STUDIES ON REFERENCE SOILS OF TAMIL NADU

Thesis submitted in part fulfilment of the requirements for
the degree of Doctor of Philosophy (Agriculture) in
Soil Science and Agricultural Chemistry to the
Tamil Nadu Agricultural University
Coimbatore.

BY

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CERTIFICATE

This is to certify that the thesis entitled **"STUDIES ON REFERENCE SOILS OF TAMIL NADU"** submitted in part fulfilment of the requirements for the degree of **Doctor of Philosophy** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** to the Tamil Nadu Agricultural University, Coimbatore is a record of **bona fide** research work carried out by **P.K.KRISHNAN** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, fellowship or other similar prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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ABSTRACT

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Fifteen pedons representing the seven agroclimatic zones of Tamil Nadu were identified. The morphological, physical, chemical and spectral reflectance characteristics of the soils were studied.

The soils varied considerably in all their properties. The solum depth was less than 1 m in Bhavanisagar and Palladam pedons.

The hue of the soils ranged from 10R in Thenkasi pedon to 10 YR in Aruppukkottai, Coimbatore, Palladam, Aduthurai, Sellur, Madurai and Ooty pedons. In Coimbatore pedon $CaCO_3$ and Fe-Mn concretions were present. Other pedons had either $CaCO_3$ or Fe-Mn concretions.

Erosion was observed to have influenced the surface texture of many pedons. Argillopedoturbation had taken place in two pedons. Moisture retention characteristics varied considerably and were positively correlated with clay.

The soil reaction ranged from strongly acidic to moderately alkaline. The Electrical Conductivity was low in almost all the pedons. Pedons located

in the hilly and high rainfall zone recorded comparatively higher organic carbon content. Silica, alumina and iron dominated the elemental composition of soils. The influence of anthropedogenic processes was evident in a pedon in the Cauvery Delta Zone. Three fractions of iron were studied viz., dithionite, oxalate and pyrophosphate extractable iron. Among the three fractions the dithionite fraction was high in all the pedons. The proportion of dithionite iron to total iron was very high in the hilly zone pedon.

Ca^{2+} dominated the exchange complex in all the pedons. The per cent base saturation was very low in the hilly zone and high rainfall zone pedons. Exchangeable acidity was negatively correlated with pH. The exchangeable acidity was low in comparison to potential acidity. Among the water soluble ions Ca^{2+} was the dominant cation and HCO_3^- was the dominant anion in most of the pedons.

Eight pedons were classified under Inceptisols, five under Alfisols and one each under Vertisol and Ultisol.

All the soils reflected high in the red and infrared bands compared to the blue and green bands. The red and infrared band data were useful in differentiating soils. Sand, SiO_2, free iron, pH_w, pH_{KCl} and total acidity were correlated with the spectral data.

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Introduction

CHAPTER 1

INTRODUCTION

Soil is the product of complete interaction of chemical, physical and biological processes, acting on the parent material. These processes are governed by climate and geomorphic interactions occurring over time. Soil properties reflect the influence of climate through its influence on soil forming processes. With changes in the processes, there are changes in the morphology, physical and chemical properties of soils. Hence soil can be considered as a dynamic body.

Improved agricultural technologies are constantly being generated, tested and verified in different zones of our country. Any technology, that seems to be appropriate or promising must be extended to larger target areas. For the transfer of agro-technology it is of fundamental importance to quantify and characterise a region's resource base. In this context the characterisation of soil, the non-renewable natural resource, is of vital importance.

Information on the capabilities and limitations of soils, are absolutely essential for their scientific management. Scientific information can not be generated for each piece of land and such exercise will be labourious and expensive. In this context, the concept of benchmark soil has been developed and accepted for generation and extrapolation of scientific information with less labour and cost. A benchmark soil is one which has larger areal extent and occupies a key interpretative position in a soil classification framework (Swindale, 1991). Experimental results of benchmark soils can be extended to many of the closely related soils classified upto soil family/soil series in the classification system.

Considerable progress has been made in Tamil Nadu State in respect of soil resource inventory studies. State Soil Survey and Land Use Organisation (SS&LUO) has completed reconnaissance soil survey in all the 166 taluks of Tamil Nadu State. Soil maps on 1:50,000 scale and soil survey reports have been prepared. The soils were classified upto soil series or soil subgroups in these studies. Recently, the National Bureau of Soil Survey and Land Use Planning has prepared the soil map of 1:250,000 scale with soils classified upto soil family. However, identification and detailed pedological investigations of soils, representing different agroclimatic zones, and major land use, have not been yet attempted. Even in the book on the 'Benchmark Soils of India' limited information on three soils of Tamil Nadu State only have been broughtout (Murthy *et al.*, 1982).

The benchmark soils generally are considered for a state or country. But for scientific soil management the regional agro-climatic zones and land use have to be taken into account. The International Soil Reference and Information Centre, The Netherlands has now coined the term 'reference soil' which represents agroclimatic zones and major land use of the zone. A comprehensive information on soils of Tamil Nadu representing agroclimatic zones and land use and their characterisation is essential to understand their properties and genesis, and to develop soil, water and crop management systems.

Remote sensing techniques are now gainfully employed by several soil scientists in soil resource appraisal studies (Natarajan and Gajbe, 1983; Govindan, 1996; Thirumagal Jothi, 1996). In all these studies either satellite data or aerial photographs have been utilised in the preparation of soil maps. Either imagery interpretation or photo interpretation elements have been used for separation of soil mapping units. Quantitative measurements of spectral data to simulate the geometry of remotely sensed data were not

recorded. As soil reflectance is a cumulative property which derives from inherent spectral behaviour of heterogenous combination of physical and chemical properties, studies on these lines would be of much use in understanding the soil characteristics and soil classification. Ramu (1994) succeeded in characterising the gypsum mined and unmined soils in Coimbatore district through spectral data. However spectral investigations on the major soils/soil series of Tamil Nadu have not been so far attempted.

In the above context, the present study was conducted with the following objectives.

* Selection and characterisation of reference soils of Tamil Nadu through morphological, physical and chemical properties
* Classification of the reference soils under USDA Soil Taxonomy
* Investigation on the factors and processes responsible for the formation of soils
* Collection of reflectance data and studying their utility in characterisation and classification of soils

Review of Literature

CHAPTER 2

REVIEW OF LITERATURE

Earlier work done on the pedological and spectral characterisation of soil is reviewed in this chapter under the following sub headings :

2.1. Pedogenic factors
2.2. Macromorphological properties
2.3. Physical properties
2.4. Physico-chemical properties
2.5. Chemical properties
2.6. Soil classification
2.7. Spectral reflectance

2.1. Pedogenic factors

2.1.1. Parent material

The effect of the composition of soil parent materials on pedogenic processes has long since been recognised.

The red soils of Tamil Nadu were observed to have been originated from acid igneous rocks with more than 65 per cent silica (Menon and Mariakulandai, 1957) and ferrugenous concretions overlying the weathered gneissic rock (Hameed Khan and Hanuman Ram, 1977).

Abnormally shallow soil profiles resulted when they were developed on parent materials excessively high in lime (Ehrlich *et al.*, 1967). Red soils are mostly derived from gneisses and schists of the Archaean period. Other rock formations from which these soils have been derived are sand stones, micaceous schists, basalts, quartzites and shales. Fine textured red soils are related to the weathering products of gneisses, charnockites and diorite that are richer in clay forming minerals such as feldspars micas and hornblende (Digar and Barde, 1982).

Most black soils are derived from basalt, though some others have formed from shales, limestone, calcic gneisses, amphiboles, dolerites, schists and alluvium (Shankara Narayana and Sarma, 1982).

Laterite soils are the residual products of weathering of pre-cambrian granite and dolerite in a semitropical environment (Gordon and Smith, 1984).

Parent materials rich in $CaCO_3$ gave rise to shallower profiles. Soil profiles derived from granite were not calcareous. Pedons developed on shales and charnockite had shown granular and crumb structure while pedons developed on granite gneiss, granite and limestone had shown subangular blocky structure in the surface horizons (Subbaiah and Manickam, 1992).

Acid soils developed on granite gneiss were characterised by yellowish red to strong brown colour, high coarse sand and clay contents, high SiO_2 and contained mottles and concretions, whereas alluvial soils developed on Mahanadhi alluvium were pale yellow to olive in colour, high in silt, fine sand and K_2O contents (Singh *et al.*, 1993).

Fe_2O_3 and MgO content of black soils developed from basalts were more than that of soils from basaltic alluvium. SiO_2, Al_2O_3 and K_2O showed a reverse trend (Singh *et al.*, 1995). Soils developed on shale were less siliceous and contained less total bases compared to soils developed on sandstone and granite. Soils developed on granite had more bases compared to soils developed on sandstone and colluvium (Walia and Rao, 1996).

2.1.2. Climate

The importance of climate in soil genesis has been accepted for over a century. Since the early identification of climate as a factor it has been basic to the understanding of soil genesis that different intensities of processes that result from climate-vegetation interaction give rise to distinctive soils.

Argillic horizons are indicators of subhumid and humid regions with alternating wet and dry periods. Spodic horizons suggest cool climates. Oxic horizons are usually found in high rainfall and high temperature zones. Calcic, petrocalcic, gypsic, petrogypsic and duripans occur in soils of arid regions (Wilding *et al.*, 1983). Hall (1983) observed that these climate horizon associations are only a first approximation because the influence of local topography, length of time of exposure as well as other factors complicate their relationships.

Temperature or actually solar radiation exerts a less evident influence on soil properties than precipitation. The effect of temperature on pedogenesis is mainly indirect as it controls the quantity of moisture available for soil forming processes, type of vegetation and thereby it decides on the quantity and nature of organic residues added to the soil. In evaluating the effect of temperature on soil processes, its effect on viscosity of soil moisture is of particular interest. Infiltration rates and moisture fluxes are known to increase significantly with increased temperature. Cumulative effects should be pedogenetically significant but an accurate evaluation of their effect in pedogenesis is still lacking (Yaalon, 1960, 1983).

Blockheim (1980) obtained a significant positive correlation with mean annual temperature for such properties as depth of oxidation, solum thickness and B horizon clay content, all of which could be attributed to better moisture infiltration.

Mild winter, hot summer and moderate rainfall were the conducive factors for the formation of blacksoils (Simonson, 1954; Ray Chaudhuri *et al.*, 1963). In South India under low rainfall conditions Alfisols were prevalent while under high rainfall Inceptisols were prevalent. Under prolonged high rains and a dry period of 3 months Ultisols occurred (Gowaikar and Datta, 1971).

Laterization occurred under a humid warm climate favouring a rapid decomposition of primary silicates and quick release of alkalies (Sivarajasingham, 1962).

Red, laterite and lateritic soils are associated with tropical and subtropical climates with conditions of high temperature and humidity. Black soils occur in tropical and subtropical, subhumid and semiarid to arid climatic environment. Blacksoils are generally found at altitudes between 300 and 600 metres (Shankaranarayana and Sarma, 1982).

2.1.3. Biotic factors

Plants affect most directly and abruptly the properties of organic carbon, total nitrogen, pH and bulk density.

Crocker (1967) found a change in the bulk density of soil from 1.5 to 1.6 g/cc to as low as 0.5 g/cc because of the presence of plant roots and residues and associated microflora. The overall effect was loosening up of the soil which then extended to the B horizon.

While studying the causes of soil boundaries in an arid region Gile (1975) observed that more vegetation and organic matter increased the clay content and thereby modified the profile development. Faunal activities also caused differences in boundaries, mixing up A and B horizons.

A general trend of depletion of nitrogen and accumulation of organic carbon with the age of pineapple plantations was observed by Tiwari *et al.* (1992). The replacement of tropical rainforest with high value plantation crops resulted in an increase of bulk density due to decline in organic matter. There was a decline in Bray's P while $CaCO_3$ was completely lost from the profiles (Mongia and Bandhyopadhyay, 1992).

Tea plantations after 14 years improved water retention characteristics

and structure of soils besides markedly increasing organic carbon and nitrogen status of surface soils (Contractor and Badanur, 1996).

Hole (1981) summarised the activities of soil fauna which include : mounding, mixing, forming voids, forming and destroying peds; regulating soil erosion, plant and animal litter; assisting the movement of air and water in soil and regulating nutrient cycling. These activities have long been recognised as having a significant role in soil formation.

The characteristic distribution and origin of channels, chambers and pedotubules produced by mesofauna (termites) were studied by Humphreys (1994). Most mesofaunal activity was confined to coarse textured top soils with approximately 8 per cent of the A and E horizons comprising fauna produced channels, chambers and pedotubules. The bulk of the topsoil consisted of biofabrics and hence defined a biomantle. The E-B horizon was lowered by the mesofauna.

2.1.4. Topography

Topography is one of the most important site factors, as slopes are fundamentally involved in pedogenesis by modifying the way water behaves. This has important consequences both mechanically, in the transport of all kinds of material, and physicochemically by affecting the water balance and Eh. The lateral movement of water which occurs downslope even where the gradient is slight and not readily apparent is responsible for pedogenic differences depending on slope position.

In some red soils of Bihar a distinct correlation of morphological and chemical properties with topographic position was found. Down the slope profile depth increased, texture became heavier and structure changed from single grain to blocky. Soil reaction changed from acidic to neutral and

organic carbon and nitrogen increased due to the process of accumulation as a result of relief and moisture regime (Sinha *et al.*, 1962).

Within soil catenas, Vertisols are always situated on lower slopes indicating the role of relief in their formation (Prasad *et al.*, 1977). In the North East Punjab, Entisols represented foot hills, while in the channel flood plains and upper terraces it was Inceptisols. Entisols with fluventic character occurred at lower terraces and flood plains (Sharma and Dev, 1985a).

In Mizoram the soils of high and low altitude are Inceptisols whereas midhills are Ultisols (Singh *et al.*, 1991a). In soils over a basaltic terrain in Rajasthan, soils associated with elevated topography were redder (7.5 YR) which gradually become grayish (10 YR) down the slope. The reddish brown colour at higher topographical positions could be due to ferri-oxyhydrates which formed due to the high organic carbon coupled with excessive drainage (Sharma *et al.*, 1996).

2.1.5. Time

Soils differ in their morphology and chemical properties with time. Thickness of the sola increased from profiles on the youngest surface to profiles on the oldest surface. Similarly the thickness of B horizon and clay content of B horizon increases from soils on the youngest surface to soils on the oldest surface (Ruhe, 1967).

2.2. Macromorphological properties

2.2.1. Soil colour

Colour is one of the characteristics of the soil that can be easily determined at field level. According to Simonson (1993) the colour of the soil depends on the content of organic matter and ferric oxides, the latter being more or less hydrated. Thicker the organic matter and ferric oxide,

coating the soil grains, the darker is the soil. Generally but not always red soils are older than yellow soils, and their drainage is better.

Myers *et al.* (1963) stated that colour is often diagnostic of major soils classification. Surface colour that differs from that of the parent materials is usually an indication of the processes involved in soil formation and may also be indicative of the factors such as excessive soluble salts or erosion.

Singh (1956) considered the formation of clay organic matter complex favouring anaerobic condition during the wet season as essential for the formation of dark colour. Dudal (1965) stated that besides clay organic matter complex, iron sulphides and manganese oxides also induce black colour. Mohr *et al.* (1972) opined that dark colour originated atleast in part in the clay fraction in which carbon occurred in a form not oxidisable with hydrogen peroxide.

Haematite was associated with 2.5YR and 5YR colours and goethite with 7.5YR and 10YR colours (Childs and Wilson, 1983).

Poorly drained soils in an alluvial pedogenic complex had a hue of 10YR, 'value' 5-6 and and chroma 2-4. Moderately to well drained soils had redder hues and higher chroma in the control sections of the pedon (Singh *et al.*, 1989).

The variations in colour pattern of east coast laterites and associated soils in Andhra Pradesh from dark yellowish brown to red is mainly due to differences in relief and consequent transportation of products of weathering (Bhaskar and Subbaiah, 1995).

The manifestation of colour in the soil is a function of free oxide to clay ratio. Wider the ratio, brighter is the colour and vice-versa (Singh *et al.*, 1995).

In some typical soils of Bihar, the 'value' notation of the colour was found to decrease with depth. The subsurface horizons showed either constant or increase of chroma as compared to the surface ones. Free $CaCO_3$ have partly influenced the colour of the soil matrix (Singh and Mishra, 1996).

The colour of soil can also be used to identify water table levels. Low chroma colours and low chroma mottling can be used to estimate water table levels (Zampella, 1994). Zobeck and Ritchie (1984) found that gray colours generally correspond to highest average water table. However, soil colours may not be accurate indicators of hydric condition in sandy soils (Couto *et al.*, 1985).

2.2.2. Mottles

The experiments conducted by Vepraskas and Bouma (1976) suggested manganese to be the primary mottle forming element as it appeared to be in solution for a large part of the time. In saturated regime iron was most prominent in mottles.

Periodic wetting and drying appears to be essential for concretion formation whereas more permanent wetting leads to mottling (Diwakar and Singh, 1994).

Mottles contain approximately 3 times more DCB extractable iron and 2.5 times more oxalate iron than soil matrix, with smaller active iron ratios. Manganese was not concentrated in mottles relative to soil matrix (Singh and Gilkes, 1996).

2.2.3. Texture

The expression of particle size distribution with or without gravel concentration can make significant differences in the interpretation of soil texture.

The coarse texture of the surface horizons is due mainly to the influence of the parent materials. The loss of clay from the surface horizon by eluviation and preferential removal of clay and silt by erosion can also result in a predominance of sand in the surface layer. (Lal, 1981).

The relative magnitude of silt : clay ratio at different depths has a special significance in terms of degree of weathering. In general the silt : clay ratio for the majority of the soils declines exponentially with depth (Lal, 1981).

The uniform texture with depth and absence of visible clay films on the peds in Yamuna alluvial plain was construed to suggest that the soils have undergone very little or no weathering and the soil forming processes are yet to make their mark (Shanwal and Ghosh, 1987).

The soils of Gangetic alluvial tract in UttarPradesh are dominated by very fine sand in the sand fraction. This indicated that the soils are not of recent origin. The distribution of silt and clay content was nearly uniform throughout the profile which showed that the eluviation/illuviation process have not takenplace considerably (Kumar and Kumar, 1993).

Some Entisols and Inceptisols of North Western Himalayas contain higher amounts of coarse fractions relative to clay fraction. The sand : silt ratio showed irregular variation in all the profiles indicating lithological discontinuities (Kaistha and Gupta, 1994). Similar views were expressed by Singh and Mishra (1996) for some Bihar soils.

The surface horizons of East Coast laterite contain high amounts of sand fractions. This is mainly due to impoverishment of finer particles by surface run off water. Higher values of coarse sand in the intermediate layers of individual profiles is due to the separated iron-oxides forming nodules or pseudo-aggregates which is one of the essential characteristics

of laterite soils under low rainfall conditions (Bhaskar and Subbaiah, 1995).

