CHARACTERISATION OF LATERITE SOILS FROM DIFFERENT PARENT MATERIALS IN KERALA

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Characterisation of laterite soils from different parent materials 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.

Vellanikkara,
28th April, 1987.

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CERTIFICATE

Certified that this thesis entitled "Characterisation of laterite soils from different parent materials in Kerala" is a record of research work done independently by Kum. Stella Jacob, 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.

Dr. V.K. Venugopal,
Chairman,
Advisory Committee

CERTIFICATE

We, the under signed, members of the Advisory Committee of Kum. Stella Jacob, a candidate for the degree of Master of Science in Agriculture with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled "Characterisation of laterite soils from different parent materials in Kerala" may be submitted by Kum. Stella Jacob in partial fulfilment of the requirement for the degree.

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INTRODUCTION

The demands of modern agrotechnology require scientific information of soils. In the context of increasing pressure of population on land, there is need for maximising production per unit area per unit time to meet the growing needs of the population. Soil management strategies must therefore be planned in such a way that the use of soils is not only to furnish immediate needs but also to ensure its ability to sustain food production in the years to come without impairing its fertility.

Basic studies on soils of the tropics have not received the kind of priority it deserves and hence we are forced to apply many concepts and practices of temperate zones to tropical regions. Agronomic trials are often wasted for want of information on soils as they can not be extrapolated too readily beyond the areas where the work is done because of the wide diversity of soils.

The high rainfall and temperature conditions of Kerala state are conducive for the laterisation process leading to the development of highly weathered, leached and infertile soils. Laterite soils cover nearly 60 per cent of the total area of the State occupying the mid-land and mid-upland regions. The alarming rate at which forest cover is removed for cultivation and other purposes has accelerated the process of laterisation further aggravating the problem. The high density of cultivation practised in the area outlines the need for indepth characterisation of these soils for their continuous and intense use efficiently.

Eversince Buchanan (1807) located the laterite formation in the type area at Angadipuram, studies on various aspects of laterite soil have been carried out by several workers. Gopalaswamy (1969), Hassan (1977), Lorenz (1978), Venugopal (1980) and Varghese (1981), Mallikarjuna et al (1979) and Nambiar et al. (1979) have also carried out geochemical investigation on the composition of rocks in relation to laterite from various locations in Kerala. However, indepth studies on laterite soils derived from different parent materials have not been carried out. The present investigation was therefore planned to characterise these extensive and agriculturally important soils particularly in relation to the parent rock. The study envisaged the following aspects.

1. Macromorphological features of the soil profiles
2. Physico-chemical characteristics of soils
3. Behaviour of iron and phosphorus fractions in relation to genesis of soils
4. Mineral assemblage of fine sand fraction
5. Chemical composition of clay fraction
6. Classification of soils under soil taxonomy

It is hoped that the study will provide adequate information and aid in exploring newer avenues in soil management to fully exploit the potentials of these soils for sustained production.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

In this chapter an attempt is made to review in a systematic manner, the work carried out till recently, on various physico-chemical characteristics of soils of the tropics, particularly the laterite soils.

1. Location and distribution

The location and distribution of laterite materials, according to Persons (1970) have been associated with temperature and rainfall conditions that characterise the earth's surface between latitudes 35°N and 35°S. In addition to those places where they have been found, they may also be expected at locations where, though they have not yet been discovered, there are environmental conditions suitable for their formation. The world distribution of laterites would therefore show areas of known laterite soil occurrence and areas where laterization process can be expected to take place.

2. Definition and nomenclature

The study of laterite has been engaging the attention of geologists and other scientists, the world over ever since Buchanan (1807) reported its occurrence in the type area at Angadipuram in Kerala. Attempts to restrict the term laterite to in-situ hardened and soft materials that harden on exposure also failed, when Blanford (1859) and Harrison (1910) respectively reported the hardening of lithomarge and red sesquioxide - poor materials. The problem became further complicated when it appeared that the reliance on the criterion of hardening alone could lead to such terms as "ferruginous", "siliceous" and "calcareous" laterite to describe various forms of the material.

Fermor (1911) abandoned the criterion of physical hardness of laterite in its natural state or on exposure, and developed a comprehensive system of nomenclature of laterite soils on the basis of their chemical composition. He defined various forms of laterites on the basis of relative contents of so called laterite constituents (Fe, Al, Ti and Mn) in relation to silica.

Martin and Doyne (1927) put forth the chemical definition of laterite and related soils based on the silica/alumina ratios of clay fractions. According to them, soils in which this ratio was less than 1.33 might be called laterite soils; ratios between 1.33 - 2.00

indicated lateritic soils and ratios above 2.0, non-lateritic soils.

Pendleton and Sharasuvena (1946) defined "laterite" soils as profiles in which a laterite horizon was found and "lateritic soils" as were in which there was an immature laterite horizon from which a true laterite horizon would develop if appropriate conditions prevailed long enough.

Alexander and Cady (1962) summarised the morphological, physical and chemical concepts proposed by various researchers. According to these workers laterite is a highly weathered material, rich in secondary oxides of iron, aluminium or both. It is nearly void of bases and primary silicates, but it may contain large amounts of quartz and kaolinite. It is either hard or capable of hardening on exposure to wetting and drying. The hardening process mainly consisted of crystallisation of amorphous oxides and dehydration.

Several terms have been coined by various workers for different soils which show resemblance to Buchanan's laterite. Thus ferruginous crusts (Alexander and Cady, 1962), indurated horizon (Maignien, 1966) and petroplinthite (Sys, 1968) all resemble Buchanan's laterite and are found in the diagnostic horizon.

3. Parent material in relation to genesis of laterites

Clare (1957) genetically grouped tropically weathered soils according to the nature of the parent rock and weathering conditions. When the parent material has high silica content and the soluble weathering products are removed, the parent silica is chemically stable and therefore remains as quartz particles. This soil is generally sandy or gravelly. However, if the weathering products are non-soluble and remain, as residual material rich in iron and aluminium oxides, they give rise to brightly coloured, fine grained soils as well as nodular lateritic gravels or cemented lateritic soils.

According to Satynarayana and Thomas (1961) the laterite that was quarried extensively in Malabar had originated from both gneissic and basaltic rocks of suitable composition. Climate and drainage played an important role in bringing out characteristic lateritic morphology.

Stephens (1961) reported that the laterites from the type locality in Angadipuram consisted of mottled vesicular, indurated horizon under red earths and developed from gneiss.

Sivarajasingham et al. (1962) observed that the laterite could be formed over a variety of parent rocks ranging from basic rocks like basalt and diorite on one side to acid rocks like granite and gneiss on the other.

In general, it would appear that the processes of laterization are more intense and more widespread on basic rocks than on quartz-rich acid rocks, but these tendencies are masked by other factors, especially geography and temperature. Indurated and soft laterite soils have been reported on such rocks as granites, gneiss and schists, thus showing that laterite soils may develop on all rocks containing aluminosilicate minerals (Brammer, 1962).

Hamilton (1964) and Dowling (1966) observed laterite soils in alluvia and colluvia and it appeared that whatever be the source materials in which laterite soils developed an adequate supply of sesquioxides was essential.

Maignien (1966) showed that laterite materials might develop on variety of parent materials provided there was a source of iron either in the parent material or in adjacent high-lying areas from which water might introduce sesquioxide to the low lying pre-existing deposits. As regards aluminous laterite materials, it appeared that though the indurated formations were strictly related to the process of laterization, they might correspond to specific conditions of the medium, like accelerated drainage, deionization and intense desilication. Only under these conditions could gibbsite form, which was the most constant constituent of aluminous laterite.

Buringh (1970) stated that acid parent material resulted in the formation of kaolinite whereas the basic materials resulted in gibbsite and iron content of parent material largely determined the sesquioxide content.

Mallikarjuna et al. (1979) studied the composition of laterite and parent rock from different regions of Kerala and observed that the residual profiles over crystalline rock were much more mature than those from sediments.

Greenland (1981) reported that the tropical red earths and latosols were highly weathered to the extent that the clay fraction consisted almost entirely of kaolinite and oxides of iron and aluminium. However, the influence of original parent material often appeared to persist in relation to physical and chemical properties.

According to Narayanaswamy and Ghosh (1985), the laterization processes of gabbro and granophyre rocks in Kerala were similar. Kaolinite was the first clay mineral to form in the process which on further desilication gave rise to gibbsite. The more the content of mobile elements in the parent rock, the faster the depletion during weathering and relative enrichment of less mobile elements was more if their content was less in parent rock.

4. Morphological characteristics

Bremmer (1962) and Ahn (1970) gave a thorough discussion on the influence of topographic site and drainage conditions on the colour variations of laterite soils. Upland, well-drained soils were frequently reddish to reddish brown or brownish red, occasionally very bright red or purplish red. These red colours denoted the presence of a non-hydrated iron oxide haematite in the soil. In the middle and lower-slope soils, drainage was little poorer than in the upper slope and summit soils. The hydrated iron oxides in these soils were mainly goethite and limonite, and their presence was responsible for the change in colour from reddish brown to warm brown or orange brown and then to yellowish brown or even brownish yellow. The colours typical of reducing conditions in soils were the bluish greys and greenish greys and neutral greys of valley-bottom soils. These colours suggested prolonged waterlogging. Where the waterlogging was intermittent or seasonal, as in that part of the profile where water table fluctuated instead of uniform grey colour, mottles were likely to be produced. These colour variations of laterite soils with local topography were a useful guide in soil identification.

According to Sivarajasingham et al. (1962), concretions were formed by successive deposition of sesquioxide films develop at the near-surface horizons, while concretion consisting of altered rock debris impregnated by ferruginous solutions occurred at greater depth.

Laterite crusts are also found on the surface, but such exposures are generally attributed to erosion. Laterite horizon may or may not be genetically related to the lower soil horizons. This layer may be red clays, detrital nodules or fragments from adjacent high lying landscape containing laterite relics of disintegrating laterite crust in which fresh soils are forming or units developing concurrently with modern soil or it may even be laterite rock or cuirasse (Ahn, 1970).

Venugopal (1980) studied the laterite catena in Kerala and reported a decrease in the chroma from crest to the valley in the case of Varkala and Poruvazhy toposequences. The surface soil colour of the upper midslope member was predominantly red. In the case of lower slope and valley profiles the colour tended to be greyish with depth in the profile.

According to Sathyanarayana and Thomas (1961) the colour of laterite soils depended on the content and form of iron hydroxide and oxides which imparted the yellow, pink, brown and red colours to the ground matrix and earthy clay.

Gopalaswamy (1969) reported that the different horizons in the laterite profile from Varkala belonging to the tertiary beds had no distinct variation in colour even upto a depth of 250 cm and recorded a constant hue of 5YR.

5. Physical properties

5.1 Bulk density and mechanical composition

Nair et al. (1966) in their studies on cultivated soils of Kerala found that the absolute specific gravity and apparent specific gravity appeared to be a function of coarser particles of soil while water holding capacity, pore space, volume of expansion and organic carbon were related to the finer particles of the soil both in quantity and quality.

Venugopal (1980) reported a bulk density range of 0.58 - 2.00 g/cm^3 for the red soil profiles in a study of lateritic catena in Varkala area of Kerala.

Varghese (1981) on a study of laterites showed the bulk density values to vary from 0.76 to 1.45 g/cm^3 from different regions of Kerala. In general, the bulk density was found to increase in subsurface horizons and lowest layer of most of the profiles was found to possess a lower bulk density than overlying horizons.

Satyanarayana (1968) reported a textural range between clayey and sandy for the red soils from various districts of Andhra Pradesh. The coarse sand fraction was negatively correlated with clay. Clay and silt contents were positively correlated.

Manickam (1977) reported a negative correlation with clay and silt contents of different laterite soils of Tamil Nadu.

Urego and Holmes (1977) observed that the soils from granite and gneiss had relatively higher proportions of coarse sand and clay and low contents of silt reflecting the predominance of quartz and feldspar in their parent materials.

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

Thulaseedharan (1983) reported in the case of laterite soils of Kerala, that most of the available water was removed at a tension less than three bars. More than 50 per cent of the available water occurred at this tension. Organic carbon was found to have no bearing on the moisture retention at various tensions. The content of clay showed significant positive correlation with moisture content of fine earth fractions at various tensions ranging from 0.3 bar to 15 bars. The effect of silt was significant and positive at tensions higher than three bars only. Significant negative correlation was obtained between the contents of coarse fractions (fine and coarse sand) and moisture retention at different tensions.

Bastin (1985) observed a positive correlation between moisture retention at 1, 2, 5 and 15 bars and clay content in red soils from different regions of Kerala. Highly significant positive correlation was obtained between clay and 15 bar moisture ($r = 0.590^{**}$).

6. Total chemical composition

Manickam (1977) observed the silica content in surface layers of laterite soils of Tamil Nadu to be 80 per cent which however decreased with depth in most of the profile while others showed no definite trend in variation with depth.

Similar observation in the content of silica and distribution in the profile with depth have been reported in the red soils of Kerala by Bastin (1985).

Venugopal (1980) found the Fe_2O_3 content of soil profiles of Varkala toposequence to range between 1.16 per cent and 10.93 per cent. The Al_2O_3 content varied from 3.13 to 25.28 per cent.

Bhattacharya et al. (1983) investigating the red soils of Karnataka derived from granite gneiss attributed higher values of total Fe_2O_3 at lower depths of soil to pedogenic factors. The total iron content varied from 7.2 to 29.0 per cent.

Bastin (1985) observed the organic carbon content of red soils of Kerala to range between 0.17 to 0.742 per cent and noted a steady decrease in organic carbon content with depth in the profile.

Raguraj (1981) reported a decrease in total N with depth in the case of laterite soil profiles of Madurai.

Koshy and Britemuthunayagam (1961) found the level of total phosphorus of soil profiles of Kerala to vary from 0.024 to 0.256 per cent.

Halim *et al.* (1963) investigating the potassium status of the UAR soils found that total potassium varied between 2.5 me/100 g in coarse textured soils to 15 me/100 g in fine textured soils. The total potassium content was highly correlated with the clay percentage and exchangeable potassium.

Hassan (1977) observed that the calcium and magnesium status of laterite soils of Kerala were very poor both in the surface and subsurface layers of the soil profile. Total calcium increased with depth while magnesium showed a reverse trend.

Arunachalam and Mosi (1973) reported a positive correlation between total iron and organic matter content of soils.

Rajagopalan (1969) reported that the total manganese in Kerala soils ranged from 103.8 to 9500 ppm.

Balaguru and Mosi (1972) on a study of Tamil Nadu soils observed a positive correlation between manganese and finer fractions of the soil.

6.1 pH and cation exchange properties

Agarwal *et al.* (1957) in a study of catenary soils in the upper Vindhyan plateau found the cation exchange capacity to increase downslope with increase in clay content, but the rate of increase was much more than what could be expected from the amount of clay.

Satyanarayana and Thomas (1961) observed the CEC (NH_4OAc) of laterite soil of Angadipuram to vary from 4.5 - 5.8 me/100 g in the profile. The value for the profile from Kasaragod area was 2.5 - 7.0 me/100 g.

On a study of the red latosols of Srilanka, De Alwis and Pluth (1976) observed a CEC (NH_4OAc) value ranging from 2.6 - 4.2 me/100 g for Gambura series while for Wilpattu series the value varied from 1.7 - 2.6 me/100 g.

Ghabru and Ghosh (1985) reported a CEC range of 10 - 22 me/100 g soil with Ca^{2+} as the dominant exchangeable cation in two soil profiles from Dhauladhar range of middle Siwaliks.

Venugopal and Koshy (1976) observed that the red soils of Kerala State were poor in exchangeable bases. The occurrence of bases decreased in the order of calcium > magnesium > potassium > sodium. The cation exchange capacity ranged from 1.62 me/100 g for laterite soils. In laterite profiles, calcium formed the predominant exchangeable base followed by magnesium.

Profile analysis of selected Oxisols and Ultisols of South America by Sanchez (1981) revealed that the Oxisols and Ultisols showed extremely low pH values throughout the profile (3.7 to 5.9 in 1:1 soil water ratio), moderate soil organic matter contents, high levels of exchangeable aluminium (0.2 to 11.6 mg/100 g), low levels of exchangeable calcium, magnesium and potassium and a low effective cation exchange capacity due to the low activity clays and a high proportion of the exchange sites saturated by aluminium (3 to 98 per cent).

6.2 Iron fractions and active iron ratio of soils

Blume and Schwertmann (1969) reported that the iron, aluminium and manganese were greatly affected by the processes of soil profile genesis.

Juo *et al*. (1974) observed 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 0.20per cent, which comprised less than 10 per cent of the total free iron oxides.

Daniels *et al.* (1975) postulated that the water table history and related oxidation reduction regime of each site was believed to be the major factor controlling extractable iron.

Schwertmann and Taylor (1977) reported that the solubility of iron in ammonium oxalate solution expressed as the active iron ratio, Fe_o/Fe_d was usually interpreted as indicating the degree of crystallinity of iron oxides in the samples.

Decrease in the active iron ratio with depth in the profile was observed by Juo (1981) in soils of West Africa and was indicative of the greater crystallinity of iron oxides in the subsurface horizons.

Bhattacharya *et al.* (1983) reported that the citrate bicarbonate dithionite extractable iron content in red soils of Karnataka derived from granite gneiss ranged from 0.88 to 4.37 per cent and constituted 20.6 to 73.7 per cent of the total iron content.

Arduino *et al.* (1984) reported that the relative age of soil could be estimated from the amount of iron, extractable 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.

Arduino *et al.* (1986) working on soils of northern Italy observed increase in the Fe_d/Fe_t and Fe_d-Fe_o/Fe_t ratios with age of the terrace. Further the mineralogy of the clay showed dominance of 2:1 minerals in the younger profile and abundance of kaolinite in soils from older terraces.

6.3 Phosphorus fractions

Many workers utilized the distribution pattern of forms of P as an indicator of intensity of soil weathering and development.

Chang and Jackson (1958) postulated that in the course 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. In two latosols 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%).

Smeck (1973) contemplated minimum contents of Ca-P in soils of advanced weathering and age. Higher contents of Al-P in relation to other fractions indicated less advanced state of weathering.

Juo and Ellis (1968) provided evidence to support 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. As they were formed, there was a tendency for them to become associated with clay fraction, because of its large surface area.

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

Williams and Walker (1969) and Smeck (1973) 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 change with soil profile development, form of P also change. Generally as pH drops with development, relatively soluble form of P decreases and occluded form increases. Consequently, relative quantities of P forms can serve as a measure of soil development (Smeck, 1973).

Walker and Syers (1976) reported that the transformation and losses of P during pedogenesis would be influenced by the nature of the phosphorus in the parent material.

7. Mineralogy of fine sand

From the mineralogical study of rock and fine sand fractions of Vindhyan soils of Mirzapur, Singh and Gangwar (1971) concluded that these soils were of residual nature. The soils of Chopan and Dudhi representing the lower Vindhyan systems were formed from different types of metamorphic, sedimentary and igneous rocks. Quartz constituted the major fraction of the fine sand of most of these soils.

Sarkar and Raj (1973) carried out mineralogical studies on the fine sand fractions of some soils of South India and observed that the minerals were generally in conformity to the parent rock. Iron bearing minerals were appreciably high in laterite with limonite being characteristic of low level laterites. Zircon was invariably present in all soil groups.

Mineralogical analysis of fine sand fractions from red latosols of SriLanka confirmed that parent materials were uniform with depth and within the series but different among the series. The near complete absence of weatherable minerals indicated intense weathering either before deposition or during soil formation (De Alwis and Pluth, 1976).

Manickam (1977) working on the laterite soils of Tamil Nadu observed quartz as the dominant mineral in the light mineral suite. In the heavy fraction haematite was predominant followed by limonite and zircon.

Rengaswamy et al. (1978) studying the relationship between geomorphology, climatic history and formation of ferruginous soils of Mysore observed that the sand fraction reflected the nature of the parent rock viz., Archean gneiss. The sand fraction of the ferruginous layers had considerable amounts of haematite.

Murali et al. (1978) reported qualitative agreement between the mineralogy of rock samples and sand fractions of soils derived from them in two toposequences in southern India. The light fraction was dominated by quartz and some feldspars. The heavy minerals consisted mainly of biotite and magnetite.

Venugopal (1980) reported a predominance of quartz in light mineral fraction of the laterite soils of Kerala. The heavy mineral suite consisted of ilmenite leucoxene, haematite, zircon, rutile and sillimanite.

8. Chemical characteristics of clay fraction

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

Iyer (1979) reported that silica contents of red soil clays varied from 31.41 to 32.33 at Varkala, 33.33 to 35.11 per cent at Pilicode and 33.90to 36.20 per cent at Patchalloor.

Lissonite (1960) used the silica sesquioxide ratios for characterising the clays from red earths of Italy and found the values to range from 1.60 to 2.09.

Bouma and Schuylenborgh (1969) reported that when applied to soil clays, the usefulness of the ratios like SiO_2/R_2O_3, SiO_2/Al_2O_3 had met with varying degrees of acceptance. They appeared to be more relevant as an index of pedogenic processess. 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) studying the physical and chemical properties of Tamil Nadu soils reported a SiO_2/R_2O_3 ratio of 1.97 for red soils and 1.23 for laterites. Significant positive correlation was obtained between clay content and SiO_2/R_2O_3.

Manickam (1977) working on laterite soils of Tamil Nadu 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.

Bigham _et al_. (1978) reported that amounts of iron, aluminium and especially silicon extracted with acid ammonium oxalate were selective for amorphous iron compounds. It was observed that only less than seven per cent of the free iron in these clays occurred in noncrystalline form or disordered state. The dithionite - citrate bicarbonate extractable iron contents of dark red Ustox and red yellow Ustox were 10.83 and 14.17 per cent respectively.

Greenland (1981) was of the view that the free iron oxides of the clay fractions of humid tropics acted as cementing agents, stabilising their porosity and these soils possessed free drainage characteristics.

Eswaran (1983) observed that many soils of the tropics were dominated by low activity clays and had effective cation exchange capacity of less than 12 me/100 g soil, if soil pH was less than 6.5 and had CEC less than 16 me/100 g clay in 1N NH_4OAc at pH 7. Some of these low activity soils were Oxisols while others were Ultisols and Alfisols and even Inceptisols and Mollisols.

9. Taxonomy of laterites

In earlier classification systems of many countries, most Oxisols were called latosol. This term was coined to designate all "zonal soils having their dominant characteristics with low silica sesquioxide ratio, low base exchange capacity, low activity of clays and low content of weatherable minerals (Kellogg, 1949).

Maignien (1966) and Sys (1968) indicated that the laterite soil could come under either Oxisols, Alfisols, Ultisols or Inceptisols of comprehensive system of classification.

Manickam (1977) grouped the east coast laterites of Tamil Nadu into Oxisols, Alfisols and Ultisols. He has further reported that the most of the soils studied could be brought under petroplinthite subgroup.

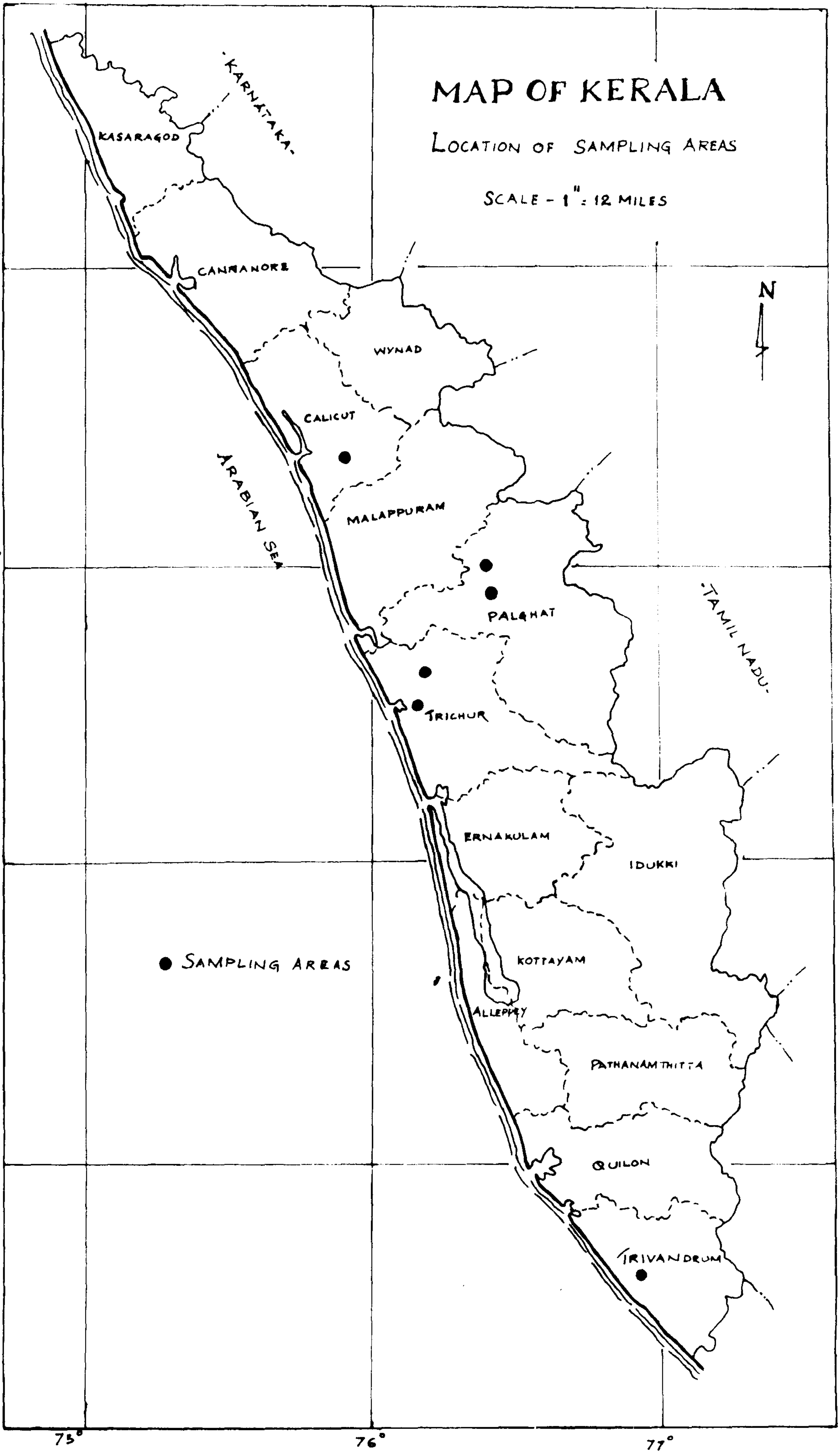
MATERIALS AND METHODS

MATERIALS AND METHODS

The investigation carried out in the present study relates mainly to six laterite soil series from different parent materials of Kerala identified using soil maps prepared by the Soil Survey Unit of the Department of Agriculture, Kerala State. The areas selected for the study are indicated in the map.

1. Field studies

The sampling areas were selected after survey of laterite areas and identification of the parent rock. The soil series mapped in the area was then identified from the soil map. Profile pits were dug in the typical areas and morphological features were observed and recorded as per the Soil Survey Manual (AISLUSO, 1970). The salient features of the areas in respect of location, physiography, drainage, vegetation and land use were also recorded. The morphological descriptions of profiles are presented in Appendix.1. The abbreviated morphology of the soil profiles is given in Table 3.


MAP OF KERALA
LOCATION OF SAMPLING AREAS
SCALE - 1": 12 MILES
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KARNATAKA
KASARAGOD
CANNANORE
WYNAD
CALICUT
MALAPPURAM
ARABIAN SEA
PALGHAT
TAMIL NADU
TRICHUR
ERNAKULAM
IDUKKI
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ALLEPPEY
PATHANAMTHITTA
QUILON
TRIVANDRUM
SAMPLING AREAS
12°
11°
10°
9°
75°
76°
77°

1.1 Sample collection

After morphological examination of the profiles, soil samples representing the different horizons in a profile were collected for laboratory examination. Core samples were also collected from each horizon for determination of bulk density. The particulars of samples collected are presented in Table 1. Rock samples and laterites from adjacent quarries were also collected from different locations for laboratory characterisation.

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 as well as the gravel were utilised for further studies separately. The hard laterites were ground in a mortar and passed through 0.15 mm sieve. The rock samples were ground in a pulveriser and passed through 100 mesh sieve. The powdered samples were utilized for further analysis.

2.2 Physical properties

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

Table 1. Details of profile samples collected

Profile No.	Soil series	Location (district)	Sample No.	Horizon	Depth (cm)
I	Thonnackal	Trivandrum	1	AP	0-14
			2	A3	14-30
			3	B2	30-57
			4	B22	57-90
			5	B23	90-180+
II	Kootala	Trichur	6	AP	0-13
			7	B1	13-53
			8	B21	53-110
			9	B22	110-180+
III	Anjur	Trichur	10	AP	0-13
			11	B1	13-40
			12	B22	40-90
			13	B23	90-160+
IV	Kanjikulam	Palghat	14	AP	0-10
			15	B1	10-48
			16	B22	48-96
			17	B23	96-145+
V	Mannur	Palghat	18	AP	0-10
			19	A3	10-21
			20	B1	21-50
			21	B22	50-110
			22	B23	110-180+
VI	Nenmanda	Calicut	23	AP	0-14
			24	B1	14-36
			25	B22	36-98
			26	B23	98-150+

density was determined by the core method outlined by Dakshinamurthi and Gupta (1968). Moisture retention studies were carried out in a pressure plate apparatus using ceramic plates (Richards, 1954). Water dispersible clay was estimated by the pipette method after dispersion using a mechanical stirrer.

