22}	60-110+	Strong brown (7.5 YR 5/8), gravelly clay; coarse moderate sub-angular blocky structure; moist firm, wet sticky and plastic; moderately slow permeability.

<u>Profile-V</u>

Location	Siruvani Dam Project area, near dam quarter.
Topography	Rolling upland - elevation 600 m
Slope	33% south direction
Surface drainage	Well drained
Natural vegetation	Shola forest

Horizon	Depth (cm)	Description
AP	0-13	Very dark greyish brown (10 YR 3/2) gravelly clay loam; medium weak granular; moist friable, wet slightly sticky and slightly plastic; large and medium sized roots plenty; moderately rapid permeability; clear smooth boundary.
A_1	13-29	Strong brown (7.5 YR 5/6) gravelly sandy loam; weak medium sub-angular blocky structure; moist firm, wet sticky and plastic; medium sized roots plenty; moderate permeability; clear wavy boundary.
A_2	29-52	Dark brown (7.5 YR 4/4) gravelly clay loam; moderate coarse sub-angular blocky; moist firm, wet sticky and plastic; large medium sized roots plenty; loose with gravel; moderate permeability; diffuse wavy boundary.

B_1	52-83	Dark brown (7.5 YR 4/4) gravelly loam; moderate coarse sub-angular blocky structure; moist firm, wet sticky and plastic; moderate permeability; diffuse wavy boundary.
B_{21}	83-120	Yellowish red (5 YR 4/6) gravelly clay loam; moderate coarse sub-angular blocky; moist firm, sticky and plastic; moderate to slow permeability; medium roots plenty; compact layer.
B_{22}	120-150+	Yellowish red (5 YR 5/8) gravelly clay loam; medium sub-angular blocky structure; moist friable, wet slightly sticky and slightly plastic; medium roots few; weathered gneiss; slow permeability.

<u>Profile-VI</u>

Location	Left side of Palghat-Coimbatore road, Near Walayar, Check post.
Topography	Flat level land
Slope	1%
Drainage	Well drained
Ground water table	~~70±~~ 21 m
Natural vegetation	Dry deciduous forest
Remarks	All the layers except for the surface horizon is very hard and compact and break into very large clods, redness increases with depth.

Horizon	Depth (cm)	Description
A_1	0-13	Reddish brown (5 YR 3/3) gravelly loam; medium weak granular; moist very friable, wet slightly sticky and slightly plastic; medium sized roots few; rapid premeability; clear smooth boundary.

B_{21}	13-33	Dark reddish brown (2.5 YR 2.5/4) gravelly clay loam; medium weak sub-angular blocky; moist very firm, wet sticky and plastic; moderate permeab-ility; diffuse wavy boundary.
B_{22}	33-70	Dark reddish brown (2.5 YR 2.5 7/4) gravelly clay; moderate coarse sub-angular blocky structure; moist very firm, wet, very sticky and very plastic; moderate to slow permeability; diffuse wavy boundary.
B_3	70-150+	Red 10 R 3/4, gravelly clay; moderate coarse sub-angular blocky structure; moist very firm, wet, very sticky and very plastic; medium roots few; very slow permeability; very compact layer.

PHYSICO - CHEMICAL CHARACTERISTICS, GENESIS AND CLASSIFICATION OF SOILS FROM FOREST ECOSYSTEMS IN KERALA

By

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ABSTRACT OF THE THESIS

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ABSTRACT

A study was conducted to evaluate the morphological, physical and chemical characteristics of soil representing different forest ecosystems in Kerala. Six soil profiles representing predominent vegetation types of Kerala, were selected for the study. The study areas were representative of the tropical evergreen, semi evergreen, moist deciduous, grasslands, hill top evergreen and dry deciduous types of forests. Profiles were excavated in these areas and detailed morphological studies of the soils were carried out. Soil samples representing the different horizons were collected for laboratory characterisation. The interrelationships of various physico-chemical characteristics and the distribution of iron and phosphorus fractions in soils were studied with a view to relate these characteristics to the genesis of the soils. Based on the available data attempts have also been made to classify the soils under soil taxonomy.