The substantial increase in clay content in Bt horizon in some soils of UttarPradesh is due to illuviation of clay. In some other soils the enrichment of clay in Bw horizon is primarily due to *in situ* weathering of parent material or colluvium rich in clay (Walia and Rao, 1996).

2.2.4. Soil structure

The structure of vertisol profile show gradual change with depth which could be helpful in differentiating the horizons (Blokhuis, 1982). Entisols had weak to moderate subangular blocky structure whereas Alfisols had moderate to strong sub-angular blocky structure (Landey *et al.*, 1982).

The salt affected flood plains of Western Madhya Pradesh had prismatic structure breaking into moderate, medium, sub-angular and angular blocks (Dubey *et al.*, 1985). The soils of Mid Shiwaliks were found to have a granular structure in the surface horizon while the sub surface horizons were structureless (Singh *et al.*, 1991b).

In sedimentary and old alluvial soils of Bihar, the structure was angular blocky even in the lower horizons (upto 155 cm), whereas in young alluvial soils the structure was massive beyond 62 cm depth (Diwakar and Singh, 1994).

The Entisols on hills, flood plains and interdunal areas of Punjab lack in structure development in the control section. The sand dune soils are single grained (Sidhu *et al.*, 1994).

Kumar and Kumar (1993) observed the presence of moderate to strong grade angular to sub angular blocky structure of medium to coarse size in some salt affected and associated normal soils of Gangetic alluvial tract in Uttar Pradesh.

Laterites occur below soil cover which are brittle and shatter when cut, and crumble to irregular masses of iron gravels. The succeeding layers possess a cellular or vesicular or honeycomb structure (Bhaskar and Subbaiah, 1995).

Inspite of clay, silt loam/loam or clay loam texture in soils very fine granular/granular structure was observed even upto 40 cm or even more in some soils of North Western Himalayas. This could be attributed to the presence of higher amount of organic matter/humus (Gupta and Tripathi, 1992).

2.2.5. Concretions

Pedogenic carbonates are the result of diagenesis in near surface environments. Carbonate nodule formation is observed to be a function of several internal characteristics such as the character of the matrix (texture, porosity), carbonate and non carbonate clay distribution, bulk density of the peds and the reciprocal influence between these factors (Wieder and Yaalon, 1974). Additional external features are also involved including carbonate content of the parent material, water regime, rate of dust deposition, duration of soil development and others (Wieder and Yaalon, 1982).

The amount and depth of occurrence of carbonates are of diagnostic significance in the pedological investigation of black soils and their presence modified the particle size distribution (Sidhu *et al.*, 1977a).

There was a regular decrease in concretions down the profile in young alluvial soils. The $CaCO_3$ concretions were of irregular shape and variable colour suggesting that they were of pedogenic origin (Diwakar and Singh, 1993).

Iron and manganese concretions are frequently encountered in soil profile characterised by high pH and subject to alternate oxidation and

reduction. Their depth of occurrence varies depending upon drainage conditions (Sidhu *et al.*, 1976).

Sandy soils as a rule do not contain concretions. This fact is a possible basis for distinguishing between a loam and a sandy podzol in a classification system (Polteva and Sokholova, 1967).

Ferrugenous nodules found in Tal land soils of Bihar, on the basis of their round shape and smooth surface appear to be detrital in origin. Their round shape may also be attributed to their concentric nature of formation and to some extent due to argillic pedoturbation in the soils of vertic characters (Diwakar and Singh, 1993).

2.2.6 Slickensides

Vertic properties such as cracks, slickensides and wedge shaped structure were observed in soils in a toposequence over basaltic terrain. Pressure faces and slickensides tilted to 30-40° to horizontal, occurred in subsoil horizon to a depth of 0.56m. High clay content, better drainage condition coupled with higher topographical position having soil water stress, accentuated contrast between alternate wetting and drying cycles manifested better expression of vertic properties in the pedons (Sharma *et al.*, 1996).

Subbaiah and Manickam (1992) observed prominent and intersecting slickensides in vertisols developed on different parent materials.

Soils of *in situ* origin have higher intensity of cracks (>2 cm wide) per unit area with more prominent slickensides tilted 25° to 40° from the horizontal than the soils of alluvial origin. Higher clay content and elevated topography which accentuates the process of alternate wetting and drying cycles, produces large amount of soils leading to better expression of vertic properties. The lower topography and poor drainage in alluvial soils restrict

the process of alternate wetting and drying resulting in weak expression of vertic properties. (Singh *et al.*, 1995).

The depth to slickensides varied between 48 to 60 cm in some Vertisols of Karnataka. The angular blocky elements as a result of intersection of slickensides were much finer in limestone and basaltic soils and were coarser in gneissic soils (Dasog *et al.*, 1990).

2.3. Physical properties

2.3.1. Bulk density

Low bulk density of surface horizons are associated with relatively high organic matter content but its progressive increase with depth are probably related to increase in coarse fraction and/or filling up of pores by eluvial material leading to compaction (Walia and Rao, 1996).

Elahi *et al.*(1996) have also reported a similar trend of increase in bulk density with increasing depth.

Organic matter is a principal binding agent in aggregate formation and its loss would contribute to an increase in bulk density (Blank and Fosberg, 1989).

2.3.2. Water retention characteristics

Water retention characteristics of soils provide information on the ability of soils to store water and the availability of stored water for crops.

The moisture retention of a black earth consisting of montmorillonite at 1/3 and 15 bars was dependent on the nature of the saturating cation, with Na giving the highest values, K the least, and Ca and Mg intermediate and essentially equal values (Swaify *et al.*, 1970).

Among the major soil groups of Kerala, the available water was found to be more in black soils. It was low in laterite, coastal alluvium and redloam soils (Ushakumari *et al.*, 1987).

There was good relation between clay content and moisture retention percentage. When correlation was worked to clay + silt, the 'r' values appreciably improved indicating the contribution of silt fraction also in the retention of moisture. Organic matter content in the soils did not correlate significantly with moisture retention percentage (Mathan *et al.*, 1991).

Inceptisols retained more water than Entisols as they had a higher clay content. Available water also was uniformly distributed in Inceptisol profile, possibly due to relatively uniform distribution of clay in the profile. Water retention at lower tensions showed relatively high variation (Chatterji *et al.*, 1995).

Sand and silt play a dominating role in determining the water retention at 10 to 33 kPa. tensions. With increase in tension to 100 kPa and eventually 16 MPa the clay fraction was found to have an edge over sand with the influence of silt remaining same throughout (Patgiri *et al.*, 1993).

2.4. Physico-chemical properties

2.4.1. Soil reaction

Mathan *et al.* (1978) studied the seasonal fluctuations of pH in red and black soils and reported that there was a deep fall in pH values during the month of March, which increased to original level and fell back again in August showing a cyclic and seasonal trend. The pH values were minimum in surface horizon and increased with depth.

Black soils associated with higher calcium carbonate always showed a higher pH. Besides $CaCO_3$, high content of bases also contributed to high soil pH (Tiwari *et al.*, 1969; Virmani *et al.*, 1982).

In red soils of UttarPradesh the tendency of pH to increase with depth was attributed to leaching and accumulation of bases. In some soils the pH

was higher in surface than in lower horizons suggesting accumulation of bases on surface through vegetation (Walia and Rao., 1996).

Ferrugenous soils are medium acid to neutral. In contrast vertisols are moderately to strongly alkaline (Pachrane *et al.*, 1996).

The pH_w values of some laterite soils in Orissa were higher by 0.7 to 1.3 than pH_{KCl} values. The positive difference between pH_w and pH_{KCl} indicates that the soils were negatively charged (Das *et al.*, 1992).

Bhattacharyya *et al.* (1994a) observed that pH_{KCl} was higher than pH_w in the subsurface horizon of a soil in Meghalaya. They reasoned that this could be due to a strongly weathered oxic horizon which is diagnostic of oxisols.

Prabhuraj and Murthy(1994) found that in soils of southern Karnataka the soil pH determined by 1M KCl solution was lower compared to water and concluded that all the soils contained considerable amount of reserve acidity.

2.4.2. Cation Exchange Capacity

The CEC of Cumbum valley soils varied from 19.96 to 37.50 me/100 g soil. The CEC of Vaigai basin varied very widely from 8.25 to 28.46 me/ 100 g soil. In the Cauvery delta, the CEC vary widely from 5.10 to 39.41 me/100 g soil (Vadivelu, 1985).

The CEC of vertisols in the dryland tracts of Tamil Nadu ranged from 34.7 to 79 me/100 g of soil (Thiyagarajan, 1985). The CEC of laterite soils of Thanjavur varied from 5.4 to 26.2 (Anbazhagan, 1994).

CEC of soils around Junagarh was not always consistent with clay content. The increase in CEC with decrease in the clay content without change in clay mineralogy and organic matter content is suggestive of the non-clay fractions towards CEC (Prasad *et al.*, 1977).

Low CEC are correlated with disappearence or absence of primary weatherable minerals, and accumulation of secondary clay minerals of low CEC, as a result of weathering process. High CEC tends to be associated with the less weathered soils, with weatherable primary minerals as a plant nutrient reserve (Buol *et al.*, 1980).

The low values of CEC in proportion to their organic matter and/or clay content in some Inceptisols of Arunachal Pradesh may be assigned either due to dominance of illitic and kaolinitic clays or due to formation of complexes of clays and sesquioxides with organic matter which lead to blocking of exchange sites (Walia and Chamuah, 1996). The CEC of vertisols was not related to organic matter and clay. CEC/clay of vertisol was >0.7 meq. but that of lateritic red soil <0.7 meq (Zhu *et al.*, 1990).

2.4.3. Exchangeable acidity

Exchangeable acidity values were generally higher at lower soil pH values. Significant correlations exist between pH_w and pH_{KCl} with exchange acidity having negative 'r' values. Higher correlation between pH_{KCl} and exchange acidity must be due to the replacement of H^+ and Al^{+++} from the exchange sites by K^+ and their presence in soil solution in active form to contribute to soil acidity (Das *et al.*, 1992).

The exchangeable acidity of soils of valley plains in Andaman ranged from 0.1 to 0.6 cmol (p^+) kg^{-1} and decreased with depth (Sahu and Bala, 1995). The exchangeable acidity of soils of southern Karnataka ranged from 0.4 to 3.8 cmol (p^+) kg^{-1} (Prabhuraj and Murthy, 1994).

2.4.4. Potential acidity

Potential acidity in different horizons of some laterite soils of Orissa varied from 3.4 to 13.5 cmol (p^+) kg^{-1}. The values showed significant positive correlations with free oxides of K and clay (Das *et al.*, 1992).

Potential acidity of some Inceptisols in Manipur ranged from 10.2 to 28.8 cmol (p^+) kg^{-1}. Organic carbon had a significant positive relationship with total acidity (Kailashkumar *et al.*, 1995).

Total potential acidity of hills were considerably higher, ranging from 15.6 to 21.2 cmol (p^+) kg^{-1} in comparison with soils of alluvial zones (9.2 to 16.2 cmol (p^+) kg^{-1}). This is possibly due to high content of organic matter, clay and free iron (Nayak *et al.*, 1996).

2.5. Chemical properties

2.5.1. Elemental composition

A scheme for the weathering behaviour of the major elements was proposed by Mason (1966). This enabled a broad division of the elements into three groups : a least mobile group Si, Al, Fe, a more mobile group Ca and Mg and a most mobile group Na and K.

Karale *et al.* (1969) found that the basaltic soils were rich in Fe_2O_3 and Al_2O_3. In contrast the granite soils were more siliceous in nature and low in R_2O_3.

In a black soil, Fe_2O_3 showed no consistent trend with depth while SiO_2 was found to decrease and Al_2O_3 increase with depth (Prasad *et al.*, 1977). In Digar and Barde (1982) observed an increase in R_2O_3 content with depth while SiO_2 remained constant.

Sesquioxide content was higher in soils developed under high rainfall and lower in soils formed under low rainfall conditions. Sesquioxide increased with depth which implied that there was intense weathering of the parent material under conditions of high rainfall (Verma *et al.*, 1987).

Among vertisols developed from different parent materials, SiO_2 content was highest in soils derived from charnockite. Fe_2O_3 content was

high in soils of yellow shales origin and Al_2O_3 in granite gneiss origin soils (Subbaiah and Manickam, 1992).

High content of SiO_2 and low values of R_2O_3 in some East Coast laterites could be due to protracted rains which retard the process of laterisation. The very low status of total CaO, MgO and K_2O in the soils may be due to low weathering of coarse size mica or due to presence of small amounts of feldspars as sources for bases (Bhaskar and Subbaiah, 1995).

Under lateritic conditions, alumina accumulated in the upper part of the weathering profile associating with Mn or Fe to form oxides and Oxihydroxides (Nahon *et al.*, 1985).

The contents of iron oxides of a vertisol and lateritic red soil derived from basalt were higher than that of the lateritic red soil from granite (Zhu *et al.*, 1990).

Free iron oxide content of vertisols formed on three parent rocks varied widely. It was highest in basaltic soil (2%), closely followed by limestone soil (1.5%) and was least in gneissic soil (0.57%) (Dasog *et al.*, 1990).

In some rice growing soils, Gupta and Tripathi (1993) found that CaO, MgO and K_2O contents constituted less than 5 percent of the soil mass, which was interpreted as a reflection of moderate weathering conditions.

The depth distribution of different elements did not follow any definite pattern indicating stratified parent material and absence of any profile homogenization associated with pedogenesis. The higher content of Ca and Na in some pedons could be due to plagioclase feldspar (Dhaliwal *et al.*, 1993).

2.5.2. Molar ratios

For understanding the degree of chemical weathering of a soil material the concept of molar ratios is applied. The use of such ratios is an important way of evaluating the relative ratios of loss of different elements during the course of weathering (Jenny, 1941).

The high SiO_2/R_2O_3 and SiO_2/Al_2O_3 ratios in the soils of Middle Shiwaliks is an indication of podzolic type of weathering (Ghabru and Ghosh, 1980).

The molar ratios of SiO_2/Al_2O_3 in soils developed from mica rich parent materials showed that SiO_2 content was much higher than Al_2O_3, thus suggesting that the process of silication was operating in the soils (Mishra and Ghosh, 1995).

The molar ratios of SiO_2/Al_2O_3, SiO_2/Fe_2O_3, SiO_2/R_2O_3 and Al_2O_3/Fe_2O_3 were lower in soils at a higher topography. It is inferred from this data that these soils are more weathered than the soils at lower topography (Sharma *et al.*, 1996).

2.5.3. Iron fractions

In many studies of soil classification and genesis it would be useful to differentiate between the free oxides formed as products of recent weathering and those inherited from the parent material (McKeague and Day, 1966). The distribution of clay and elements such as Fe are greatly affected by the process of soil genesis (Blume and Schwertmann, 1969). The colour of soil horizons are used as a criterion to help separate soil great groups. Thus, as coloured compounds, iron oxides impart a characteristic colour when present. So the distribution of these becomes important (Stonehouse and St. Arnaud, 1971).

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McKeague and Day (1966) tentatively proposed that horizons in which dithionite extractable Fe exceeds that in the C horizons by 1% or more be disignated as Bf horizons. Stonehouse and St. Arnaud (1971) interpreted low values of dithionite iron as an indication of limited weathering of silicate minerals. They reported that the active iron ratios (Fe_o/Fe_d) can be used to separate well drained and poorly drained soils. The upper horizons of well drained soils have a ratio of <0.35 whereas poorly drained soils have a ratio in excess of 0.35.

Rutherford and Kemp (1983) interpreted Fe_o - Fe_p values as an indication of mineralistion of organometallic complexes or simply *in situ* weathering. MacVicar *et al.* (1984) were of the opinion that DCB-Fe values indicated absolute accumulation of Fe moreso in soils having an intermediate stage of weathering. According to them DCB-Fe values also indicated the release of Fe from primary minerals and accumulation of Fe by losses of silca and bases.

Ratios of oxalate to dithionite extractable Fe generally decreased with depth and were usually below 0.33 in all horizons. This data indicate the accumulation of Fe and Al weathering products in the sola of these soils but little or no translocation of Fe (McKeague and Day, 1966).

Fe_d maximum usually occurs in the uppermost portion of the B horizon and almost always corresponds to the horizon of maximum clay accumulation and maximum total iron accumulation (Stonehouse and St. Arnaud, 1971).

Arudino *et al.* (1984) found Fe_o to range from 1-21.5% of Fe_t and Fe_o from 0 to 84.77 of Fe_t in some soils of Italy. Higher amounts of Fe_d was observed in Alfisols than in the intergrades and Vertisols suggesting that more amorphous iron had been transformed to crystalline in these soil.

The Fe_d : Fe_t was higher for Alfisols and lower for Vertisols whereas Fe_o : Fe_d was higher in Vertisols because crystallisation rate was higher in Alfisols (Seshagiri Rao *et al.*, 1992).

2.5.4. Extractable Mn

Manganese extracted by sodium hydrosulfite (Sodium dithionite) is called free Mn (Daniels *et al.*, 1962). Dithionite extractable Mn approximately equals the amount of easily reducible Mn (Jarvis, 1984).

In a well drained soil free Mn, Fe and clay were uniform in all layers, as good aeration and neutral pH apparently favoured immobilization of both Mn and Fe. In a illdrained soil free Fe and clay corresponded quite well but low pH and/or slight wetness favoured mobilisation and loss of Mn especially from 15-30 inch layer (Daniels *et al.*, 1962).

2.5.5. Water soluble salts

The proportionate distribution of salts varies with soil type. Alluvial soils had more of water soluble Ca^{2+} and Mg^{2+} while red soils had more of water soluble K^+ and black soils of more of Na^+ (Loganathan and Krishnamoorthy, 1979). In some Punjab soils the anions were present in the descending order of abundance CO_3^{2-}, HCO_3^-, Cl and SO_4^{2-}. SO_4^{2-} and Cl^- being more mobile were carried down while HCO_3^- was retained upstream (Vinayak *et al.*, 1981).

Ravikumar *et al.* (1987) reported that the surface horizons had higher water soluble K which decreased with depth. Subhas Chandra Bose *et al.* (1987) observed lower amount of water soluble K in sandy clay loam soils and higher amount in sandy loam soils.

In Benchmark soils of Punjab, the surface layers had significantly higher content of water soluble K than sub surface layers in the aridic zone. It is attributed to the upward translocation of K from lower depths in

response to high evaporation demand in the aridic zone (Sidhu and Bhangu, 1993).

In a Typic Natraqualf water soluble Na^+ was more than Ca^{2+} and Mg^{2+}. Soluble Ca^{2+} and Mg^{2+} were precipitated by CO_3^{2-} and HCO_3^- resulting in an increase in the ratio of soluble Na^+ to Ca^{2+} and Mg^{2+} in soil solution (Srivastava and Srivastava, 1994).