3. Chemical properties

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

3.1 Analysis of profile samples

Soil reaction was determined in 1:1 soil water and 1N KCl suspension using a Systronic pH meter. Electrical conductivity was determined in 1:2 soil water suspension using Elico conductivity meter. Organic carbon was determined by Walkley and Black method and total nitrogen by semi-micro-Kjeldahl method (Soil Survey Staff, 1967).

Total SiO_2, Al_2O_3, Fe_2O_3, TiO_2, MnO_2, P_2O_5, K_2O, CaO and MgO were determined in the perchloric-nitric acid (1:2) extracts (Hesse, 1971). Total SiO_2 was determined gravimetrically. Total iron and aluminium were determined by o-phenanthroline and xylenol orange method respectively while total CaO and MgO were estimated by EDTA method as outlined by Hesse (1971). Total P_2O_5 content was estimated by vanadophosphoric yellow colour method (Jackson, 1958), total potassium by flame photometry using an EEL flame photometer and total MnO_2 by atomic absorption spectrophotometry.

Cation exchange capacity was determined by the NH_4OAc method and also by sum of bases (NH_4OAc) and exchangeable acidity was determined using $BaCl_2$ - TEA (Soil Survey Staff, 1967). Exchangeable potassium and sodium were read using EEL flame photometer (Jackson, 1958). Exchangeable calcium and magnesium in the neutral 1N NH_4OAc extract were estimated by EDTA titration method (Hesse, 1971).

Free iron oxide was extracted using dithionite citrate-bicarbonate method (Mehra and Jackson, 1960). Amorphous iron oxide was extracted using ammonium oxalate (Schwertmann, 1964). Iron was determined by the o-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 Analysis of gravel, laterite and rock samples

Total chemical analysis of powdered gravel, laterite and rock samples were carried out in 1:2 perchloric-nitric acid extracts by the same method outlined under soils.

3.3 Separation and analysis of clay fraction

The clay fraction of samples was separated by the method suggested by Jackson (1975).

Total SiO_2, Al_2O_3, Fe_2O_3 and free iron oxide fractions of clay were determined in the sodium carbonate fusion extract as outlined by Hanna (1964) adopting the methods mentioned earlier.

4.1 Petrographic study of rocks and fine sand fractions of soils

Thin sections of rocks were prepared and minerals identified under a polarising microscope by the methods described by Kerr (1977).

The sand fractions of the soils were separated by sedimentation during mechanical analysis, and treated with $SnCl_2$ to remove iron oxide coatings. The dried samples were separated to heavy and light minerals suites using bromoform of specific gravity 2.8 (Carver, 1971). The heavy and light fractions were sampled by cone and quartering and mounted as a microscopic slide using Canada balsam outlined by Krumbein and Pettijohn (1938). Identification of minerals was carried out using a petrologic microscope and quantified by the counting method described by Carver (1971).

5. 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 student's 't' test.

RESULTS

RESULTS

1. Environmental factors influencing the study areas

1.1 Climate

Climatic water balances of four representative stations viz., Trivandrum, Vellanikkara (Trichur), Palghat and Calicut are computed and depicted in Fig. 1 to 4. The potential evapo-transpiration (PET) was calculated following Thornthwaite (1948). Water balances were computed following the revised budgeting technique of Thornthwaite and Mather (1955). A field capacity of 250 mm was assumed for all the stations.

As seen from the figures, in all the stations, the variation in PET was comparatively small. It was seen that there were two peaks of rainfall, the second one occurring in October in all the four stations. At Palghat and Vellanikkara, the first peak occurred in July whereas at Trivandrum, it was in June. At Calicut both June and July receive high amounts of rainfall. At Trivandrum, rainfall increased from March onwards and by the end of first week of May it balanced the PET. Then onwards, it was always higher than PET till the middle of December except in the second fortnight of September. Field capacity was

FIG. (1). CLIMATIC WATER BALANCE OF TRIVANDRUM

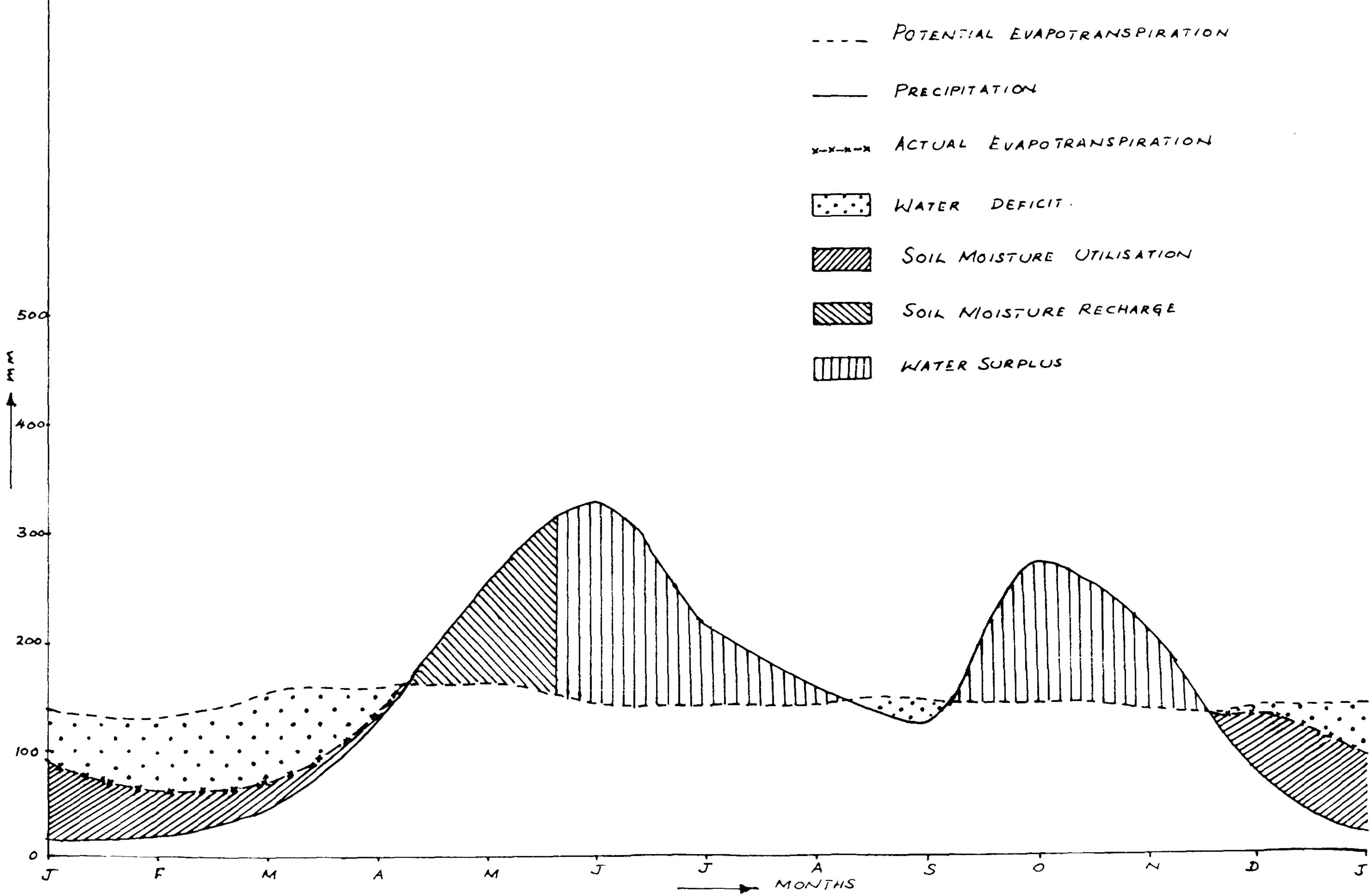
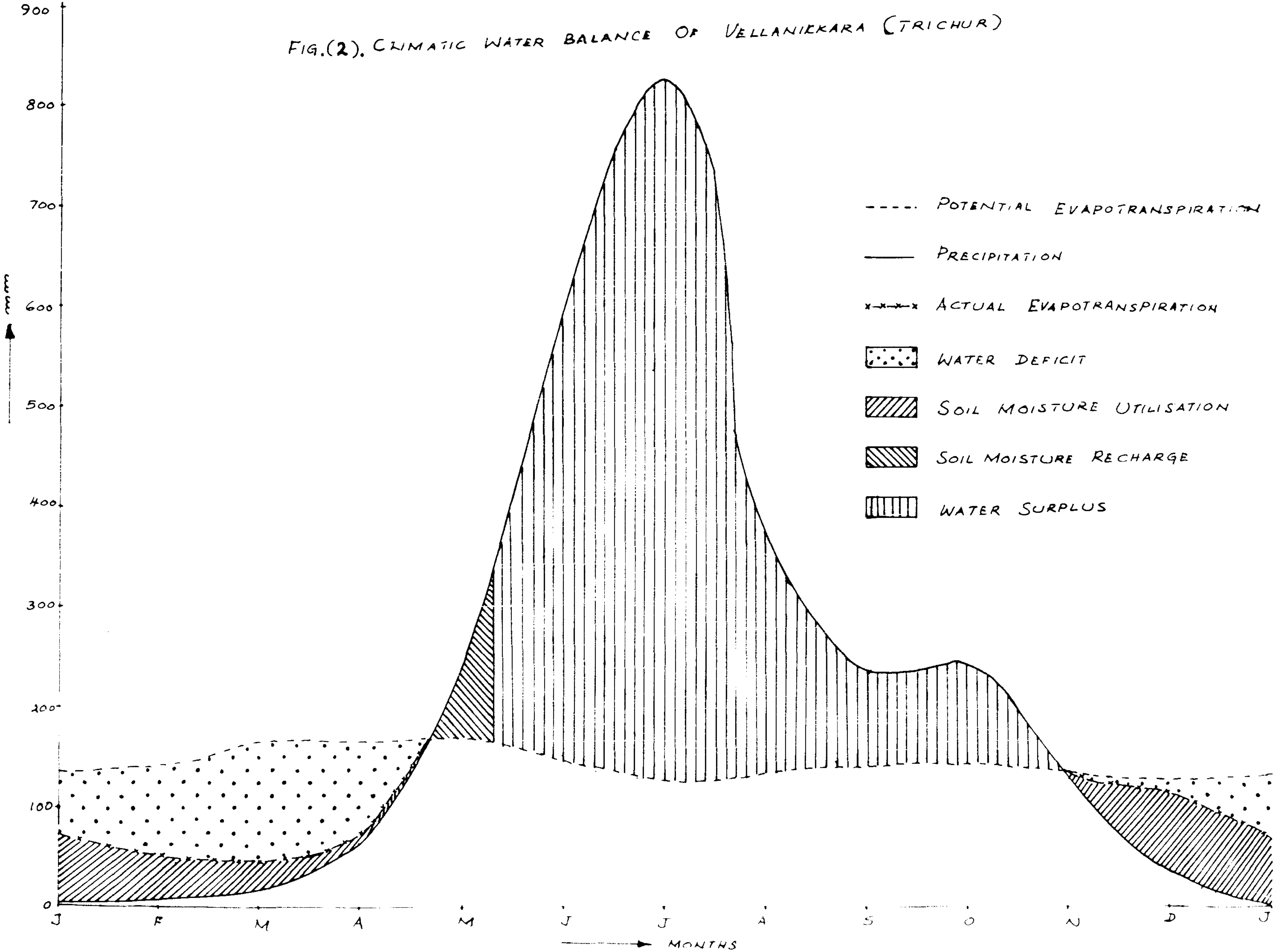


FIG.(2). CLIMATIC WATER BALANCE OF VELLANIKKARA (TRICHUR)



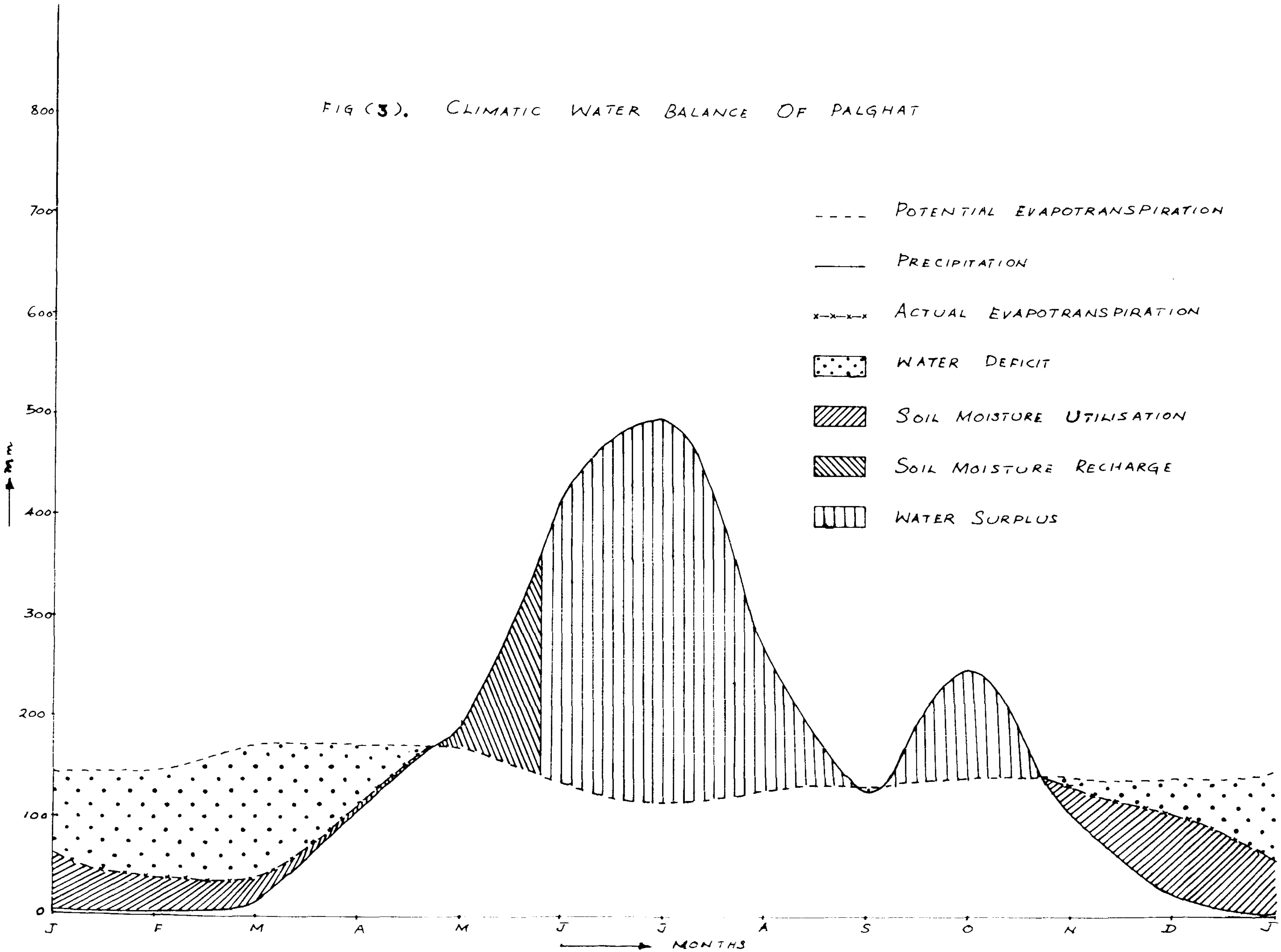
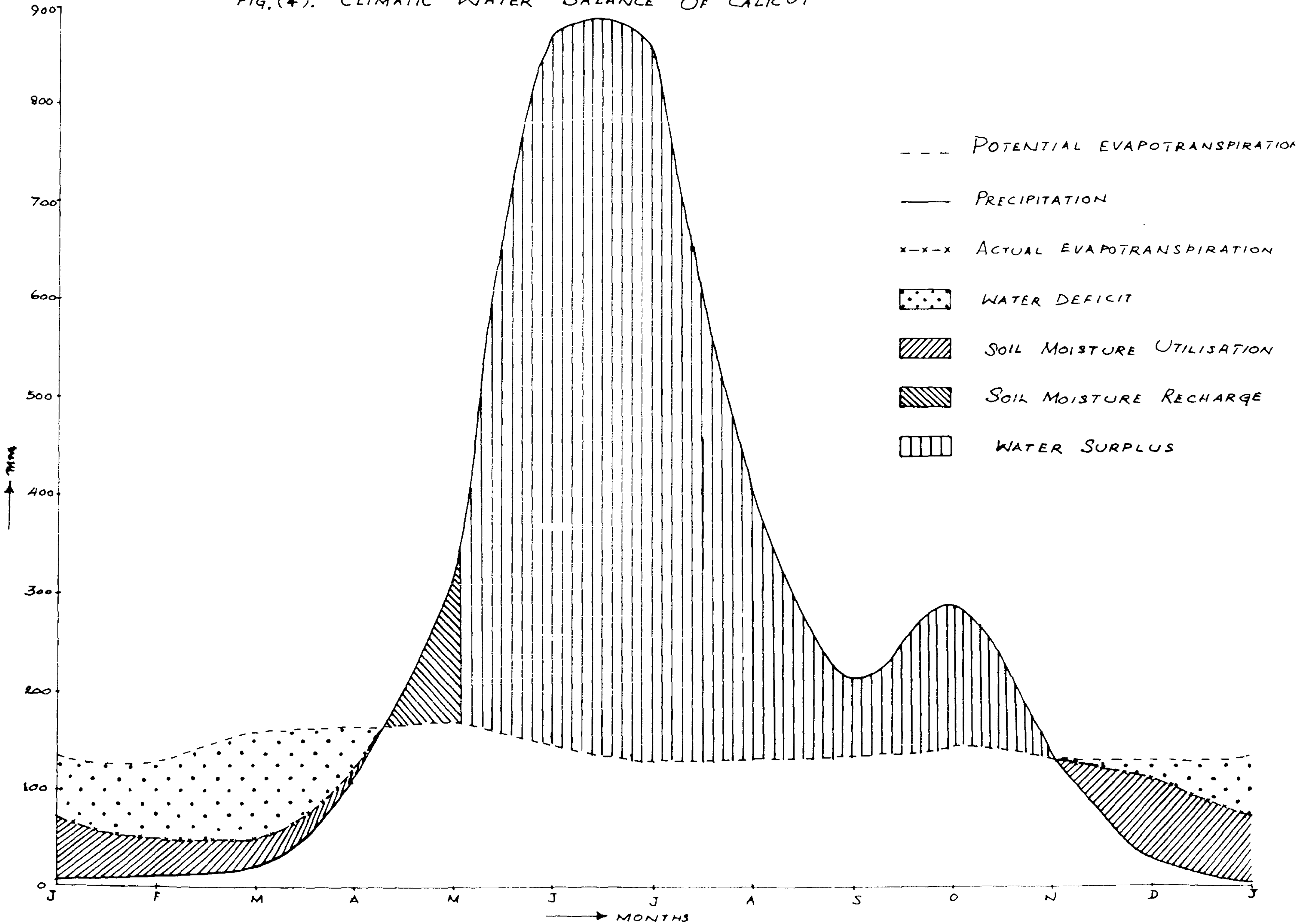


FIG (3). CLIMATIC WATER BALANCE OF PALGHAT
POTENTIAL EVAPOTRANSPIRATION
PRECIPITATION
ACTUAL EVAPOTRANSPIRATION
WATER DEFICIT
SOIL MOISTURE UTILISATION
SOIL MOISTURE RECHARGE
WATER SURPLUS
800
700
600
500
400
300
200
100
0
mm
J
F
M
A
M
J
J
A
S
O
N
D
J
MONTHS

FIG. (4). CLIMATIC WATER BALANCE OF CALICUT



attained by the third week of June and water surplus amounted to 366 mm. From middle of December upto May, rainfall was less than PET amounting to a water deficit of 234 mm.

At Vellanikkara, the rainfall increased from March onwards and by the end of third week of May, it balanced the PET. Then onwards it was always higher than PET till November. Field capacity was attained by the beginning of second week of June and water surplus amounted to 1501 mm. From November upto the end of third week of May, rainfall was less than PET amounting a water deficit of 375 mm.

At Palghat, the rainfall increased from March onwards and by the end of May, it balanced the PET. Then onwards it was always higher than PET, till the end of November. Field capacity was attained by the last week of June with water surplus of 732 mm. From the end of November upto May, the rainfall was less than PET amounting to a water deficit of 419 mm.

At Calicut, the rainfall increased from March onwards and by the beginning of May, it balanced the PET. Then it was always higher than PET, till the beginning of

December. Field capacity was attained by the beginning of June and the water surplus was 1885 mm. From the early December upto the beginning of May, the rainfall was less than PET with a water deficit of 327 mm.

1.2 Geology

The nature of the parent rock identified in the area and its mineralogy are given in Table 2.

Out of the six locations that were identified on the basis of parent material, five have been developed from residual rocks, while Thonnackal series identified in Trivandrum district has been derived from tertiary sediments viz., the Warkalli formation.

1.3 Agricultural land use

All the locations identified for the study formed part of the mid-land region of Kerala which was characterised by undulating terrain with hills and valleys. The crest of the hills and side slopes were predominantly cultivated with crops like coconut and cashew intercropped with tapioca, other annual root and vegetable crops, interspersed with fruit trees like jack, mango etc.

Table 2. Parent rock identified in the sampling sites

Profile No.	Location	Soil series	Rock type	Predominant minerals
I	Trivandrum (Pallipuram)	Thonnackal	*Tertiary sediments of Warkalli formation	Not sampled
II	Trichur (Alur)	Kootala	Hornblende-biotite-diopside granulite	Quartz, plagioclase, hornblende, diopside opaques
III	Trichur (Vellattanjur)	Anjur	Intermediate charnockite	Plagioclase, quartz, hyperstheme, biotite, opaques
IV	Palghat (Mundur)	Kanjikulam	Biotite gneiss	Quartz, microcline, perthite, biotite, opaques
V	Palghat (Mannur)	Mannur	Diopside granulite	Quartz, plagioclase, hornblende, diopside
VI	Calicut (Iringal)	Nenmanda	Hornblende-biotite gneiss	Quartz, plagioclase, hornblende (green), wollastonite

*The 'Warkalli formation' refer to the geological formations described by King (1882) in the type locality Varkala in Trivandrum district. Varkala was spelt as 'Warkalli' in the original paper.

2. Profile morphology

An abbreviated comparative morphology of the profiles is presented in Table 3 and the detailed morphological descriptions are presented in Appendix 1. Plates 1 to 8 present the feature of the area sampled for the study.

The colour of the soils is mostly in the hues 2.5 YR, 5 YR, 7.5 YR, 10 YR and 10 R. The values are 3, 4 and 5 and chroma 6 and 8. The Thonnackal series located in Trivandrum had yellowish brown surface soils tending to yellowish red in the subsurface layers. Yellowish red and reddish brown surface soils were observed in Nenmanda and Anjur series. In respect of all other soils, the colour was predominantly red. Another feature common to all soils investigated was an increase in redness in the subsurface layers compared to surface horizons.

The surface horizons of all the profiles showed a medium weak granular structure followed by medium to coarse subangular blocky in the lower horizons. Good structural development with depth in the profile was a feature common to all soils included under the study.

Coarse fragments (more than 2 mm fraction) was a predominant fraction of soil ranging from 7.97 per cent

Typical laterite land scape

Plate 1. Trichur - Kootala series

Plate 2. Calicut - Nenmanda series

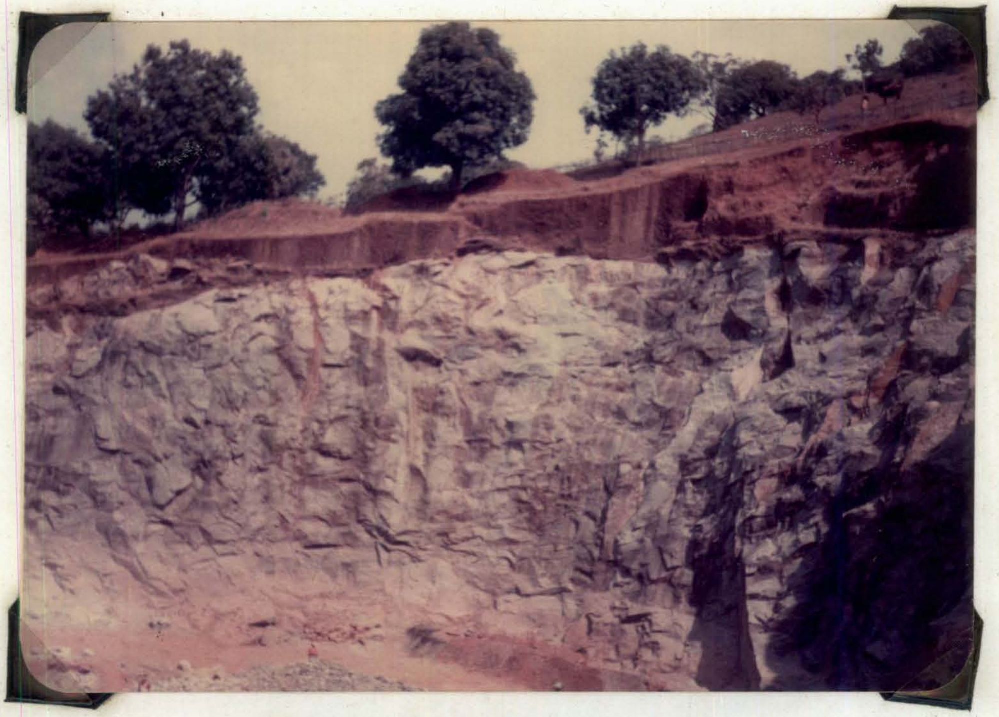


Plate 1

Plate 2

Plate 3. Laterite soils from tertiary sediments in Pallipuram, Trivandrum - Thonnackal series

Plate 4. Laterite soils from hornblende-biotite diopside-granulite, Trichur - Kootala series

Plate 3

Plate 4

Plate 5. Laterite soils from intermediate charnockite,
Trichur - Anjur series

Plate 6. Laterite soils from liotite-gneiss,
Palghat - Kanjikulam series

Plate 5

Plate 6

Plate 7. Diopside-granulite exposure in Palghat - Mannur series

Plate 8. Laterite soils from hornblende-biotite gneiss, Calicut - Nenmanda series

Plate 7

Plate 8

Table 3. Abbreviated morphological descriptions* of the soil profiles

Profile No. and series	Horizon and depth (cm)	Munsell colour dry	Munsell colour moist	Texture	Structure	Consistence	Boundary	Remarks
I. Thonnackal	AP 0-14	10YR 4/3	10YR 5/6	scl	$m_1$gr	mvfr,wso,wpo	cs	Soft mud like deposit with plenty of grass roots
	A3 14-30		10YR 5/6	gscl	$m_2$gr	mfr,wss,wpo	gs	Soft mud like deposit with increase in clay
	B21 30-57		7.5YR 5/6	gsc	$m_2$sbk	mfi,ws,wp	ds	Very dense layer with pisolithic gravel
	B22 57-90		5YR 5/6	gsc	$m_2$sbk	mfi,ws,wp	ds	Very dense layer with plenty of quartz gravel
	B23 90-180+		5YR 5/6	gsc	$c_2$sbk	mfi,ws,wp	-	Distinct to prominent 10 YR 5/8 and 2 YR 4/8 mottles plenty quarriable laterite
II. Kootala	AP 0-13		5YR 5/4	gc	$m_1$gr	mvfr,wso,wpo	cw	Gneissic boulders plenty
	B1 13-53		2.5YR 4/6	gc	$m_1$sbk	mfi,wss,wps	dw	-
	B21 53-110		2.5YR 4/6	gc	$m_2$sbk	mfi, wss, wps	dw	-
	B22 110-180+		5YR 5/8	gc	$c_2$sbk	mvfi,ws,wp	-	Faint to distinct mottles plenty
III. Anjur	AP 0-13		2.5YR 3/6	gc	$m_1$gr	mvfr,wss,wps	cs	Fine quartz gravel plenty
	B1 13-40		2.5YR 3/6	gsc	$m_1$sbk	mfi,ws,wp	gs	Very compact layer
	B22 40-90		2.5YR 4/6	gc	$c_2$sbk	mfi,ws, wp	dw	Few iron concretions
	B23 90-160+		10YR 4/6	gc	$m_2$sbk	mfi,ws,wp	-	Fine iron concretions plenty

(Contd.)

Table 3. (Contd.)

Profile No. and series	Horizon and depth (cm)	Munsell colour dry	Munsell colour Moist	Texture	Structure	Consistence	Boundary	Remarks
IV. Kanjikulam	AP 0-10	5YR 4/6	2.5 YR 4/6	gc	$m_1$gr	dl,mvfr,ws,wp	cs	
	B1 10-48		2.5 YR 5/6	gc	$m_1$sbk	mvfr,wss,wps	gs	
	B22 48-96		2.5 YR 4/6	gc	$m_1$sbk	mfi,ws,wp	gw	
	B23 96-145+		2.5 YR 4/6	gc	$c_2$sbk	mfi,ws,wp	-	
V.Mannur	AP 0-10		10 R 4/6	gc	$m_1$gr	mfr,wss,wps	cs	
	A3 10-21		10 R 4/8	gc	$m_1$gr	mfr,wss,wps	gw	
	B1 21-50		10 R 3/6	gc	$m_2$sbk	mfi,ws,wp	dw	
	B22 50-110		2.5 YR 4/6	gc	$c_2$sbk	mfi,ws,wp	dw	
	B23 110-180+		10 R 4/6	gc	$c_2$sbk	mfi,ws,wp	-	Many medium sized strong brown and reddish yellow mottles
VI.Nenmanda	AP 0-14		5 YR 4/8	gcl	$m_1$gr	mvfr, wso,wpo	cs	Ferruginous gravel and cobbles plenty
	B1 14-36		10 YR 4/8	gc	$m_1$sbk	mfr,wss,wps	dw	Pisolithic gravel and cobbles plenty
	B22 36-98		10 R 4/8	gc	$m_2$sbk	mfr,ws,wp	dw	Cobbles and stones plenty, fine quartz gravel present
	B23 98-150+		10 R 4/8	gsc	$m_2$sbk	mfi,ws,wp	-	Fine quartz gravel present

*Symbols are as suggested by Soil Survey Staff (1951)

(No.1) in Thonnackal series to 75.51 per cent (No.25) in Nenmanda series. The horizons of all the profiles except the surface horizons of Thonnackal series had gravel content far exceeding the requirements to qualify the soil textural class as gravelly. The characteristics of coarse fractions identified in the various soils are given in Table 4. Plate 9 gives the morphological feature of the gravels from the different soil series sampled.