The surface soils from all the profiles were rich in organic matter and had darker colours, ranging from greyish brown to brown. Increasing redness in the subsurface horizon though noticed in all the soils, was a conspicuous feature observed in the soils from the dry deciduous forests.

Weak granular structure in the surface followed by subangular blocky structure in the subsurface layers was a feature common to all the soils. Coarse fragments, mostly in the form of secondary laterite gravel constituted a major portion of the soils under investigation. Wide variations in texture was observed between the soils from various ecosystems. Increase in clay content with depth was another feature observed in all the soils. Silt was the lowest, among the various size fractions. Positive and significant correlation was obtained between moisture at 0.3 and 15 bar with clay, while available water and clay showed a positive but nonsignificant correlation. The maximum water holding capacity and volume expansion were found to be closely related to the nature and content of clay and organic matter. The soils under dry deciduous forests registered the highest volume expansion and maximum water holding capacity.

All the soils under investigation were found to be acidic in reaction. Organic carbon, nitrogen and C/N ratios were high in the surface horizons with decreasing profile trends in soils from most of the locations. Silica constituted the predominant constituent in all the soils followed by Al_2O_3. Iron oxide content was less than Al_2O_3

and showed a positive correlation with clay. The total reserves of MgO, CaO, K_2O and P_2O_5 were low as is expected of humid tropical soils.

The CEC was low as is expected of highly weathered tropical soils. The CEC determined by the sum of cations methods recorded higher values as compared to ammonium acetate method. The exchange acidity recorded higher values and did not reveal much variations within the soil profile and also between locations. The moist deciduous soils with the highest organic carbon content had the highest exchange acidity and the soil from the dry deciduous forests recorded lower values for exchange acidity. The percentage base saturation recorded for dry deciduous soils was also the highest among the soils investigated. The exchange complex was predominantly occupied by the exchangeable Ca and Mg. The exchangeable cations were in the order Ca $>$ Mg $>$ K $>$ Na for soils from semi evergreen, moist deciduous and dry deciduous forests, while in the case of tropical evergreen, grasslands and hill top evergreen, the exchangeable sodium showed a slight increase over exchangeable potassium. Greater accumulation of bases was also observed in the upper horizons of all the profiles. The percentage base saturation was calculated by using CEC_s and NH_4OAc methods. The percentage base saturation showed higher values in the surface in tropical evergreen, moist deciduous, grasslands and hill top evergreen.

The dithionite extractable iron (Fe_d) constituted the major portion of the total iron in all the soils under investigation. Positive and significant correlation was obtained between total Fe and Fe_d. Accumulation of Fe_d was noticed in the subsurface horizons of the profiles. Based on the degree of freeness of iron in soils, the grasslands were the most weathered, followed by semi evergreen, hill top evergreen, tropical evergreen and the least weathered, the moist deciduous. An interesting observation was the outstanding influence of iron oxides in soil colour which was clearly brought out by increasing redness down the profile, following the distribution of iron oxides. Very low values were observed for the Fe_o and the active iron ratio (Fe_o/Fe_d) for all the soils under investigation.

Among the active inorganic P fractions, Fe-P formed the dominant constituent in all the soils indicating the highly weathered nature of the soil. Based on the contents of Ca-P, grasslands were the most mature followed by hill top evergreen, moist deciduous, tropical evergreen, semi evergreen and dry deciduous. The ratio of $\frac{Fe\text{-}P + Al\text{-}P}{Ca\text{-}P}$ had been worked out as indicator of the degree of weathering of soils and judged from this, the soils from the grasslands were more mature than those from dry deciduous forests.

Silica formed the dominant constituent of the clay fraction. Judged from the SiO_2/Al_2O_3 ratio of clay fraction, most of the soils under investigation belonged to ferrallitic group.

Based on the available data, the soils have been classified under soil taxonomy upto sub group level. Pedons I, III, IV and VI have been classified at Typic Haplohumults, Pedon II as Typic Humitropepts and Pedon V as Oxic Humitropepts.