2.6. Soil classificaiton

Digar *et al.* (1973) classified the red laterite soils of Machkund catchment in Orissa and Andhra Pradesh as Udic Haplustalfs, Ultic Paleustalfs and Ultic Rhodustalfs. Irugur series and Palathurai series, both red soils of Tamil Nadu, were classified as Udic Rhodustalf and Typic Rhodustalf respectively by Hameed Khan and Hanuman Ram (1977). Some red soils of Bihar were classified as Typic Haplustalfs (Tiwary and Mishra, 1992). Walia and Rao (1996) classified red soils in Bundelkhand region of Uttar Pradesh as Typic/Dystric Ustrochrepts and Ultic Haplustalf.

The deep black soils of India were classified as Vertisols by many workers. Srinivasan *et al.* (1969) proposed a modification in the classification system by way of recognising a vertic subsurface horizon. Subbaiah and Manickam (1987) classified black soils of Andhra Pradesh as Typic/Entic Pellusterts and Typic/Entic Chromusterts. Singh *et al.* (1995) classified the black soils from basalt and basaltic alluvium in Rajasthan as Chromic Haplusterts and Typic Haplusterts.

Manickam (1977) classified the laterite soils of Tamil Nadu into Typic Eutritoxs, Typic Haplustoxs, Oxic Haplustalf, Oxic Rhodustalf and Typic Paleustults. Kudrat *et al.* (1995) classified laterite soils of a part of Ajoy catchment in West Bengal as Typic Haplustalfs, Typic Ustochrepts and Aeric Haplaquepts. Natarajan (1995) classified some typical laterite soils in

peninsular India into Ustic Kanhaplohumult, Typic Kandiustalf and Rhodic Kandiustalf.

Murthy (1978) grouped alluvium derived rice growing soils into Haplaquents, Ustifluvents, Udifluvents, Ustochrepts and Haplustalfs. Vadivelu (1985) classified alluvium derived rice soils in Coimbatore district of Tamil Nadu as Aquic Eutropept and Vertic Eutropept. He classified alluvial soils of Cauvery delta as Udic Chromusterts. Soils of valley plains of middle Andaman island were classified as Fluventic Eutropepts, Aquic Eutropepts and Aeric Tropaquepts (Sahu and Bala, 1995). Sarkar *et al.* (1993) classified the soils of Sundarban delta of lower Indo-Gangetic deltaic zone as Vertic Haplaquepts, Aeric Haplaquepts and Typic Haplaquepts.

Singh *et al.* (1991b) classified the soils of North-West Himalayas into Typic Hapludalf, Typic Eutrochrept and Lithic Udorthent. Soils of citrus growing belt of North Cachar hills are acidic with low base saturation and classified under Ultisols and Alfisols (Chakravarty and Barua, 1983).

Singh *et al.* (1991a) classified soils of high altitude in Mizoram as Umbric Dystrochrepts, mid hill soils as Typic Hapludults and low altitude soils as Umbric Dystrochrepts. Bhattacharyya *et al.* (1994a) classified soils of Manipur and Meghalaya, which receive a mean annual rainfall of 2000 to 4000 mm as Typic Kandihumults and Typic Haplohumults. Soils in wet-temperate and sub alpine/moist alpine climatic zones of North-West Himalayas, where the mean annual rainfall varies from 500-3000 mm, were classified as Andic Haplohumult, Ultic Paleudalf, Cumulic Hapludoll and Entic Vermudoll (Gupta and Tripathi, 1992).

Sahu and Dash (1993) classified the coastal soils of Orissa as Typic Haplaquept, Halic Haplaquept and Typic Fluvaquent. Soils of coastal plains in Gujarat were classified originally as Typic Chromusterts. Based on recent

modifications recommended by the International Committee on Management of Vertisols (ICOMERT), these soils were reclassified as Halic Calciustert and Sodic Calciustert (Bhattacharyya *et al.*, 1994b).

2.7. Spectral reflectance

Spectral reflectance of soil is the amount of Electro Magnetic Radiation (EMR) reflected by the soil in relation to the amount incident on it. Although all of the constituents of the soil assume some importance in bestowing spectral character to the soil, five soil parameters were found to be highly correlated with spectral reflectance. They were CEC, clay content, organic matter content iron content, and moisture content of the soil (Montgomery *et al.*, 1972).

Mathews *et al.* (1973) studying the spectral reflectance curves of selected soils observed that clay type, amount of organic matter, free iron oxides and salt, influence the intensity of energy reflected by soils in the 0.5 to 2.6 μm range.

Krishnan *et al.* (1980) found that the visible wavelength region provides better information than the infrared wavelength region for determining the orgnic matter content.

The effect of various iron compounds on the spectral reflectance and colour of soils is not proportional to their relative water content and is manifested differently in different soils and genetic horizons. Weakly crystallised iron compounds had the stronger effect on their spectral reflectance and colour of soils (Karmanaov, 1981).

Reflectivity gradually increases with depth in various subgroups of chernozems, chestnut and sierozem soils. Soils and horizons with an elevated content of iron are easily distinguished by the inflection characteristic for pure Fe_2O_3. The intensity of the reflection in the region from 500-640 μm is inversely

proportional to the iron content. Soils with well defined structure reflect 15 to 20% less light energy than structureless soils (Obukhov and Orlov, 1964).

Soils with high organic matter content have lower reflectance values compared to organic matter poor soils (Bhargava and Mariam, 1992).

Cation exchange capacity showed negative correlations with soil reflectance especially near infra red bands. The correlation between CEC and soil reflectance were higher than correlation between clay content and soil relfectance values. It seemed that CEC acted as a natural integrating factor for clay type and content as well as for organic matter content (Abdel-Hamid, 1993).

Muscovite with light colour and low Fe_2O_3 content gave reflectance value as high as 80 to 90%, whereas its weathered product and also the weathered biotite, which were darker in colour and relatively high in Fe_2O_3 content showed much lower reflectance (Mishra *et al.*, 1993).

Materials and Methods

CHAPTER 3

MATERIALS AND METHODS

The details of collection of profile samples, soil analysis and statistical analysis are presented in this chapter.

3.1. Site selection

Tamil Nadu lies between 76°14' and 80°21' E longitude and 8°4' and 13°54'N latitude. It has a total geographical area of 13 m ha. The state is divided into four geomorphic zones *viz.*, Coastal plain, Eastern ghats, Central plateau and Western ghats. Based on altitude, annual rainfall and annual PET (Potential Evapo-Transpiration), Tamil Nadu has been divided into 7 agro climatic zones (Table 1). For the present study, based on agroecological zones at first level, major land use at second level and areal extent at third level, fifteen reference soils were selected. The locations of the sites and site characteristics are given in Fig.1. and Table 2 respectively.

3.2. Pedon morphology

Profiles were opened in the selected sites and their macromorphological characteristics were described as outlined in FAO (1990).

3.3. Soil sampling

Horizonwise soil samples were collected from the 15 pedons for various laboratory analyses. The samples were air dried and gently powdered using a wooden mallet. They were sieved through a 2mm sieve to separate the coarse fragments (>2mm). The fine earth samples were stored in separate containers and used for analysis.

Table 1. Agro-climatic zones of Tamil Nadu

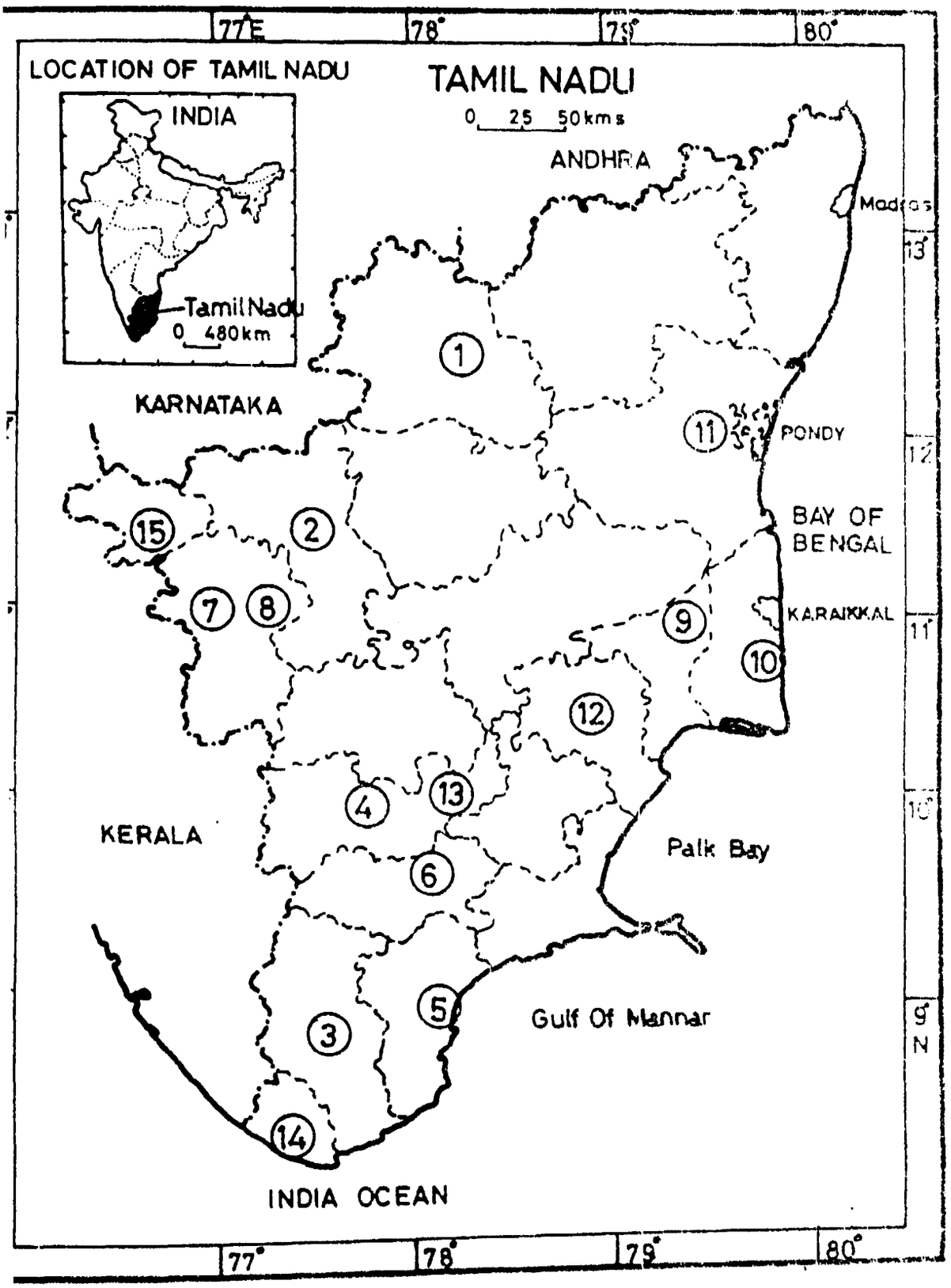
Zonal Number	Name of the zone	Altitude (m)	Annual rainfall (mm)	Annual PET (mm)
1.	North eastern zone	100-200	1105	1700
2.	North western zone	200-600	875	1727
3.	Western zone	200-600	718	1622
4.	Cauvery Delta zone	100-200	984	1932
5.	Southern zone	100-600	857	1825
6.	High rainfall zone	100-200	1420	1516
7.	Hilly zone	2000 and above	2124	1213

(Palaniappan *et al.*, 1993)

Table 2. **Details of Pedon locations**

Pedon No.	Village	Taluk	District	Agro Climatic Zone	Land use
1.	Paiyur	Krishnagiri	Dharmapuri	North Western Zone	Millets, Groundnut, Mango
2.	Bhavanisagar	Gobichettipalayam	Periyar	Western Zone	Groundnut, Turmeric, Paddy
3.	Thenkasi	Thenkasi	Nellai Kattabomman	Southern Zone	Citrus, Paddy
4.	Periyakulam	Periyakulam	Madurai	Southern Zone	Fruit trees, Vegetables
5.	Sathankulam	Tuticorin	V.O.Chidambaranar	Southern Zone	Cultivable Waste
6.	Aruppukkottai	Aruppukkottai	Kamarajar	Southern Zone	Cotton, Sunflower, Millets
7.	Coimbatore	Coimbatore	Coimbatore	Western Zone	Sunflower, Millets
8.	Palladam	Palladam	Coimbatore	Western Zone	Pasture and Minor millets
9.	Aduthurai	Tiruvidaimarudur	Thanjavur	Cauvery Delta Zone	Rice
10.	Sellur	Nagapattinam	Nagai-Quaid-E-Millet	Cauvery Delta Zone	Rice
11.	Vridhachalam	Vridhachalam	South Arcot	North Eastern Zone	Groundnut, Gingelly, Cashew, Pulses
12.	Vamban	Alangudi	Pudukkottai	Southern Zone	Pulses, Groundnut, Cashew
13.	Madurai	Madurai	Madurai	Southern Zone	Rice
14.	Pechiparai	Kalkulam	Kanniyakumari	High rainfall Zone	Rubber, Banana, Arecanut, Coconut
15.	Ooty	Udhagamandalam	Nilgiris	Hilly Zone	Tea, Potato, Cauliflower, Cabbage

Fig 1 LOCATION MAP OF PEDONS



3.4. Physical properties

3.4.1. Particle size distribution

Particle size distribution was determined as per the procedure given by Gupta and Dakshinamoorthy (1980).

3.4.2. Bulk density

Core samples were taken for the depth upto 1m from each pedon using a core cutter and dried in an oven at 105°C for the determination of bulk density (Gupta and Dakshinamoorthy, 1980).

3.4.3. Water dispersible clay

Water dispersible clay was estimated by using water as the dispersing agent (Singh, 1980).

3.4.4. Aggregation Index

Aggregation Index was derived using the following formula given by ISRIC (1992).

$$\text{Aggregation Index} = 100 \times \left(1 - \frac{\text{Water dispersible clay}}{\text{Total clay}}\right)$$

3.4.5. Moisture retention

The moisture retained at 33 kPa and 1500 kPa were determined using a pressure plate apparatus (Richards, 1965). The difference between moisture percentages at 33 kPa and 1500 kPa was taken as available water.

3.5. Physico-chemical properties

3.5.1. pH

pH of the soil was potentiometrically measured in the supernatant suspension of 1:2.5 soil water mixture and 1:2.5 KCl mixture (Peech, 1965). The difference in pH between these two was recorded as ΔpH. pH was also measured in a 1:1 soil water mixture (Soil Conservation Service, 1992).

3.5.2. EC

The electrical conductivity of the 1:2.5 soil water mixture was determined using a conductivity bridge (Piper, 1966).

3.5.3. Organic carbon

Organic carbon was determined by the chromic acid wet digestion method of Walkley and Black as described by Jackson (1958).

3.5.4. $CaCO_3$ equivalent

$CaCO_3$ was determined by treating the soil with a known aliquot of 0.2M HCl and back titrating the unused acid with standard alkali (Hesse, 1971).

3.5.5. Gypsum content

Gypsum was estimated by precipitating it and dissolving in acetone and determining the electrical conductivity (Hesse, 1971).

3.6. Elemental analysis

One gram of soil was digested with perchloric and nitric acids. The digest was extracted with dilute HCl and the filtrate was made upto volume (Hesse, 1971).

3.6.1. Silica

The residue after filtration of $HClO_4$-HNO_3 digestion extract was ignited, weighed and reported as SiO_2 (Hesse, 1971).

3.6.2. Sesquioxides

The sesquioxides in a known aliquot of the perchloric acid extract were precipitated as their hydroxides using NH_4OH in the presence of NH_4Cl. The precipitate was filtered, washed free of chloride, ignited and weighed. The filtrate was made upto volume and used for the analysis of Ca and Mg.

3.6.3. Total iron and manganese

The iron content in the perchloric acid extract was estimated by aspirating the same directly into the Atomic Absorption Spectrophotometer and expressed as Fe_2O_3 (Hesse, 1971). The content of Mn was also estimated similarly.

3.6.4. Total zinc and copper

One gram of soil was digested with a mixture of sulphuric acid and perchloric acids. It was diluted with normal hydrochloric acid and made upto volume. Total Zinc and Cu in this extract were estimated using Atomic Absorption Spectrophotometer (Holmes, 1945).

3.6.5. Alumina

The Al_2O_3 content was deduced by substracting the Fe_2O_3 content from the sesquioxide content.

3.6.6. Total calcium and magnesium

The determination of Ca and Mg was done in the filtrate obtained after the removal of sesquioxide, by versenate method (Hesse, 1971). Their contents were expressed as CaO and MgO.

3.6.7. Total sodium and potassium

1:1 Hydrochloric acid extract of the soils was prepared as per the procedure of Piper (1966) and made to volume. It was diluted and neutralised. The sodium and potassium contents were estimated using a flame photometer (Stanford and English, 1949).

3.6.8. Total phosphorus

The phosphorus concentration in the perchloric acid extract was estimated by the Vanadomolybdic method (Hesse, 1971).

3.7. Molar ratios

The molar concentrations of SiO_2, Fe_2O_3, Al_2O_3, CaO, MgO, K_2O and Na_2O were worked out and the following molar ratios were worked out. SiO_2 : R_2O_3 ; SiO_2 : Al_2O_3 ; SiO_2 : Fe_2O_3 ; Al_2O_3 : Fe_2O_3 ; CaO+MgO : Al_2O_3 ; CaO : MgO; K_2O+Na_2O : Al_2O_3; K_2O: Na_2O.

3.8. Fractions of Fe and Mn

3.8.1. Dithionite extractable Fe and Mn

The soil samples were heated in a complexing mixture of sodium citrate/bicarbonate to which solid sodium dithionite was added as reducing agent. Iron and Manganese in the extract were measured by Atomic Absorption Spectrophotometer (AAS) (Mehra and Jackson, 1960). The iron content was expressed as free iron oxides.

3.8.2. Acid ammonium oxalate extractable iron

Soil samples were shaken with a complexing ammonium oxalate solution at pH 3.0 dissolving the amorphous compounds of iron which were estimated by AAS (McKeague and Day, 1966).

3.8.3. Pyrophosphate extractable iron

Soil samples were shaken with 0.1M sodium pyrophosphate solution which selectively extracts iron complexed to organic matter. The iron content was measured by AAS (Bascomb, 1968).

3.9. Fractions of phosphorus

3.9.1. Citric acid soluble phosphorus

The soil samples were extracted with 1 per cent citric acid solution. Phosphate in the extract was determined colorimetrically with the blue ammonium molybdate method with ascorbic acid as reducing agent (Laboratory for Soil and Crop Testing, 1979).

3.9.2. Bray P

The readily acid soluble forms of P were extracted by a combination of HCl and NH_4F. Phosphate in the extract was determined colorimetrically with the blue ammonium molybdate method with ascorbic acid as reducing agent (Bray and Kurtz, 1945).

3.9.3. Olsen P

The soil samples were extracted with 0.5M sodium bicarbonate solution at pH 8.5. Phosphate in the extract was determined colorimetrically (Olsen *et al.*, 1954).