The textural class of soils was predominantly clay except for the surface horizons of Thonnackal series which was sandy clay loam and Nenmanda series which recorded clay loam texture. Uniform clay textures was a feature in the case of Anjur, Mannur and Kanjikulam series. The consistency at different moisture levels showed variations in accordance with the changes in the clay fraction.

The soils from all the locations under investigation were well drained both externally and internally being located in upland physiographic positions. All the profiles except Thonnackal series lacked the presence of laterite pan even at depth of 1.8 m. The last layer of Thonnackal, Kootala and Mannur series showed the presence of distinct to prominent mottles.

Plate 9. Characteristics of coarse fragments (> 2mm)

1. Pisoliths and quartz pebbles - Thonnackal series
2. Laterite gravel and quartz - Kootala series
3. Laterite gravel - Anjur series
4. Laterite gravel - Kanjikulam series
5. Laterite gravel and quartz pebbles - Mannur series
6. Laterite gravel - Nenmanda series

Plate 9

Table 4. Characteristics of coarse fragments identified in soils (After Clare and Beaven, 1962)

Profile No. and soil series	Nature of gravel	Description	Colour	Size (mm)	Content % (mean of profiles)
I Thonnackal	Quartz	Irregular-angular pointed edges, fissured on surface	Light red surface staining	1-2	
	Pisolithic	Round with polished surface	Yellowish red	2-15	35.58
	Laterite rock pieces	Irregular shaped with yellowish red and pink deposition	Reddish yellow and strong brown	5-15	
II Kootala	Quartz	Irregular fissured	Reddish yellow to strong brown staining	1-3	
	Pisolithic	Polished surface, rounded edges, irregular shape	Yellowish red	5-40	54.75
	Laterite rock pieces	Irregular shape	Yellowish red	5-40	
III Anjur	Quartz	Irregular, angular and pointed edges, fissured on surface	Reddish yellow to strong brown staining on surface	5-20	37.58
	Laterite rock pieces	Irregular	Yellowish red	5-20	

(Contd.)

Table 4. (Contd.)

Profile No. and soil series	Nature of gravel	Description	Colour	Size (mm)	Content % (mean of profiles)
IV Kanjikulam	Laterite rock pieces	Irregular	Red	5-40	53.23
	Quartz	Fine irregular coated with iron oxide	Light red	1-4	
V Mannur	Laterite rock pieces	Irregular	Red	3-30	54.15
	Quartz	Irregular iron oxide coating fissured on surface	Light red surface staining	1-5	
VI Nenmanda	Pisolithic	Polished surface irregular shape	Red	1-4	61.82

3. Physical properties

Mechanical composition, bulk density, moisture retention characteristics, mean and range values of profiles are given in Table 5 to 7. Fig. 5 illustrates the distribution of the particle size fraction of soils.

3.1 Mechanical composition

Coarse sand formed the predominant size fraction ranging from 25.44 per cent (No.12) for Anjur series to 56.79 per cent (No.26) for Nenmanda series. The fine sand fraction varied from 3.18 per cent (No.18) for Mannur series to 23.23 per cent (No.1) for Thonnackal series. Decrease in the content of sand (coarse sand and fine sand) with depth was a feature observed in both Kootala and Kanjikulam series. No definite pattern of variation in the sand content with depth in the profile was observed in respect of the other soils investigated. Silt was the lowest among the size fractions and its content ranged from 1.72 per cent (No.11) in Anjur series to 12.82 per cent (No.18) of Mannur series. A definite decrease in silt content with depth was noted only for Nenmanda series. The highest clay content of 60.00 per cent (No.20) was observed in Mannur series and the lowest, 23.00 per cent (No.1) was obtained for Thonnackal series. In all the

Table 5. Mechanical composition and bulk density of soils

Soil series, sample No. and depth (cm)		Coarse fragments (>2mm) %	Size class and particle diameter (mm)				Textural class	Water dispersible clay %	Coarse sand/ fine sand	Silt/ clay	Bulk density (g/cm^3)
			Coarse sand 2–0.2 %	Fine sand 0.2 – 0.02 %	Silt 0.02 – 0.002 %	Clay <0.002 %					
1		2	3	4	5	6	7	8	9	10	11
<u>Thonnackal</u>											
1	0–14	7.97	48.37	23.23	5.40	23.00	Sandy clay loam	5.00	2.08	0.235	1.74
2	14–30	20.64	47.68	18.57	5.03	28.72	Sandy clay loam	3.00	2.57	0.175	1.51
3	30–57	59.10	43.72	13.72	3.19	39.67	Sandy clay	6.00	3.16	0.080	1.64
4	57–90	47.22	37.80	11.90	3.84	46.43	Sandy clay	–	3.18	0.083	1.78
5	90–180+	42.98	35.95	17.67	2.58	43.80	Sandy clay	–	2.03	0.059	1.46
<u>Kootala</u>											
6	0–13	62.71	41.87	11.53	11.46	35.14	Clay	8.00	3.63	0.326	1.75
7	13–53	54.97	32.10	10.40	8.17	49.33	Clay	12.50	3.09	0.166	1.47
8	53–110	58.30	29.87	5.26	10.15	54.72	Clay	5.00	5.68	0.185	1.41
9	110–180+	43.03	27.57	5.07	12.10	55.26	Clay	5.00	5.44	0.219	1.22
<u>Anjur</u>											
10	0–13	24.92	35.08	11.20	7.15	46.57	Clay	6.00	3.13	0.154	1.20
11	13–40	29.39	49.75	17.15	1.72	31.38	Sandy clay	4.00	2.90	0.055	1.50
12	40–90	39.97	25.44	9.12	7.44	58.00	Clay	3.00	2.79	0.128	1.58
13	90–160+	56.02	50.32	8.05	5.63	36.00	Clay	3.00	6.25	0.156	1.62

(Contd.)

Table 5. (Contd.)

1		2	3	4	5	6	7	8	9	10	11
Kanjikulam											
14	0-10	45.90	42.88	10.26	7.86	39.00	Clay	1.00	4.18	0.201	1.58
15	10-48	54.09	41.59	7.52	6.20	44.69	Clay	5.00	5.53	0.139	1.57
16	48-96	63.88	35.84	4.84	2.06	57.26	Clay	1.00	7.40	0.036	1.61
17	96-145+	49.06	30.31	6.96	12.38	50.35	Clay	1.00	4.35	0.246	1.47
Mannur											
18	0-10	50.00	48.17	3.18	12.82	35.83	Clay	12.00	15.15	0.358	1.70
19	10-21	52.40	27.78	8.54	10.98	52.70	Clay	8.00	3.25	0.208	1.41
20	21-50	48.78	27.86	4.23	7.90	60.00	Clay	10.00	6.59	0.132	1.46
21	50-110	58.19	39.31	8.48	10.58	41.63	Clay	2.00	4.64	0.254	1.65
22	110-180+	61.14	31.86	11.19	5.83	51.12	Clay	-	2.85	0.114	1.56
Hanmanda											
23	0-14	58.46	50.84	11.87	6.77	30.52	Clay loam	8.00	4.28	0.222	1.20
24	14-36	69.68	45.93	7.86	5.20	41.01	Clay	6.00	5.84	0.127	1.64
25	36-98	75.51	45.07	4.38	5.20	45.35	Clay	2.00	10.29	0.115	1.57
26	98-150+	43.54	56.79	6.26	2.30	34.65	Sandy clay	-	9.07	0.066	1.51

Table 6. Moisture retention characteristics of soils
(Per cent by weight)

Soil series sample No. and depth (cm)		Soil moisture at tension (bars)		Available water (0.3 - 15 bar)	Ratio of 15 bar moisture to clay
		0.3	15		
Thonnackal					
1	0-14	10.20	6.44	3.76	0.28
2	14-30	10.92	8.81	2.11	0.31
3	30-57	17.23	11.57	5.66	0.29
4	57-90	15.82	9.57	6.25	0.21
5	90-180+	22.45	18.73	3.72	0.43
Kootala					
6	0-13	20.70	15.74	4.96	0.45
7	13-53	20.05	15.60	4.45	0.32
8	53-110	31.58	21.64	9.94	0.40
9	110-180+	31.50	21.42	10.08	0.39
Anjur					
10	0-13	14.14	8.21	5.93	0.18
11	13-40	26.59	17.73	8.86	0.57
12	40-90	21.42	14.77	6.65	0.25
13	90-160+	25.21	17.73	7.48	0.49
Kanjikulam					
14	0-10	26.54	18.75	7.79	0.48
15	10-48	22.33	14.33	8.00	0.32
16	48-96	24.54	18.43	6.11	0.32
17	96-145+	22.10	16.85	5.25	0.37
Mannur					
18	0-10	19.19	11.46	7.73	0.32
19	10-21	24.75	16.73	8.02	0.32
20	21-50	27.11	17.59	9.52	0.29
21	50-110	26.92	17.28	9.64	0.42
22	110-180+	25.67	17.94	7.73	0.35
Nemmanda					
23	0-14	19.99	13.15	6.84	0.43
24	14-36	18.91	13.41	5.50	0.32
25	36-98	21.36	14.37	6.99	0.32
26	98-150+	18.05	13.18	4.87	0.14

Table 7. Physical properties of soils, mean and range values for profiles

Constituent	Soil series					
	Thonnackal	Kootala	Anjur	Kanjikulam	Mannur	Nenmanda
Coarse fragments % (>2 mm)	7.97–59.10 (35.58)	43.03–62.71 (54.75)	24.92–56.02 (37.58)	45.93–63.88 (53.23)	48.78–61.14 (54.15)	43.54–75.51 (61.82)
Coarse sand % (2–0.2 mm)	35.95–48.37 (42.64)	27.57–41.87 (32.85)	25.44–50.32 (40.15)	30.31–42.88 (37.66)	27.78–48.17 (35.00	45.07–56.79 (49.66)
Fine sand % (0.2–0.02 mm)	11.90–23.23 (17.02)	5.07–11.53 (8.07)	8.05–17.15 (11.38)	4.84–10.26 (7.40)	3.18–11.19 (7.12)	4.38–11.87 (7.59)
Silt % (0.02–0.002 mm)	2.58–5.40 (4.01)	8.17–12.10 (10.47)	1.72–7.44 (5.49)	2.06–12.38 (7.13)	5.83–12.82 (9.62)	2.30–6.77 (4.87)
Clay % (<0.002 mm)	23.00–46.43 (36.32)	35.14–55.26 (48.61)	31.88–58.00 (42.99)	39.00–57.26 (47.83)	35.83–60.00 (48.26)	30.52–45.35 (37.88)
Water dispersible clay %	3.0 –6.0 (4.67)	5.0–12.5 (7.63)	3.0 –6.0 (4.00)	1.0–5.0 (2.00)	2.0–12.0 (8.00)	2.0–8.0 (5.33)
Bulk density (g/cm3)	1.46–1.78 (1.63)	1.22–1.75 (1.46)	1.20–1.62 (1.48)	1.47–1.61 (1.56)	1.41–1.70 (1.56)	1.20–1.64 (1.48)
Soil moisture at 0.3 bar, %	10.20–22.45 (15.32)	20.05–31.58 (25.96)	14.14–26.59 (21.80)	22.10–26.54 (23.88)	19.19–27.11 (24.69)	18.05–21.36 (19.58)

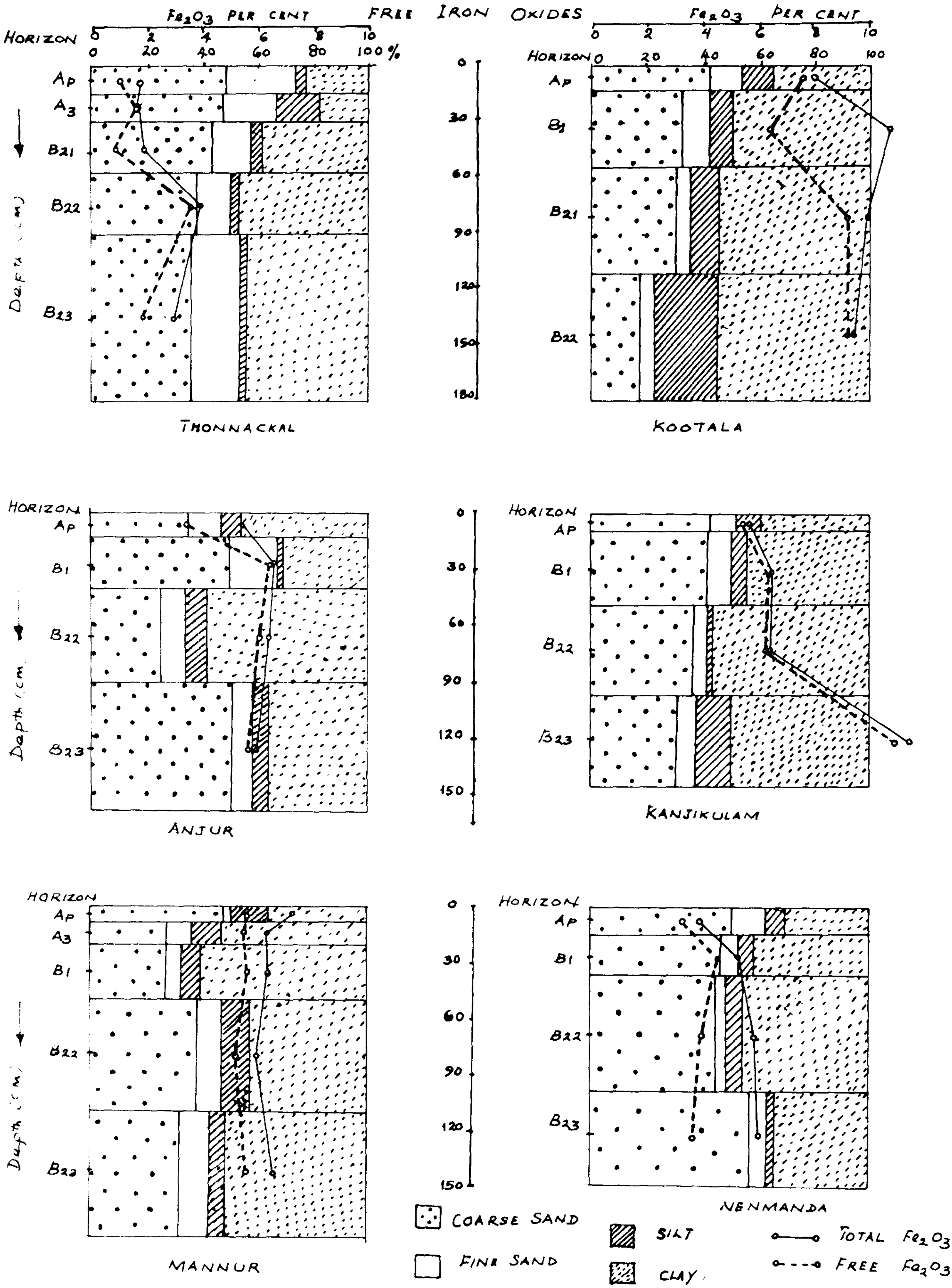
(Contd.)

Table 7. (Contd.)

Constituent	Soil series					
	Thonnackal	Kootala	Anjur	Kanjikulam	Mannur	Nenmanda
Soil moisture at 15 bars, %	6.44–18.73 (11.02)	15.60–21.64 (18.60)	8.21–17.73 (14.61)	14.33–18.75 (17.09)	11.46–17.94 (16.20)	13.15–14.37 (13.53)
Available water, %	2.11–6.25 (4.30)	4.45–10.08 (7.36)	5.93–8.86 (7.23)	5.25–8.00 (6.79)	7.73–9.64 (8.59)	4.87–6.99 (6.05)
Moisture at 15 bar/ clay	0.21–0.43 (0.30)	0.32–0.45 (0.39)	0.18–0.57 (0.37)	0.32–0.48 (0.37)	0.29–0.42 (0.34)	0.14–0.43 (0.30)
Coarse sand/ fine sand	2.03–3.18 (2.60)	3.09–5.68 (4.46)	2.77–6.25 (3.77)	4.18–7.40 (5.37)	2.85–15.15 (6.50)	4.28–10.29 (7.37)
Silt/clay	0.059–0.235 (0.126)	0.166–0.326 (0.224)	0.055–0.156 (0.123)	0.036–0.246 (0.160)	0.114–0.358 (0.210)	0.066–0.222 (0.130)

Mean values are given in parenthesis

FIG. (5). DISTRIBUTION OF PARTICLE SIZE FRACTIONS, TOTAL AND FREE IRON OXIDES



soils investigated clay movement was observed by way of increase in its content with depth. Maximum accumulation of clay in the lowest layer of soil profile was observed in the case of Kootala series while clay accumulation in intermediate layers was noted for other soils.

Correlations of coarse sand and fine sand with clay were negative and significant ($r = -0.881^{**}$, $r = -0.608^{**}$). Water dispersible clay ranged from 0.00 (No.4, 5, 22, 26) in Thonnackal, Mannur and Nenmanda series to 12.50 per cent (No.7) in Kootala series.

The coarse sand/fine sand ratio of soils varied from 2.03 (No.5) of Thonnackal series to 15.15 (No.18) of Mannur series. No definite pattern of variation with depth was observed in the soils investigated. The silt/clay ratios of the soil ranged from 0.036 (No.16) of Kanjikulam series to 0.358 (No.18) of Mannur series. The ratio showed a decreasing trend with depth in the case of Thonnackal and Nenmanda series while in other soils no definite pattern of variation was observed with depth.

3.2 Bulk density

The bulk density values ranged from 1.20 g/cm^3 of Anjur (No.10) and Nenmanda (No.23) series to 1.78 g/cm^3 (No.4) of Thonnackal series. A definite decrease in bulk density with depth was observed in Kootala series while the reverse trend was noted in Anjur series. A negative relationship was obtained between bulk density and organic matter.

3.3 Moisture retention characteristics

The amount of water held at various moisture tensions is presented in Table 6.

The amount of water held at 1/3 bar often taken as field capacity of soil, varied from 10.20 to 22.45, 20.05 to 31.58, 14.14 to 26.59, 22.10 to 26.54, 19.19 to 27.11 and 18.05 to 21.36 per cent for Thonnackal, Kootala, Anjur, Kanjikulam, Mannur and Nenmanda series respectively. The maximum content of 31.58 per cent was observed for Kootala series (No.8) while the minimum value of 10.20 (No.1) was recorded for Thonnackal series. The field capacity values did not show any definite pattern of variation with depth in the profile.

The moisture at 15 bar designated as wilting point was the highest in Kootala series with 21.64 per cent (No.8), the lowest value, 6.44 per cent (No.1) being recorded in Thonnackal series. The moisture content varied from 8.21 to 17.73 per cent, 14.33 to 18.75 per cent, 11.46 to 17.94 per cent, 13.15 to 14.37 per cent in Anjur, Kanjikulam, Mannur and Nenmanda series respectively.

Clay content and moisture retention at 1/3 bar showed a positive correlation but was not significant. Highly significant positive correlation was obtained between clay and 15 bar moisture (r = 0.537**).

The available water content which was the difference between water held at 0.3 bar and 15 bar was highest in Kootala series (No.9) with a value of 10.08 per cent. The lowest moisture content 2.11 per cent (No.2) was observed in Thonnackal series. For the other soils, the available water content varied from 5.93 to 8.86, 5.25 to 8.00, 7.73 to 9.64, 4.87 to 6.99 per cent for Anjur, Kanjikulam, Mannur and Nenmanda series respectively. Significant positive correlation of available water content with clay was observed (r = +0.435*).

Ratios of moisture at 15 bar to clay content varied from 0.14 (No.26) of Nenmanda series to 0.57 (No.11) of Anjur series. For the other soils, the ratio varied from 0.21 to 0.43, 0.32 to 0.45, 0.32 to 0.48 and 0.29 to 0.42 for Thonnackal, Kootala, Kanjikulam and Mannur series respectively.

4. Chemical characteristics

4.1 Soil reaction, electrical conductivity and organic constituents

The pH, conductivity, and organic constituents of samples are given in Table 8(a). Mean and range values are given in Table 8(b).

The soils were in general acidic with pH (1:1 soil:water) ranging from 4.40 (No.2 and 5) in Thonnackal series to 6.30 (No.10) in Anjur series. Only Anjur series with pH 6.3 (No.10) and Mannur series with pH 5.6 (No.18) recorded values higher than 5.50. No definite trend in pH with depth was noted.

The pH in 1N KCl (1:1 soil: solution) ranged from 3.00 (No.7) in Kootala series to 5.00 (No.10) in Anjur series. In this case also no definite pattern of variation in the profile was observed.

The electrical conductivity of soils was very low and showed very little variation within the profile and between the soil series. The range observed was from 0.010 mmho/cm (No.26) of Nemmanda to 0.085 mmho/cm (No.1 and 18) of Thonnackal and Mannur series respectively.

The organic carbon content of soils varied from 0.105 per cent (No.13) of Anjur series to 1.200 per cent

Table 8(a) Soil reaction, electrical conductivity and organic constituents

Soil series sample No. and depth (cm)		Soil reaction 1:1 (H_2O)	Soil reaction 1:1 (KCl)	Electrical conductivity (1:2) (mmho/cm)	Organic carbon %	Total nitrogen %	Carbon/nitrogen ratio
Thonnackal							
1	0-14	4.70	3.10	0.085	0.360	0.058	6.21
2	14-30	4.40	3.15	0.080	0.375	0.043	8.72
3	30-57	4.60	3.20	0.045	0.195	0.079	2.47
4	57-90	4.45	3.40	0.045	0.270	0.029	9.31
5	90-180+	4.40	3.25	0.045	0.158	0.022	7.18
Kootala							
6	0-13	4.95	3.40	0.040	1.200	0.115	10.43
7	13-53	4.70	3.00	0.020	0.750	0.137	5.47
8	53-110	4.85	3.15	0.019	0.420	0.087	4.83
9	110-180+	4.60	3.30	0.030	0.390	0.115	3.39
Anjur							
10	0-13	6.30	5.00	0.055	0.435	0.101	4.31
11	13-40	4.85	3.30	0.025	0.450	0.108	4.17
12	40-90	5.10	4.00	0.020	0.195	0.036	5.42
13	90-160+	5.20	4.15	0.020	0.105	0.058	1.81
Kanjikulam							
14	0-10	4.55	3.50	0.033	0.825	0.079	10.44
15	10-48	4.90	3.25	0.030	0.840	0.072	11.67
16	48-96	4.90	3.50	0.030	0.495	0.058	8.53
17	96-145+	5.05	4.25	0.018	0.180	0.029	6.21
Mannur							
18	0-10	5.60	4.15	0.085	0.690	0.094	7.34
19	10-21	5.25	3.75	0.035	0.698	0.115	6.07
20	21-50	4.90	3.80	0.025	0.488	0.065	7.51
21	50-110	5.15	4.10	0.020	0.330	0.014	23.57
22	110-180+	4.80	3.40	0.010	0.330	0.043	7.67
Nanmanda							
23	0-14	4.85	3.45	0.035	1.080	0.108	10.00
24	14-36	4.60	3.40	0.025	0.540	0.036	15.00
25	36-98	4.85	3.75	0.011	0.200	0.036	5.55
26	98-150+	5.30	4.00	0.010	0.195	0.036	5.42

Table 8(b). Soil reaction, electrical conductivity and organic constituents, mean and range values for profiles

Constituents	Soil series					
	Thonnackal	Kootala	Anjur	Kanjikulam	Mannur	Nenmanda
Soil reaction 1:1 (H_2O)	4.40–4.70 (4.51)	4.60–4.95 (4.78)	4.85–6.30 (5.36)	4.55–5.05 (4.85)	4.80–5.60 (5.14)	4.60–5.30 (4.90)
Soil reaction 1:1 (KCl)	3.10–3.40 (3.22)	3.00–3.40 (3.21)	3.30–5.00 (4.11)	3.25–4.25 (3.63)	3.40–4.15 (3.84)	3.40–4.00 (3.65)
Electrical conductivity (1:2) (mmho/cm)	0.045–0.085 (0.060)	0.019–0.040 (0.027)	0.020–0.055 (0.030)	0.018–0.033 (0.028)	0.010–0.085 (0.035)	0.010–0.035 (0.020)
Organic carbon %	0.158–0.375 (0.272)	0.390–1.200 (0.690)	0.105–0.450 (0.296)	0.180–0.840 (0.585)	0.330–0.698 (0.507)	0.195–1.080 (0.054)
Total nitrogen %	0.022–0.079 (0.046)	0.087–0.137 (0.114)	0.036–0.108 (0.076)	0.029–0.079 (0.059)	0.014–0.115 (0.066)	0.036–0.108 (0.054)
Carbon/nitrogen ratio	2.47–9.31 (6.78)	3.39–10.43 (6.03)	1.81–5.42 (3.93)	6.21–11.67 (9.21)	6.07–23.57 (10.43)	5.42–15.00 (8.99)

(No.6) of Kootala series. The organic carbon variations in the profile showed a steady decrease with depth for Nenmanda and Kootala series only.

The total nitrogen content varied from 0.014 per cent (No.21) for Mannur series to 0.137 per cent (No.7) for Kootala series. Kanjikulam series showed a definite decrease in nitrogen content with depth while others did not show any pattern of variation. Highly significant positive correlation between organic carbon and nitrogen was observed ($r = 0.648^{**}$).

The C/N ratio varied from 1.81 (No.13) for Anjur series to 23.57 (No.21) of Mannur series. The C/N ratio showed definite decrease with depth in Kootala series while others showed definite trend in variation in the profile.

4.2 Total elemental composition of soils

The total elemental composition of soils and the mean and range values for profiles are given in Table 9. The SiO_2 content of all the soils recorded high values ranging from 39.30 per cent (No.9) of Kootala series and (No.17) of Kanjikulam series to 89.40 per cent (No.1) of Thonnackal series. A definite decrease with depth in the

Table 9(a). Total chemical analysis of soils

Soil series sample No. and depth (cm)		Per cent whole soil									TiO_2
		SiO_2	Al_2O_3	Fe_2O_3	MnO_2	MgO	CaO	Na_2O	K_2O	P_2O_5	ppm
Thonnackal											
1	0–14	89.40	2.94	1.66	0.008	0.05	0.11	0.20	0.24	0.049	3.79
2	14–30	62.40	5.80	1.60	0.006	0.05	0.12	0.20	0.24	0.025	4.64
3	30–57	62.40	12.14	1.86	0.006	0.14	0.10	0.10	0.96	0.037	7.88
4	57–90	63.00	15.43	3.97	0.010	0.23	0.16	0.30	0.60	0.049	13.67
5	90–180+	52.70	17.81	2.94	0.016	0.16	0.13	0.20	0.36	0.025	7.28
Kootala											
6	0–13	44.20	19.44	8.06	0.046	0.44	0.13	0.30	0.36	0.634	21.53
7	13–53	53.00	20.92	10.88	0.068	0.42	0.13	0.20	0.72	0.831	22.14
8	53–110	45.00	27.42	9.98	0.044	0.37	0.18	0.25	0.24	0.698	24.17
9	110–180+	39.30	28.40	9.40	0.038	0.28	0.13	0.15	1.38	0.682	25.86
Anjur											
10	0–13	71.50	8.76	5.44	0.070	0.28	0.14	0.20	0.54	0.087	11.02
11	13–40	68.50	19.68	6.72	0.125	0.51	0.12	0.15	0.72	0.087	13.33
12	40–90	56.50	19.74	6.46	0.092	0.26	0.10	0.10	0.48	0.099	9.12
13	90–160+	53.40	23.65	5.95	0.060	0.26	0.13	0.10	0.48	0.099	13.67
Kanjikulam											
14	0–10	44.90	13.18	5.82	0.047	0.21	0.12	0.10	0.36	0.074	9.43
15	10–48	55.00	18.54	6.46	0.002	0.12	0.11	0.10	0.54	0.074	10.38
16	48–96	58.30	23.20	6.40	0.076	0.19	0.12	0.30	0.72	0.074	8.50
17	96–145+	39.30	29.34	11.46	0.022	0.21	0.09	0.10	0.60	0.099	14.36
Mannur											
18	0–10	59.50	30.10	7.30	0.060	0.28	0.13	0.10	0.48	0.061	21.34
19	10–21	40.60	18.06	6.34	0.063	0.23	0.12	0.30	0.48	0.049	13.67
20	21–50	43.90	24.20	6.40	0.044	0.23	0.15	0.10	0.15	0.074	9.43
21	50–110	47.00	26.85	5.95	0.028	0.19	0.13	0.10	0.48	0.074	12.66
22	110–180+	40.00	23.81	6.59	0.019	0.09	0.13	0.20	0.84	0.061	11.68
Manmanda											
23	0–14	60.00	18.46	3.94	0.024	0.14	0.14	0.20	0.48	0.061	6.40
24	19–36	49.40	25.75	5.25	0.033	0.14	0.13	0.30	0.20	0.074	8.02
25	36–98	40.00	26.91	5.89	0.019	0.21	0.10	0.15	1.80	0.061	8.82
26	98–150+	40.00	25.18	6.02	0.017	0.12	0.11	0.25	0.60	0.099	9.76

Table 9(b). Total chemical analysis of soils, mean and range values for profiles

Constituents %	Soil series					
	Thonnackal	Kootala	Anjur	Kanjikulam	Mannur	Nenmanda
SiO_2	52.70-89.40 (65.98)	39.30-53.00 (45.38)	53.40-71.50 (62.48)	39.39-58.30 (49.38)	40.00-59.50 (46.20)	40.00-60.00 (47.35)
Al_2O_3	2.94-17.81 (10.82)	19.44-28.40 (24.05)	8.76-23.65 (17.96)	13.18-29.34 (21.07)	18.06-30.10 (23.40)	18.46-26.91 (24.08)
Fe_2O_3	1.60-3.97 (2.41)	8.06-10.88 (9.58)	5.44-6.72 (6.14)	5.82-11.46 (7.54)	5.95-7.30 (6.52)	3.94-6.02 (5.28)
MnO_2	0.006-0.016 (0.009)	0.038-0.068 (0.049)	0.060-0.125 (0.087)	0.002-0.076 (0.037)	0.019-0.063 (0.043)	0.017-0.033 (0.023)
MgO	0.05-0.23 (0.13)	0.28-0.44 (0.38)	0.26-0.51 (0.33)	0.12-0.21 (0.18)	0.09-0.28 (0.20)	0.12-0.21 (0.15)
CaO	0.10-0.16 (0.12)	0.13-0.18 (0.14)	0.10-0.14 (0.12)	0.09-0.12 (0.11)	0.12-0.15 (0.13)	0.10 - 0.14 (0.12)
Na_2O	0.10-0.30 (0.20)	0.15-0.30 (0.23)	0.10-0.20 (0.14)	0.10-0.30 (0.15)	0.01-0.03 (0.16)	0.15-0.30 (0.23)
K_2O	0.24-0.96 (0.48)	0.24-1.380 (0.68)	0.48-0.72 (0.56)	0.36-0.72 (0.56)	0.15-0.84 (0.49)	0.20-1.8 (0.77)
P_2O_5	0.025-0.049 (0.037)	0.634-0.831 (0.711)	0.087-0.099 (0.093)	0.074-0.099 (0.080)	0.049-0.074 (0.064)	0.061-0.099 (0.074)
TiO_2 (ppm)	3.79-13.67 (7.45)	21.53-25.86 (23.43)	9.12-13.33 (11.79)	8.50-14.36 (10.67)	9.43-21.34 (13.76)	6.40-9.76 (8.25)

content of silica was noted in Anjur and Nenmanda series while others showed no definite trend in variation with depth.

The Al_2O_3 content varied from 2.94 per cent (No.1) in Thonnackal series to 30.10 per cent (No.18) in Mannur series. A steady increase with depth in the content of Al_2O_3 was noted in Thonnackal, Kootala, Kanjikulam and Anjur series while other soils showed no definite pattern of variation with depth. There was a significant positive correlation between clay content and total Al_2O_3 (0.469*).

In the case of Fe_2O_3 the range observed was from 1.60 per cent (No.2) in Thonnackal series to 11.46 per cent (No.17) in Kanjikulam series. Increase in the content of iron with depth was observed in Nenmanda soil while others showed irregular distribution with depth. There was a highly significant correlation between clay content and total Fe_2O_3 ($r = 0.527^{**}$).

The variation with regard to total MnO_2 content of soils was from 0.002 per cent (No.15) for Kanjikulam series to 0.125 per cent (No.11) in Anjur series. The content of MnO_2 showed erratic distribution with depth in all soils investigated. A positive correlation between clay content and MnO_2 was observed, but was not significant.

The content of CaO in soils ranged from 0.09 per cent (No.17) in Kanjikulam series to 0.18 per cent (No.8) in Kootala series. No definite pattern of distribution with depth was observed in any of the soils studied.

The content of MgO in soils also showed no definite depthwise variation in the profile. The MgO status ranged from 0.05 per cent (No.1 and 2) of Thonnackal series to 0.51 per cent (No.11) of Anjur series.

Total potassium showed no definite depth-wise variation in the profile. The K_2O content varied from 0.15 per cent (No.20) in Kanjikulam series to 1.80 per cent (No.25) in Nenmanda series.

Total P_2O_5 content ranged from 0.025 per cent (No.2 and 5) in Thonnackal series to 0.831 per cent (No.7) in Kootala series. An increasing trend in P_2O_5 content with depth was noted in Anjur and Kanjikulam series while others showed no definite pattern of variation with depth. Clay content and total P_2O_5 showed a positive correlation, but was not significant.

The highest value for TiO_2 was 25.86 ppm (No.9) for Kootala series, while Thonnackal series recorded the lowest value of 3.79 ppm (No.1). An increasing content with depth was noted for Kootala and Nenmanda series, while others showed an irregular variation with depth.

4.3 Chemical composition of gravel

The chemical composition of gravel is presented in Table 10(a) and mean and range values of profiles in Table 10(b). As compared to the soils, the chemical composition of gravel showed a depletion of SiO_2 and accumulation of constituents like Fe_2O_3, Al_2O_3, MgO, CaO and Na_2O. The content of TiO_2 in the gravel was also high compared to that in soils. The mean value of profiles showed the highest SiO_2 content of 53.50 per cent for Thonnackal series and the lowest of 30.08 per cent for Nenmanda series. Concomittant reduction in SiO_2 and accumulation of constituents Fe_2O_3 and Al_2O_3 were conspicuous, resulting in the drastic reduction in molar ratios. Thus SiO_2/Al_2O_3, SiO_2/Fe_2O_3 and SiO_2/R_2O_3 ratios of the gravel for all the profiles registered a decrease as compared to the soils. The mean values for the profiles showed that the SiO_2/Al_2O_3 varied from 2.15 for Kootala series to 6.15 for Anjur series. The SiO_2/Fe_2O_3 ranged from 3.73 for Nenmanda to 13.06 for Thonnackal series. In respect of SiO_2/R_2O_3, the lowest (1.19) was recorded for Nenmanda series and the highest (3.21) for Thonnackal series.

Table 10 (a). Total chemical analysis of coarse fragments (gravel)

Soil series sample No. and depth (cm)		Total content, per cent									TiO_2 ppm	Molar ratios		
		SiO_2	Al_2O_3	Fe_2O_3	MnO_2	CaO	MgO	K_2O	Na_2O	P_2O_5		SiO_2/Al_2O_3	SiO_2/Fe_2O_3	SiO_2/R_2O_3
Thonnackal														
1	0–14	48.8	24.00	9.60	0.017	0.12	0.28	0.20	0.14	0.062	17.55	3.46	13.55	2.76
2	14–30	48.5	28.84	8.96	0.016	0.13	0.14	0.11	0.67	0.085	23.75	2.87	14.43	2.39
3	30–57	48.5	22.04	8.96	0.021	0.18	0.21	0.14	0.34	0.101	9.43	5.07	14.43	2.97
4	57–90	64.6	5.68	24.32	0.013	0.14	0.19	0.45	0.47	0.062	8.02	11.31	7.07	4.35
5	90–180+	57.0	21.00	9.60	0.022	0.16	0.14	0.80	0.18	0.051	8.19	4.61	15.83	3.57
Koctala														
6	0–13	34.6	28.42	19.58	0.016	0.12	0.12	0.30	0.14	1.329	16.47	2.07	4.73	1.44
7	13–53	38.5	21.96	23.04	0.016	0.13	0.21	0.20	0.40	1.391	16.47	2.99	4.46	1.79
8	53–110	26.7	36.80	16.00	0.024	0.10	0.14	0.20	0.14	1.088	21.34	1.23	4.45	0.97
9	110–180+	33.3	24.46	23.04	0.036	0.11	0.16	0.30	0.54	0.370	17.19	2.31	3.85	1.45
Anjur														
10	0–13	53.5	11.44	12.16	0.033	0.12	0.35	0.50	0.14	0.230	14.71	7.96	11.73	4.74
11	13–40	30.8	12.56	23.04	0.033	0.10	0.20	0.20	0.14	0.191	11.02	4.17	3.56	1.92
12	40–90	46.5	17.12	17.28	0.117	0.15	0.50	0.75	0.14	0.219	13.00	4.61	7.18	2.81
13	90–160+	40.0	8.72	20.48	0.047	0.14	0.50	0.20	0.14	0.179	21.15	7.85	5.21	3.13
Kanjikulam														
14	0–10	38.5	17.84	21.76	0.030	0.10	0.25	0.15	0.14	0.651	21.34	3.67	4.72	2.06
15	10–48	38.5	17.84	21.54	0.030	0.05	0.45	0.50	0.14	0.483	21.34	3.67	4.75	2.07
16	48–96	31.9	21.24	21.76	0.040	0.05	0.45	0.75	0.18	0.191	20.94	2.56	3.91	1.55
17	96–145+	48.5	11.20	12.40	0.014	0.16	0.35	0.30	0.18	0.074	17.18	7.35	10.36	4.30
Mannur														
18	0–10	37.0	20.80	22.40	0.092	0.10	0.35	0.25	0.14	0.315	19.00	3.02	4.41	1.79
19	10–21	32.7	19.00	19.20	0.106	0.12	0.30	0.30	0.20	0.285	15.05	2.93	4.54	1.78
20	21–50	38.5	25.16	16.64	0.057	0.14	0.25	0.30	0.40	0.279	18.29	2.60	6.17	1.83
21	50–110	33.9	25.00	16.00	0.019	0.13	0.40	0.30	0.67	0.179	18.65	2.31	5.65	1.64
22	110–180+	35.6	25.04	18.56	0.016	0.12	0.33	0.20	0.14	0.258	13.49	2.42	5.11	1.64
Nemmanda														
23	0–14	38.5	26.20	19.20	0.016	0.15	0.02	0.20	0.14	0.191	14.35	2.50	5.35	1.70
24	14–36	22.3	35.56	23.04	0.016	0.13	0.23	0.20	0.14	0.191	19.00	2.42	2.58	0.75
25	36–98	32.3	27.52	26.88	0.022	0.10	0.16	0.10	0.14	0.151	4.36	1.61	3.20	1.23
26	98–150+	27.2	39.60	19.20	0.016	0.16	0.26	0.20	0.14	0.123	2.97	3.23	3.78	1.07

Table 10(b). Total chemical analysis of gravel, mean and range values for profiles

Constituents %	Soil series					
	Thonnackal	Kootala	Anjur	Kanjikulam	Mannur	Nenmanda
SiO_2	48.50–64.60 (53.48)	26.70–38.50 (33.28)	30.80–53.50 (42.70)	31.90–48.50 (39.35)	32.70–38.50 (35.54)	22.30–38.50 (30.08)
Al_2O_3	5.68–28.04 (20.31)	21.96–36.80 (27.91)	8.72–17.12 (12.46)	11.20–21.24 (17.03)	19.00–25.16 (23.00)	26.20–39.60 (32.02)
Fe_2O_3	8.96–24.32 (12.29)	16.00–23.04 (20.42)	12.16–23.04 (18.24)	12.40–21.76 (19.37)	16.00–22.40 (18.56)	19.20–26.88 (22.08)
MnO_2	0.013–0.022 (0.018)	0.016–0.036 (0.023)	0.033–0.117 (0.058)	0.014–0.040 (0.029)	0.016–0.106 (0.058)	0.016–0.022 (0.018)
MgO	0.14–0.28 (0.19)	0.12–0.21 (0.16)	0.20–0.50 (0.39)	0.25–0.45 (0.38)	0.25–0.40 (0.33)	0.02–0.23 (0.17)
CaO	0.12–0.18 (0.14)	0.10–0.13 (0.11)	0.10–0.15 (0.13)	0.05–0.16 (0.10)	0.10–0.14 (0.12)	0.10–0.16 (0.13)
Na_2O	0.14–0.67 (0.36)	0.14–0.54 (0.31)	0.14–0.14 (0.14)	0.14–0.18 (0.16)	0.14–0.67 (0.31)	0.14–0.14 (0.14)
K_2O	0.11–0.80 (0.34)	0.20–0.30 (0.25)	0.20–0.75 (0.41)	0.15–0.75 (0.43)	0.20–0.30 (0.27)	0.10–0.20 (0.18)
P_2O_5	0.051–0.101 (0.072)	0.370–1.391 (2.0.40)	0.179–0.230 (0.205)	0.074–0.651 (0.350)	0.179–0.315 (0.250)	0.123–0.191 (0.164)
TiO_2 (ppm)	8.02–23.75 (13.39)	16.47–21.34 (17.87)	11.02–21.15 (14.97)	17.18–21.34 (20.20)	13.49–19.00 (16.89)	2.97–19.00 (10.17)
<u>Molar ratios</u>						
SiO_2/Al_2O_3	2.87–11.31 (5.46)	1.23–2.99 (2.15)	4.17–7.96 (6.15)	2.56–7.35 (4.31)	2.31–2.93 (2.67)	1.61–3.23 (2.44)
SiO_2/Fe_2O_3	7.07–15.83 (13.06)	3.85–4.73 (4.37)	5.21–11.73 (6.92)	3.91–10.36 (5.94)	4.41–6.17 (5.18)	2.58–5.35 (3.73)
SiO_2/R_2O_3	2.39–4.35 (3.21)	0.97–1.79 (1.41)	1.92–4.74 (3.15)	1.55–4.30 (2.50)	1.64–1.83 (1.74)	0.75–1.70 (1.19)

4.4 Relative accumulation of constituents

The accumulation of constituents in gravel relative to fine earth is presented in Table 11(a). The mean and range values for the profiles are shown in Table 11(b). In all the soils investigated, there was less accumulation of SiO_2 as compared to Fe_2O_3 and Al_2O_3. Between the sesquioxides, accumulation of Fe_2O_3 appeared to be more compared to Al_2O_3. The mean values for the profile showed the highest accumulation of Fe_2O_3 in Thonnackal series followed by Nenmanda, Anjur, Kanjikulam, Mannur and Kootala. Thonnackal series showed the highest order of accumulation among the various soils investigated for Al_2O_3, Fe_2O_3, MnO_2, MgO, CaO and TiO_2. In respect of other soils, all the other elements showed greater accumulation in the gravel as compared to soil, as indicated by the higher ratios.

5. Cation exchange properties

Cation exchange properties of soils are presented in Table 12(a). Mean and range values are given in Table 12(b).

5.1 Cation exchange capacity

The cation exchange capacity (NH_4OAc) of soils ranged from 2.80 me/100 g (No.26) of Nenmanda series to

Table 11(a). Relative accumulation of constituents in gravel and fine earth

Soil series sample No. and depth (cm)		Ratio of element in gravel/element in fine earth									
		SiO_2	Al_2O_3	Fe_2O_3	MnO_2	MgO	CaO	Na_2O	K_2O	P_2O_5	TiO_2
Thonnackal											
1	0-14	0.546	8.16	5.78	2.13	5.60	1.06	0.70	0.83	1.27	4.63
2	14-30	0.777	4.97	5.60	2.67	2.80	1.09	3.35	0.46	3.45	5.12
3	30-57	0.777	1.82	4.82	3.50	1.50	1.79	3.40	0.15	2.70	1.20
4	57-90	1.025	0.37	6.12	1.30	0.83	0.84	1.57	0.75	1.27	0.59
5	90-180+	1.082	1.18	3.27	1.38	0.88	1.31	0.90	2.22	2.04	1.13
Kootala											
6	0-13	0.783	1.46	2.43	0.35	0.27	0.92	0.47	0.83	2.08	0.76
7	13-53	0.726	1.05	2.12	0.24	0.50	0.93	2.00	0.28	1.67	0.74
8	53-110	0.568	1.34	1.60	0.55	0.38	0.56	0.56	0.83	1.56	0.88
9	110-180+	0.847	0.86	2.45	0.95	0.57	0.86	3.60	0.22	0.54	0.66
Anjur											
10	0-13	0.748	1.31	2.24	0.47	1.25	0.82	0.70	0.93	2.63	1.33
11	13-40	0.450	0.64	3.43	0.26	0.39	0.79	0.93	0.28	2.17	0.83
12	40-90	0.823	0.87	2.67	1.27	1.92	1.57	1.40	1.56	2.22	1.43
13	90-160+	0.749	0.37	3.44	0.78	1.92	1.15	1.40	0.42	1.82	1.55
Kanjikulam											
14	0-10	0.857	1.35	3.74	0.64	1.19	0.81	1.40	0.42	9.09	2.26
15	10-48	0.700	0.96	3.33	0.57	3.75	0.50	1.40	1.39	6.67	2.05
16	48-96	0.547	0.92	3.40	0.53	2.37	0.47	0.60	1.04	2.56	2.46
17	96-145+	1.234	0.38	1.08	0.64	1.67	1.85	1.80	0.50	0.75	1.20
Mannur											
18	0-10	0.622	0.69	3.06	1.53	1.25	0.70	1.40	0.52	5.26	0.89
19	10-21	0.805	1.05	3.03	1.68	1.30	0.98	0.67	0.63	5.88	1.10
20	21-50	0.877	1.04	2.60	1.30	1.09	0.94	4.00	2.00	2.94	1.94
21	50-110	0.721	1.20	2.69	0.68	2.11	1.05	6.70	0.63	2.44	1.47
22	110-180+	0.890	1.05	2.82	0.84	3.67	0.88	0.70	0.24	4.17	1.15
Nemmanda											
23	0-14	0.642	1.42	4.87	0.67	0.14	1.01	0.70	0.42	3.13	2.24
24	14-36	0.451	1.38	4.39	0.48	1.64	0.95	0.47	1.00	2.56	2.37
25	36-98	0.808	1.02	4.56	1.16	0.76	0.97	0.93	0.06	2.50	0.49
26	98-150+	0.680	1.57	3.19	0.94	0.13	1.45	0.56	0.33	1.25	0.30

Table 11 (b). Relative accumulation of constituents in gravel and fine earth, mean and range value for profiles

Constituents Ratio of element in gravel to element in fine earth	Soil series					
	Thonnackal	Kootala	Anjur	Kanjikulam	Mannur	Nemmanda
SiO_2	0.546–1.082 (0.841)	0.568–0.847 (0.731)	0.450–0.823 (0.693)	0.547–1.234 (0.835)	0.622–0.890 (0.783)	0.451–0.808 (0.645)
Al_2O_3	0.37 –8.16 (3.30)	0.86–1.46 (1.18)	0.37–1.31 (0.80)	0.38–1.35 (0.90)	0.69–1.20 (1.01)	1.02–1.57 (1.35)
Fe_2O_3	3.27–6.12 (5.12)	1.60–2.45 (2.15)	2.24–3.44 (2.95)	1.08–3.74 (2.89)	2.60–3.06 (2.84)	3.19–4.87 (4.25)
MnO_2	1.30–3.50 (2.20)	0.24–0.95 (0.52)	0.26–1.27 (0.70)	0.53–0.64 (0.60)	0.68–1.68 (1.21)	0.48–1.16 (0.81)
MgO	0.83–5.60 (2.32)	0.27–0.57 (0.43)	0.39–1.92 (1.37)	1.19–3.75 (2.25)	1.09–3.67 (1.88)	0.13–1.64 (0.67)
CaO	0.84–1.31 (1.22)	0.56–0.93 (0.82)	0.79–1.57 (0.92)	0.50–1.85 (0.91)	0.70–1.05 (0.91)	0.95–1.45 (1.09)
Na_2O	0.70–3.40 (1.98)	0.47–3.60 (1.66)	0.70–1.40 (1.11)	0.60–1.80 (1.30)	0.67–6.70 (2.69)	0.47–0.93 (0.67)
K_2O	0.15–2.22 (0.88)	0.22–0.83 (0.54)	0.28–1.56 (0.80)	0.42–1.39 (0.84)	0.24–2.00 (0.80)	0.06–1.00 (0.45)
P_2O_5	1.27–3.45 (2.15)	0.54–2.08 (1.46)	1.82–2.63 (2.21)	0.75–9.09 (4.77)	2.44–5.88 (4.14)	1.25–3.13 (2.36)
TiO_2	0.59–5.12 (2.53)	0.66–0.88 (0.76)	0.83–1.55 (1.29)	1.20–2.46 (1.99)	0.89–1.94 (1.31)	0.30–2.37 (1.35)

Table 12(a). Cation exchange properties of soils

Soil series sample No. and depth (cm)	Exchangeable cations Ca	Mg	K	Na	KCl Al	Sum of bases	Exchange acidity	CEC *CEC_s	NH_4OAc pH 7	*CEC_s me/100 g clay	Base saturation % Sum of cations	NH_4OAc pH 7
	(me/100 g soil)											
Thonnackal												
1 0–14	0.916	0.683	0.049	0.092	0.243	1.739	4.14	5.88	4.30	25.70	29.58	40.44
2 14–30	1.003	0.044	0.064	0.092	0.596	1.203	3.96	5.16	7.95	18.10	23.30	15.13
3 30–57	1.105	0.015	0.029	0.087	0.668	1.236	5.22	6.46	6.55	16.40	19.14	18.87
4 57–90	1.105	0.669	0.042	0.097	0.838	1.914	5.40	7.31	5.10	15.70	26.17	37.53
5 90–180+	1.090	0.465	0.039	0.087	0.790	1.681	5.94	7.62	5.80	17.30	22.06	28.98
Kootala												
6 0–13	2.195	0.603	0.208	0.120	0.243	3.126	11.70	14.83	12.95	42.20	21.08	24.14
7 13–53	1.715	0.864	0.083	0.087	0.829	2.749	14.94	17.69	12.90	35.90	15.57	21.31
8 53–110	2.021	0.887	0.071	0.152	0.689	3.131	12.78	15.91	12.90	29.10	19.68	24.27
9 110–180+	1.991	0.843	0.087	0.122	0.369	3.043	10.26	13.30	13.90	25.40	27.87	21.89
Adjur												
10 0–13	3.430	0.131	0.321	0.125	0.009	4.007	2.88	6.86	5.20	14.80	58.18	77.06
11 13–40	2.674	0.814	0.186	0.167	0.313	3.841	5.58	9.42	11.00	29.90	40.77	34.29
12 40–90	2.820	0.523	0.080	0.130	0.008	3.553	10.44	13.99	8.85	23.90	25.39	40.15
13 90–160+	2.907	0.799	0.077	0.130	0.008	3.914	6.12	10.03	8.50	27.90	39.00	46.05
Kanjikulam												
14 0–10	1.948	1.759	0.083	0.109	0.129	3.899	6.48	10.38	7.95	26.70	37.57	49.04
15 10–48	2.994	0.930	0.077	0.136	0.123	4.137	9.36	13.50	12.00	30.20	30.65	34.48
16 48–96	2.645	0.407	0.071	0.098	0.192	3.221	8.28	11.50	14.95	20.50	28.01	21.55
17 96–145+	2.500	0.438	0.064	0.217	0.013	3.219	7.20	10.42	7.70	20.60	30.90	41.81
Mannur												
18 0–10	1.395	1.730	0.385	0.141	0.008	3.643	5.40	9.04	9.50	25.20	40.30	38.35
19 10–21	2.878	1.119	0.353	0.158	0.018	4.508	7.56	12.07	9.50	22.90	37.35	47.45
20 21–50	2.878	0.974	0.240	0.163	0.010	4.255	8.28	12.54	9.30	20.80	33.94	45.75
21 50–110	2.616	0.690	0.205	0.174	0.004	3.685	5.22	8.95	10.70	21.30	41.38	34.44
22 110–180+	1.424	0.756	0.160	0.152	0.289	2.492	10.05	12.53	10.00	24.50	19.89	24.92
Mannanda												
23 0–14	1.454	0.073	0.144	0.130	0.137	1.801	7.02	8.82	5.50	28.90	20.42	32.75
24 14–36	0.669	0.029	0.561	0.120	0.284	1.874	6.84	8.71	4.90	21.20	21.51	38.24
25 36–98	0.611	0.581	0.040	0.109	0.053	1.341	4.32	5.66	3.05	12.50	23.69	43.97
26 98–150+	0.611	0.262	0.400	0.060	0.015	0.973	5.22	6.19	2.80	17.80	15.71	34.75

*CEC_s (Sum of bases + KCl extractable Al)

Table 12(b). Cation exchange properties of soils, mean and range values for the profiles

Constituents	Thonnackal	Kootala	Anjur	Kanjikulam	Mannur	Nemmanda
Exchangeable Cations						
Ca	0.916-1.105 (1.044)	1.715-2.195 (1.981)	2.674-3.43 (2.958)	1.948-2.994 (2.522)	1.395-2.878 (2.240	0.611-1.454 (0.836)
Mg	0.015-0.683 (0.375)	0.603-0.887 (0.799)	0.131-0.814 (0.567)	0.407-1.759 (0.884)	0.756-1.730 (1.054)	0.029-0.581 (0.236)
K	0.029-0.640 (0.045)	0.071-0.208 (0.112)	0.077-0.321 (0.166)	0.064-0.083 (0.074)	0.160-0.385 (0.269)	0.040-0.561 (0.196)
Na	0.087-0.097 (0.091)	0.087 - 0.152 (0.120)	0.125 - 0.167 (0.138)	0.098 - 0.217 (0.140)	0.141 - 0.174 (0.158)	0.060 - 0.13 (0.105)
Al	0.243-0.838 (0.627)	0.243-0.829 (0.533)	0.008-0.313 (0.085)	0.013-0.192 (0.114)	0.004-0.289 (0.066)	0.015-0.284 (0.122)
Sum of bases	1.203-1.914 (1.555)	2.749-3.131 (3.012)	3.553-4.007 (3.829)	3.219-4.137 (3.619)	2.492-4.508 (3.717)	0.978-1.874 (1.497)
Exchange acidity	3.96-5.94 (4.93)	10.26-14.94 (12.42)	2.88-10.44 (6.26)	6.48-9.36 (7.83)	5.22-10.05 (7.30)	4.32-7.02 (5.85)
CEC Sum of Cations	5.16-7.62 (6.49)	13.30-17.69 (15.43)	6.86-13.99 (8.39)	10.38-13.50 (11.45)	8.91-12.54 (11.02)	5.66-8.82 (7.35)
NH_4OAc pH7	4.30-7.95 (5.94)	12.90-13.90 (13.16)	5.20-11.20 (8.44)	7.70-14.95 (10.65)	9.30-10.70 (9.80)	2.80-5.50 (4.06)
Ratio of Clay/ NH_4OAc CEC	0.048-0.086 (0.062)	0.062-0.093 (0.074)	0.061-0.132 (0.097)	0.060-0.118 (0.086)	0.054-0.102 (0.080)	0.028-0.063 (0.038)
Base saturation						
sum of cations	19.14-29.58 (24.05)	15.57-27.87 (21.05)	25.39-58.18 (40.84)	28.01-37.57 (31.78)	19.89-41.38 (34.57)	15.71-23.69 (20.33)
NH_4OAcpH7	15.13-40.44 (28.19)	21.31-24.27 (22.90)	34.29-77.06 (49.50)	21.55-49.04 (36.72)	24.92-47.45 (38.18)	32.75-43.97 (37.43)

14.95 me/100 g (No.16) of Kanjikulam series. The CEC values showed no definite variation with depth in all the soils. The CEC was positively correlated to organic matter content of soils but was not significant. Clay was also positively correlated with CEC (r = 0.418*) which was significant.

The CEC determined by sum of cations was highest for Kootala series (No.7) with 17.69 me/100 g and the lowest for Thonnackal series (No.2) with 5.16 me/100 g. Profile means indicated highest value of 15.43 me/100 g and lowest of 6.49 me/100 g for the above two series. For other soils, the values were 10.08, 9.09, 11.01, and 7.34 me/100 g for Anjur, Kanjikulam, Mannur and Nenmanda series respectively.

5.2 Exchange acidity

The highest mean value of 12.42 me/100 g soil was obtained for Kootala, while the lowest of 4.93 me/100 g was recorded for Thonnackal series. In respect of other soils, the values were 6.26, 7.83, 7.30 and 5.85 me/100 g for Anjur, Kanjikulam, Mannur and Nenmanda series respectively.

CEC_s/100 g clay varied from 12.5 (No.25) in Nenmanda series to 42.2 me/100 g clay (No.6) in Kootala series.

5.3 Exchangeable cations

The exchangeable calcium content of different soils studied varied from 0.611 me/100 g (No.25 and 26) of Nenmanda series to 3.430 me/100 g (No.10) of Anjur series. Definite decrease in exchangeable calcium with depth was noted in Nenmanda series only. The exchangeable calcium showed positive significant correlation with CEC (r = 0.544**).

In the case of exchangeable magnesium, the range observed was from 0.015 me/100 g (No.3) in Thonnackal series to 1.759 me/100 g (No.14) in Kanjikulam series. Maximum accumulation of exchangeable magnesium was noted in surface layers of Thonnackal, Kanjikulam and Mannur series, while intermediate layers showed accumulation in Kootala, Anjur and Nenmanda series. The exchangeable magnesium showed positive correlation with CEC which was not significant.