3.10. Total N

The total nitrogen content of the soils were determined using a Kjeltech autosystem as per the procedure of Bremner and Mulvaney (1982).

3.11. Water soluble ions

1:5 soil water extract was prepared by shaking the suspension for 30 minutes and centrifuging (Hesse, 1971).

Water soluble sodium and potassium were estimated in the extract by flame photometer (Jackson, 1958).

Water soluble calcium and magnesium were estimated volumetrically by Versenate titration (Jackson, 1958).

Chloride in the extract was estimated by titration with standard silver nitrate (Hesse, 1971).

Carbonate and bicarbonate were estimated by titrating with standard sulphuric acid using phenolphthalein and methyl orange as indicators respectively (Hesse, 1971).

Sulphate in the extract was precipitated as $BaSO_4$ using barium chloride and estimated gravimetrically (Jackson, 1958).

3.12. Exchange properties

3.12.1. Cation exchange capacity

Cation exchange capacity of the soils was determined by the neutral Normal ammonium acetate method (Jackson, 1958; Chapman, 1965). The ammonium acetate extract obtained from the CEC estimation was used to determine the exchangeable base.

3.12.2. Exchangeable bases

Exchangeable sodium and potassium were estimated using a flame photometer and exchangeable calcium and magnesium by versenate titration (Jackson, 1958).

3.13. Forms of acidity

3.13.1. Exchangeable acidity

Soil samples were percolated with 1M KCl solution. The acidity brought into solution by various sources, principally by H^+ and Al^{3+} was measured by titrating with standard alkali (Thomas, 1982).

3.13.2. Extractable acidity

The soil samples were shaken with $BaCl_2$ - Tri-Ethanol Amine buffer solution at pH 8.2. After centrifugation a known volume of the supernatant solution was titrated with acid to measure the residual base (Blakemore *et al.*, 1987).

3.14. Effective CEC

Effective CEC (ECEC) was calculated using the following formula (ISRIC, 1992).

ECEC (in cmol (p^+) kg^{-1} soil) = Exchangeable (Na+K+Ca+Mg) + Exchangeable acidity

3.15. Spectral reflectance

Spectral reflectance measurements were made under solar illumination using a Ground Truth Radiometer (Optomech model 041). The

measurements were made in 4 bands *viz.*,

Blue	0.45 - 0.52 µm
Green	0.52 - 0.60 µm
Red	0.62 - 0.68 µm
Infra Red	0.77 - 0.86 µm

The soil samples were spread on a clean sheet of black cloth, so as to be in the field of view of 15° of the GTR. Barium sulphate coated plate was used as the standard. The soil reflectance percentage was worked out as follows :

$$\text{Soil reflectance percentage} = \frac{\text{Reflectance from soil}}{\text{Reflectance from } BaSO_4 \text{ plate}} \times 100$$

3.16. Statistical analysis

The relationship among the physical, chemical and spectral reflectance properties of the soils were subjected to statistical scrutiny. Correlation and regression equations were developed following the procedure outlined by Snedcor and Cochran (1967).

Results

CHAPTER 4

RESULTS

A brief description of the morphological properties of the soils, results of laboratory analyses of soil samples and statistical interpretation of data are presented in this chapter.

4.1. Morphological properties (Tables 3 and 4; Annexure I)

4.1.1. Land form and site characteristics

The land forms of the location of the pedons varied widely. Pedons 1, 3 and 8 were examined on undulating plain. Pedons 2, 4 and 5 were located on peneplains with undulating topography. The land form of Pedon 6 was a gently sloping plain. In the case of Pedon 7 it was peneplain with flat topography. The land forms of Pedon 9 and 10 were delta plain and marine land respectively. Pedons 11, 12 and 13 occurred on lateritic land form. Pedons 14 and 15 had a rolling topography.

The slope of these land forms were found to vary from 0 to 1 per cent in Pedons 3, 5, 7, 9, 10, 11, 12 and 13; from 15 to 20 per cent in Pedon 15.

Pedons 1, 2, 3, 4, 5, 11, 12, 14 and 15 were well drained. Pedons 6, 7 and 13 were moderately well drained. Pedons 9 and 10 were imperfectly drained while Pedon 8 was excessively drained.

Surface cracks were observed in Pedons 6, 7, 9 and 10.

4.1.2. Soil characteristics

4.1.2.1. Solum depth

The depth of the solum was less than 100 cm in Pedons 2 and 8. In Pedons 1, 6 and 13 the depth of the solum was between 100 to 150 cm. In Pedons 3 and 12 the solum depth was from 150 cm to 2 m. In Pedons 4, 5, 7, 9, 10, 11, 14 and 15 the solum depth was more than 2 m.

Table 3. Morphological properties (Pedons 1 to 7)

Property	Pedon 1	Pedon 2	Pedon 3	Pedon 4	Pedon 5	Pedon 6	Pedon 7
Land form	Undulating plain	Peneplain with undulating topography	Undulating plain	Peneplain with undulating topography	Sandy plain with undulating topography	Gently sloping plain	Peneplain with flat topography
Slope %	1-3	1-3	0-1	1-3	0-1	1-3	0-1
Erosion	e2	e1	e1	e2	e3	e2	e1
Drainage	Well drained	Well drained	Well drained	Well drain	Well drained	Moderately well drained	Moderately well drained
Surface cracks	Absent	Absent	Absent	Absent	Absent	Present	Present
Solum depth	100 cm	60 cm	160 cm	>2m	>2m	112 cm	>2m
Soil colour (moist)							
Surface	5YR 4/3	2.5YR 3/4	10R 3/6	7.5YR 4/4	2.5YR 4/6	10YR 3/2	10YR 3/2
Subsurface	2.5YR 3/6	2.5YR 3/4	10R 3/4	2.5YR 3/4	2.5YR 3/4	10YR 3/1	10YR 3/2 and 10YR 5/3
Texture							
Surface	s - ls	cl	c	sl	sl	c	scl
Subsurface	(g) - sc	(sg) - sl	(g) sl-sc	sl - scl	scl	l	scl-sc

Contd...

Table 3. Contd...

Property	Pedon 1	Pedon 2	Pedon 3	Pedon 4	Pedon 5	Pedon 6	Pedon 7
Structure							
Surface	1 fgr	3c sbk	2m sbk	1m gr	1f gr	1m sbk	1f sbk
Subsurface	2m sbk	3c sbk	1m sbk	2m sbk	1m sbk-gr	3c abk	3c abk
Mottling							
Surface	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Subsurface	Absent	Absent	Absent	Absent	Absent	Absent	Present
Distinctness	-	-	-	-	-	-	Prominent
Colour	-	-	-	-	-	-	10YR 2/2
Concretions							
$CaCO_3$	Absent	Absent	Absent	Absent	Absent	Present	Present
Fe-Mn	Absent	Absent	Present	Absent	Absent	Absent	Present
Calcareousness	Non calcareous	Non calcareous	Non calcareous	Non calcareous	Non calcareous	Calcareous	Calcareous
Special Features							
Slickensides	Absent	Absent	Absent	Absent	Absent	Present	Present
Clay films	Absent	Absent	Absent	Present	Present	Absent	Absent
Pressure faces	Absent	Absent	Absent	Absent	Absent	Present	Present
Gravels	Irregular quartz gravels in subsurface	Irregular quartz gravels in subsurface	Quartz gravels throughout profile	Quartz gravels present	Absent	Absent	Absent
Biological activity	Absent	Termite channels	Termite channels	Termite channels	Termite channels	Absent	Absent

Table 4. Morphological properties (Pedons 8 to 15)

Property	Pedon 8	Pedon 9	Pedon 10	Pedon 11	Pedon 12	Pedon 13	Pedon 14	Pedon 15
Land form	Undulating plain	Delta plain	Marine land	Lateritic land form	Lateritic land form	Lateritic land from	Low hill rolling with topography	Mountain with rolling topography
Slope %	3-5	0-1	0-1	0-1	0-1	0-1	3-5	15-20
Erosion	e3	e0	e0	e1	e1	e1	e2	e4
Drainage	Excessively drained	Imperfectly drained	Imperfectly drained	Well drained	Well drained	Moderately well drained	Well drained	Well drained
Surface cracks	Absent	Present	Present	Absent	Absent	Absent	Absent	Absent
Solum depth	80 cm	> 2m	>2m	>2m	170 cm	150 cm	>2m	>2m
Soil colour (moist)								
Surface	10YR 4/4	10YR 3/2	10YR 4/2	10YR 4/3	2.5YR 3/4	10YR 3/2	7.4YR 3/4	10YR 3/3
Subsurface	10YR 4/4	10YR 3/3 and 4/2	10YR 4/1 10YR 5/2	5YR 4/6	2.5YR 3/6	10YR 4/6 7.5YR 5/8	2.5YR 4/6	10YR 3/6, 5/6
Texture								
Surface	(g) sl	c	c	ls-s	scl	sc	(sg)-sc	c
Subsurface	(vg) sl	cl-c	sl-cl	sl-sc	sc	scl-c	(vg) scl-sc	cl-c

Contd...

Table 4. Contd...

Property	Pedon 8	Pedon 9	Pedon 10	Pedon 11	Pedon 12	Pedon 13	Pedon 14	Pedon 15
Structure								
Surface	1 fgr	1f sbk	3c sbk	1f sbk	2c sbk	2m sbk	1m Cr	1f sbk
Subsurface	1m gr	3c sbk	3m sbk	3c sbk	2m sbk	3c sbk	1m sbk	2m sbk
Mottling								
Surface	Absent	Present	Present	Absent	Absent	Absent	Absent	Absent
Subsurface	Absent	Present	Present	Absent	Absent	Present	Absent	Present
Distinctness	-	Distinct	Distinct	-	-	Distinct	-	Distinct
Colour	-	10YR 2/1	10YR 5/6 10 YR 5/2	-	-	2.5YR 2/4	-	10YR 3/1
Concretions								
$CaCO_3$	Present	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Fe-Mn	Absent	Present	Present	Absent	Present	Present	Present	Absent
Calcareousness	Calcareous	Non calcareous	Non calcareous	Non calcareous	Non calcareous	Non calcareous	Non calcareous	Non calcareous
Special Features								
Slickensides	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Clay films	Absent	Absent	Present	Present	Present	Absent	Absent	Present
Pressure faces	Present	Present	Absent	Absent	Absent	Absent	Absent	Absent
Gravels	Lime and quartz gravels present	Absent	Absent	Absent	Ferruginous gravels present	Ferruginous gravels present	Quartz and ferruginous gravels present	Absent
Biological activity	Absent	Absent	Rodent activity	Termite channels	Termite channels	Absent	Absent	Earthworm channels

4.1.2.2. Colour

The moist colour of the surface horizons varied widely. In Pedons 6, 7, 8, 9, 10, 11, 13 and 15 the hues were 10YR. The hue was 7.5 YR in Pedons 4 and 14; 5YR in Pedon 1, and 2.5 YR in Pedons 2, 5 and 12. The hue was 10 R in Pedon 3. The 'value' varied from 3 to 4 and the chroma from 2 to 6.

The hue of the subsurface horizons was 10 YR in Pedons 6, 7, 8, 9, 10, 13 and 15; 7.5 YR in some horizons of Pedon 13; 5 YR in Pedon 11 and 2.5 YR in Pedons 1, 2, 4, 5, 12 and 14. The 'value' ranged from 3 to 5 and chroma from 2 to 8.

4.1.2.3. Texture

The texture of the surface soils was clayey in Pedons 3, 6, 9, 10 and 14. In Pedon 2 the texture was clay loam. The texture was sandy clay loam in Pedons 7 and 12; sandy loam in Pedons 4, 5 and 8; loamy sand in Pedons 1 and 11 and sandy clay in Pedons 13 and 14.

The texture of the subsurface horizons also varied widely. The subsurface texture was clayey in Pedon 6; clayloam to clay in Pedons 9 and 15; sandy clay loam to clay in Pedons 5, 7, 10, 13 and 14; sandy loam to sandy clay in Pedons 3, 4 and 11; sandy loam in Pedons 2 and 8 and sandy clay in Pedons 1 and 12.

4.1.2.4. Structure

The structure of the surface horizons was subangular blocky in Pedons 2, 3, 6, 7, 9, 10, 11, 13 and 15. Granular structure was noticed in Pedons 1, 4, 5 and 8. Pedon 14 was found to have a crumb structure.

The dominant structure of the subsurface horizons was angular blocky in Pedons 6 and 7 and granular in Pedon 8. In all the remaining pedons the structure was subangular blocky.

4.1.2.5. Mottling

Mottlings were present in surface and subsurface horizons in Pedons 9 and 10. In Pedons 13 and 15 mottlings were observed in the subsurface horizons only.

The colour of the mottling was 10 YR 2/1 in Pedon 9; 10 YR 5/2 to 10 YR 5/6 in Pedon 10; 2.5 YR 2/4 in Pedon 13 and 10 YR 3/1 in Pedon 15.

4.1.2.6. Concretions

Both $CaCO_3$ and Fe-Mn concretions were observed in Pedon 7. In Pedons 6 and 8 $CaCO_3$ concretions were present. In Pedons 3, 9, 10, 12, 13 and 14 Fe-Mn concretions were noticed.

4.1.2.7. Calcareousness

Only pedons 6, 7 and 8 were calcareous. The remaining twelve pedons were non-calcareous.

4.1.2.8. Coarse fragments

Quartz gravels were present throughout the profile in Pedon 4. In Pedons 1 and 2 irregular quartz gravels were present in the subsurface. Lime and quartz gravels were present in Pedon 8. In Pedons 12, 13 and 14 ferruginous gravels were noticed.

4.1.2.9. Special features

Slickensides were observed in Pedons 6 and 7. Clay films were observed in Pedons 4, 5, 10, 11, 12 and 15. Pressure faces were noticed in Pedons 4, 5, 8, 10, 11, 14 and 15. Signs of biological activity were observed in some of the pedons. In Pedons 4, 5, 11, 12, 14 and 15 termite activity was observed. In Pedon 10, rodent activity was noticed.

4.2. Physical properties

4.2.1. Particle size fractions (Table 5 ; Annexure IIa)

4.2.1.1. Clay

The clay content of the pedons varied from 3.40 per cent in Pedon 1 to 57.67 per cent in Pedon 6. The mean clay content was more than 35 per cent in Pedons 6 and 12, 18 to 35 per cent in Pedons 1, 2, 3, 5, 7, 9, 10, 11, 13, 14 and 15, and less than 18 per cent in Pedons 4 and 8.

In Pedons 8 and 9, a decreasing trend with depth was noticed. In Pedons 6, 11 and 12 an increasing trend was observed. The other pedons showed irregular pattern of clay distribution (Fig.2).

4.2.1.2. Silt

The range of silt content was between 1.56 per cent in Pedon 1 and 25.91 per cent in Pedon 10. The mean silt content was less than 10 per cent in Pedons 1, 3, 4, 5, 7, 8, 11, 12, 13 and 14. It was more than 10 per cent in other pedons (2, 6, 9, 10 and 15).

Silt content increased with depth in Pedon 1. A decreasing trend was noticed in Pedons 2 and 13. The remaining pedons exhibited an irregular distribution of silt content with depth (Fig.2).

4.2.1.3. Very coarse sand

The values of very coarse sand (1.00-2.00 mm) ranged from 0.50 per cent in Pedon 10 to 53.25 per cent in Pedon 13. The mean values of very coarse sand was less than 10 per cent in Pedons 4, 5, 6, 7, 11 and 15. The mean values were between 10 and 20 per cent in Pedons 1, 2, 9 and 12. The remaining pedons (3, 8, 13 and 14) recorded mean values of 20 per cent and more.

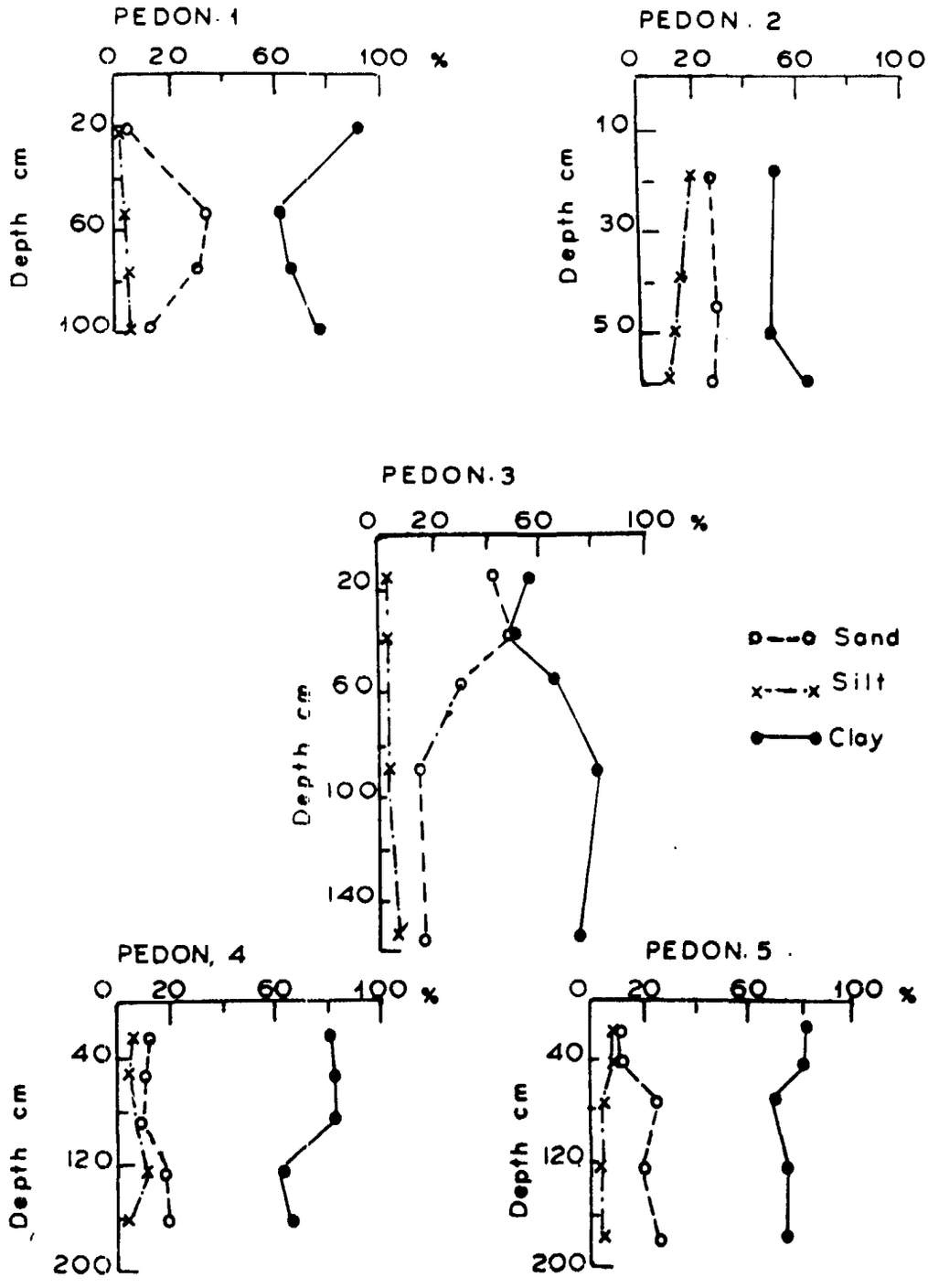
There was an increasing pattern of distribution of very coarse sand in Pedon 2. In the case of Pedons 3, 9 and 10 the increase was only upto a