The content of exchangeable potassium varied from 0.029 me/100 g (No.3) in Thonnackal series to 0.561 me/100 g (No.24) in Nenmanda series. The exchangeable sodium content ranged from 0.060 me/100 g (No.26) of Nenmanda series to 0.217 me/100 g (No.17) of Kanjikulam series. Definite decrease in exchangeable potassium with depth was noticed in Anjur, Kanjikulam and Mannur series and the same trend in exchangeable sodium was noted in Nenmanda series. All other soils did not show any definite profile variation with depth. The correlation coefficients of exchangeable potassium and sodium with CEC were positive but not significant.

Potassium chloride extractable aluminium recorded slightly lower values and ranged from 0.004 me/100 g (No.21) of Kanjikulam series to 0.838 me/100 g (No.4) of Thonnackal series. Irregular variation in the exchangeable aluminium content with depth was observed in all the soils. Base saturation was calculated based on sum of cation and ammonium acetate CEC. For most of the soils investigated base saturation by sum of cation method was less than that calculated by NH_4OAc method. In case of Mannur series, the reverse was true. The highest base saturation values by both methods were obtained for Anjur series and the lowest values in Kootala series. The base saturation for other soils investigated showed a decrease in the order Nenmanda, Kanjikulam, Mannur and Thonnackal series by NH_4OAc method, and Mannur, Kanjikulam, Thonnackal and Nenmanda by sum of cation method. Trends in profile variation of this property could not be discerned in any of the soils investigated. This was true of base saturation calculated by both the methods.

Percentage base saturation was significantly correlated to exchangeable calcium ($r = 0.463^{*}$) and exchangeable potassium ($r = 0.442^{*}$). Only nonsignificant positive correlation was observed between percentage base saturation and exchangeable magnesium and exchangeable sodium.

6. Extractable iron and active iron ratio

The total Fe_2O_3, dithionite - citrate-bicarbonate extractable iron (Fe_d), oxalate extractable iron (Fe_o) and active iron ratio are presented in Table 13(a) and mean and range value for profiles are given in Table 13(b). The depthwise variations in free iron oxides and total iron are shown in Figure 5.

The Fe_d ranged from 0.85 per cent (No.3) of Thonnackal series to 10.87 per cent (No.17) in Kanjikulam series. The Fe_d showed maximum accumulation in the lower most layer of profile in Kootala and Kanjikulam series. Fe_d showed positive and highly significant correlation with total iron ($r = 0.930^{**}$), clay ($r = 0.522^{**}$) and silt ($r = 0.617^{**}$). The Fe_d showed significant negative correlation with coarse sand ($r = -0.491^{**}$) and fine sand ($r = -0.599^{**}$).

Table 13(a). Iron oxide fractions in soils

Soil series sample No. and depth (cm)		% Fe_2O_3			$\frac{Fe_d}{Fe_t} \times 100$	Active iron ratio Fe_o/Fe_d	Fe_d/clay
		*Fe_t	*Fe_d	*Fe_o			
Thonnackal							
1	0-14	1.66	1.04	0.13	62.65	0.125	0.05
2	14-30	1.60	1.56	0.27	97.50	0.173	0.05
3	30-57	1.86	0.85	0.12	45.70	0.141	0.02
4	57-90	3.97	3.69	0.21	92.95	0.057	0.08
5	90-180+	2.94	1.84	0.24	62.59	0.130	0.04
Kootala							
6	0-13	8.06	7.83	0.23	97.15	0.029	0.22
7	13-53	10.88	6.44	1.15	59.19	0.179	0.13
8	53-110	9.98	9.22	1.01	92.38	0.110	0.17
9	110-180+	9.40	9.22	0.95	98.09	0.103	0.17
Anjur							
10	0-13	5.44	3.48	0.04	63.97	0.011	0.07
11	13-40	6.72	6.44	0.02	95.83	0.003	0.21
12	40-90	6.46	6.08	0.20	94.12	0.033	0.10
13	90-160+	5.95	5.73	0.10	96.30	0.017	0.16
Kanjikulam							
14	0-10	5.82	5.39	0.06	92.61	0.011	0.14
15	10-48	6.46	6.44	0.12	99.69	0.019	0.14
16	48-96	6.40	6.26	0.06	97.81	0.010	0.11
17	96-145	11.46	10.87	0.01	94.85	0.001	0.22
Mannur							
18	0-10	7.30	5.73	0.01	78.49	0.002	0.16
19	10-21	6.34	5.56	0.50	87.70	0.090	0.11
20	21-50	6.40	5.73	0.24	89.53	0.042	0.10
21	50-110	5.95	5.23	0.01	87.90	0.002	0.13
22	110-180+	6.59	5.73	0.04	86.95	0.007	0.11
Nanmanda							
23	0-14	3.94	3.35	0.03	85.03	0.009	0.11
24	14-36	5.25	4.61	0.31	87.81	0.067	0.11
25	36-98	5.89	4.03	0.21	68.42	0.052	0.09
26	98-150+	6.02	3.75	0.01	62.29	0.003	0.11

* Fe_t - Total iron   *Fe_d - Dithionite citrate bicarbonate extractable iron

*Fe_o - Oxalate extractable iron

Table 13(b). Iron oxide fractions in soils, mean and range values for profiles

Constituents	Soil series					
	Thonnackal	Kootala	Anjur	Kanjikulam	Mannur	Nenmanda
Fe_t%	1.60–3.97 (2.41)	8.06–10.88 (9.58)	5.44–6.72 (6.14)	5.82–11.46 (7.54)	5.95–7.30 (6.52)	3.94–6.02 (5.28)
Fe_d%	0.85–3.69 (1.80)	6.44–9.22 (8.18)	3.48–6.44 (5.43)	5.39–10.87 (7.24)	5.23–5.73 (5.60)	3.35–4.61 (3.94)
Fe_o%	0.12–0.27 (0.19)	0.23–1.15 (0.84)	0.02–0.20 (0.09)	0.01–0.12 (0.06)	0.01–0.50 (0.16)	0.01–0.31 (0.14)
$\frac{Fe_d \times 100}{Fe_t}$	45.70–97.50 (72.28)	59.19–98.09 (86.70)	63.97–96.30 (87.56)	92.61–99.69 (96.24)	78.49–89.53 (86.11)	62.29–87.81 (78.89)
Fe_o/Fe_d	0.057–0.173 (0.125)	0.029–0.179 (0.105)	0.003–0.033 (0.016)	0.001–0.019 (0.010)	0.002–0.090 (0.029)	0.003–0.067 (0.033)
$\frac{Fe_d}{Clay}$	0.02–0.08 (0.05)	0.13–0.22 (0.17)	0.07–0.21 (0.14)	0.11–0.22 (0.15)	0.10–0.16 (0.12)	0.09–0.11 (0.11)

Fe_d expressed as percentage of total iron often referred to as "degree of freeness of iron oxide" was found to be maximum in Kanjikulam series (92.60 to 99.69 per cent) followed by Anjur series (63.97 to 96.30 per cent), Kootala (59.19 to 98.09 per cent), Mannur (78.49 to 89.53 per cent), Nemmanda series (62.29 to 87.81 per cent) and Thonnackal series (45.70 to 97.50 per cent).

The oxalate extractable iron recorded low values compared to Fe_d. The mean values for the profiles vary from 0.06 to 0.84 per cent in Kanjikulam and Kootala series respectively. Correlation of oxalate iron with total iron (r = 0.468*) and clay content (r = 0.399*) was positive and significant while with coarse sand it was negative (r = -0.161). A negative correlation was observed between Fe_o and fine sand but was not significant. Silt also showed a positive correlation with Fe_o which was not significant. Ratio of Fe_o to Fe_d termed the active iron ratio was also very low ranging from 0.001 (No.17) of Kanjikulam series to 0.179 (No.7) of Kootala series. Both the oxalate extractable iron and active iron ratio did not show any trend of variation in the profile.

Fe_d/clay ratio ranged from 0.02 (No.3) of Thonnackal series to 0.22 (No.6) of Kootala and (No.17) of

Kanjikulam series. Higher ratios near the surface were observed in Kootala, Mannur and Anjur series while the reverse trend was noted in Kanjikulam. However Nenmanda series maintained a constant value with depth in the profile(No.3).

7. Phosphorus fractions

Data on phosphorus fractions and range and mean values for profiles are given in Table 14. The depth wise distribution is shown in Fig.6.

Fe-P formed the major part of total P and ranged from 8.44 ppm (No.3 and No.4) of Thonnackal series to 1003.55 ppm (No.9) of Kootala series.

The Al-P ranged from 1.02 ppm (No.5) of Thonnackal series to 404.55 ppm (No.7) of Kootala series.

With regard to Ca-P, it varied from 1.83 ppm (No.26) in Nenmanda series to 70.25 ppm (No.7) in Kootala series.

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

The lowest value for saloid P was 0.69 ppm (No.3) of Thonnackal series and highest value was 7.91 (No.24) of Kootala series.

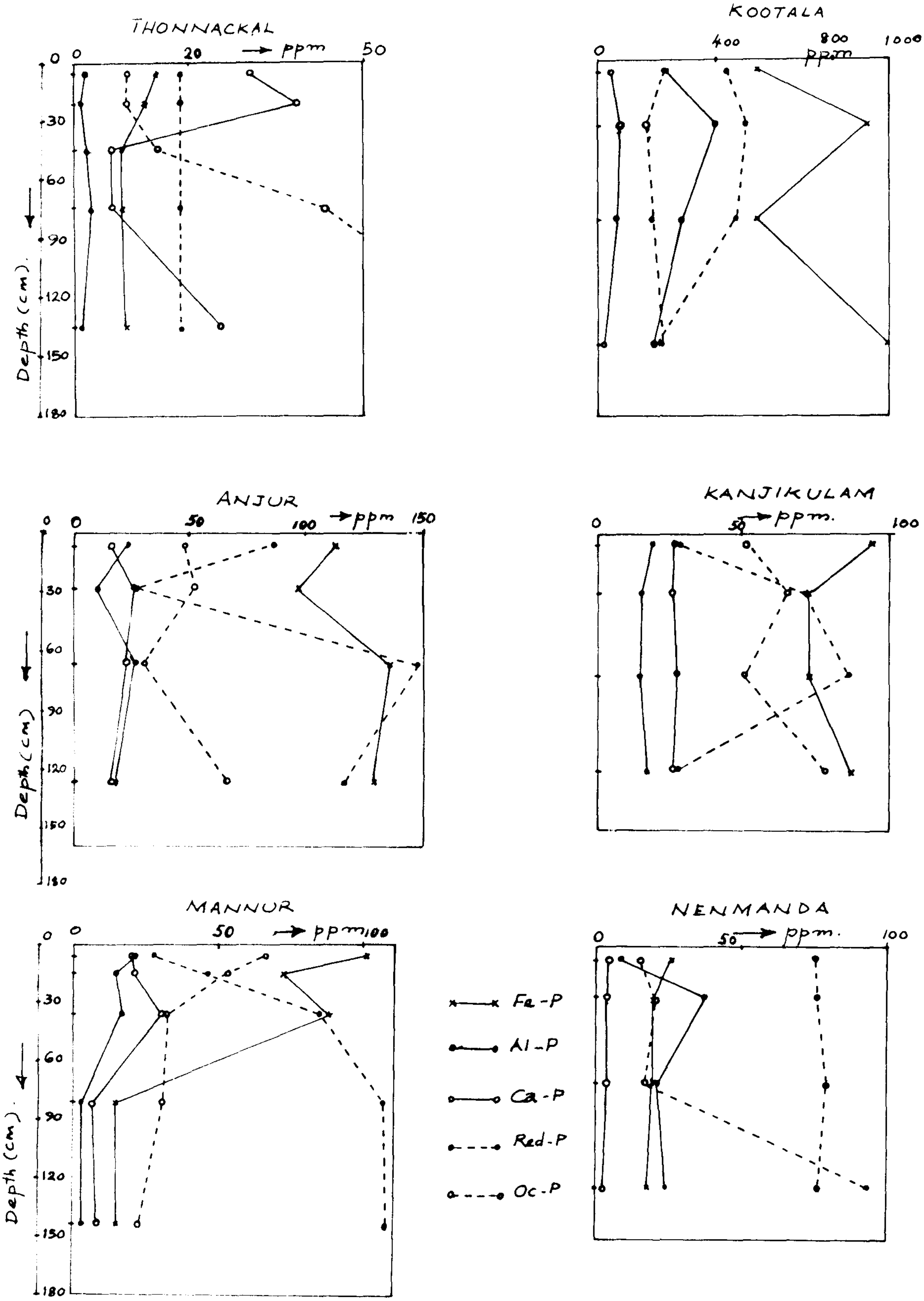
Table 14(a). Phosphorus fractions in soil (ppm)

Soil series sample No. and depth (cm)		Total P	Active inorganic P			Sum	Saloid P	Reductant P	Occluded P	Active fraction %		
			Fe-P	Al-P	Ca-P					Fe-P	Al-P	Ca-P
Thonnackal												
1	0-14	214.00	14.50	2.10	30.38	46.98	4.99	18.15	9.26	30.86	4.47	64.67
2	14-30	107.32	12.13	1.29	38.55	51.97	1.38	18.15	9.26	23.34	2.48	74.18
3	30-57	160.97	8.44	2.34	6.25	17.03	0.69	18.15	14.47	49.56	13.74	36.70
4	57-90	214.00	8.44	2.93	6.25	17.62	3.37	18.15	43.41	47.90	16.63	35.47
5	90-180+	107.32	9.33	1.02	25.00	35.35	6.41	18.15	70.90	26.39	2.89	70.72
Kootala												
6	0-13	2768.50	541.42	230.28	41.87	813.57	3.77	437.45	218.07	66.55	28.30	5.15
7	13-53	3627.77	922.53	404.55	70.25	1397.33	1.87	503.90	159.56	66.02	28.95	5.03
8	53-110	3048.75	541.42	278.67	60.92	881.01	0.92	496.88	184.51	61.45	31.63	6.92
9	110-180+	2978.00	1003.55	192.44	16.85	1212.84	0.92	205.33	224.09	82.74	15.87	1.39
Anjur												
10	0-13	378.05	112.16	23.46	16.88	152.50	3.77	85.70	48.58	73.55	15.38	11.07
11	13-40	378.05	96.94	9.12	24.83	130.89	1.15	27.50	51.63	74.06	6.97	18.97
12	40-90	431.70	136.93	26.48	21.33	184.74	1.38	148.58	29.88	74.12	14.33	11.55
13	90-145+	431.70	128.48	17.50	15.33	161.31	2.08	116.50	64.15	79.65	10.85	9.50
Kanjikulam												
14	0-10	322.68	94.77	18.95	26.02	139.74	5.78	27.50	51.63	67.82	13.42	18.62
15	10-48	322.68	73.21	14.64	15.23	103.08	1.38	70.61	65.98	71.02	14.20	14.77
16	48-96	322.68	73.21	14.64	16.88	104.73	0.92	85.66	48.58	69.90	13.98	16.12
17	96-145+	431.70	87.54	17.51	15.79	120.84	2.80	217.50	78.88	72.44	14.49	13.07
Mannur												
18	0-10	268.29	102.15	20.43	19.63	142.21	3.28	27.50	65.05	71.83	14.37	13.80
19	10-21	213.99	73.21	14.64	20.21	108.06	2.32	46.35	52.40	67.75	13.55	18.70
20	21-50	322.68	87.54	17.51	30.40	135.45	3.77	85.66	32.93	64.63	12.93	22.44
21	50-110	322.68	14.70	2.94	6.08	23.72	0.69	106.10	31.10	61.97	12.39	25.64
22	110-180+	268.29	15.63	3.13	8.54	27.30	0.69	107.08	22.99	57.25	11.47	31.28
Nenmanda												
23	0-14	268.29	25.23	7.51	3.69	36.43	1.38	75.61	14.66	69.26	20.61	10.13
24	14-36	322.68	19.76	37.29	2.77	59.82	7.91	75.61	19.76	33.03	62.34	4.63
25	36-98	268.29	19.76	20.94	3.23	43.93	4.98	78.08	16.63	44.98	47.67	7.35
26	98-150+	431.70	17.65	23.41	1.83	42.89	5.66	75.61	92.04	41.15	54.58	4.27

Table 14(b). Phosphorus fractions in soil (ppm), mean and range values for profiles

Constituents ppm	Soil series					
	Thonnackal	Kootala	Anjur	Kanjikulam	Mannur	Nenmanda
Total P	107.32-214.00 (160.72)	2768.50-3627.77 (3105.76)	378.05-431.70 (404.88)	322.68-431.70 (349.94)	213.99-322.68 (279.19)	268.29-431.70 (322.74)
Active inorganic P						
Ca	6.25-38.55 (21.29)	16.85-70.25 (47.47)	15.33-24.83 (10.59)	15.23-26.02 (18.48)	6.08-30.40 (16.97)	1.83-3.69 (2.88)
Al	1.02-2.93 (1.94)	192.44-404.55 (276.49)	9.12-26.48 (19.14)	14.64-18.95 (16.44)	2.94-20.43 (11.73)	7.51-37.29 (22.29)
Fe	8.44-14.50 (10.57)	541.42-1003.55 (752.23)	96.94-136.93 (118.63)	73.21-94.77 (82.18)	14.70-102.15 (58.65)	17.65-25.23 (20.10)
Sum	17.03-51.97 (33.79)	813.57-1397.33 (1076.19)	130.89-184.74 (157.36)	103.08-139.74 (117.10)	23.72-142.21 (87.35)	36.43-59.82 (45.77)
Saloid P	0.69-6.41 (3.37)	0.92-3.77 (1.87)	1.15-3.77 (2.10)	0.92-5.78 (2.72)	0.69-3.77 (2.15)	1.38-7.91 (4.98)
Reductant P	18.15-18.15 (18.15)	205.33-503.90 (294.78)	27.50-148.58 (94.57)	27.50-85.66 (52.82)	27.50-107.08 (74.54)	75.61-78.08 (76.23)
Occluded P	9.26-70.90 (29.46)	159.56-224.09 (196.56)	29.88-64.15 (48.56)	48.58-78.88 (61.27)	22.99-65.05 (40.89)	14.60-92.04 (35.77)
Percentage of active fraction						
Fe-P	23.34-49.56 (35.61)	61.45-82.74 (69.19)	73.55-79.65 (75.35)	67.82-72.44 (70.30)	57.25-71.83 (64.69)	33.03-69.26 (47.11)
Al-P	2.48-16.63 (8.04)	15.87-28.95 (26.19)	6.67-15.38 (11.88)	13.42-14.49 (14.02)	11.47-14.37 (12.94)	20.61-62.34 (46.30)
Ca-P	35.47-74.18 (56.35)	1.39-6.92 (4.62)	9.50-18.97 (12.77)	13.07-18.62 (15.65)	13.80-31.28 (22.37)	4.27-10.13 (6.60)

FIG. (6). DISTRIBUTION OF FRACTIONS OF INORGANIC PHOSPHORUS IN SOIL PROFILE



The occluded P varied from 9.26 ppm (No.1 and 2) in Thonnackal series to 224.09 ppm (No.9) of Kootala series. There was no definite pattern in the distribution of saloid P, reductant P and occluded P with depth in all the series.

Fe-P formed the predominant among the active fractions on all the soils investigated except Nemmanda and Thonnackal series. This was followed by Ca-P and Al-P respectively in the case of Anjur, Kanjikulam and Mannur series. In Kootala series Fe-P was followed by Al-P and then Ca-P. Thonnackal series however showed a predominance of Ca-P followed by Fe-P and then Al-P.

Significant positive correlation was observed between CEC and Ca-P (r = 0.504**). Positive and significant correlation was noted for Al-P with silt (0.393*), total Fe_2O_3 (0.634**), CEC (0.520**) and dithionite iron (0.474*).

Significant positive correlation was obtained for Fe-P with silt (0.448**), total Fe_2O_3 (0.649**), CEC (0.603**) and dithionite iron (0.554**). Significant negative correlation was obtained between Fe-P and coarse sand (-0.395*).

Significant positive correlation was obtained for reductant P with total Fe_2O_3 (0.591**), CaO (0.434*) CEC (0.535**) and dithionite iron (0.471*).

Positive and significant correlation was obtained for occluded P with silt (0.483*) and Fe_2O_3 (0.678**) CEC (0.568**) and dithionite iron (0.476*).

8. Chemical composition of clay fraction and molar ratios

The results of chemical analysis of clay and molar ratios are presented in Table 15.

Silica formed the major constituent of clay and it varied from 26.3 per cent (No.23) of Nenmanda series to 43.2 per cent (No.22) of Mannur series. The silica content showed a decrease with depth in the case of Kootala series. In respect of other soils, no definite pattern of distribution with depth was obtained.

The content of Al_2O_3 was the highest in Thonnackal series (No.2) with 36.2 per cent while the lowest value of 10.6 per cent (No.6) was recorded for Kootala series. Irregular distribution with depth in the Al_2O_3 content was a feature common to all the soils investigated.

Table 15(a). Chemical composition, molar ratios and cation exchange capacity of clay fraction

Soil series sample No. 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	*Fe_d %	CEC me/100 g
Thonnackal								
1 0–14	34.0	34.0	14.0	1.70	6.47	1.35	0.53	35
2 14–30	37.8	36.2	8.8	1.78	11.43	1.42	0.30	35
3 30–57	40.0	29.6	10.4	2.30	10.25	1.88	0.30	44
4 57–90	36.8	35.0	12.0	1.79	8.16	1.47	0.35	33
5 90–180+	40.0	28.0	12.0	2.42	8.88	1.91	0.34	45
Kootala								
6 0–13	40.0	10.6	32.4	6.41	3.29	2.17	1.24	35
7 13–53	36.0	22.7	29.8	2.69	2.69	1.47	1.30	44
8 53–110	36.0	24.4	29.6	2.51	3.24	1.38	1.24	46
9 110–180+	33.5	24.4	26.6	2.34	3.35	2.17	1.36	44
Anjur								
10 0–13	33.2	27.1	23.4	2.08	3.78	1.34	1.01	41
11 13–40	35.9	22.7	24.8	2.68	3.85	1.58	0.35	36
12 40–90	36.2	24.3	22.2	2.53	4.34	1.60	0.38	41
13 90–160+	36.3	22.2	21.8	2.75	4.43	1.71	0.39	38
Kanjikulam								
14 0–10	36.0	22.2	25.8	2.75	3.71	1.58	1.01	46
15 10–48	35.9	20.8	22.2	2.93	4.30	1.74	0.68	44
16 48–96	35.8	19.3	22.2	3.16	4.30	1.82	0.58	46
17 96–145+	35.8	25.1	21.4	2.43	4.46	1.57	0.53	44
Mannur								
18 0–10	36.8	25.9	21.6	2.41	4.53	1.58	1.61	49
19 10–21	38.6	27.4	18.6	2.39	4.52	1.67	0.68	45
20 21–50	36.4	30.5	19.2	2.03	5.05	1.45	0.79	41
21 50–110	38.8	29.2	18.8	2.26	5.50	1.60	0.63	41
22 110–180+	43.2	29.9	14.6	2.46	7.88	1.87	0.68	41
Nenmanda								
23 0–14	26.3	34.5	18.0	1.30	3.89	0.97	1.06	44
24 14–36	28.9	27.5	20.0	1.79	3.86	1.22	2.08	38
25 36–98	32.8	28.0	21.0	1.99	4.16	1.35	1.06	44
26 98–150+	30.1	30.7	21.8	1.67	3.68	1.15	0.84	41

Table 15 (b). Chemical composition, molar ratios and cation exchange capacity of clay fraction, mean and range values for profiles

Constituents	Soil series					
	Thonnackal	Kootala	Anjur	Kanjikulam	Mannur	Nenmanda
SiO_2 %	34.0–40.0 (37.72)	33.5–40.0 (36.38)	33.2–36.3 (35.40)	35.8–36.0 (35.88)	36.4–43.2 (38.76)	26.3–32.8 (29.53)
Al_2O_3 %	28.0–36.2 (32.56)	10.6–24.4 (20.53)	22.2–27.1 (24.08)	19.3–25.1 (21.85)	25.9–30.5 (28.58)	28.0–34.5 (30.18)
Fe_2O_3 %	8.8–14.0 (11.44)	26.6–32.4 (29.60)	21.8–24.8 (23.05)	21.4–25.8 (22.90)	14.6–21.6 (18.56)	18.0–21.8 (20.20)
<u>Molar ratios</u>						
SiO_2/Al_2O_3	1.70–2.42 (2.00)	2.34–6.41 (3.49)	2.08–2.78 (2.52)	2.43–3.16 (2.82)	2.03–2.46 (2.31)	1.30–1.99 (1.69)
SiO_2/Fe_2O_3	6.47–11.43 (9.04)	2.69–3.35 (3.14)	3.78–4.43 (4.10)	3.71–4.46 (4.19)	4.52–7.88 (5.50)	3.68–4.16 (3.90)
SiO_2/R_2O_3	1.35–1.91 (1.61)	1.38–2.17 (1.80)	1.34–1.71 (1.56)	1.57–1.82 (1.68)	1.45–1.87 (1.63)	0.97–1.35 (1.17)
Fe_d %	0.30–0.53 (0.36)	1.24–1.36 (1.29)	0.35–1.01 (0.53)	0.53–1.01 (0.70)	0.63–1.61 (0.88)	0.84–2.08 (1.26)
CEC me/100 g	33–45 (38.40)	35–46 (42.25)	36–41 (39.00)	44–46 (45.00)	41–49 (43.40)	38–44 (41.75)

In respect of Fe_2O_3 content of the clay, Kootala (No.6) showed the highest value of 32.4 per cent while Thonnackal series (No.2) recorded the lowest value of 8.8 per cent. The Fe_2O_3 content of clay fraction showed a steady decrease with depth in the case of Kanjikulam series and a reverse trend in Nenmanda.

The SiO_2/Al_2O_3 ratio ranged from 1.30 (No.23) of Nenmanda series to 6.41 (No.6) of Kootala series. A decreasing trend with depth in the SiO_2/Al_2O_3 ratio was observed in Kootala series while in others it was erratic.

The SiO_2/Fe_2O_3 ratio of clay fraction did not show variation within the soil profile. The ratio varied from 2.69 (No.7) of Kootala to 11.43 (No.2) of Thonnackal series.

The silica/sesquioxide ratio recorded low values as compared to other molar ratios. The range observed was 0.97 (No.23) of Nenmanda series to 2.17 (No.6 and 9) of Kootala series. The ratio showed a tendency to increase down the profile in the case of Anjur series with no trend of variation observed in the other soils under investigation.

The dithionite extractable iron content of clay fraction was the highest in Nenmanda series with a value of 2.08 per cent (No.24). The lowest value of 0.30 per cent (No.2 and 3) was noted for Thonnackal series.

The cation exchange capacity of the clay fraction ranged from 33 me/100 g (No.4) of Thonnackal series to 49 me/100 g (No.18) of Mannur series. Irregular distribution of CEC of clay with depth was observed in all soils except for Mannur series where a definite decrease with depth was noted.

9. Chemical analysis of rock and laterites

The results of chemical analysis of parent rock and laterites collected from different locations are given in Table 16. Plates 10 to 15 present the nature of the laterite rock obtained from different areas. Distribution of silica, iron and aluminium oxides are shown in Fig.7.