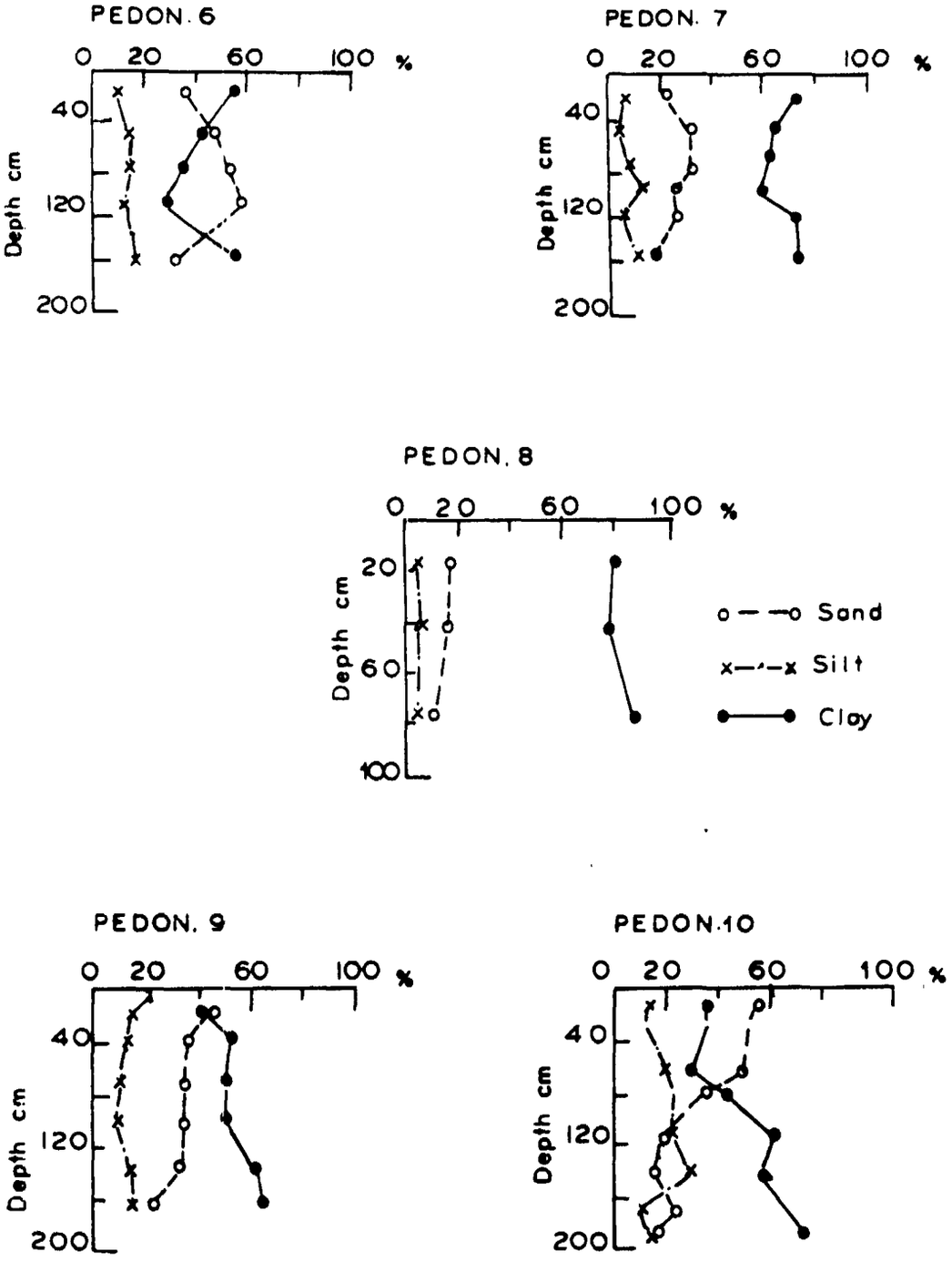
Table 5. Range and mean values of particle size fraction (Per cent)

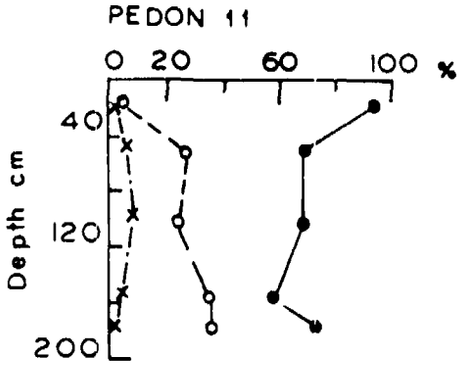
Pedons	Clay		Silt		Very coarse sand		Coarse sand		Medium sand		Fine sand		Very fine sand		W.D. clay	
	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M
Pedon 1	3.40-35.90	21.48	1.56-7.14	3.49	12.16-23.02	10.18	14.41-30.64	21.94	8.79-17.70	11.83	14.04-23.56	17.30	4.36-6.78	5.70	0.97-10.26	6.42
Pedon 2	27.38-32.08	28.50	10.27-20.61	15.26	5.43-18.11	13.19	3.81-15.72	10.17	5.69-9.76	8.02	14.40-24.19	17.82	3.84-9.31	7.04	8.07-16.72	13.02
Pedon 3	14.04-50.04	30.93	2.10-5.46	2.92	10.71-39.51	27.75	6.29-13.59	10.21	6.53-11.25	8.82	9.26-18.42	14.20	3.91-6.59	5.32	3.19-11.28	6.77
Pedon 4	9.26-27.63	17.00	5.16-11.28	6.88	5.82-14.45	9.78	12.24-26.00	18.08	9.76-19.40	14.84	21.84-29.43	24.07	7.18-13.27	9.90	1.87-9.21	5.44
Pedon 5	10.38-26.91	18.90	2.83-8.33	5.06	1.84-3.11	2.28	10.76-17.61	14.03	18.38-24.33	21.26	29.05-37.20	32.79	2.38-8.66	5.60	1.28-3.28	2.51
Pedon 6	31.11-57.67	44.31	9.50-14.94	13.13	2.14-4.50	3.05	3.00-9.08	4.94	6.95-12.14	9.19	11.38-26.71	19.08	3.91-7.98	6.31	25.78-34.25	29.92
Pedon 7	18.21-31.20	25.38	4.08-15.53	8.13	0.93-3.21	2.12	3.34-7.45	4.91	18.17-24.03	21.06	26.42-40.25	31.61	6.68-8.52	7.54	12.90-18.10	14.63
Pedon 8	10.27-16.58	12.31	3.04-4.43	3.78	23.53-30.75	26.65	12.12-15.59	14.30	10.22-12.11	11.37	17.70-20.31	18.95	8.21-15.08	6.56	6.41-13.81	10.21
Pedon 9	22.45-44.52	33.08	9.37-14.87	12.30	9.00-16.99	13.47	5.96-10.76	8.42	6.32-12.88	8.67	13.21-19.90	16.71	3.53-12.16	7.36	10.87-20.41	16.36
Pedon 10	14.26-53.71	32.74	10.60-25.91	16.63	0.50-18.77	8.78	0.49-5.71	1.71	0.93-3.61	2.17	6.13-15.14	10.43	12.45-45.29	27.54	1.26-41.26	17.03
Pedon 11	5.90-35.92	25.66	2.56-7.59	4.64	0.75-1.46	1.09	15.12-28.46	19.17	16.79-30.21	23.01	18.77-27.46	22.65	2.92-4.36	3.78	1.87-14.39	9.68
Pedon 12	33.80-44.84	39.60	2.91-4.44	3.86	6.85-30.20	12.93	4.51-10.45	8.25	4.61-10.63	8.43	11.02-24.27	19.22	6.29-9.00	7.72	7.20-14.80	11.08
Pedon 13	20.18-36.94	28.96	3.35-8.77	6.23	6.72-53.25	21.09	9.15-16.25	12.66	3.98-10.51	8.15	7.05-21.69	16.25	3.24-8.94	6.71	6.18-18.28	10.86
Pedon 14	20.43-33.92	28.82	2.69-10.09	6.77	21.92-44.28	30.66	10.33-16.18	13.62	4.00-9.89	6.17	6.32-15.59	10.2	2.89-5.50	3.81	3.12-9.81	6.47
Pedon 15	30.21-41.12	34.48	10.08-14.81	12.08	6.38-12.32	8.63	8.05-16.07	11.41	8.75-11.85	10.59	12.63-19.07	15.87	5.00-9.05	6.91	6.21-10.21	7.12

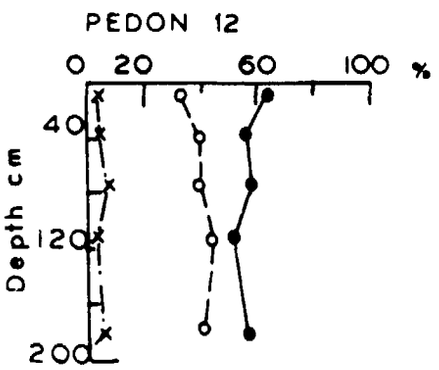
R Range M : Mean W.D. clay : Water Dispersible clay

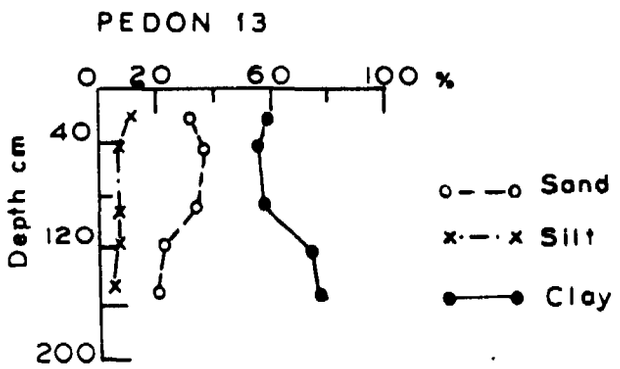
FIG. 2 DEPTHWISE DISTRIBUTION OF PARTICLE SIZE FRACTIONS

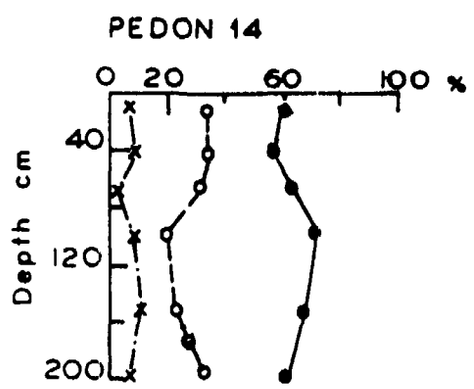


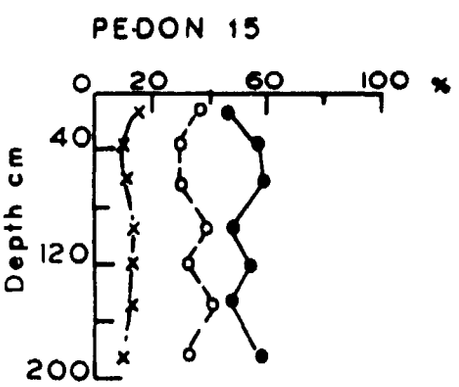

PEDON. 6
0 20 60 100 %
40
120
200
Depth cm
PEDON. 7
0 20 60 100 %
40
120
200
Depth cm
PEDON. 8
0 20 60 100 %
20
60
100
Depth cm
o — —o Sand
x—·—x Silt
Clay
PEDON. 9
0 20 60 100 %
40
120
200
Depth cm
PEDON.10
0 20 60 100 %
40
120
200
Depth cm


PEDON 11
0 20 60 100 %
40
120
200
Depth cm


PEDON 12
0 20 60 100 %
40
120
200
Depth cm


PEDON 13
0 20 60 100 %
40
120
200
Depth cm
Sand
Silt
Clay


PEDON 14
0 20 60 100 %
40
120
200
Depth cm


PEDON 15
0 20 60 100 %
40
120
200
Depth cm

certain depth and a decreasing trend was noticed thereafter. The depth function was variable in other pedons.

4.2.1.4. Coarse sand

The coarse sand (1.00-0.50 mm) content ranged from 0.49 per cent in Pedon 10 to 30.64 per cent in Pedon 1. The mean values were less than 10 per cent in Pedons 6, 7, 9, 10, 12 and 15. In Pedons 2, 3, 4, 5, 8, 11, 13 and 14, it was 10 to 20 per cent and in Pedon 1, it was more than 20 per cent.

The coarse sand content decreased upto 74 cm depth and increased thereafter in Pedon 1. In Pedon 14, a decreasing trend was observed upto 100 cm depth and thereafter an increase was observed. The distribution was irregular in the remaining pedons.

4.2.1.5. Medium sand

The range of medium sand (0.50-0.25 mm) content was from 0.93 per cent in Pedon 10 to 30.21 per cent in Pedon 11. The mean values were less than 10 per cent in Pedons 2, 3, 6, 9, 10, 12, 13 and 14; 10 to 20 per cent in Pedons 1, 4, 8 and 15 and more than 20 per cent in Pedons 5, 7 and 11.

The medium sand decreased upto 74 cm and then increased in Pedon 1. The pattern of distribution was irregular in other Pedons.

4.2.1.6. Fine sand

The fine sand (0.25-0.10 mm) content varied from 6.13 per cent in Pedon 10 to 40.25 per cent in Pedon 7. The mean values were more than 20 per cent in Pedons 4, 5, 7 and 11, while in the remaining pedons the values ranged from 10 to 20 per cent.

A decreasing trend of distribution of fine sand was noticed in Pedons 1 and 12. In Pedons 2, 6 and 14 the decrease was uniform except in the bottom most layer. The rest of the pedons exhibited an irregular pattern of distribution of fine sand.

4.2.1.7. Very fine sand

The very fine sand (0.10-0.05 cm) content varied from 2.38 per cent in Pedon 5 to 45.29 per cent in Pedon 10. The mean values were more than 10 per cent in Pedon 10; 5 to 10 per cent in Pedons 1, 2, 3, 4, 5, 6, 7, 8, 9, 12, 13 and 15; less than 5 per cent in other pedons.

A gradual decrease of very fine sand with depth was observed in Pedon 1. The trend was reverse in the case of Pedon 8. The distribution pattern was irregular in other pedons.

4.2.1.8. Water dispersible clay

The range of water dispersible clay was from 0.97 per cent in Pedon 1 to 41.26 per cent in Pedon 10. The mean values were less than 5 per cent in Pedon 5; 5 to 10 per cent in Pedons 1, 3, 4, 11, 14 and 15; more than 10 per cent in other pedons. Water dispersible clay was found to decrease with depth in Pedon 2. In other Pedons the trend was irregular.

4.2.2. Ratios of particle size fractions (Table 6; Annexure IIa)

4.2.2.1. Silt/clay ratio

The ratio of silt/clay varied from 0.05 in Pedon 3 to 1.66 in Pedon 10. The mean values of this ratio was more than 0.50 in Pedons 2 and 10. In all other pedons the ratio was less than 0.50. The ratio varied within a narrow range of 0.07 to 0.12 in Pedons 12, 13 and 15. In other pedons a wide variation was observed.

4.2.2.2. Sand/silt ratio

The ratio of sand/silt ranged from 2.17 in Pedon 6 to 60.92 in Pedon 1. The ratio was less than 5 in Pedons 2, 6, 9, 10 and 15; 5 to 10 in Pedon 7; 10 to 15 in Pedons 4, 12, 13 and 14; 15 to 30 in Pedons 3, 5 and 11; more than 30 in Pedon 1.

Table 6. Range and mean values of ratios of particle size fractions

Pedons	Silt / Clay		Sand / Silt		Coarse sand / Fine sand		Aggregation index	
	R	M	R	M	R	M	R	M
Pedon 1	0.07-0.46	0.27	10.79-60.92	30.17	0.96-1.90	1.28	0.42-0.55	0.60
Pedon 2	0.38-0.74	0.54	2.49-6.07	4.08	0.16-1.06	0.66	0.40-0.71	0.55
Pedon 3	0.05-0.31	0.13	14.12-39.93	25.28	0.60-0.90	0.71	0.63-0.86	0.76
Pedon 4	0.19-0.68	0.48	5.49-15.58	12.14	0.53-1.17	0.77	0.18-0.81	0.63
Pedon 5	0.11-0.80	0.38	9.76-26.01	18.51	0.29-0.57	0.43	0.82-0.88	0.86
Pedon 6	0.23-0.48	0.31	2.17-5.68	3.38	0.19-0.38	0.26	0.17-0.41	0.31
Pedon 7	0.17-0.61	0.34	3.80-17.52	8.58	0.11-0.26	0.16	0.25-0.53	0.41
Pedon 8	0.18-0.38	0.28	17.87-26.44	22.19	0.68-0.83	0.75	0.16-0.38	0.31
Pedon 9	0.27-0.61	0.39	2.73-5.91	4.58	0.40-0.67	0.51	0.37-0.69	0.49
Pedon 10	0.20-1.66	0.70	1.49-6.31	3.42	0.07-0.79	0.25	0.18-0.91	0.49
Pedon 11	0.08-0.32	0.23	9.08-35.76	18.28	0.68-1.10	0.85	0.38-0.68	0.58
Pedon 12	0.06-0.13	0.10	12.36-17.96	14.91	0.38-0.52	0.43	0.59-0.82	0.71
Pedon 13	0.17-0.29	0.22	6.76-22.82	11.89	0.62-1.30	0.85	0.43-0.73	0.62
Pedon 14	0.08-0.48	0.26	6.83-24.02	11.42	1.04-2.09	1.43	0.70-0.85	0.78
Pedon 15	0.29-0.41	0.35	3.25-5.92	4.56	0.49-0.96	0.69	0.75-0.87	0.79

R = Range M = Mean

4.2.2.3. Coarse sand/fine sand ratio

The coarse sand/fine sand ratio ranged from 0.07 in Pedon 10 to 2.09 in Pedon 14. The mean value of this ratio was more than 1 in Pedons 1 and 14. In all the other pedons the mean value was less than 1.

4.2.2.4. Aggregation index

The value of the aggregation index varied from 0.16 in Pedon 8 to 0.91 in Pedon 10. The mean values of this index was less than 0.50 in Pedons 6, 7, 8, 9 and 10. In the remaining pedons the index value was more than 0.50.

4.2.3. Moisture retention characteristics (Table 7; Annexure IIb)

4.2.3.1. Moisture retention at 33 kPa

Moisture retention at 33 kPa ranged from 4.28 per cent in Pedon 11 to 43.21 per cent in Pedon 6. The mean values were less than 10 per cent in Pedon 8; 10 to 20 per cent in Pedons 1, 2 and 3; 20 to 30 per cent in Pedons 3, 10, 11, 13, 14 and 15; more than 30 per cent in Pedons 6, 7, 9 and 12.

The values of moisture retention at this tension decreased with depth in Pedons 2 and 3. In the rest of the pedons the depthwise distribution was irregular.

4.2.3.2. Moisture retention at 1500 kPa

Moisture retention at 1500 kPa varied from 2.12 per cent in Pedon 1 to 23.90 per cent in Pedon 6. The mean values were less than 10 per cent in Pedons 1, 2, 4, 5, 8 and 15; 10 to 20 per cent in Pedons 3, 7, 9, 10, 11, 12, 13 and 14; more than 20 per cent in Pedon 6.

Excepting Pedon 2, where a decreasing trend with depth was observed, in all other pedons the depthwise distribution was irregular.

Table 7.Range and mean values of moisture retention characteristics

Pedons	B.D. Mg M^{-3}		33 KPa %		1500 KPa %		AWC %		Air dry moisture %	
	R	M	R	M	R	M	R	M	R	M
Pedon 1	1.46-1.69	1.59	4.68-28.68	17.99	2.12-15.32	9.50	2.56-13.36	8.49	0.98-1.46	1.23
Pedon 2	1.38-1.56	1.46	11.69-18.63	14.66	5.84-10.28	7.78	5.85-8.35	6.88	3.21-4.38	3.96
Pedon 3	1.24-1.47	1.38	10.69-29.65	22.04	4.78-14.03	10.48	5.91-16.28	11.57	2.76-5.61	4.07
Pedon 4	1.33-1.45	1.39	10.68-23.38	17.69	4.12-12.83	8.96	6.56-11.30	8.73	2.08-3.93	2.76
Pedon 5	1.47-1.72	1.62	7.83-9.88	8.83	4.32-6.33	5.34	2.88-5.13	3.49	0.93-1.21	1.04
Pedon 6	1.27-1.57	1.41	34.34-43.21	39.81	18.63-23.90	20.94	15.51-20.56	18.87	4.93-7.73	6.33
Pedon 7	1.29-1.57	1.48	28.31-39.87	34.20	13.14-19.21	15.61	14.76-23.09	18.59	3.88-5.78	4.56
Pedon 8	1.41-1.66	1.55	8.29-14.18	11.98	3.98-7.10	6.00	4.31-7.08	5.98	1.08-1.97	1.58
Pedon 9	1.23-1.53	1.42	29.21-42.35	35.77	15.30-22.94	18.74	13.91-18.93	17.03	3.19-5.43	4.26
Pedon 10	1.18-1.55	1.42	13.78-43.62	28.38	7.70-22.33	14.65	5.72-24.28	13.73	3.28-6.02	4.74
Pedon 11	1.34-1.57	1.48	4.28-31.62	21.49	2.22-16.33	10.59	2.06-15.29	10.90	1.09-4.76	3.36
Pedon 12	1.31-1.54	1.44	30.62-40.62	34.87	16.32-21.93	18.78	14.30-18.69	16.08	3.83-5.83	4.63
Pedon 13	1.42-1.58	1.54	20.63-32.58	28.08	9.47-16.83	12.66	11.16-16.85	13.94	2.83-3.12	3.01
Pedon 14	1.18-1.39	1.26	16.30-30.32	24.39	8.69-16.18	13.11	7.12-15.12	11.29	3.87-5.61	5.04
Pedon 15	1.16-1.41	1.30	17.83-22.91	20.06	7.87-11.41	8.92	10.13-13.41	11.14	3.01-5.93	5.04

R = Range M = Mean

4.2.3.3. Available water content

The available water content was found to vary from 2.06 per cent in Pedon 11 to 24.28 per cent in Pedon 11. The mean values of available water content were less than 10 per cent in Pedons 1, 2, 4, 5 and 8. In pedons 3, 10, 13, 14 and 15, the values were 10 to 15 per cent, and in Pedons 6, 7, 9 and 12 the values were than 15 per cent.

In Pedon 2, a decreasing trend with depth was observed. The distribution was irregular in other pedons.

4.2.3.4. Bulk density

The lowest bulk density of 1.16 Mg m^{-3} was recorded in Pedon 15 while Pedon 5 recorded the highest value of 1.72 Mg m^{-3}. Unlike the moisture retention characteristics, the bulk density values followed a notable pattern with depth. All the pedons excepting Pedons 1 and 14 showed an increase in bulk density with depth.

4.3. Physico-chemical properties (Table 8; Annexure IIc)

4.3.1. pH (1:1 soil water)

The values of this pH ranged from 3.5 in Pedon 10 to 8.51 in Pedon 7. The mean values of this pH were less than 6 in Pedons 1, 5, 11, 12, 14 and 15. In Pedons 2, 3, 4, 6, 9, 10 and 13, the mean values were between 6 and 8. The mean values in Pedons 7 and 8 were more than 8.

The pH was found to increase with depth in Pedons 1, 8 and 14 and decrease with depth in Pedon 11. In Pedon 9 the pH increased upto a depth of 103 cm and decreased thereafter.

4.3.2. pH (1 : 2.5 soil : water)

The pH of 1:2.5 soil water extract varied from 4.63 in Pedon 15 to 8.73 in Pedon 8. In Pedons 5, 12, 14 and 15 the mean values of this pH

Table 8. Range and mean values of physico-chemical properties

Pedons	1:1 pH		1:2.5 pH_w		1:2.5 pH_{KCl}		ΔpH		EC dSm^{-1}		OC %		$CaCO_3$ Equivalent		Gypsum %	
	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M
Pedon 1	5.80-6.13	5.98	5.90-6.33	6.15	5.40-5.72	5.53	0.18-0.85	0.62	0.043-0.080	0.065	0.10-0.19	0.15	0.08-0.23	0.11	-	-
Pedon 2	5.90-6.20	6.03	6.10-6.85	6.43	4.65-4.96	4.82	1.45-1.89	1.61	0.351-0.412	0.382	0.17-0.25	0.21	0.12-0.35	0.23	-	-
Pedon 3	5.65-6.76	6.30	6.15-7.33	6.71	4.50-5.82	4.97	1.39-2.42	1.74	0.038-0.073	0.054	0.15-0.28	0.22	0.10-0.21	0.18	-	-
Pedon 4	7.32-7.72	7.54	7.84-8.15	8.02	7.38-7.68	7.49	0.41-0.66	0.54	0.053-0.081	0.068	0.13-0.25	0.18	-	-	-	-
Pedon 5	4.33-5.20	4.81	4.93-5.50	5.10	3.15-4.48	3.53	1.02-1.95	1.57	0.032-0.203	0.083	0.10-0.17	0.13	-	-	-	-
Pedon 6	7.51-8.00	7.71	8.00-8.21	8.09	7.20-7.71	7.33	0.70-1.00	0.88	0.100-0.154	0.123	0.25-0.55	0.35	2.13-8.78	4.19	0.54	-
Pedon 7	8.00-8.51	8.27	8.21-8.71	8.42	7.02-7.30	7.17	1.00-1.51	1.24	0.070-0.190	0.127	0.15-0.63	0.38	5.04-9.24	7.44	0.73-1.12	-
Pedon 8	8.00-8.10	8.07	8.33-8.73	8.60	7.30-7.55	7.47	1.03-1.18	1.13	0.240-0.470	0.360	0.28-0.54	0.40	8.07-13.45	11.60	2.08-3.47	2.76
Pedon 9	6.91-7.32	7.11	7.40-8.20	7.76	6.51-7.21	6.66	0.78-1.80	1.16	0.140-0.500	0.310	0.10-0.62	0.26	1.32-2.13	1.68	-	-
Pedon 10	3.50-7.62	6.90	5.10-8.30	7.61	4.80-6.83	6.40	0.30-2.18	1.29	0.300-2.600	1.350	0.03-0.77	0.34	0.41-1.42	1.01	0.74-1.12	0.99
Pedon 11	4.63-6.30	5.18	6.22-6.62	6.43	5.05-5.20	5.12	1.12-1.52	1.31	0.062-0.120	0.085	0.06-0.38	0.23	-	-	-	-
Pedon 12	4.61-6.00	5.31	5.15-6.90	5.95	3.22-5.90	4.07	1.00-2.25	1.88	0.062-0.154	0.090	0.09-0.53	0.25	-	-	-	-
Pedon 13	7.41-7.90	7.59	8.30-8.60	8.39	7.01-7.31	7.17	1.10-1.39	1.22	0.131-0.321	0.237	0.20-0.42	0.26	-	-	-	-
Pedon 14	4.40-5.10	4.77	4.80-5.15	5.07	3.92-4.49	4.16	0.70-1.05	0.91	0.021-0.062	0.041	0.12-1.57	0.72	-	-	-	-
Pedon 15	4.52-4.85	4.70	4.63-5.08	4.90	4.20-4.63	4.40	0.23-0.70	0.50	0.021-0.053	0.037	0.29-2.60	1.04	-	-	-	-

R = Range M = Mean

were less than 6. The values were between 6 and 8 in Pedons 1, 2, 3, 9 and 10, and in Pedons 4, 6, 7, 8 and 13 the values were more than 8.

In Pedon 1, 2 and 8 the pH increased with depth, while a reverse trend was observed in Pedon 13. This pH increased upto a depth of 89 cm in Pedon 3 and decreased thereafter. In pedon 9 the pH increased upto 103 cm, below which it decreased. The remaining pedons did not exhibit any particular pattern of distribution.

4.3.3. pH (Soil : 1M KCl)

In all pedons pH_{KCl} was lower than that of the pH measured in 1:2.5 soil water extract. pH_{KCl} was found to vary from 3.15 in Pedon 5 to 7.71 in Pedon 6. The mean values of pH_{KCl} were less than 6 in Pedons 1, 2, 3, 5, 11, 12, 14 and 15. In Pedons 9 and 10 the mean values were between 6 and 7. The mean values in Pedons 4, 6, 7, 8 and 13 were more than 7.

pH_{KCl} was found to increase with depth in Pedons 2 and 8. In Pedon 15 an increasing trend with depth was observed but for a small decrease in the 62 to 95 cm depth. The depthwise distribution was irregular in other pedons.

4.3.4. ΔpH

The values of ΔpH varied from 0.18 in Pedon 1 to 2.42 in Pedon 3. The mean values of ΔpH were less than 1 in Pedons 1, 4, 6, 14 and 15. The values were more than 1 in the rest of the pedons.

4.3.5. Electrical conductivity

The lowest value of 0.021 dSm^{-1} was recorded in Pedons 14 and 15 while the highest value of 2.6 dSm^{-1} was observed in Pedon 10. The mean values of EC were less than 0.1 dSm^{-1} in Pedons 1, 3, 4, 5, 11, 12, 14 and 15. In Pedons 2, 6, 7, 8, 9 and 13 the mean values were between 0.1 to 0.5 dSm^{-1}. The mean value was more than 1 dSm^{-1} in Pedon 10.

In Pedons 6, 8 and 10 the EC increased with depth, while in Pedon 12 it decreased with depth. Depthwise trend was not observed in other pedons.

4.3.6. Organic carbon

Organic carbon content of the pedons ranged from 0.03 per cent in Pedon 10 to 2.60 per cent in Pedon 15. The mean values of organic carbon were more than 0.4 per cent in Pedons 14 and 15. In the remaining pedons the mean values were less than 0.4 per cent. Pedons 14 and 15 had comparatively higher organic carbon in their sola.

The organic carbon was generally found to decrease with depth in most of the pedons.

4.3.7. $CaCO_3$ equivalent

Pedons 4, 5, 11, 12, 13, 14 and 15 had absolutely no calcium carbonate in their sola. Among the remaining pedons the highest value of 13.28 was recorded in Pedon 8 and the lowest value of 0.08 was observed in Pedon 1. The mean values of calcium carbonate equivalent were less than 1 in Pedons 1, 2 and 3; 1 to 5 in Pedons 6, 9 and 10; and more than 5 in Pedons 7 and 8.

The calcium carbonate equivalent was found to increase with depth in Pedons 1, 2 and 8. In the rest of the pedons no depthwise trend was observed.

4.3.8. Gypsum

Gypsum was present only in Pedons 6, 7, 8 and 10. It was observed in all the horizons of Pedon 8. In the remaining three pedons the lower horizons only had gypsum, the content of which varied from 0.54 to 1.12 per cent. In Pedon 8 the gypsum content varied from 2.08 to 3.47 per cent.

4.4. Chemical composition

4.4.1. Elemental composition (Table 9; Annexure IId)

4.4.1.1. Silica (SiO_2)

The silica content of the soils were observed to vary from 39.51 per cent in Pedon 15 to 86.40 per cent in Pedon 10. The mean values of silica content were 50 to 60 per cent in Pedons 14 and 15; 60 to 70 per cent in Pedons 1, 2, 3, 6, 7 and 13 and more than 70 per cent in Pedons 4, 5, 8, 9, 10, 11, 12.

In Pedon 2 an increase in silica content with depth was observed. A reverse trend was noticed in Pedon 4. The rest of the pedons showed an irregular trend in the distribution with depth.

4.4.1.2. Total iron (Fe_2O_3)

The highest Fe_2O_3 content of 14.63 per cent was observed in Pedon 3 while the lowest content of 1.89 per cent was recorded in Pedon 6. The mean values of total iron content were less than 5 per cent in Pedons 1,6,7,10 and 11. The mean value was more than 10 per cent in Pedon 3. In the remaining pedons the mean values were between 5 and 10 per cent.

An increasing trend with depth was observed in Pedon 15. In Pedon 11 the total iron increased upto 156 cm depth and marginally decreased upto 177 cm depth. The depthwise distribution was irregular in other pedons.

4.4.1.3. Free iron oxide

The free iron oxide content ranged from 0.34 per cent in Pedon 7 to 12.56 per cent in Pedon 3. The mean values of iron oxide were more than 5 per cent in Pedons 3, 12, 14 and 15. In the remaining Pedons the mean values were less than 5 per cent. In Pedons 6 and 7 the free iron oxide was less than 1 per cent in all the horizons whereas in Pedons 3 and 14 it was more than 6 per cent in all the horizons.

ıble 9. Range and mean values of elemental composition (Per cent)

dons	SiO_2		Total Fe_2O_3		Al_2O_3		R_2O_3		CaO		MgO		K_2O		Na_2O		Free Fe_2O_3	
	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M
ɔon 1	62.11		2.79-		10.21-		13.00-		0.88-		0.32-		0.194-		0.320		1 79-	
	79.10	68.79	5.87	4.85	19.84	16.21	25.15	21.06	1.50	1.18	1.43	0.94	0.594	0.367	0.394	0.359	4.40	3.32
ɔon 2	63.11-		7.31-		10.81-		18.12-		1.68-		0.96-		0.558-		0.351-		4.30-	
	76.53	68.91	7.71	7.55	15.82	13.84	23.44	21.39	1.93	1.80	1.82	1.32	0.622	0.593	0.447	0.396	5 45	4.99
ɔon 3	61.92-		9.34-		14.81-		25.16-		0.77-		0.63-		0.139-		0.233-		6.79-	
	64.91	63.55	14.63	11.35	19.20	16.37	31.37	27.73	1.50	1.20	1.36	0.95	0.317	0.243	0.394	0.327	12.56	8.57
ɔon 4	65.80-		5.51-		9.21-		15.82-		4.31-		1.16-		0.113-		0.355-		2.97-	
	82.80	75.88	9.24	7.65	20.14	13.75	29.38	21.40	7.40	5.28	3.48	1.71	0.229	0.155	0.528	0.433	5 15	3.85
ɔon 5	72.30-		6.13-		10.97-		19.25-		0.90-		0.23-		0.100-		0.176-		4.45-	
	78.20	74.46	8.28	6.97	18.21	15.43	24.89	22.40	1.23	1.04	0.71	0.44	0.188	0.163	0.455	0.308	5.03	4.76
ɔon 6	58.70-		1.89-		11.83-		13.72-		7.25-		1.29-		0.166-		0.361-		0.49-	
	71.40	64.92	6.88	3.79	15.43	13.41	22.31	17.20	72.51	11.01	4.48	3.17	0.317	0.218	0.685	0.441	0.99	0.75
ɔon 7	63.00-		3.79-		10.91-		14.78-		5.71-		3.53-		0.391-		0.448-		0.34-	
	69.50	65.97	4.69	4.23	18.21	14.12	22.90	18.34	9.33	7.10	6.98	4.70	0.528	0.452	0.528	0.482	0.86	0.52
ɔon 8	66.20-		4.25-		11.33-		15.58-		4.73-		1.99-		0.366-		0.386-		2.27-	
	79.40	70.67	5.64	5.02	19.25	16.30	24.43	21.32	11.57	8.29	2.70	2.46	0.507	0.427	0.444	0.409	2.62	2.44
ɔon 9	69.70		5.18-		10.28-		16.70-		2.41-		1.44-		0.322-		0.420-		1.69	
	76.21	72.79	6.88	6.11	17.21	13.83	22.39	19.93	4.02	3.13	3.03	2.46	0.443	0.402	0.892	0.648	2.33	1.97
ɔon 10	66.24-		2.33-		6.81-		9.14-		2.91-		1.03-		0.323-		0.550-		0.47-	
	86.40	76.73	7.45	4.52	16.28	11.01	23.73	15.53	5.22	3.86	3.18	2.27	0.734	0.518	0.974	0.697	2.23	1.30
ɔon 11	62.10-		2.17-		7.31-		9.48-		0.78-		0.56-		0.130-		0.253-		1.19-	
	80.31	74.10	5.69	4.76	20.98	12.65	26.46	17.41	1.26	1.04	0.71	0.59	0.240	0.204	0.339	0.296	5.31	3.45
ɔon 12	70.54-		7.41-		11.37-		19.19-		1.25-		0.20-		0.175-		0.292-		5.15-	
	74.70	71.88	8.98	7.94	14.28	12.66	22.22	20.59	2.31	1.70	2.39	0.83	0.306	0.228	0.397	0.355	7.15	5.83
ɔon 13	61.30-		5.19-		13.21-		18.40-		2.69-		0.80-		0.323-		0.441		2.16-	
	70.81	67.94	6.69	5.96	20.28	16.43	26.24	22.39	6.95	4.50	2.95	1.93	0.873	0.606	0.837	0.637	3.69	3.05
ɔon 14	46.72-		8.34-		19.26-		29.58-		0.78-		0.32-		0.078-		0.279-		6.72-	
	52.11	50.48	11.55	9.74	25.12	21.72	33.64	31.46	1.46	1.19	1.03	0.56	0.140	0.111	0.346	0.322	10.04	8.25
ɔon 15	39.50-		6.01-		20.81-		27.46-		1.02-		0.23-		0.217-		0.225-		5.03-	
	61.60	54.13	10.61	7.64	29.94	25.18	40.55	32.82	1.57	1.28	0.96	0.74	0.611	0.449	0.373	0.300	9.77	6.43

= Range M = Mean

The free iron oxide decreased with depth in Pedons 2 and 8. In Pedon 6 it decreased from 19 cm. In other pedons the depthwise distribution was irregular.