The analysis of rock revealed the siliceous nature as shown by high SiO_2 content ranging from 76.80 per cent (Thonnackal series) to 87.60 per cent (Mannur series). Al_2O_3, Fe_2O_3 and CaO were the other major constituents. The composition of laterites indicated drastic reduction in the content of SiO_2 and rise in Al_2O_3 and Fe_2O_3 and a consequent sharp fall in the molar ratios. The SiO_2/R_2O_3 ratios of laterite rocks were low except in the case of laterite samples from Thonnackal and Mannur series. The SiO_2/R_2O_3 ratios ranged from

Table 16. Total chemical analysis of rocks and laterites

Location of sample	Sample	SiO_2	Al_2O_3	Fe_2O_3	MnO_2	CaO	MgO	K_2O	Na_2O	P_2O_5	TiO_2 ppm	Molar ratios $\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$
		Per cent												
Trivandrum	Rock	76.80					Not sampled							
Thonnackal	Laterite	76.80	8.00	3.20	0.005	0.14	0.02	0.12	0.05	0.025	3.48	16.00	64.00	12.80
	*L/R													
Trichur	Rock	79.20	6.28	5.12	0.092	0.36	0.16	1.08	0.40	0.802	7.00	22.00	41.25	11.61
Kootala	Laterite	30.20	28.96	16.64	0.015	0.14	0.14	0.42	0.10	0.718	15.49	1.79	4.81	1.30
	L/R	00.38	4.61	3.25	0.160	0.37	0.88	0.39	0.25	0.895	2.21	-	-	-
Trichur	Rock	84.75	0.52	4.48	0.052	0.17	0.21	0.78	0.30	0.191	4.72	28.20	50.35	18.08
Anjur	Laterite	29.50	24.80	16.00	0.044	0.14	0.30	0.36	0.05	0.325	22.36	2.04	4.90	1.44
	L/R	0.35	47.69	3.57	0.846	0.85	1.43	0.46	0.17	1.700	4.74	-	-	-
Palghat	Rock	81.00	7.08	5.12	0.021	0.16	0.75	1.50	0.50	0.482	8.73	19.29	42.19	13.24
Kanjikulam	Laterite	33.30	27.36	16.64	0.022	0.10	0.35	0.24	0.05	0.325	7.39	2.07	5.38	1.50
	L/R	0.41	3.86	3.25	1.050	0.58	0.47	0.16	0.10	0.674	0.85	-	-	-
Palghat	Rock	87.60	3.00	3.20	0.035	0.13	0.94	1.44	0.20	0.191	8.81	48.67	73.00	29.20
Mannur	Laterite	61.90	16.80	6.40	0.008	0.13	0.42	0.24	0.10	0.151	2.61	6.24	25.75	5.02
	L/R	0.71	5.60	2.00	0.229	0.98	0.45	0.17	0.50	0.791	0.30	-	-	-
Calicut	Rock	83.40	3.60	3.20	0.040	0.16	0.98	1.02	0.20	0.073	6.02	39.71	69.50	25.27
Nenmanda	Laterite	43.30	31.68	9.92	0.013	0.14	0.14	0.24	0.10	0.140	6.22	2.32	12.32	1.95
	L/R	0.52	8.80	3.10	0.325	0.92	0.14	0.24	0.50	1.920	0.97	-	-	-

*L/R Element in laterite/element in rock

Quarriable laterites

Plate 10. Thonnackal series. Note the pink deposits of lithomarge

Plate 11. Kootala series

Plate 10

Plate 11

Quarriable laterites

Plate 12. Anjur series

Plate 13. Kanjikulam series

Plate 12

Plate 13

<u>Quarryable laterites</u>

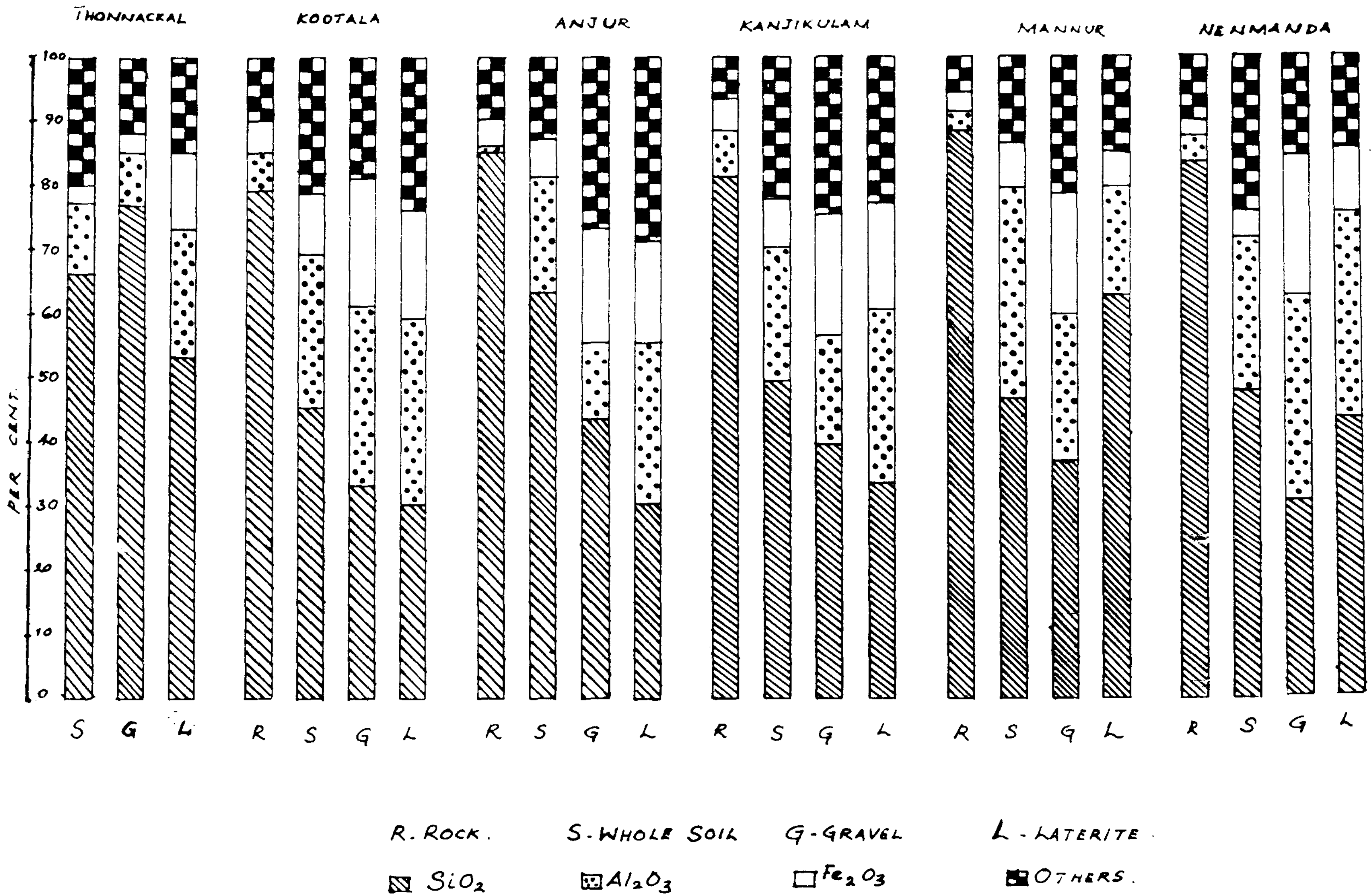
Plate 14. Kannur series

Plate 15. Nenmanda series

Plate 14

Plate 15

FIG. (7). CONTENT OF SILICA, IRON AND ALUMINIUM OXIDES IN PARENT ROCK, WHOLE SOIL, GRAVEL, AND LATERITE.



1.30 to 12.80, while the same for parent rock varied from 11.61 to 29.20.

The maximum SiO_2 content in rock was observed in Mannur series (87.60 per cent) while the lowest value was recorded in Kootala series (79.20 per cent). The highest value of SiO_2 in laterite was noted in Thonnackal series (76.80 per cent) and the lowest was in Anjur series (29.50 per cent). The L/R ratio was highest in Mannur series (0.71) and lowest in Anjur series (0.35).

Kootala and Kanjikulam series recorded a highest value of Fe_2O_3 in rock (5.12 per cent) while Thonnackal, Mannur and Nenmanda recorded the lowest value (3.20 per cent). Kootala and Kanjikulam recorded a highest value of Fe_2O_3 in laterite of 16.64 per cent while the lowest was observed in Thonnackal series (3.20 per cent). The highest L/R value of 3.57 was observed for Anjur series while Mannur series recorded the lowest value of 2.00.

Kanjikulam series ranked first in Al_2O_3 content of rock (7.08 per cent) and Anjur series recorded the lowest value (0.52 per cent) in Al_2O_3 content. Nenmanda series showed the highest value for Al_2O_3 in laterite with 31.68 per cent and Thonnackal series recorded the lowest value of 8.00 per cent. The highest L/R ratio for Al_2O_3

was noted in Anjur series (47.69) while Kanjikulam series recorded the lowest value of 3.86.

With regard to MnO_2 in rock, Kootala series recorded the highest value (0.092 per cent) while Kanjikulam series recorded the lowest value (0.021 per cent). The lowest content of MnO_2 in laterite (0.005 per cent) was observed in Thonnackal series while Anjur recorded the highest of 0.044 per cent. The L/R ratio of MnO_2 was high in Kanjikulam series (1.050) and low in Kootala series (0.160).

Kootala series recorded the highest value of CaO in rock (3.60 per cent) while Mannur series reported the lowest value of (1.31 per cent). The values for laterites ranged from 0.95 per cent in Kanjikulam series to 1.44 per cent in Anjur and Nenmanda series. The L/R value ranged from 0.37 in Kootala series to 0.98 in Mannur series.

The total MgO content in rock ranged from 0.16 per cent in Kootala series to 0.98 per cent in Nenmanda series. The MgO content for laterite varied from 0.02 per cent in Thonnackal series to 0.42 per cent in Mannur series. The L/R value ranged from 0.14 in Nenmanda series to 1.43 in Anjur series.

The content of K_2O in the rock ranged from 0.78 per cent in Anjur series to 1.50 per cent in Kanjikulam. In the case of laterites, the K_2O value varied from 0.12 per cent in Thonnackal series to 0.42 per cent in Kootala series.

The variation with regard to total Na_2O in the rock samples was from 0.20 per cent in Mannur and Nenmanda series to 0.50 per cent in Kanjikulam series. The Na_2O content in laterites varied from 0.05 per cent in Thonnackal, Anjur and Kanjikulam series to 0.10 per cent in Kootala, Mannur and Nenmanda series. The L/R ratio ranged from 0.10 in Kanjikulam series to 0.50 in Mannur and Nenmanda series.

The P_2O_5 content in the rock varied from 0.073 per cent in Nenmanda series to 0.802 per cent in Kootala series. In laterites, the value varied from 0.025 per cent in Thonnackal series to 0.718 per cent in Kootala series. The L/R value ranged from 0.674 in Kanjikulam series to 1.920 in Nenmanda series.

The TiO_2 content in rock varied from 4.72 ppm in Anjur series to 8.81 ppm in Mannur series. The value with regard to laterites ranged from 2.61 ppm in Mannur series to 22.36 ppm in Anjur series. The L/R value ranged from 0.30 in Mannur series to 4.74 in Anjur series.

The molar ratio, SiO_2/Al_2O_3 varied from 19.29 in Kanjikulam to 48.67 in Mannur soils. The same for laterite was from 1.79 in Kootala to 16.00 in Thonnackal series. In respect of SiO_2/Fe_2O_3, the ratio for rock ranged from 41.25 to 73.00 for Kootala and Mannur series respectively, while it was 4.81 to 64.00 for laterite. The SiO_2/R_2O_3 ratio however varied from 11.61 in Kootala to 29.20in Mannur while for the laterite it recorded the lowest values among the ratios varying from 1.30 to 12.80 for Thonnackal series.

10. Mineralogy of fine sand

Mineralogical composition of fine sand fraction of soils is given in Table 17 and Fig.8. Plates 16 to 19 depict the features of important minerals identified. Light minerals predominated in all the series and it ranged from 55.83 per cent (No.6) of Kootala series to 97.87 per cent (No.12) of Anjur series. The heavy mineral varied from 2.13 per cent (No.12) of Anjur series to 44.17 per cent (No.6) of Kootala series.

The light mineral suite consisted entirely of quartz in all the profiles.

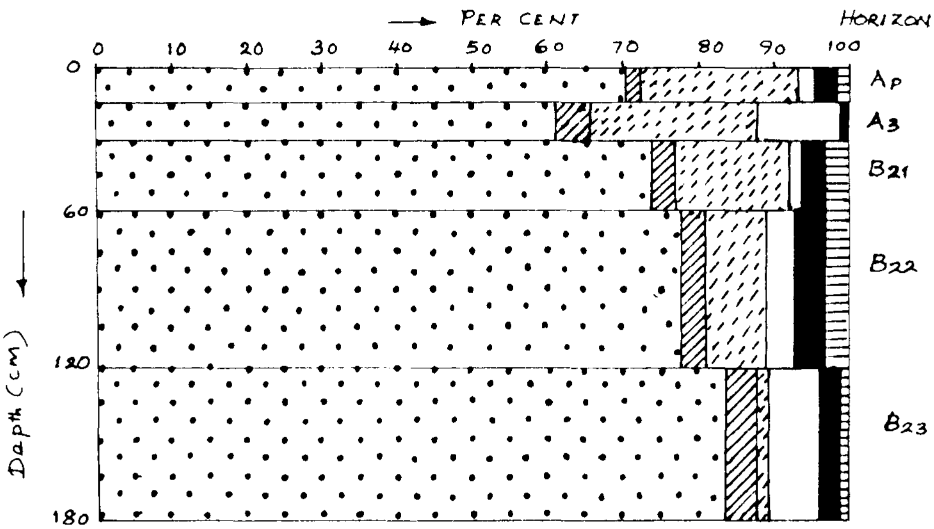
Table 17(a). Mineralogical composition of fine sand fractions of soils

Soil series sample No. and depth (cm)		Heavy minerals %						Heavy minerals %	Light minerals Quartz (%)
		Opaques	Zircon	Sillimante	Mica	Rutile	Sphene		
Thonnackal									
1	0–14	3.46	0.11	1.04	0.13	0.17	0.13	4.94	95.06
2	14–30	5.53	0.42	1.99	1.00	0.12	-	9.06	90.94
3	30–57	30.53	1.25	6.33	0.83	1.30	1.30	41.54	58.46
4	57–90	6.60	0.27	0.70	0.31	0.30	0.28	8.46	91.54
5	90–180+	14.39	0.64	0.22	1.08	0.59	0.22	17.24	82.76
Kootala									
6	0–13	32.68	1.46	0.93	7.27	1.33	0.50	44.17	55.83
7	13–53	29.27	2.20	1.06	3.23	2.22	0.22	38.20	61.80
8	53–110	20.83	0.54	7.31	0.54	1.15	1.43	31.80	68.20
9	110–180+	18.55	1.20	0.24	3.75	0.20	0.24	24.18	75.82
Anjur									
10	0–13	1.65	0.17	0.03	0.49	0.03	0.01	2.38	97.62
11	13–40	2.38	1.10	0.18	0.13	0.10	0.10	3.99	96.01
12	40–90	1.04	0.59	0.01	0.43	0.01	0.05	2.13	97.87
13	90–160+	1.65	0.97	0.11	1.97	-	-	4.70	95.30
Kanjikulam									
14	0–10	6.65	1.86	0.22	-	0.59	—	9.33	90.67
15	10–48	2.54	1.20	0.20	0.50	0.09	-	4.53	95.47
16	48–96	23.45	2.56	0.53	0.09	2.27	-	26.90	73.10
17	96–145+	7.19	1.75	0.28	0.03	0.22	-	9.47	90.53
Mannur									
18	0–10	6.81	1.24	2.11	1.12	0.30	-	11.58	88.42
19	10–21	22.49	5.60	1.58	1.11	0.20	-	30.98	69.02
20	21–50	3.21	1.75	0.10	0.16	0.02	-	5.24	94.76
21	50–110	4.35	1.39	0.08	0.02	0.02	-	5.86	94.14
22	110–180+	1.68	0.48	0.12	0.07	0.08	-	2.43	97.57
Nenmenda									
23	0–14	1.42	0.87	0.62	0.09	0.12	-	3.12	96.88
24	14–36	2.12	1.10	0.81	0.09	0.17	-	4.35	95.65
25	36–98	2.26	1.14	0.74	0.17	0.30	-	4.61	95.39
26	98–150+	2.10	0.74	0.78	0.23	0.36	-	4.22	95.78

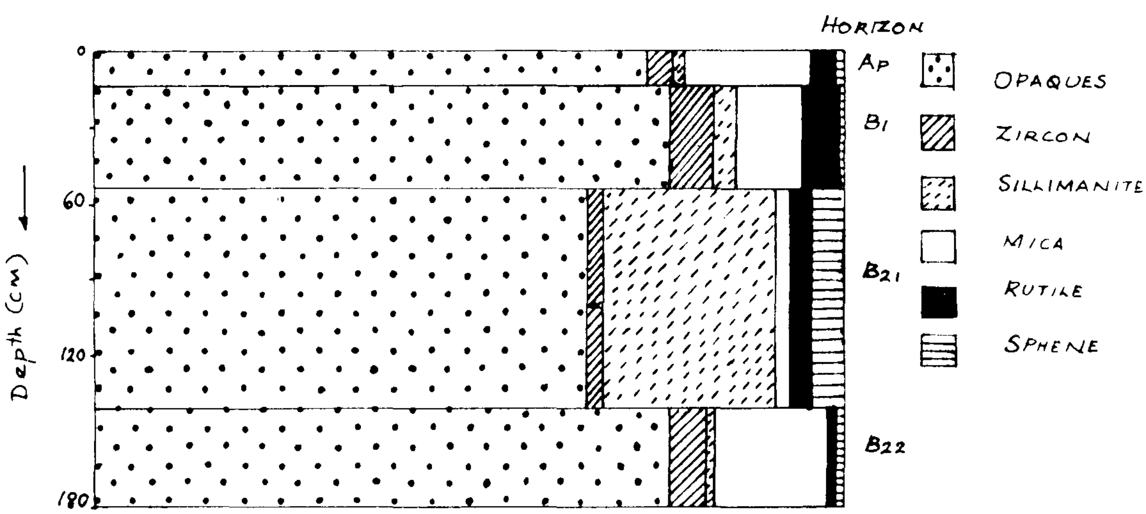
Table 17(b). Mineralogical composition of fine sand fractions of soils (per cent), mean and range values

Constituents %	Soil series					
	Thonnackal	Kootala	Anjur	Kanjikulam	Mannur	Nenmanda
Heavy minerals						
Opaques	5.53–30.53 (12.10)	18.55–32.68 (25.33)	1.04–2.38 (1.68)	2.54–23.45 (9.96)	1.68–22.49 (7.71)	1.42–2.26 (1.98)
Zircon	0.11–1.25 (0.54)	0.54–2.20 (1.35)	0.17–1.10 (0.71)	1.20–2.56 (1.84)	0.48–5.60 (2.09)	0.74–1.14 (0.96)
Sillimanite	0.70–6.33 (2.06)	0.24–7.31 (2.39)	0.01–0.18 (0.08)	0.20–0.53 (0.31)	0.08–2.11 (0.80)	0.62–0.81 (0.74)
Mica	0.13–1.08 (0.67)	0.54–7.27 (3.70)	0.13–1.97 (0.76)	0.00–0.50 (0.16)	0.02–1.12 (0.50)	0.09–0.23 (0.15)
Rutile	0.12–1.30 (0.50)	0.20–2.22 (1.23)	0.00–0.10 (0.04)	0.09–0.59 (0.30)	0.02–0.30 (0.12)	0.12–0.36 (0.24)
Sphene	0.00–1.30 (0.39)	0.22–1.43 (0.60)	0.00–0.10 (0.04)	– (0)	– (0)	– (0)
Heavy mineral	4.94–41.54 (16.25)	24.18–44.17 (34.59)	2.13–4.70 (3.30)	4.53–26.90 (12.56)	2.43–30.98 (11.22)	3.12–4.61 (4.07)
Light minerals Quartz	58.46–95.06 (83.75)	55.83–75.82 (65.41)	95.30–97.87 (96.70)	73.10–95.47 (87.44)	69.02–97.57 (88.78)	95.39–95.88 (95.93)

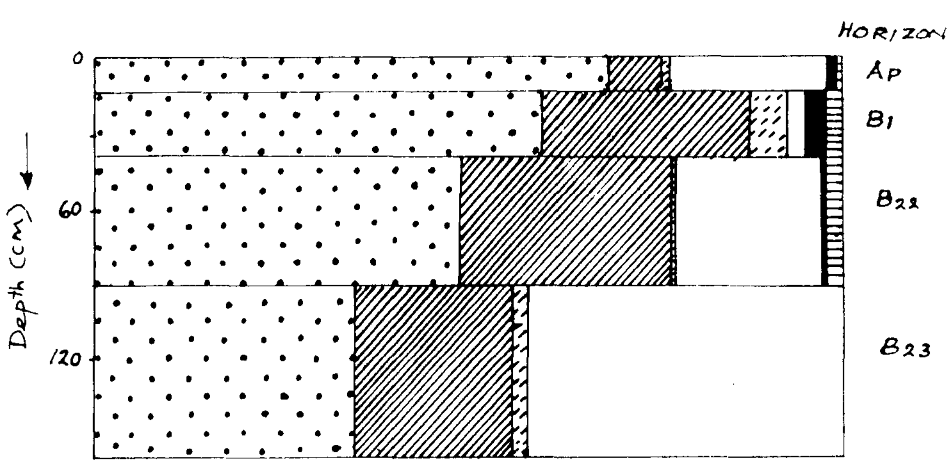
FIG. 8 (a). MINERALOGICAL COMPOSITION OF THE HEAVY FRACTION OF FINE SAND



THONNACKAL

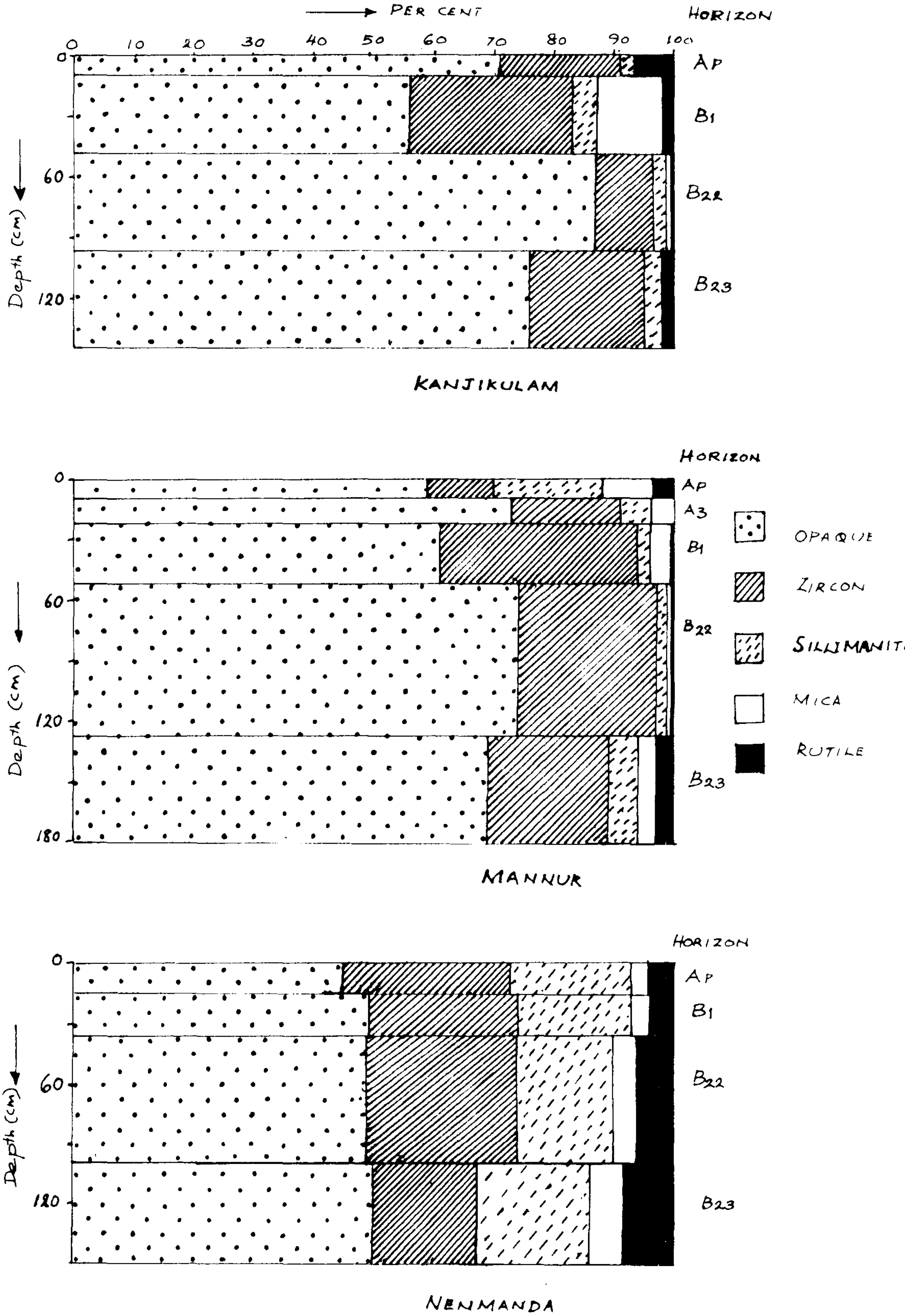


KOOTALA



ANJUR

FIG 8 (b) MINERALOGICAL COMPOSITION OF THE HEAVY FRACTION OF FINE SAND



The heavy mineral suite consisted of opaques, zircon, sillimanite and minor quantities of mica rutile and sphene.

The opaques in the heavy mineral ranged from 1.04 per cent (No.12) of Anjur series to 32.68 per cent (No.6) of Kootala series.

The content of zircon in the heavy mineral suite varied from 0.11 per cent (No.1) of Thonnackal series to 5.60 per cent (No.19) of Mannur series.

No definite trend in the distribution of opaques and zircon with depth was observed.

The mica varied from trace (No.14) in Kanjikulam series to 7.27 per cent (No.6) in Kootala series. Nenmanda series showed an increasing trend in the content of mica with depth while others showed an irregular pattern with depth.

The sillimanite in the heavy mineral suite varied from 0.01 per cent (No.12) in Anjur series to 7.31 per cent (No.8) in Kootala series. No definite trend in the content of sillimanite with depth was observed.

Small quantities of rutile were present in all the profiles.

Plate 16. Sillimanite - x 15 Crystals under crossed nicols

Plate 17. Sillimanite - x 15 Crystals under reflected light

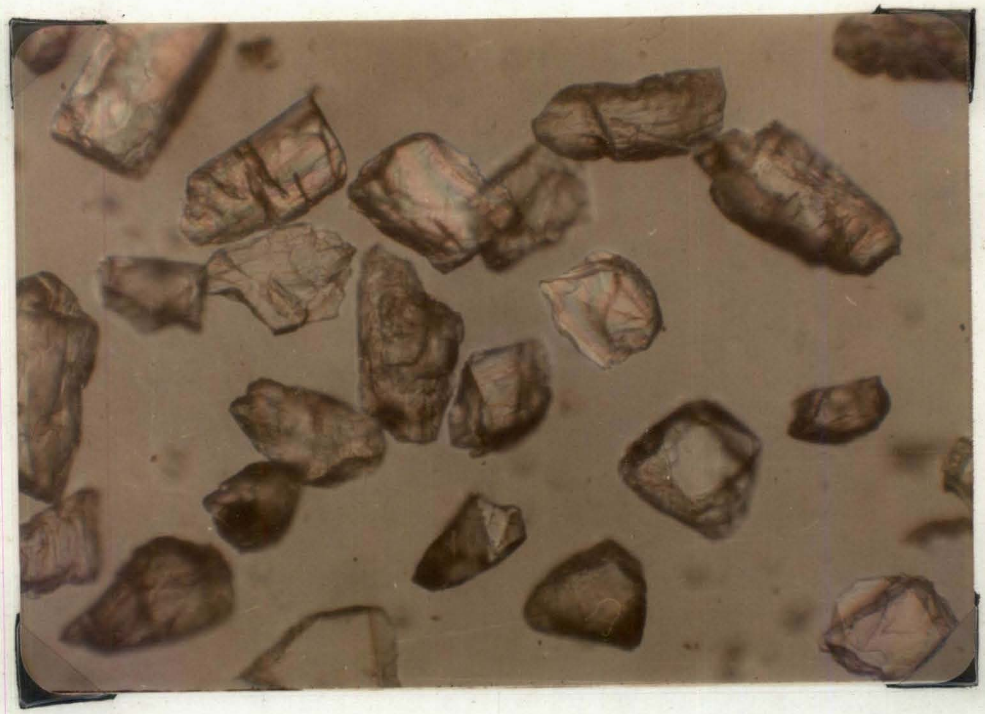


Plate 16

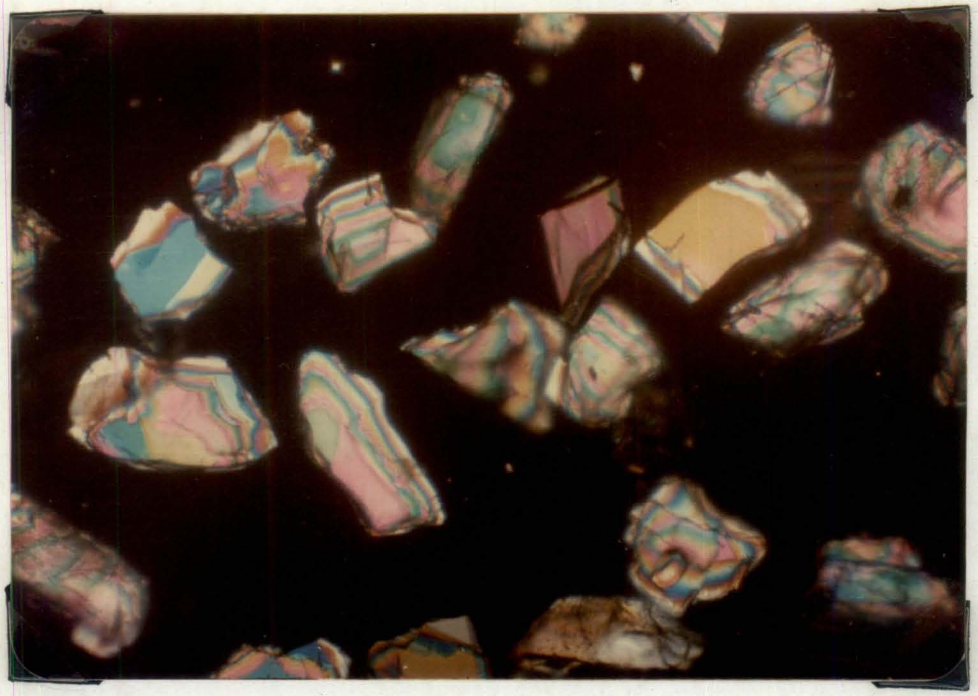


Plate 17

Plate 18. Zircon - x 15. Elongated and stumpy crystals showing the dark boarder. Note the opaque inclusion

Plate 19. Sample - x 10. Cluster of minerals - rutile (red), sillimanite, zircon and opaques

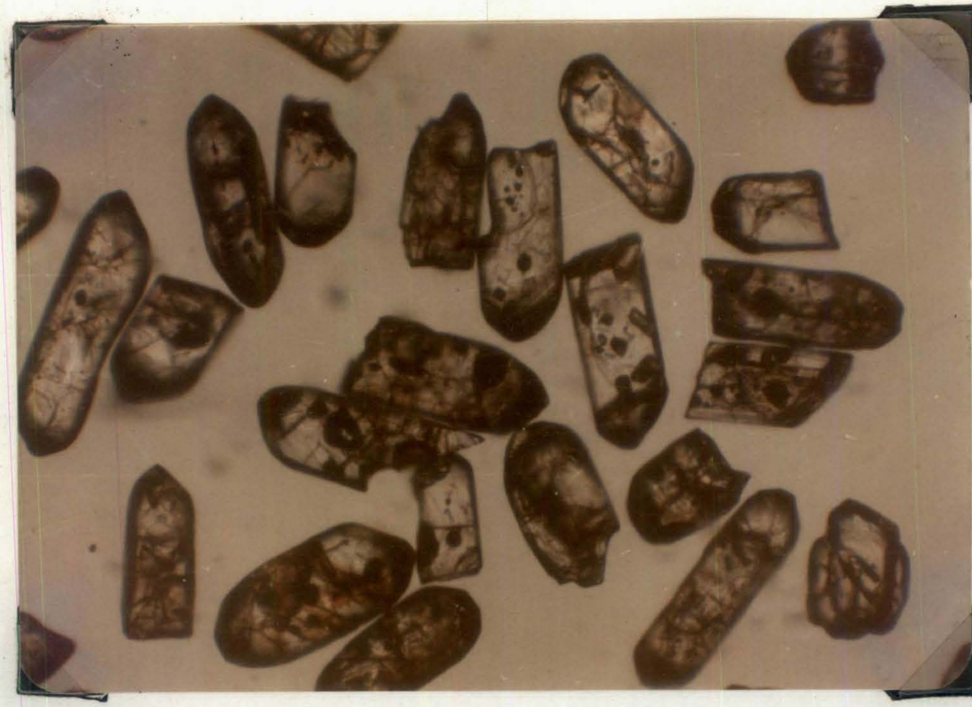


Plate 18

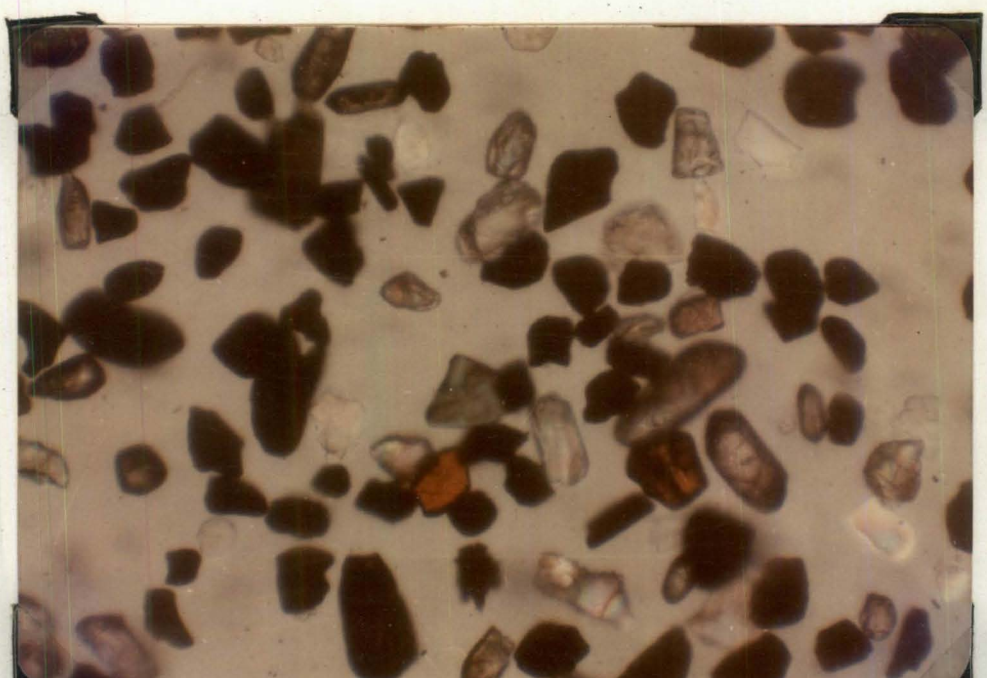


Plate 19

Sphene was completely absent in Kanjikulam, Mannur and Nenmanda series. It ranged from trace to 1.30 per cent, 0.22 to 1.43 per cent and trace to 0.10 per cent in Thonnackal, Kootala and Anjur series respectively.