4.4.1.4. Alumina (Al_2O_3)

The alumina content was found to vary from 6.81 per cent in Pedon 10 to 29.94 per cent in Pedon 15. The mean alumina content was 10 to 15 per cent in Pedons 2, 4, 6, 7, 9, 10, 11 and 12; 15 to 20 per cent in Pedons 1,3,5,8 and 13; and more than 20 per cent in Pedons 14 and 15.

In Pedon 2, a decrease in the alumina content with depth was observed. Alumina content increased with depth in Pedon 8. Pedons 1 and 13 showed an increase in alumina content upto 74 cm and 121 cm depth respectively and decreased thereafter.

4.4.1.5. Sesquioxides (R_2O_3)

The sesquioxide content ranged from 9.14 per cent in Pedon 10 to 40.55 per cent in Pedon 15. The mean values of sesquioxide content were between 15 and 20 per cent in Pedons 6, 7, 9, 10 and 11. In Pedons 1, 2, 4, 5, 8, 12 and 13 the mean values were from 20 to 25 per cent. In Pedons 3, 14 and 15 the mean values were more than 25 per cent.

The distribution of sesquioxides was observed to increase with depth in Pedons 8 and 11, and decrease with depth in Pedon 2. The distribution was irregular in other pedons.

4.4.1.6. Total calcium (CaO)

The CaO content of the soils varied from 0.77 per cent in Pedon 3 to 22.51 per cent in Pedon 6. The mean values of CaO were less than 5 per cent in Pedons 1, 2, 3, 5, 9, 10, 11, 12, 13, 14 and 15; 5 to 10 per cent in Pedons 4,7 and 8; and more than 10 per cent in Pedon 5. Pedons 6 and 7 had CaO content of more than 5 per cent in all horizons.

The total calcium content increased with depth in Pedon 8. The pattern of distribution was irregular in other pedons.

4.4.1.7. Total magnesium (MgO)

The MgO content of the pedons ranged from 0.23 per cent in Pedon 5 to 6.98 per cent in Pedon 7. In Pedons 1, 3, 5, 11, 12, 14 and 15 the mean values of MgO content were less than 1 per cent. In Pedons 2, 4 and 13 the mean values were from 2 to 4 per cent. In Pedons 6, 7, 8, 9 and 10 the mean values of MgO content were more than 2 per cent. The MgO content was less than 1 per cent in all the horizons of Pedons 5, 11 and 15.

The depthwise distribution was irregular in all the pedons.

4.4.1.8. Total potassium (K_2O)

The lowest K_2O content of 0.078 per cent was recorded in Pedon 14. Pedon 13 recorded the highest K_2O content of 0.873 per cent. The mean values of K_2O content were more than 0.5 per cent in Pedons 2, 10 and 13. In all other Pedons the mean K_2O values, were less than 0.5 per cent. Pedon 14 had the least K_2O content in its solum with less than 0.2 per cent K_2O in all the horizons.

The K_2O content was found to increase with depth in Pedons 1 and 8. In Pedons 3 and 12 the K_2O content decreased upto 89 cm and 110 cm depth respectively and increased thereafter. In the remaining pedons the depthwise distribution was irregular.

4.4.1.9. Total sodium (Na_2O)

The Na_2O content varied from 0.176 per cent in Pedon 5 to 0.974 per cent in Pedon 10. The mean values of Na_2O were more than 0.4 per cent in Pedons 4,6,7,8,9,10 and 13. In all the other pedons the mean Na_2O content was less than 0.4 per cent. In Pedon 10 the Na_2O content was more than 0.5 per cent in all the horizons.

An increase in the content of Na_2O with depth was observed in Pedon 6. In Pedon 5 the Na_2O content decreased upto 123 cm depth and increased beyond that. The distribution was irregular in other pedons.

4.4.2. Molar ratios (Table 10; Annexure IIe)

4.4.2.1. Silica : Sesquioxide ratio ($SiO_2 : R_2O_3$)

The values of silica sesquioxide ratios of the soils showed wide variations. The lowest ratio of 1.83 was recorded in Pedon 15 while the highest ratio of 17.63 was recorded in Pedon 10. The mean values of this ratio were less than 5 in Pedons 3, 14 and 15. In Pedon 10 the mean value was more than 10. In the rest of the pedons the mean values ranged from 5 to 10.

The ratio tended to increase with depth in Pedon 2. A decrease in the ratio, with depth was observed in Pedons 4, 8, 11 and 13. The depthwise distribution was irregular in other pedons.

4.4.2.2. Silica : Alumina ratio ($SiO_2 : Al_2O_3$)

The silica : alumina ratio varied from 2.24 in Pedon 15 to 21.48 in Pedon 10. The mean values of this ratio were less than 5 in Pedons 14 and 15, and more than 10 in Pedons 4,10 and 11. In the remaining pedons the mean values were between 5 and 10.

The ratio decreased with depth in Pedon 8 while a reverse trend was observed in Pedon 2. There was no regular pattern in depthwise distribution in other pedons.

4.4.2.3. Silica : Ferric oxide ratio ($SiO_2 : Fe_2O_3$)

The silica : ferric oxide ratios of the soils ranged from 9.89 in Pedon 15 to 98.35 in Pedon 11. The mean values of this ratio were less than 20 in Pedons 3, 14 and 15; 20 to 40 in Pedons 1, 2, 4, 5, 8, 9, 12 and 13; more than 40 in Pedons 6, 7, 10 and 11.

Table 10. Range and mean values of molar ratios

Pedons	SiO_2 / R_2O_3		SiO_2 / Al_2O_3		SiO_2 / Fe_2O_3		Al_2O_3 / Fe_2O_3		CaO + Mgo / Al_2O_3		CaO/Mgo		K_2O + Na_2O / Al_2O_3		K_2O/Na_2O	
	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M
Pedon 1	4.54-11.19	6.65	5.31-13.15	7.90	31.08-57.24	37.90	4.62-5.85	5.31	0.12-0.39	0.28	0.74-1.98	1.11	0.049-0.072	0.083	0.40-0.99	0.66
Pedon 2	5.19-8.39	6.44	6.77-12.01	8.81	22.01-27.81	24.32	2.32-3.25	2.87	0.38-0.56	0.49	0.70-1.02	1.05	0.082-0.109	0.095	0.92-1.05	0.99
Pedon 3	4.00-5.08	4.61	5.61-7.34	6.64	11.25-18.47	15.28	1.71-2.79	2.31	0.22-0.36	0.28	0.58-1.39	1.02	0.039-0.066	0.050	0.29-0.90	0.51
Pedon 4	4.29-10.16	7.62	5.54-15.00	10.63	18.93-39.94	27.93	1.78-3.41	2.79	0.58-1.96	1.17	1.05-4.29	2.65	0.050-0.098	0.068	0.20-0.29	0.23
Pdeon 5	5.46-8.16	6.47	6.74-12.10	8.51	25.10-32.09	28.67	2.08-4.27	3.54	0.14-0.31	0.20	0.91-3.19	1.99	0.022-0.088	0.048	0.29-0.44	0.37
Pedon 6	6.11-7.64	7.03	7.02-9.22	8.26	27.58-82.55	54.64	3.51-10.45	6.75	1.43-3.59	2.08	1.16-4.62	2.79	0.061-0.097	0.072	0.23-0.55	0.34
Pedon 7	5.05-8.12	6.78	5.87-9.94	8.11	35.70-47.90	41.76	4.42-6.08	5.23	1.56-2.25	1.79	0.59-2.92	1.45	0.066-0.940	0.235	0.49-0.73	0.62
Pedon 8	5.00-9.59	6.57	5.85-11.89	7.96	31.20-49.65	38.31	4.18-5.82	5.03	1.12-1.45	1.31	1.26-3.08	2.47	0.059-0.100	0.074	0.54-0.84	0.69
Pedon 9	5.76-8.99	7.12	6.87-12.58	9.31	27.50-35.76	31.94	2.51-5.20	3.63	0.76-1.07	0.88	0.57-1.45	0.98	0.068-0.183	0.115	0.25-0.69	0.43
Pedon 10	5.64-17.63	10.94	7.32-21.48	13.74	25.04-98.33	54.92	3.18-5.83	3.99	0.74-2.39	1.32	0.75-3.30	1.41	0.106-0.259	0.168	0.35-0.68	0.49
Pedon 11	4.31-15.67	9.13	5.02-18.64	11.38	30.12-98.35	48.23	3.27-6.00	4.29	0.18-0.44	0.30	0.78-1.62	1.29	0.034-0.076	0.061	0.34-0.55	0.45
Pedon 12	6.31-7.76	6.90	8.52-11.15	9.70	20.87-25.68	24.20	2.28-3.00	2.51	0.24-0.72	0.40	0.69-6.01	2.88	0.057-0.076	0.066	0.33-0.69	0.43
Pedon 13	4.32-7.09	5.80	5.13-8.93	7.20	27.34-35.59	30.49	3.55-5.33	4.33	0.65-1.24	0.85	0.77-4.56	2.30	0.075-0.127	0.103	0.40-0.84	0.61
Pedon 14	2.59-3.30	3.08	3.15-4.39	3.99	11.46-16.48	13.99	2.61-4.62	3.59	0.13-0.20	0.17	0.78-3.27	1.98	0.024-0.035	0.030	0.15-0.25	0.23
Pedon 15	1.83-4.14	3.13	2.24-4.98	3.73	9.89-25.34	19.94	3.83-6.84	5.83	0.10-0.22	0.17	0.83-4.12	1.59	0.028-0.054	0.040	0.38-1.29	1.00

R = Range M = Mean

In Pedons 1,11 and 15 the silica : ferric oxide ratio was found to decrease with depth. In Pedon 2 a reverse trend was observed. In the rest of the pedons the depthwise distribution was irregular.

4.4.2.4. Alumina : Ferric oxide ratio (Al_2O_3 : Fe_2O_3)

The lowest alumina : ferric oxide ratio of 1.71 was observed in Pedon 3 while the highest ratio of 10.45 was observed in Pedon 6. The mean values of this ratio were more than 5 in Pedons 1, 6, 7, 8 and 15. In all other Pedons the mean values were less than 5. The ratio was comparatively lower in Pedons 3 and 12, where the ratios were less than 3 in all the horizons.

The ratios was found to decrease with depth in Pedon 2 and increase with depth in Pedon 8. In the remaining pedons the depthwise distribution was irregular.

4.4.2.5. Alkaline earth : Alumina ratio (CaO + MgO : Al_2O_3)

This ratio was observed to vary from 0.12 in Pedon to 3.59 in Pedon 6. The mean values of this ratio were more than 1 in Pedons 4,6,7,8 and 10. In all other Pedons the mean values were less than 1. Pedons 14 and 15 had comparatively lower alkaline earth : alumina ratios.

The ratio was found to increase with depth in Pedon 2. In Pedons 11,12 and 13 the ratio decreased with depth. The depthwise distribution was irregular in the rest of the pedons.

4.4.2.6. Calcic : Magnesic ratio (CaO : MgO)

The CaO : MgO ratio was observed to vary from 0.61 in Pedon 3 to 6.01 in Pedon 12. The mean values of this ratio were more than 2 in Pedons 4, 6, 8, 12 and 13; 1 to 2 in Pedons 1, 2, 3, 5, 7, 10, 11, 14 and 15 ; less than 1 in Pedon 9.

The ratio increased with depth in Pedon 8. In Pedon 4 the ratio increased from 23 cm to 163 cm depth. In the rest of the pedons the depthwise distribution was irregular.

4.4.2.7. Alkali : Alumina ratio ($Na_2O + K_2O : Al_2O_3$)

The alkali : alumina ratio of the soils were observed to range from 0.022 in Pedon 5 to 0.259 in Pedon 10. The mean values of this ratio were more than 0.1 in Pedons 7, 9, 10 and 13. In the remaining pedons the mean values were less than 0.1.

In Pedons 2 and 6, there was an increase with depth. In other pedons the distribution of alkali : alumina ratio was irregular with depth.

4.4.2.8. Potassic : Sodic ratio ($K_2O : Na_2O$)

The $K_2O : Na_2O$ ratio ranged from 0.15 in Pedon 14 to 1.29 in Pedon 15. The mean values of this ratio were more than 0.5 in Pedons 1,2,3,7,8,13 and 15. In the rest of the pedons the mean values were less than 0.5.

The ratio increased with depth in Pedons 1 and 8. A reverse trend was observed in Pedon 12. In the remaining pedons there was no regular pattern in depthwise distribution.

4.5. Nutrient composition (Table 11; Annexure IIf)

4.5.1. Total nitrogen

The total nitrogen content varied from 0.012 per cent in Pedon 2 to 0.239 per cent in Pedon 15. The mean values of total nitrogen were more than 0.1 per cent in Pedons 14 and 15; 0.05 to 0.1 per cent in Pedons 1,3,12 and 13; and less than 0.05 per cent in the remaining pedons. The total nitrogen content was more than 0.05 per cent in all the horizons of Pedons 12,14 and 15.

Table 11. Range and mean values of nutrient composition

Pedons	Total N (%)		Total P (ppm)		CSP (ppm)		Bray P (ppm)		Olsen P (ppm)		Total Fe (%)		Total Zn (ppm)		Total Cu (ppm)		Total Mn (ppm)	
	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M
Pedon 1	0.034-0.077	0.053	379-916	650	17-81	50.75	Tr-23	7.5	Tr-13	5.25	1.95-4.08	3.38	16-80	49.25	50-65	59.25	180-322	264
Pedon 2	0.012-0.066	0.046	298-767	474	3-31	17.66	Tr-1	0.33	Tr-3	1.00	5.11-5.39	5.28	69-92	78.0	85-108	92.67	399-462	431
Pedon 3	0.032-0.122	0.064	283-972	624	5-60	22.00	2-5	3.60	Tr-4	2.00	6.53-10.23	7.94	15-82	56.80	86-130	114.80	443-2313	1159
Pedon 4	0.030-0.041	0.036	790-1930	1172	3-52	14.40	2-6	3.80	2-6	3.60	3.85-6.46	5.35	60-115	86.80	63-98	75.60	341-683	510
Pedon 5	0.034-0.042	0.037	320-1127	799	3-62	18.20	1-7	4.00	Tr-6	4.00	4.29-5.79	4.87	30-46	35.40	50-63	56.80	223-408	318
Pedon 6	0.019-0.057	0.038	820-3070	1378	3-51	13.40	2-6	3.20	1-4	2.00	1.32-4.81	2.65	35-125	70.60	57-92	69.00	327-1564	921
Pedon 7	0.019-0.060	0.038	980-1520	1233	52-205	110.00	1-5	2.33	1-6	2.50	2.65-3.28	2.96	65-91	74.67	53-69	60.17	543-809	660
Pedon 8	0.034-0.044	0.040	394-2294	1073	29-41	34.00	1-2	1.33	Tr-3	1.00	2.97-3.94	3.51	43-64	55.00	73-98	85.67	334-378	356
Pedon 9	0.028-0.109	0.048	715-1256	866	4-645	193.50	1-4	2.00	1-5	2.50	3.62-4.81	4.27	50-86	68.50	77-91	83.00	383-563	445
Pedon 10	0.018-0.102	0.041	334-960	708	36-200	74.25	3-14	6.50	4-6	5.0	1.63-5.21	3.16	39-102	61.38	48-86	64.00	93-513	259
Pedon 11	0.042-0.052	0.046	228-923	588	19-82	33.40	Tr-23	7.00	Tr-13	4.8	1.52-4.27	3.44	39-52	46.40	54-82	66.80	234-278	259
Pedon 12	0.065-0.101	0.067	193-794	529	2-6	3.60	2-7	3.40	Tr-11	4.00	5.18-6.28	5.55	37-63	47.80	67-76	71.80	351-583	426
Pedon 13	0.034-0.150	0.063	676-990	797	2-21	2.21	1-5	3.00	Tr-8	2.20	3.63-4.68	4.17	26-121	83.80	51-113	73.20	527-736	594
Pedon 14	0.066-0.198	0.123	256-1431	698	5-30	16.0	Tr-4	1.00	Tr-7	1.17	5.96-8.08	6.99	41-68	52.17	65-100	79.83	151-265	194
Pedon 15	0.054-0.239	0.118	753-1465	955	18-38	25.71	1-8	4.86	Tr-16	7.14	4.20-7.42	5.34	76-101	88.86	91-126	106.15	153-262	207

CSP = Citrate Soluble Phosphorus R = Range M = Mean

In most of the pedons the surface horizons had comparatively higher total nitrogen than other horizons. In Pedons 2,9,14 and 15, a decrease in total nitrogen with depth was observed.

4.5.2. Total phosphorus

The total P content of the soils varied from 193 ppm in Pedon 12 to 3070 ppm in Pedon 6. The mean values of total P content were less than 500ppm in Pedon 2 and more than 1000 ppm in Pedons 4,6,7 and 8. In all other pedons the mean values were between 500 and 1000 ppm.

In Pedon 8 the total P content was found to decrease with depth. In the remaining pedons the depthwise distribution was irregular.

4.5.3. Citric acid Soluble Phosphorus (CSP)

The CSP content ranged from 2 ppm in Pedons 12 and 15 to 645 ppm in Pedon 9. The mean values were more than 50 ppm in Pedons 1,7,9 and 10. In the remaining pedons the mean values were less than 50 ppm. The CSP content was more than 250 ppm between 103 and 164 cm depth in Pedon 9. In most of the pedons the highest CSP content was observed in the surface horizons.

In Pedons 6, 12 and 13, a decreasing trend with depth was observed. In Pedon 2 a reverse trend was noticed. In the remaining pedons depthwise distribution was irregular.

4.5.4. Bray P

The highest Bray P content of 23 ppm was recorded in the surface horizons of Pedons 1 and 11. In Pedons 1, 2, 11 and 14 only traces of Bray P was recorded in some of their horizons. The mean values of Bray P were more than 5 ppm in Pedons 1, 10 and 11. In all the other pedons the mean values were less than 5.

In Pedons 4, 8, 11 and 12 the Bray P was observed to decrease with depth. The depthwise distribution was irregular in other pedons.

4.5.5. Olsen P

The highest olsen P content of 16 ppm was recorded in Pedon 15. As in the case of Bray P, some pedons had only traces of Olsen P in some of their horizons. In most of the pedons the surface horizons had the highest Olsen P content. The mean values of Olsen P were more than 5 ppm, only in Pedons 1,10 and 15.