11. Soil classification

The classification of soils under soil taxonomy was attempted. The analytical characters of profiles required for classification are given in Table 18. Micromorphological studies and other analytical parameters to confirm the presence of clay skins, the basic requirement of Alfisol and Ultisol were lacking. However, field observations showed the absence of clay skins which was taken as the basis for ruling out the possibility of accommodating these soils under Alfisols and Ultisols. The ochric epipedon and cambic horizon, the requirements of Inceptisol were also lacking in all the soils. The identification of an oxic horizon and other characteristics has enabled the classification of all the soils under investigation as Oxisols. Attempts have also been made to classify the soils upto the family level with the available data. Thus Thonnackal series belonged to the fine loamy, kaolinitic, isohyperthermic family of Typic Haplorthox, while Kootala, Anjur, Kanjikulam, Mannur and Nenmanda series belonged to the clayey, kaolinitic, isohyperthermic family of Typic Haplorthox.

Table 18. Analytical characters used for classification of soils

Horizon	Depth (cm)	Clay %	Water dispersible clay%	15 bar moisture/ clay	Silt/ clay	Organic carbon %	NH_4OAc CEC me/100g clay	*ECEC me/100 g clay	Base saturation%	
									NH_4OAc	Sum of cations
1	2	3	4	5	6	7	8	9	10	11
<u>Thonnackal series</u>										
AP	0-14	23.00	5.00	0.28	0.24	0.360	18.70	8.60	40.44	29.58
A3	14-30	28.72	3.00	0.31	0.18	0.375	27.70	6.20	15.13	23.30
B21	30-57	39.67	6.00	0.29	0.08	0.195	16.50	4.80	18.87	19.14
B22	57-90	46.43	-	0.21	0.08	0.270	11.00	5.90	37.53	26.17
B23	90-180+	43.80	-	0.43	0.06	0.158	13.00	5.60	28.98	22.06
<u>Kootala series</u>										
AP	0-13	35.14	8.00	0.45	0.33	1.200	36.90	9.50	24.14	21.08
B1	13-53	49.23	12.50	0.32	0.17	0.750	26.20	9.30	21.31	15.57
B21	53-110	54.72	5.00	0.40	0.19	0.420	23.60	6.90	24.27	19.68
B22	110-180+	55.26	5.00	0.39	0.22	0.390	25.20	6.20	21.89	27.87
<u>Anjur series</u>										
AP	0-13	46.57	6.00	0.18	0.15	0.435	11.20	8.60	77.06	58.18
B1	13-40	31.58	4.00	0.57	0.05	0.450	35.70	13.20	34.29	40.77
B22	40-90	58.00	3.00	0.25	0.13	0.195	15.30	6.10	40.15	25.39
B23	90-160+	36.00	3.00	0.49	0.16	0.105	23.60	10.90	46.05	39.00

(Contd.)

*ECEC - Effective Cation Exchange Capacity - NH_4OAc extractable bases + 1N KCl extractable Al

Table 18. (Contd.)

1	2	3	4	5	6	7	8	9	10	11
Kanjikulam series										
AP	0–10	39.00	1.00	0.48	0.20	0.825	20.40	10.30	49.04	37.57
B1	10–48	44.69	5.00	0.32	0.14	0.840	26.90	11.80	34.48	30.65
B22	48–96	57.26	1.00	0.32	0.03	0.495	26.10	5.90	21.55	28.01
B23	96–145+	50.35	1.00	0.37	0.25	0.180	15.30	6.40	41.81	30.90
Mannur series										
AP	0–10	35.80	12.00	0.32	0.36	0.690	26.50	10.20	38.35	40.30
A3	10–21	52.70	8.00	0.32	0.21	0.698	18.00	8.60	47.45	37.35
B1	21–50	60.06	10.00	0.29	0.13	0.488	17.60	7.10	45.75	33.94
B22	50–110	41.63	2.00	0.42	0.25	0.330	25.70	8.90	34.44	41.38
B23	110–180+	51.12	–	0.33	0.11	0.330	19.60	5.40	24.92	19.89
Nenmanda series										
AP	0–14	30.52	8.00	0.43	0.22	1.080	18.00	6.30	32.75	20.42
B1	14–36	41.01	6.00	0.32	0.13	0.540	18.90	2.80	38.24	21.51
B22	36–98	45.35	2.00	0.32	0.01	0.200	6.70	3.10	43.97	23.69
B23	98–150+	35.65	–	0.14	0.06	0.195	8.10	2.90	34.75	15.71

Table 19. Coefficients of simple linear correlation (r) between soil characteristics (number of pairs = 26)

Sl.No.	X Soil characteristics	Y	r
1	Clay	Bulk density	-0.267
2	Clay	Moisture retention at 1/3 bar	0.135
3	Clay	Moisture retention at 15 bar	0.537**
4	Clay	Available water	0.435*
5	Clay	Coarse sand	-0.881**
6	Clay	Fine sand	-0.608**
7	Clay	Total Fe_2O_3	0.527**
8	Clay	Total P_2O_5	0.253
9	Clay	Total K_2O	0.208
10	Clay	Total Al_2O_3	0.469*
11	Clay	Cation exchange capacity	0.418*
12	Clay	Fe_d	0.522**
13	Clay	Fe_o	0.399*
14	Silt	Fe_d	0.617**
15	Silt	Fe_o	0.329
16	Fine sand	Fe_d	-0.599**
17	Fine sand	Fe_o	-0.161
18	Coarse sand	Fe_d	-0.491**
19	Coarse sand	Fe_o	-0.491**
20	Total iron	Fe_d	0.930**

(Contd.)

Table 19. (Contd.)

Sl.No.	X Soil characteristics	Y	r
21	Total iron	Fe_o	0.468**
22	Organic carbon	Total nitrogen	0.648**
23	Exchangeable calcium	Cation exchange capacity	0.544**
24	Exchangeable magnesium	Cation exchange capacity	0.371
25	Exchangeable potassium	Cation exchange capacity	0.202
26	Exchangeable sodium	Cation exchange capacity	0.317
27	Organic carbon	Cation exchange capacity	0.354
28	Exchangeable calcium	Percentage base saturation	0.463*
29	Exchangeable magnesium	Percentage base saturation	0.225
30	Exchangeable potassium	Percentage base saturation	0.442*
31	Exchangeable sodium	Percentage base saturation	0.242 *
32	pH	Percentage base saturation	0.754**
33	Clay	Total manganese	0.223
34	Silt	Total manganese	0.072
35	Fine sand	Total manganese	-0.156
36	Coarse sand	Total manganese	-0.193

* Significant at 5% level

** Significant at 1% level

Table 20. Correlation coefficients between soil properties and P fractions (n = 26)

Sl.No.	Soil property	Ca-P	Al-P	Fe-P	Saloid-P	Reductant P	Occluded P
1	Clay	0.104	0.233	0.144	0.065	-0.189	0.232
2	Silt	0.275	0.393*	0.448**	-0.126	0.053	0.483**
3	Coarse sand	0.203	-0.353	-0.395*	0.011	-0.328	-0.303
4	Total Al_2O_3	-0.112	0.246	0.269	-0.031	-0.246	-0.108
5	Fine sand	0.158	-0.179	-0.305	-0.042	-0.301	-0.281
6	Total Fe_2O_3	0.374	0.634**	0.649**	*0.133	0.591**	0.678**
7	Total CaO	0.342	-0.121	0.213	-0.228	0.434*	0.251
8	CEC	0.504**	0.520**	0.603**	-0.271	0.535**	0.568**
9	pH	-0.147	0.106	0.112	-0.179	-0.141	-0.011
10	Organic carbon	0.292	0.335	-0.064	0.019	0.335	0.288
11	Dithionite iron	-0.313	0.474*	0.554**	-0.145	0.471*	0.476*

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

DISCUSSION

DISCUSSION

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

1. Profile morphology

Deep red colour is a dominant feature of the highly weathered tropical soils. The soils from different locations had striking similarity in colour with deeper red hues predominating. Increasing red colour with depth in the profile was another feature observed. Highly weathered tropical soils have haematite dominating the mineral assemblage of the sand fraction which has strong pigmenting effect resulting in bright red colours. This is especially so in better drained soils in warm climate (Schwertmann, 1971). Intense red colour has also been associated with free iron oxide content (Webster, 1965). Red coloured soils with haematite in the fine sand fraction in the upper slope members of the catena in Kerala have been reported by Venugopal (1980). The richness in iron oxide especially the free iron oxides which constitute a major portion of the total iron coupled with the well drained condition, both external and internal has been responsible for the intense red colour of soils.

Medium weak granular structure in the surface layers followed by moderate, subangular blocky structure in the subsurface layers is the sequence of soil structural type observed in all the profiles studied. Granular structure, a feature in surface horizons is the result of organic matter additions which act as cementing agents in their development. However, the low content of organic matter of the soils has been mainly responsible for the development of weak structures on the surface layers. However the good structural development as observed by subangular blocky structures is the result of conducive drainage condition of the site and the profile and high sesquioxide content. Sesquioxides are excellent binding agents in the process of structure development in soils and the well developed structures observed in the present study are the result of the above mentioned factors.

Coarse fragments formed a predominant part of all the horizons in the soil profile studied except for the surface horizon of Thonnackal series. The gravel was found to be concentrated mainly in the subsurface layers and includes pisolithic and quartz types. Accumulation of gravel as a dense subsurface layer has been observed in Thonnackal series. These soils are developed from sedimentary material (Tertiary sediments of the Warkalli formation). The occurrence of such dense gravelly layers below the surface is an indication that the comparatively lesser gravelly upper layer and gravel free surface soils are deposits over the lower layer, suggesting the polycyclic origin of these soils being derived from sedimentary material. Watson (1965) working on Rhodesian soils also observed the development of stone layers and ferricrete boulders in the subsurface layers of profile as a result of erosion and subsequent deposition of soil layers. The occurrence of quartz in the coarse fragments is the result of residual accumulation consequent on intense weathering of the quartz rich parent materials. Ferruginous gravels also predominated in the coarse fragments. Mohr and Van Baren (1959) observed that ferruginous laterite gravel may be considered as disintegration products of fossilised laterite. The above observations of the gravel lead to the conclusion that they may be formed by dehydration of fragmented laterite debris. The comparable values of molar ratios of clay fraction, gravel and laterite rock also indicate their pedogenic origin. Granulation of iron compounds and subsequent induration after the kaolinite has been saturated with iron oxides were postulated by Rengaswamy *et al.* (1978). They further observed this process to operate only when the ratio of iron oxide by clay was above 0.12. The iron oxide clay ratio for all the soils (mean value for the profiles) is above this value except for Thonnackal series and this points to their pedogenic origin.

2. Mechanical analysis

Sand formed the predominant size fraction. The soils from all the areas are developed from acid igneous rocks with quartz predominating the light mineral suite. Acid igneous rocks on weathering produce quartz rich infertile soils, the higher sand fraction owes its origin to the parent material from which the soils are developed.

Among the size fraction, silt was the lowest. The intense weathering conditions of the tropics have been responsible for the complete transformation of the feldspars to clays with insignificant proportions of silt

(Radwanski and Olier, 1959). The clay fraction in all the soils showed migration to lower layers and is mainly the result of high rainfall conditions ($>$2500 mm) of the study areas. Sandy clay loam surface textures followed by clay to sandy clay in the subsurface layers of the profile were the typical sequence of textural class observed.

Among the textural ratios, the silt clay ratio was taken as an index of weathering in soils. Van Wambeke (1967) has reported values of silt clay ratio less than 0.15 and weatherable minerals 3% as indicative of highly weathered soils. Judged from the above, all the soils registered low ratios indicating their highly weathered nature. The complete absence of weatherable minerals in the fine sand fraction (Table 17) also strengthens the above contention.

The bulk density values did not reveal appreciable differences between the soil series. The preponderence of coarse fraction in the soils has clearly reflected on the bulk density values as indicated by the higher values observed in the sample No.1 of Thonnackal series. The decreasing trend in the bulk density values of Kootala series and the slight increasing trend in Anjur also parallel the distribution of sand fraction.

Organic matter has a depressing effect on bulk density values clearly shown by the negative correlation between organic matter and bulk density. However, the low levels of organic matter in the soils did not have a marked influence on the bulk density values.

3. Moisture retention

The moisture retained at 1/3 bar (profile means) varied from 15.3 to 25.9 per cent and closely follow the clay content. Positive relationship between clay and moisture at 1/3 bar was also observed. Kootala, Kanjikulam and Mannur series with higher clay content showed greater values for field capacity.

The above trends were also seen in respect of moisture at 15 bar and also available water. Significant positive correlation has also been obtained with clay for both these characteristics. In general, the available water content of the soils was poor and the variations observed closely followed the distribution of clay. Another feature was the high content of coarse fragments in the soils which drastically affected the soil volume exposed to the roots and hence the soils capacity to supply water. This highlights the need of taking into account the gravel content of soils also in addition to clay and organic matter in arriving at the available water of the soils. Thulaseedharan (1983) has also made similar observations. Prediction equations to arrive at the available water were developed taking into account the gravel content, organic carbon and texture of the soil.

4. Chemical characteristics

4.1 Soil reaction and electrical conductivity

The soils from all the locations were in general acid (pH 5.5) as was expected on highly weathered and leached soils of tropics (Vine, 1956). The acidic nature of the parent rocks, intense weathering and leaching of bases are the factors responsible for the acidity. As expected the pH in 1:1 KCl recorded lower values, indicating a net negative charge.

The electrical conductivity values recorded were very low and showed little variation within the profile and between soil series. The soils from all locations were from the mid-land regions of the state and practically nonsaline.

4.2 Organic carbon

Organic carbon content of soils was also rather low and showed decreasing trend with depth in Nemmanda and Kootala series only. The total N content in different profiles was also low and Kanjikulam showed a decrease in N content with depth, while others did not reveal any pattern of variation. Highly significant positive correlation between organic carbon and N was observed ($r = 0.648^{**}$). The C/N ratio (profile means) also showed low values ranging from 3.93 to 8.99. Low values for organic matter in the tropics were attributed to rapid decomposition and depletion due to high temperature (Raychaudhuri et al., 1943).

5. Total elemental composition of soils

The silica content of all the soils (Table 9) recorded high values ranging from 39.30 per cent in Kootala and Kanjikulam series to 89.40 per cent of Thonnackal series. The mechanical analysis of soils showed a predominance of sand in all the soils investigated. The Thonnackal series which is having the highest mean content of sand showed the highest content of silica. Close relationship between silica content and sand fraction of soils was observed by Agarwal et al. (1957) on catenary soils of Indian plateau. Quartz being the predominant mineral of the fine sand fraction of red and laterite soils of Kerala, the higher values of silica observed in the present investigation are expected.

The Al_2O_3 content varied from 2.94 per cent in Thonnackal series (No.1) to 30.10 per cent (No.18) in Mannur series. A steady increase in the content of Fe_2O_3 with depth was noted in Thonnackal, Kootala, Kanjikulam and Anjur series while other soils showed no definite pattern of variation in the profile. In the case of Fe_2O_3 the range observed was from 1.60 per cent (No.2) in Thonnackal series to 11.46 per cent (No.17) in Kanjikulam series. Increase in the content of iron with depth was observed in Nenmanda soil, while others showed irregular distribution with depth. There was a significant positive correlation between clay content and total Al_2O_3 ($r = 0.469^{*}$) and total Fe_2O_3 ($r = 0.527^{**}$).

Al_2O_3 content of all the soils dominated over Fe_2O_3 except in the case of Anjur and Kanjikulam series. The distribution of Fe_2O_3 and Al_2O_3 closely followed the variations in the clay content. Positive and significant correlation was obtained between clay and these constituents. The above pattern of variation observed is suggestive of the capacity of clay to retain these oxides. The laterite soils being rich in kaolinite and hydrous oxides account for the high content of sesquioxides in the soils.

The total reserves of CaO, MgO, K_2O and Na_2O were very low in all the soils investigated. This was in accordance with the findings of Venugopal (1980) in laterite soils of Kerala and Bastin (1985) in red soils of Kerala. The total P_2O_5 content was also low compared to K_2O content except in Kootala series which agreed with the findings of Nair (1973) on red soils of Kerala. The total reserve of plant nutrients is mainly a function of the mineralogy of the sand fraction (Hughes, 1981). The fine sand fractions of red and laterite soils in Kerala showed quartz as the dominant mineral with few weatherable minerals. The soils of the state are derived mainly from acid crystalline rocks which are again poor in bases. Thus low reserves of major nutrients in the soil are the reflection of parent geology of the soils as revealed by the present study.

6. Chemical composition of gravel

The chemical composition of gravel showed a depletion of SiO_2 and accumulation of constituents especially Fe_2O_3 and Al_2O_3 (Table 10). The coarse fragments observed in most of the soils included pisolithic, laterite and quartz gravel. As discussed earlier, the ferruginous laterite gravels are end products of pedogenic processes. These gravels clearly show accumulation of most of the constituents as compared to soils (Table 11). High gravel/fine earth ratios of constituents have been observed for Fe_2O_3, Al_2O_3, MgO, P_2O_5 and Na_2O. Accumulation of Fe, Mo, Ga, V, and P_2O_5 in gravel relative to fine earth, was reported by Turton _et al._ (1962) in gravelly laterites of Australia. Enrichment of constituents in the gravel from different depth did not show any pattern, but gravel from the upper layers of the soil profile appeared to accumulate the elements to a greater extent. This can be attributed to the alternate wet and dry conditions and consequent well oxidised nature of the upper layers of the soil profile. The concentration of iron and other elements in the form of concentric skins making them more harder and rounded are the result of the above processes.

7. Cation exchange properties

The CEC of the soils was low as was expected of highly weathered tropical soils (Table 12). No appreciable differences within the profiles and between soil series were observed. The CEC of soils rich in kaolinite, halloysite, hydrated oxides of Fe and Al and other low activity clays is usually low (Coleman and Thomas, 1967). The soils under investigation have been developed through progressive stage of weathering under heavy rainfall and high temperature conditions and hence low CEC of soils can be attributed to the nature of the clay fraction.

The CEC determined by sum of cations method recorded higher values than NH_4OAc method in majority of soils and this agrees with the observations of earlier workers on soils containing higher proportion of 1:1 clay minerals. The higher values of CEC_s suggest that a higher proportion of exchange sites in these soils is pH dependent and probably blocked by Fe and Al hydroxy ions (Coleman and Thomas, 1967). The Al extracted by 1N KCl is less than 1 me/100 g and hence the exchange acidity value approximates the pH dependent exchange capacity (Fiskell, 1970). Thus the CEC_s gives a better representation of the surface characters of latosols and other acid soils (Chapman, 1965; Fiskell, 1970).

The CEC values of upper horizons are clearly influenced by organic matter and this is more so in Kootala series which registered a higher organic matter status. Thus the effect of organic matter is revealed more strongly by the variations of calculated CEC/100 g clay with depth. The upper horizons of all the series with higher organic matter content showed higher CEC values while in the lower horizons with less organic matter and greater clay per cent and inert oxides, the CEC values were less. So the differences in the CEC can mainly be attributed to the variation in the clay and organic matter contents, which agrees with the findings of De Alwis and Pluth (1976) on red latosols of Sri Lanka.

Exchangeable Ca and Mg were the predominant bases in the exchange complex. The mean values for the profiles of the exchangeable bases were in the order Ca Mg K Na for Anjur, Mannur and Nemmanda series. In Thonnackal, Kootala and Kanjikulam series the exchangeable Na was slightly on the higher side as compared to exchangeable K. The surface horizons of the profile showed relatively higher content of exchangeable Ca, Mg and K apparently due to phytocycling which retains these bases against leaching. The acid generating cations, exchangeable Al extracted by 1M KCl was very low for all the soils and profile trends were erratic. Low levels of extractable Al in Oxisols have been reported by Coleman and Thomas (1967).

The exchange acidity did not reveal appreciable differences within the profiles and between the soil series except for Kootala series, where slightly higher values (profile means) were observed. In general, the exchange acidity was found to be more in the subsurface horizons. Kootala series with the highest value for exchange acidity recorded the lowest pH in 1N KCl. The predominance of acid generating cations in the exchange complex and dominance of H over Al have been reported by Bastin (1985).

Percentage base saturation was calculated by both methods using CEC_s (CEC-sum of cations method) and NH_4OAc, the former recording slightly lower values. The percentage base saturation generally followed the pattern of exchangeable Ca distribution. The upper horizons of all the soils invariably showed higher base saturation suggesting less efficient leaching and retention by the organic fraction.

8. Extractable iron and active iron ratio

The dithionite extractable iron oxide (Fe_d) gives a reasonable estimate of the pedogenic free iron oxide in soils while that extracted by oxalate (Fe_o) represents the more or less amorphous forms of iron. The difference between the two is a measure of crystalline oxides (Mc Keague and Day, 1966; Mehra and Jackson, 1960). The Fe_d constituted a major portion of the total iron in the soils. The mean values for the profiles ranged from 72.2 to 96.2 per cent. The accumulation of Fe_d was mostly in the subsurface horizons and followed the total clay suggesting a possible movement of iron oxides passively along with colloids into the B horizon (Blume and Schwertmann, 1969). The Fe_d/clay ratios showed slightly higher values near the surface in Kootala, Anjur and Mannur series indicating the preference of clay over iron oxides. In respect of Kanjikulam and Thonnackal series lower layers showed accumulation while in Nenmanda series, more or less constant value was maintained. Movements of iron oxides by suspension with fine particles or adsorption and subsequent movement with clays have been postulated by Parks (1965). The variations noted in the ratios with depth may be attributed to the above processes.

Fe_d expressed as per cent of total iron referred to as degree of freeness of iron is often an indication of the age of the soils (Alexander, 1974). Based on this, the Kanjikulam was the oldest, followed by Anjur, Kootala, Mannur, Nenmanda and Thonnackal series. Observations on relative age of soils based on the degree of freeness of iron have been reported by Arduino _et al_. (1984) in Alfisols of Italy.

Another striking feature is the outstanding influence of free iron oxides on soil colour. The increasing redness of the profile with depth concurrent with Fe_d distribution clearly brings out this relationship.

The Fe_o recorded low values for all the soils and did not reveal much variation. However, slightly higher values have been observed for Kootala series. The slightly higher organic matter content of Kootala soils might have been responsible for the enrichment of amorphous oxides indicating the inhibitory effect of organic matter in the crystallisation of iron oxides. Juo _et al_. (1974) have reported low values of Fe_o for soils developed from acidic rocks.

Consistent with low values of Fe_o the active iron ratio also registered very low values. Alexander (1974) has reported strinkingly low values approaching zero in old tropical soils. Judged from the above, Kanjikulam series was the oldest, followed by Anjur, Mannur, Nenmanda, Kootala and Thonnackal series.

The strikingly low values obtained in the present study lend support to the above observation.

9. P fraction

The transformation of inorganic P during soil weathering followed a sequence of Ca-P, Al-P, Fe-P and occluded P is often taken as an index of pedogenesis (Chang and Jackson, 1958).

Fe-P formed the dominant fraction among the active inorganic fraction represented by Fe-P, Al-P and Ca-P (Table 14). The mean for the profiles showed the lowest value (35.61 per cent) for Thonnackal series and the highest (75.35 per cent) for Anjur series. Kootala series recorded the highest content of Fe-P and Thonnackal series the lowest. The Fe_t and Fe_d (Table 13) distribution showed that Kootala and Thonnackal series had the highest and the lowest respectively indicating a close relationship of Fe-P with the above constituents. This is further strengthened by the positive significant correlation between Fe-P and the above constituents.

Another interesting observation was that Fe-P content and its distribution were not influenced by clay, sand and pH as indicated by the absence of correlation with these factors. Chang and Chu (1961) observed that the distribution of Fe-P was governed only to a certain extent by clay and sand fraction, but was more influenced by pedogenic processes.

According to Chang and Jackson (1958) as weathering intensifies Ca-P decreases and Fe-P increases forming the dominant fraction of highly weathered soil. The results of the present study showed the Fe-P to predominate the active inorganic fractions of all the soils except Thonnackal indicating their strongly weathered nature.

Slightly higher contents of Al-P was observed in Kootala and Nenmanda series. Al-P was negatively correlated with sand, clay and pH. This fraction was found to be more influenced by the content of free Al_2O_3 and 1:1 clay and also the water movement, both horizontal and vertical (Smeck, 1973). Total Al_2O_3 content of Kootala and Nenmanda series showed high values (Table 10) and this may be the probable reason for the higher levels of Al-P observed in these soils.

Low levels of Ca-P could be taken as an index of advanced stages of weathering in soils (Chang and Jackson, 1958). All the soils under investigation are acidic, have low CEC and exchangeable Ca and these factors would have contributed to the small levels of Ca-P fraction. Judged from the above, Nenmanda series with a minimum of Ca-P is highly weathered as compared to Thonnackal with slightly higher content of this fraction. The absence of significant correlation with particle size fraction and chemical constituents reveals that the content of Ca-P is more influenced by pedogenic process. However, the relationship between total CaO and this fraction is found to be positive but not significant. The higher levels of Ca-P observed in Thonnackal series can possibly be due to its sedimentary origin.

All the soils appeared to have relatively higher amount of occluded P, the highest being recorded in Kootala and the lowest in Nenmanda series. Syers et al. (1969) and Smeck (1973) have reported higher levels of occluded P at the expense of Ca-P and Al-P in intensely weathered soils. The content and distribution of occluded P depended more on chemical reaction and age of soil rather than texture and chemical composition (Fife, 1963).

Reductant P of soils shows higher levels than occluded P in all the series except Kanjikulam. All profiles have appreciable amounts of Fe_d and hence account for higher levels of this fraction (Swindale, 1966).

This is strengthened by positive and significant relationship of this fraction with Fe_d. Thus Kootala series with the highest Fe_d had the highest reductant P while the lowest was observed in Thonnackal which had very low levels of Fe_d. This in turn reflects the age of the soils also. Earlier reports by Smeck (1973) and Manickam (1977) agree with the findings of the present study.

9.1 *P* fraction in relation to pedogenesis

Highly weathered soils according to Chang and Jackson (1958) contain appreciable amounts of Fe-P with concomittant reduction in other fractions. The fact that Fe-P predominated the inorganic P fraction of all the soil is by itself an indication of their highly weathered nature. Acidic nature of the soils, absence of free $CaCO_3$, accumulation of sesquioxides and clay in considerable amounts are features characteristics of intense pedogenesis as is reflected in the behaviour of the various P fractions. The observations of the present study, lend support to the findings of earlier workers (Williams and Walker, 1969 and Manickam, 1977).

10. Chemical composition of clay and molar ratios (Table 15)

Determination of chemical composition of clay and molar ratios has relevance in soil formation and serves pedogenetic purposes. Silica is the most dominant constituent of clay fraction and its content did not vary much between soil series and within the profile suggesting the more or less uniform nature of the clay fraction.

The Fe_2O_3 content also did not reveal much variations except for Thonnackal series which recorded low content. Thonnackal series developed from sedimentary materials viz., the tertiary sediments while Kootala, Anjur, Kanjikulam, Mannur and Nenmanda are of residual origin. Mallikarjuna et al. (1979) reported relatively higher contents of Fe in residual laterites as compared to sedimentary formation. According to Mc Farlane (1976) Fe_2O_3 and Al_2O_3 behave antipathetically, increase of Fe_2O_3 content is matched by a decrease in Al_2O_3 and vice versa. The results of the present study clearly bring about this trend.

The SiO_2/Al_2O_3 ratio (Ki value) is taken as a criterion for designating laterite soils. Buringh (1970) has suggested a SiO_2/Al_2O_3 ratio of 2 (1.7) for ferrallitic soils and a value of 1.33 for SiO_2/R_2O_3 ratio was suggested by Martin and Doyne (1927) for true laterites. Judged from the above, Thonnackal and Nemmanda are designated as ferrallitic or true laterites while for all other soils, the ratios are above the stipulated value. SiO_2/Fe_2O_3 ratio recorded very high values for all the soils, while SiO_2/R_2O_3 ratio showed a reverse trend.

Higher molar ratios for laterite soils of Kerala from different locations have been reported by earlier workers (Venugopal, 1980; Varghese, 1981). The major processes affecting composition of soils and clays in humid climates is the differential leaching of silica preferential to Fe and Al (Crompton, 1960). The variation observed in the molar ratios is suggestive of the above processes in operation under the high rainfall conditions ($>$ 2500 mm) and consequent intense leaching prevailing in the different study area.

11. Chemical composition of parent rock, laterite, gravel and molar ratios

The rocks from all the locations are felsic in nature rich in quartz and poor in ferro magnesium minerals and feldspars (Table 2). Chemical composition (Table 9) reveal a very high content of SiO_2. Fe_2O_3 and Al_2O_3 were the other major constituents with small amounts of bases. The molar ratios as expected are very high.

The chemical analysis of laterite showed a reversal in the trend with depletion of SiO_2, accumulation of Fe_2O_3 and Al_2O_3 and consequent fall in the molar ratios. The molar ratios of SiO_2/Al_2O_3, SiO_2/Fe_2O_3 and SiO_2/R_2O_3 for Thonnackal series showed very high values and can be attributed to the high content of quartz embedded in these laterite. This was true in respect of laterite samples from Mannur series also.

The molar ratios of gravel (Table 10) follow the same pattern as in the case of laterites and those of the clay fraction and give further evidence to the pedogenic origin of coarse fragments in these soils.

12. Mineralogy of fine sand fraction (Table 17)

Information on mineralogy of fine sand fraction is of significance on studies of soil evolution. Apart from morphology, physical and chemical studies, the mineralogical investigation of the fine sand fraction gives an idea about the primary mineral assemblage of the parent material of the soils. Laterite soil being highly weathered is likely to contain very few weatherable minerals and, in fact, only resistant minerals are expected in the mineral assemblage of this soil. Depending on the pedogenic environment and nature of the parent material, the type, content and distribution of minerals differ in the successive horizons of the soil profile.

The light minerals suite is dominated by quartz. The predominance of quartz in the light fraction at the expense of feldspars and ferromagnesium minerals is indicative of the highly weathered nature of the soils. It is also significant that feldspars were not present in any of the samples examined. Nair (1978) working on the rice soils of Wynad and Iyer (1979) in his studies of the red and laterite soil associations of Kerala had observed the predominance of quartz in the light fraction. Similar observations were made by Manickam (1977) on laterite soils of Tamil Nadu and Venugopal (1980) on laterite soils of Kerala.

The heavy minerals formed a very low fraction of the total. The heavy fraction did not show regular trend in their distribution within the profiles. Zircon is invariably present in all the profiles and is suggestive of its residual accumulation due to its stability. The aluminium-bearing mineral, sillimanite is present in higher quantities in Thonnackal and Kootala while in other series, it is very less. In the content of mica and rutile, Kootala series ranked first containing 3.70 per cent and 1.23 per cent respectively. The content of sphene is very low and is even absent in Kanjikulam, Mannur and Nenmanda series.

As indicated earlier, the complete absence of feldspars and predominance of quartz in the fine sand fraction of all the samples show a high degree of weathering and indicate senile nature of the soils. The increased accumulation of opaques (red and black) in the sand fraction further strengthens the above observation. Turton *et al*. (1962) working on the laterite soils of Australia observed a striking contrast in the degree of weathering in non-lateritic soils as compared to the laterite groups, the latter showing an accumulation of opaques, as a result of the removal of other constituents by weathering.

13. Genesis of laterite in relation to parent material

Among the six soils investigated, five have developed from residual rocks while Thonnackal series was developed from sedimentary materials (tertiary sediments).

The chemical and mineralogical composition of rock clearly brings about their acidic nature with high content of silica and large proportion of stable minerals like zircon, rutile and quartz as revealed by the mineralogy of fine sand fraction. All the soils investigated had a predominance of sand, a feature characteristics of soils developed from the rock types observed (Karale et al., 1969). The soil reaction is acidic and is the result of the interaction of parent rock and the highly intense weathering and leaching condition prevailing in the locations resulting in removal of bases and silica.

Lorez (1978) in a study of the development of laterites in Kerala from the acid ingenous rocks observed that the rocks undergo primary ferralitisation with export of SiO_2 and bases leading to yellow saprolite. The upper horizons undergo pedoplasmation, lateral mass transport and homogenisation with loss of relict rock structure, while the lower horizons undergo plinthisation. The process leads to the formation of an yellow solum consisting of kaolinite, converted into red saprolite as a result of plinthisation. Subsequent mixing due to erosion and colluviation leads to a reddish solum with transported products of plinthisation. Nambiar et al. (1979) working on laterites derived from anorthosite, gabbro, granophyre and charnockites in Kerala have reported comparable chemical composition in respect of major constituents irrespective of varying parent materials and further observed that more the mobile element in the rock, greater is the depletion during laterisation. On the other hand relative enrichment of elements in the laterite is greater, if the content in the parent rock is less.

Thus in the prevailing weathering environment of the State, the intensity of weathering reactions as outlined above is governed mainly by the dominating climatic factor which ultimately decides the characteristic of the soil rather the parent material. The laterite soils studied do not have developed from parent rocks with contrasting mineralogical and in turn chemical composition. The physico-chemical properties and other characteristics of the soil series derived from these rocks do not however bring out any dominant features in their composition that can be attributed to the parent rock. The results discussed so far bring out that under the high temperature and heavy rainfall conditions existing in the State, the effect of parent material is obliterated and the properties of soils appear to be mainly governed by the dominating climatic factor conditioned by the relief of the area.

14. Soil classification

One of the main difficulties in classification of tropical soils according to Isbell (1980) is whether they are to be placed under Oxisols, Ultisols or Alfisols. These soils usually have a deep solum, weak differentiation of horizons, gradual increase in clay content with depth and dominated by kaolin and sesquioxides. The identification of diagnostic argillic and oxic horizons is fraught with practical problems particularly when micromorphological studies are lacking.

None of the soils under the present investigation could be classified under Inceptisols. The soils lacked the characteristic ochric epipedon, cambic horizon and presence of weatherable minerals which are the basic requirements for this order.

Alfisols should have the characteristic requirement of an argillic horizon. Though all the profiles showed indications of clay migration, field observation did not reveal the presence of clay skins, which is an absolute requirement for an argillic horizon. The soils also showed complete absence of weatherable minerals in the fine sand fractions and also recorded low base saturation (< 35 per cent) by the sum of cation method. These features rule out the possibility of accommodating the soils under this order.

An argillic horizon, percentage base saturation values <35 per cent by the sum of cation method are the features of Ultisols. The second criterion holds good for most of the soils, but the absence of argillic horizon precludes the classification of these soils under this order.

So based on the morphology and analytical characteristics the soils under investigation could be grouped under the order Oxisols. The Oxisols according to Soil Survey Staff, 1975 should meet one of these two requirements.

1(a) have an oxic horizon at some depth within 2 m of the soil surface or (b) have plinthite that forms a continuous phase within 30 cm of the soil surface, and the soil is saturated with water within this depth at some time of the year in most years; and

2 do not have a spodic horizon or argillic horizon that overlies the oxic horizon.

The oxic horizon is defined by a number of characteristics and includes

1. Is at least 30 cm thick.
2. Has a fine earth fractions that retain 10 me or less ammonium ions per 100 g clay from an unbuffered 1M NH_4Cl solution, or has less than 10 me of bases extractable with NH_4OAc, plus aluminium extractable with 1M KCl per 100 g clay.
3. Has an apparent cations exchange capacity of the fine-earth fraction of 16 me or less per 100 g clay with NH_4OAc at pH 7, unless there is an appreciable content of aluminium interlayered chlorite.
4. Does not have more than traces of primary alumino silicates such as feldspars, micas, glass and ferro-magnesium minerals.
5. Has textures of sandy loam or finer in the fine-earth fraction and has more than 15 per cent clay.

6. Has mostly gradual or diffuse boundaries between its subhorizons.

7. Has less than 5 per cent by volume that shows rock structure.

As mentioned earlier plinthite was observed beyond 180 cm in all the profiles except Thonnackal series. The subsurface horizons in all the soils possessed moderate subangular blocky structure which breaks down to fine crumbs. These according to Van Wambeke et al. (1983) are characteristics of old parent materials which are thoroughly weathered. The boundaries of the Oxic horizon with the adjacent horizons in all the soils are diffused and definite clay increase with depth was observed. However, field examination did not reveal the presence of clay skins. The minimum clay content stipulated (15%) for the oxic horizon is satisfied for all the soils. The silt/clay ratios also conform to the values suggested by Van Wambeke (1967). The effective CEC/100 g clay (NH_4OAc extractable bases + KCl extractable Al) for oxic horizon was <10 me/100 g as required. The water dispersible clay of the Oxic horizon was very low. In all the profiles weatherable minerals in the fine sand fraction was $< 3\%$ and rock structure was completely absent. Based on the above features all the soils can be brought under the order Oxisols.

Sub order

The soils under investigation can not be grouped under Aquox, Torrox, Humox and Ustox as they fail to satisfy the characteristics outlined. The Orthox sub order includes Oxisols with a short dry season, occur near the equator have yellowish to reddish colour with hues of 5YR to 10YR. The Oxic horizons are redder with depth with strong brown colours in the upper part. They are never saturated with water and do not have plinthite within 30 cm from the soil surface. The soils have the features outlined above and hence can be placed under the sub order Orthox.

Great groups

The soils had effective CEC $>$1.5 me/100 g clay and had base saturation by NH_4OAc method $< 35\%$ within 1.25 m and hence can be classified under Haplorthox.

Sub groups

Red or dark red mottles within 1.25 m of soil surface, $<$5% by volume of plinthite in all subhorizons within 1.25 m; textures of sandy clay loam of fine earth in all parts of oxic horizon within 1.25 m; hues redder than 10 YR in all parts of the upper 75 cm becoming redder with depth are features which qualify these soils to be grouped under sub group Typic Haplorthox.

Family differentiation

The texture differentiation was based on $<$ 2 mm fraction. Thonnackal series had sandy clay loam to sandy clay texture while sandy and clay was observed for all other soils. Thonnackal series had $>$ 15 per cent sand fraction in the fine earth and clay content between 18 and 34 per cent. So this series comes under the fine loamy class. In the case of other soils the fine earth has $>$ 35 per cent clay and hence come under the class clayey.

Clay mineralogy

Detailed mineralogical studies of the clay fraction were not undertaken. Earlier reports by

Venugopal (1980) had revealed the dominance of kaolinite with smaller amounts to chlorite. Based on the above the soils come under the kaolinitic class.

Soil temperature

In the absence of soil temperature data, the soils have been tentatively classified under Isohyperthermic class.

SUMMARY

SUMMARY

In the present investigation, an attempt has been made to evaluate the morphological, physical, chemical and mineralogical characteristics of laterite soils occurring in different regions of Kerala in relation to the parent rock. Six soil series representing laterite soils identified by the Soil Survey Unit of Department of Agriculture, Kerala State were selected for the investigation. The soil series identified were Thonnackal, Kootala, Anjur, Kanjikulam, Manzur and Nemmanda located in Trivandrum, Trichur, Palghat and Calicut districts. Soil samples representing the different horizons were collected for laboratory studies. The physico-chemical characteristics of the soils, behaviour of iron and phosphorus fractions of samples were investigated with a view to study the interrelationship between various properties and to relate these characteristics to the genesis of the soils. Mineralogy of the fine sand fraction was also carried out. Placement of these soils under soil taxonomy was also attempted based on the available data. The salient findings are summarised below.

1. The soils from different locations had striking similarity in colour with red hues predominating.

Increasing red colour with depth in the profile was another feature observed.

2. Coarse fragments formed a predominant part of the horizons of the soil profile studied except for the surface horizon of Thonnackal series. The gravel was found to be concentrated mainly in the subsurface layers and include both pisolithic and quartz types.

3. Sand formed the predominant part of all the soils. The predominant textural class was clay. All profiles showed an increase in the content of clay with depth.

4. Very low values for silt/clay ratios were observed for all the soil series indicating the fairly old parent material from which these soils were derived.

5. The available water of soils were poor and the variation observed closely followed the distribution of clay. Kootala Series had the highest available water content while Thonnackal series recorded the lowest value.

6. In general all the soils were acidic in reaction with low values of electrical conductivity.

7. Organic carbon, nitrogen content and carbon/nitrogen ratio of soils were low. Highly significant positive correlation between organic carbon and nitrogen was observed.

8. The silica content recorded high values for all the soils, highest being in Thonnackal series and lowest in Kootala series.

9. There was considerable variation in total Fe_2O_3 and Al_2O_3. Correlation between clay content and the above constituents were positive and significant.

10. The total reserves of CaO, MgO, K_2O and P_2O_5 were very low and is mainly a reflection of the mineralogy of the sand fraction which was dominated by quartz.

11. The chemical composition of gravel showed a depletion of SiO_2 and accumulation of constituents especially Fe_2O_3 and Al_2O_3. However all the elements appeared to accumulate in the gravel as compared to the soil.

12. The cation exchange capacity of soils were low. The cation exchange capacity of soils determined by sum of cations and NH_4OAc methods. The former recorded lower values than the latter. The exchangeable bases of the

soils were in the order Ca > Mg > K > Na in the case of Anjur, Mannur and Nenmanda series while in Thonnackal, Kootala and Kanjikulam series exchangeable sodium was slightly higher than potassium.

13. Among the acid generating cations, exchangeable aluminium recorded very low values.

14. Percentage base saturation did not show appreciable variation between the soil series and generally followed the exchangeable Ca distribution.

15. The Fe_d (dithionite extractable iron) formed the predominant iron fraction. Based on the 'degree of freeness of iron' in soils, Kanjikulam series was the oldest in respect of age followed by Anjur, Kootala, Mannur, Nenmanda and Thonnackal.

16. The active iron oxide ratio (Fe_o/Fe_d) recorded very low values for all the soil series.

17. Among the active inorganic phosphorus fractions, Fe-P formed the dominant fraction in all the series except for Thonnackal indicating their highly weathered nature. However judged from the content of

Ca-P, Nenmanda series with the minimum Ca-P was highly weathered as compared to Thonnackal.

18. Silica formed the predominant fraction of the clay. Judged from the SiO_2/Al_2O_3 ratio of clay fraction, Thonnackal and Nenmanda were designated as ferralitic or true laterites while all other soils, the ratios were above the stipulated value. The silica/sesquioxide ratio was the lowest among the molar ratios.

19. Chemical composition of rocks reveal a very high content of SiO_2. Fe_2O_3 and Al_2O_3 were the other major constituents with small amounts of bases. The laterite rock analysed showed a reversing trend with lower silica content and accumulation of sesquioxides.

20. Fine sand fraction was predominated by light minerals in all the series which comprised entirely of quartz. The heavy mineral suite consisted of opaques, zircon, sillimanite and minor quantities of mica, rutile and sphene.

21. The soils did not reveal contrasting characteristics in their composition that can be attributed to the parent material. Under the influence of the high temperature and heavy rainfall conditions existing in the

state, the effect of parent material has been obliterated and properties of the soils appear to be mainly governed by the dominating climatic factor conditioned by the relief of the area.

22. Based on the available data Thonnackal series was classified under fine loamy kaolinitic isohyperthermic family of Typic Haplorthox while others belong to the clayey, kaolinitic isohyperthermic family of Typic Haplorthox.

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APPENDIX

APPENDIX I

Description of soil profiles

Profile I

Location — Near CRPF camp at Pallipuram - Andoorkonam road in Pallipuram Village, Trivandrum Taluk, Trivandrum district.

Topography — Flat level land on summit of hill

Drainage — Well drained

Groundwater table — 30 m

Land use — Cashew, tapioca and coconut.

Remarks — The surface is a soft deposit free of gravel. Gravel content increasing with depth from the B horizon and is present as a dense layer just above laterite layer.

Parent material — Tertiary sediments

Series — Thonnackal

Horizon	Depth (cm)	Description
AP	0-14	Very pale brown (10 YR 7/3), yellowish brown (10 YR 5/6), moist; sandy clay loam; very friable, nonsticky and nonplastic; fine grass roots plenty; modeteraly rapid permeability; clear smooth boundary.

A3	14-30	Yellowish brown (10 YR 5/6), gravelly sandy clay loam; medium moderate granular; friable, slightly sticky, nonplastic; few fine roots; soft mud like material; moderately rapid permeability; gradual smooth boundary.
B2	30-57	Strong brown (7.5 YR 5/6), gravelly sandy clay; medium moderate subangular blocky structure; firm, sticky and plastic, diffuse smooth boundary; moderate permeability; very dense layer with pisolithic gravel.
B22	57-90	Yellowish red (5 YR 5/6), gravelly sandy clay; medium moderate subangular blocky; firm, sticky and plastic; diffuse smooth boundary; very dense layer; predominant quartz gravel; moderately slow permeability.
B23	90-180+	Yellowish red (5 YR 5/6), distinct to prominent yellowish brown (10 YR 5/8) and red (2.5 YR 4/8) mottles plenty (more than 20 per cent); gravelly sandy clay; coarse moderate subangular blocky structure, firm, sticky and plastic; quarriable laterite.

Profile XI

Location	Alur village, Thalapally Taluk, Trichur district near Ponmala quarry.
Topography	25-33% slope towards west, bunded land.
Drainage	Well drained, medium run off
Ground water table	30 m
Land use	Coconut, cashew and mango
Parent material	Hornblende biotite gneiss
Series	Kootala

Horizon	Depth (cm)	Description
AP	0-13	Dark reddish brown (5 YR 5/4), gravelly clay; weak medium; granular structure; very friable, non sticky and nonplastic; gnessic cobbles of size 8 cm plenty; few fine roots; rapid permeability; clear wavy boundary.
B1	15-53	Red (2.5 YR 4/6), gravelly clay; weak medium; subangular blocky; firm, slightly sticky and slightly plastic; fine roots plenty; moderate rapid permeability; diffuse wavy boundary.

B21	53-110	Red (2.5 YR 4/6), gravelly clay; medium moderate subangular blocky; firm, slightly sticky and plastic; few fine roots; moderate permeability; diffuse boundary.
B22	110-180+	Yellowish red (5 YR 5/8), faint to distinct medium sized yellowish brown 7.5 YR 5/8 mottles plenty; gravelly clay; coarse; moderate; subangular blocky structure; very firm, sticky and plastic; moderately slow permeability.

<u>Profile III</u>

Location — Vellanttanjur village, Thalapally Taluk, Trichur district.

Topography — Bottom of slope 5% in the west direction

Drainage — Well drained

Ground water table 30 m

Land use — Tapioca, cowpea and coconut

Parent material — Intermediate charnockite

Series — Anjur

Horizon	Depth	Description
AP	0-13	Dark red (2.5 YR 3/5), gravelly clay; medium; weak granular; very friable, slightly sticky and slighty plastic; fine roots plenty; fine quartz gravel plenty; rapid permeability; clear smooth boundary.

B1	13-40	Dark red (2.5 YR 3/6), gravelly sandy clay; weak medium subangular blocky; very compact; firm, sticky and plastic; fine roots abundant; moderately rapid permeability; gradual smooth boundary.
B22	40-90	Dark red (2.5 YR 4/6), gravelly clay; coarse moderate subangular blocky; firm, sticky and plastic; few iron concretions; fine roots few; moderate permeability; diffuse wavy boundary.
B23	90-160+	Red (10 R 4/6), gravelly clay; moderate medium subangular blocky, firm, sticky and plastic; fine iron concretions plenty; moderately slow permeability.

Profile IV

Location	Mundur in Mundur village, Palghat Taluk, Palghat district.
Topography	Nearly level, gently sloping, 2% slope at the site, bunded land.
Drainage	Well drained, medium run off
Ground water table 35 m	
Land use	Coconut, cashew and tapioca.
Parent material	Biotite gneiss
Series	Kanjikulam

Horizon	Depth (cm)	Description
AP	0-10	Yellowish red (5 YR 4/6), 2.5 YR 4/6 red; moist; gravelly clay; weak medium granular structure; dry loose, moist very friable, non sticky and non plastic; few fine roots; rapid permeability; clear smooth boundary.
B1	10-48	Red (2.5 YR 5/6), gravelly clay; weak medium subangular blocky structure; very friable, slightly sticky and slightly plastic; few fine roots; rapid permeability; gradual smooth boundary.
B22	48-96	Red (2.5 YR 4/6), gravelly clay; weak medium sub angular blocky structure; firm, sticky and plastic; moderately rapid permeability; gradual wavy boundary.
B23	96-145+	Red (2.5 YR 4/6), gravelly clay; medium coarse sub angular blocky structure; firm, sticky and plastic, moderately slow permeability.

Profile V

Location	Mannur in Mannur village, Palghat Taluk, Palghat district.
Topography	Rolling, 10% slope in north direction.
Drainage	Well drained
Ground water table	40 m
Land use	Coconut and tapioca
Parent rock	Diopside granulite
Series	Mannur

Horizon	Depth (cm)	Description
AP	0-10	Red (10 R 4/6), gravelly clay; medium weak granular friable, slightly sticky and slightly plastic; few fine roots; rapid permeability; clear smooth boundary.
A3	10-21	Red (10 R 4/8), gravelly clay; medium weak granular; friable, slightly sticky and slightly plastic; few fine roots; rapid permeability; gradual wavy boundary.
B1	21-50	Red (10 R 3/6), gravelly clay; medium moderate subangular blocky; firm, sticky and plastic; medium roots plenty; moderately rapid permeability; diffuse wavy boundary.

B22	50-110	Red (2.5 YR 4/6), gravelly clay; moderate coarse sub angular blocky; firm, sticky and plastic; medium roots few; moderately rapid permeability, diffuse wavy boundary.
B23	110-180+	Red (10 R 4/6), gravelly clay; moderate coarse sub angular blocky; firm, sticky and plastic; many medium sized mottles; strong brown (7.5 YR 5/8); reddish yellow (5 YR 6/8); moderately slow permeability.

<u>Profile VI</u>

Location	Iringal, on the side of NH 17 close to Iringal quarry, Iringal village, Calicut district.
Topography	15% slope in east direction, bunded land
Ground water table	20 m
Vegetation and land use	Native grass and shrubs, coconut and cashew.
Remarks	The soil surface is gravelly with plenty of pisolithic gravel and cobbles.
Parent material	Hornblende gneiss.
Series	Nermanda

x

B23	98-150+	Red (10 R 4/8), gravelly sandy clay; moderate medium sub angular blocky structure; firm, sticky and plastic; fine iron concretions plenty; stones few and fine quartz gravel plenty; medium roots few; moderately slow permeability.

Horizon	Depth (cm)	Description
AP	0-14	Yellowish red (5 YR 4/8), gravelly clay loam; medium weak granular; very friable, non sticky and non plastic; few fine iron concretion; fine roots plenty; ferruginous pisolithic gravel plenty; rapid permeability; clear smooth boundary.
B1	14-36	Red (10 R 4/8), gravelly clay; weak medium sub angular blocky; friable, slightly sticky and slightly plastic; fine iron concretions plenty; ferruginous (pisolithic) gravel and cobbles (5 cm - 10 cm) more than 50%; medium and fine roots few; moderately rapid permeability; diffuse wavy boundary.
B22	36-98	Red (10 R 4/8), gravelly clay; moderate medium sub angular blocky; friable, sticky and plastic; iron concretions plenty; cobbles and stones plenty; fine quartz gravel; medium and fine roots few; moderate permeability, diffuse wavy boundary.

CHARACTERISATION OF LATERITE SOILS FROM DIFFERENT PARENT MATERIALS IN KERALA

By

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ABSTRACT OF THESIS

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ABSTRACT

In the present investigation, an attempt has been made to evaluate the morphological, physical, chemical and mineralogical characteristics of laterite soils occurring in different regions of Kerala in relation to the parent rock. Six soil series representing laterite soils identified by the Soil Survey Unit of Department of Agriculture, Kerala State were selected for the investigation. The soil series identified were Thonnackal, Kootala, Anjur, Kanjikulam, Mannur and Nenmanda located in Trivandrum, Trichur, Palghat and Calicut districts. Soil samples representing the different horizons were collected for laboratory studies. The physico-chemical characteristics of the soils, behaviour of iron and phosphorus fractions of samples were investigated with a view to study the interrelationship between various properties and to relate these characteristics to the genesis of the soils. Mineralogy of the fine sand fraction was also carried out. Placement of these soils under soil taxonomy was also attempted based on the available data. The salient findings are summarised below.

The soils from different locations had striking similarity in colour with red hues predominating. Coarse fragments formed a predominant portion of the soil and was mainly concentrated in the subsurface horizons. Most of the elements were found to be concentrated to the gravel as compared to the soil.

Sand formed the predominant size fraction but the textural class of the soils was mostly clay. Increasing clay content with depth was a characteristic feature. The silt/clay ratios were very low indicating the highly weathered nature of the soils. The available water capacity was poor and the variations observed closely followed the distribution of clay. Kootala series had the highest available water capacity while Thonnackal recorded the lowest.

The soils were in general acidic with very low electrical conductivity. The content of C, N and C/N ratios were very low. Silica formed the predominant fraction followed by Fe_2O_3 and Al_2O_3. The total reserves of CaO, MgO, K_2O, P_2O_5 were very low and is a reflection of the mineralogy of the fine sand fraction which was dominated by quartz.

The cation exchange capacities of the soils were very low. The CEC_5 recorded still lower values as compared to NH_4OAc method. The exchangeable bases were in the order Ca>Mg>K>Na in the case of Anjur, Mannur and Nenmanda series while in Thonnackal, Kootala and Kanjikulam series, exchangeable Na was slightly higher than K. Among the acid generating ions extractable aluminium was very low. The percentage base saturation was low and did not show appreciable variation between soil series.

The Fe_d formed the predominant iron fraction and based on the degree of freeness of iron in soils, Kanjikulam series was the oldest followed by Anjur, Kootala, Mannur, Nenmanda and Thonnackal. The active iron ratio (Fe_o/Fe_d) recorded very low values for all the soils.

Among the inorganic P fraction Fe-P was dominant in all the soils except Thonnackal series. Nenmanda series had the lowest content of Ca-P. All the soils were highly weathered based on the behaviour of P fraction.

Silica was the dominant fraction of clay. Based on SiO_2/Al_2O_3 ratio, Thonnackal and Nenmanda were designated as ferralitic or true laterites. The SiO_2/R_2O_3 ratio was the lowest among the molar ratios.

The rocks were siliceous in nature with poor content of bases. The fine sand fraction of the soil also revealed a predominance of quartz and very little weatherable minerals. The heavy graction consisted of mainly opaques, zircon, sillimanite, mica, rutile and sphene.

The soils did not reveal contrasting characteristics in their composition that can be attributed to the parent material. Under the influence of the high temperature and heavy rainfall conditions existing in the state, the effect of parent material has been obliterated and properties of the soils appear to be mainly governed by the dominating climatic factor conditioned by the relief of the area.

Based on the available data Thonnackal series was classified under fine loamy kaolinitic isohyperthermic family of Typic Haplorthox while others belong to the clayey, kaolinitic isohyperthermic family of Typic Haplorthox.