4.5.6. Total iron

The total iron content of the soils ranged from 1.95 per cent in Pedon 1 to 10.23 per cent in Pedon 3. The mean values of total iron content were more than 5 per cent in Pedons 2, 3, 4, 12, 14 and 15. In the remaining pedons the mean values were less than 5 per cent. Total iron content was more than 5 per cent in all the horizons in Pedons 2, 3, 12 and 14.

In Pedon 15, the total iron content was found to increase with depth. In all other pedons, the depthwise distribution was irregular.

4.5.7. Total zinc

The total zinc content of the soils ranged from 15 ppm in Pedon 3 to 125 ppm in Pedon 6. The mean values of total zinc were less than 50 ppm in Pedons 1, 5, 11 and 12. In the remaining pedons the mean values were more than 50 ppm. The surface horizons of most of the pedons had comparatively lesser total zinc than subsurface horizons.

The depthwise distribution was irregular in all pedons except Pedon 8 where an increasing trend was recorded.

4.5.8. Total copper

The total copper content of the pedons varied from 46 ppm in Pedon 10 to 130 ppm in Pedon 3. In Pedons 3 and 15, the mean values of total

copper content were more than 100 ppm. In all other pedons the mean values were between 50 and 100ppm.

The total copper content in Pedons 2,8 and 11 was found to increase with depth. In Pedon 7 it decreased upto 120 cm depth and increased thereafter.

4.5.9. Total manganese

The highest total manganese content of 2,313 ppm was recorded in Pedon 3 while the lowest content of 93 ppm was recorded in Pedon 10. The mean values of total manganese were less than 500 ppm in Pedons 1, 2, 5, 8, 9, 10, 11, 12, 14 and 15; 500 to 1000 ppm in Pedons 4, 6, 7 and 13; and more than 1000 ppm in Pedon 3. In Pedon 3, 54 to 89 cm depth registered 2,313 ppm and 89 to 155 cm depth recorded 1,891 ppm of total manganese. In Pedon 6, 19 to 52 cm depth had 1,563 ppm of total manganese.

In Pedons 1, 2, 4, 5 and 8 the total manganese content increased with depth. Depthwise distribution was irregular in other pedons.

4.6. Fractions of iron and manganese (Table 12; Annexure IIg)

4.6.1. Dithionite-citrate-bicarbonate iron (Fe_d)

The Fe_d content varied from 0.24 per cent in Pedon 7 to 8.78 per cent in Pedon 3. The mean values of Fe_d content were less than 1 per cent in Pedons 6, 7 and 10; 1 to 5 per cent in Pedons 1, 2, 5, 8, 9, 11, 12, 13 and 15; more than 5 per cent in Pedons 3 and 14.

In Pedons 2 and 8, the Fe_d content decreased with depth. It increased upto 123 cm depth in Pedon 5 and decreased thereafter. In the rest of the pedons the depthwise distribution was irregular.

4.6.2. Oxalate iron (Fe_o)

In all the pedons, the Fe_o content was comparatively lower than that

Table 12. Range and mean values of Fe and Mn fractions

Pedons	Fe_d (%)		Fe_o (%)		Fe_p (%)		Fe_d/Fe_t (%)		Fe_o/Fe_t (%)		Fe_p/Fe_t (%)		Fe_d-Fe_o/Fe_t		Fe_o/Fe_d		Mn_d (ppm)		Mn_d/Mn_t (%)	
	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M
Pedon 1	1.25-3.08	2.32	0.200-0.590	0.430	0.021-0.043	0.033	60.78-81.53	68.18	9.07-15.57	12.37	0.71-1.13	0.99	0.52-0.66	0.56	0.15-0.19	0.18	55-152	105	30.58-47.20	38.78
Pedon 2	3.01-3.81	3.49	0.240-0.331	0.292	0.008-0.015	0.012	58.90-71.48	66.09	4.50-6.48	5.54	0.15-0.29	0.22	0.52-0.67	0.60	0.06-0.11	0.08	178-243	209	44.51-52.59	48.30
Pedon 3	4.75-8.78	5.99	0.981-1.780	1.430	0.018-0.061	0.042	70.24-85.83	74.63	10.56-24.24	18.62	0.25-0.63	0.52	0.47-0.75	0.56	0.12-0.33	0.25	296-1875	948	64.40-94.76	75.65
Pedon 4	2.08-3.60	2.69	0.401-0.813	0.591	0.059-0.120	0.080	40.74-55.73	50.36	9.45-12.76	11.00	1.34-1.88	1.50	0.31-0.45	0.39	0.19-0.25	0.22	141-367	240	36.36-60.52	46.35
Pedon 5	3.11-3.52	3.33	1.02-1.43	1.230	0.038-0.063	0.048	59.24-75.37	68.91	21.84-28.71	25.23	0.82-1.35	1.00	0.35-0.54	0.44	0.29-0.42	0.37	115-276	182	48.73-67.65	55.78
Pedon 6	0.34-0.69	0.52	0.108-0.143	0.124	0.018-0.042	0.031	14.35-34.85	22.39	2.97-8.86	5.61	0.87-2.42	1.36	0.11-0.26	0.17	0.21-0.32	0.25	123-505	388	32.31-52.95	42.90
Pedon 7	0.24-0.60	0.39	0.041-0.130	0.082	0.006-0.031	0.014	7.67-20.76	13.22	1.31-4.50	2.82	0.19-1.07	0.49	0.06-0.16	0.10	0.17-0.25	0.21	203-363	273	36.17-45.98	40.98
Pedon 8	1.59-1.83	1.70	0.111-0.146	0.131	0.004-0.008	0.005	42.89-61.62	49.48	3.07-4.92	3.81	0.10-0.22	0.15	0.39-0.57	0.46	0.07-0.08	0.08	102-158	123	28.57-41.80	34.24
Pedon 9	1.18-1.63	1.38	0.021-0.550	0.303	0.008-0.093	0.024	26.22-36.30	32.31	0.47-12.25	7.08	0.18-2.07	0.54	0.22-0.28	0.25	0.02-0.34	0.21	118-223	187	20.96-52.78	43.02
Pedon 10	0.33-1.56	0.91	0.043-0.207	0.112	0.002-0.031	0.017	14.24-44.81	29.75	0.98-8.47	4.01	0.06-1.53	0.60	0.12-0.37	0.26	0.04-0.25	0.13	13-257	96	12.62-50.10	30.59
Pedon 11	0.83-3.71	2.41	0.32-1.16	0.770	0.011-0.027	0.017	54.60-76.58	65.85	11.24-30.29	22.61	0.28-0.86	0.54	0.34-0.76	0.46	0.13-0.47	0.35	138-162	149	53.38-67.22	57.83
Pedon 12	3.60-5.00	4.08	0.897-1.251	1.070	0.027-0.071	0.046	69.44-79.61	73.56	15.61-22.44	19.42	0.52-1.27	0.83	0.47-0.60	0.54	0.20-0.32	0.27	187-372	251	53.17-63.81	58.29
Pedon 13	1.51-2.58	2.13	0.105-0.326	0.226	0.014-0.053	0.034	41.01-63.86	50.81	2.89-8.07	5.41	0.34-1.19	0.81	0.36-0.56	0.45	0.07-0.13	0.11	211-517	341	39.72-73.24	56.38
Pedon 14	4.70-7.02	5.77	0.301-0.711	0.560	0.032-0.081	0.059	79.20-91.09	85.85	5.83-9.94	8.25	0.53-1.00	0.87	0.69-0.78	0.74	0.06-0.13	0.10	73-135	105	45.60-89.40	55.43
Pedon 15	3.52-6.83	4.49	0.28-0.88	0.440	0.042-0.118	0.084	75.70-92.05	83.08	3.77-14.26	8.78	1.00-2.76	1.71	0.65-0.88	0.75	0.04-0.18	0.11	53-114	89	33.65-52.33	42.66

R = Range M = Mean

of the Fe_d. The Fe_o content ranged from 0.021 per cent in Pedon 9 to 1.78 per cent in Pedon 3. The mean values of Fe_o were less than 0.5 per cent in Pedons 1, 2, 6, 7, 8, 9, 10, 13 and 15; 0.5 to 1.00 per cent in Pedons 4, 11 and 14; more than 1 per cent in Pedons 3, 5 and 12. Only Pedon 5 had more than 1 per cent Fe_o in all its horizons.

The Fe_o content increased with depth in Pedon 2 and decreased with depth in Pedon 8. In Pedons 1, 4, 5, 6, 9, 13 and 15, it increased upto a certain depth and decreased thereafter.

4.6.3. Pyrophosphate iron (Fe_p)

This fraction recorded lowest values among the three fractions of iron, *viz.*, Fe_d, Fe_o and Fe_p. The Fe_p content varied from 0.002 per cent in Pedon 10 to 0.12 per cent in Pedon 4. The mean values of Fe_p were more than 0.05 per cent in Pedons 4, 14 and 15. In all other pedons the mean values were less than 0.05 per cent.

In Pedons 2,8 and 15 the Fe_p content increased with depth. The depthwise distribution was irregular in other pedons.

4.6.4. Fe_d/Fe_t per cent

This was computed by dividing Fe_d by Fe_t and multiplying by 100. Similar computations were made in sections 4.6.5., 4.6.6. and 4.6.10.

The values varied from 7.67 in Pedon 7 to 92.05 in Pedon 15. The mean values were less than 50 in Pedons 6, 7, 8, 9 and 10. In the remaining pedons the mean values were more than 50.

The depthwise distribution was irregular in all pedons except Pedon 2 where a decreasing trend was observed.

4.6.5. Fe_o/Fe_t per cent

The values ranged from 0.47 in Pedon 9 to 30.29 in Pedon 11. The

mean values were less than 10 in Pedons 2, 6, 7, 8, 9, 10, 13, 14 and 15; 10 to 20 in Pedons 1, 3, 4 and 12; more than 20 in Pedons 5 and 11.

In Pedon 2 the values were observed to increase with depth. A reverse trend was observed in Pedon 8. The depthwise distribution was irregular in other pedons.

4.6.6. Fe_p/Fe_t per cent

The values varied from 0.06 in Pedon 10 to 2.76 in Pedon 15. The mean values were 1 or more in Pedons 4, 5, 6 and 15. In the remaining pedons the mean values were less than 1.

The depthwise distribution was irregular in all pedons except Pedon 2 which recorded an increasing trend with depth.

4.6.7. Active iron (Fe_o/Fe_d)

The ratio of Fe_o : Fe_d varied from 0.02 in Pedon 9 to 0.47 in Pedon 11. The mean values of this ratio were less than 0.2 in Pedons 1, 2, 8, 10, 13, 14 and 15. In all other pedons the mean values of this ratio were more than 0.2.

The ratio was observed to increase with depth in Pedons 2 and 6. In Pedons 1, 4, 13 and 15, the ratio increased upto a certain depth and decreased thereafter. In the rest of the pedons the depthwise distribution was irregular.

4.6.8. $\dfrac{Fe_d - Fe_o}{Fe_t}$

The values of this ratio ranged from 0.06 in Pedon 7 to 0.88 in Pedon 15. The mean values of this ratio were less than 0.5 in Pedons 4, 5, 6, 7, 8, 9, 10, 11 and 13. In the remaining pedons the mean values were more than 0.5.

The depthwise distribution of this ratio was irregular in all the pedons.

Pedons	CEC cmol (p$^+$) kg^{-1}		ECEC cmol (p$^+$) kg^{-1}		Exch. Ca cmol (p$^+$) kg^{-1}		Exch. Mg cmol (p$^+$) kg^{-1}		Exch. Na cmol (p$^+$) kg^{-1}		Exch. K cmol (p$^+$) kg^{-1}		BSP	
	R	M	R	M	R	M	R	M	R	M	R	M	R	M
Pedon 1	7.50-11.30	9.71	4.01-8.24	6.71	1.61-4.27	3.01	1.31-3.47	2.32	0.08-0.14	0.13	0.42-0.18	0.85	52.13-70.00	63.95
Pedon 2	10.34-18.40	15.35	7.84-13.28	10.76	2.83-6.62	4.92	2.10-4.81	3.71	0.08-0.12	0.11	0.23-1.30	0.70	57.04-68.67	62.25
Pedon 3	11.41-31.72	20.02	11.34-24.52	17.42	4.60-12.14	8.00	4.53-9.61	6.74	0.06-0.27	0.16	0.75-1.10	0.96	72.32-88.60	80.95
Pedon 4	9.70-21.1	14.39	7.98-17.08	11.76	5.54-12.42	8.19	1.34-4.59	2.85	0.06-0.18	0.12	0.21-0.68	0.34	73.69-84.95	79.54
Pedon 5	8.72-11.42	10.17	3.17-5.22	4.11	1.01-2.20	1.37	0.82-1.82	1.28	0.02-0.06	0.04	0.04-0.36	0.17	22.36-33.86	27.94
Pedon 6	43.81-56.90	50.86	40.55-52.01	46.63	23.89-33.43	29.21	10.11-18.01	14.64	1.09-1.72	1.43	0.61-0.83	0.72	87.83-92.83	90.41
Pedon 7	21.31-38.98	31.00	18.52-35.84	28.09	9.22-18.42	14.19	6.83-14.74	11.56	0.53-1.14	0.88	0.32-0.79	0.58	80.23-94.30	86.97
Pedon 8	15.41-18.92	17.47	13.67-17.22	15.46	7.63-8.78	8.18	3.60-6.21	4.94	0.62-0.72	0.65	0.72-1.18	1.00	82.13-86.84	84.51
Pedon 9	26.41-46.30	35.71	22.08-42.73	32.94	13.94-27.28	19.72	6.40-16.03	11.17	0.72-1.18	0.93	0.30-0.73	0.49	81.22-94.88	89.69
Pedon 10	20.43-39.60	28.29	13.71-36.87	24.00	5.51-14.72	9.06	5.82-14.10	9.20	0.78-7.52	3.29	0.71-2.18	1.19	62.75-91.12	77.69
Pedon 11	9.18-17.52	13.97	7.45-13.50	10.91	3.21-6.22	4.98	2.54-5.10	3.78	0.08-0.16	0.13	0.41-1.24	0.98	67.97-72.66	70.31
Pedon 12	29.46-33.26	31.48	19.80-27.73	24.58	10.26-15.41	13.47	6.41-10.26	8.31	0.30-0.53	0.42	0.47-0.98	0.81	60.93-84.22	73.01
Pedon 13	13.82-24.40	19.27	12.17-21.79	17.20	3.23-11.72	8.38	3.00-8.00	5.23	1.11-1.82	1.46	0.63-1.92	1.30	81.07-94.43	84.54
Pedon 14	11.32-19.82	16.27	3.81-5.80	4.99	1.02-2.11	1.58	1.36-1.97	1.75	0.09-0.17	0.12	0.42-1.21	0.84	23.03-28.51	26.26
Pedon 15	10.31-17.24	15.19	3.08-4.26	3.92	1.42-2.13	1.81	0.93-1.68	1.47	0.09-0.15	0.11	0.11-0.23	0.18	19.67-26.10	23.61

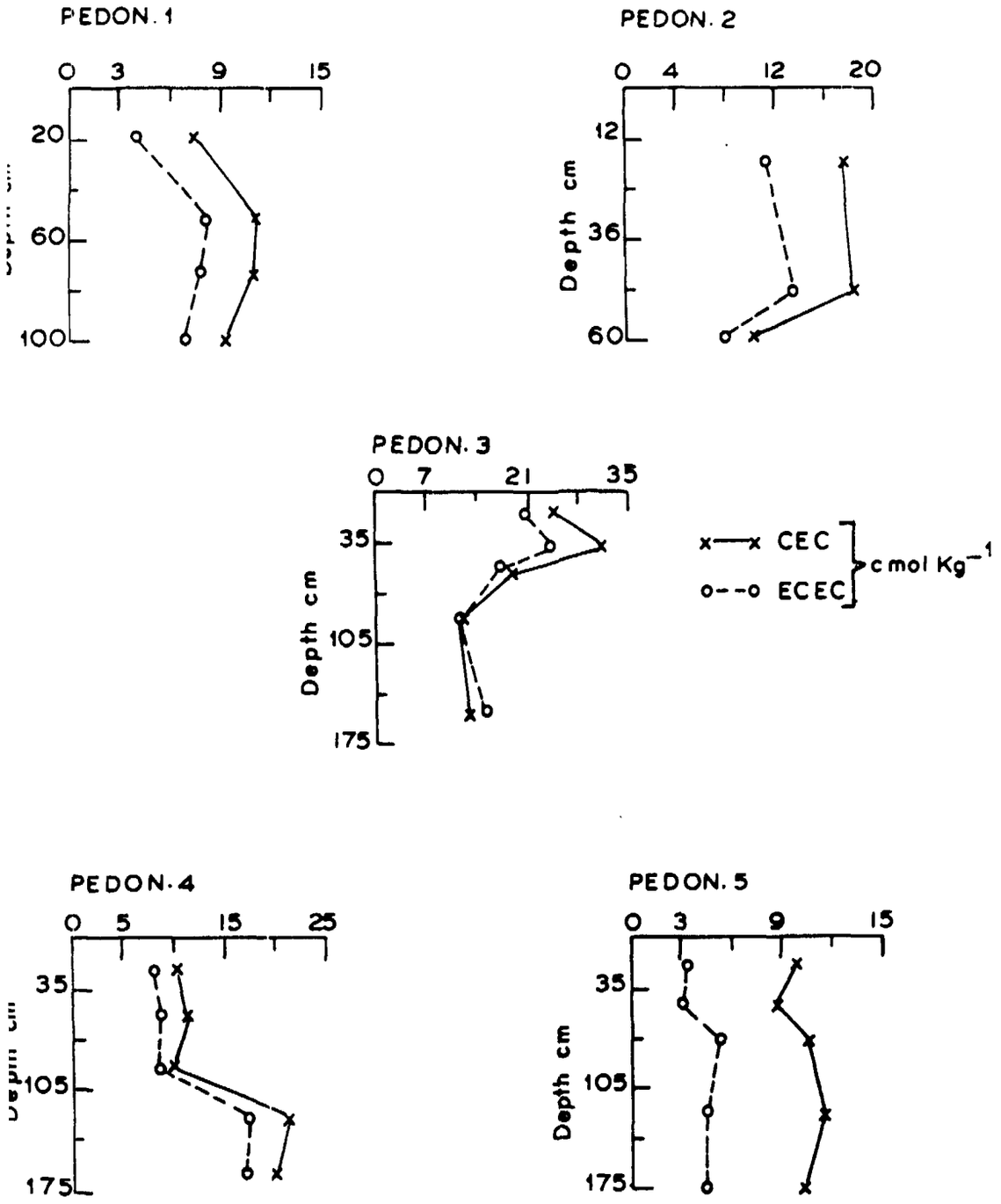
BSP = Base Saturation Percent R = Range M = Mean

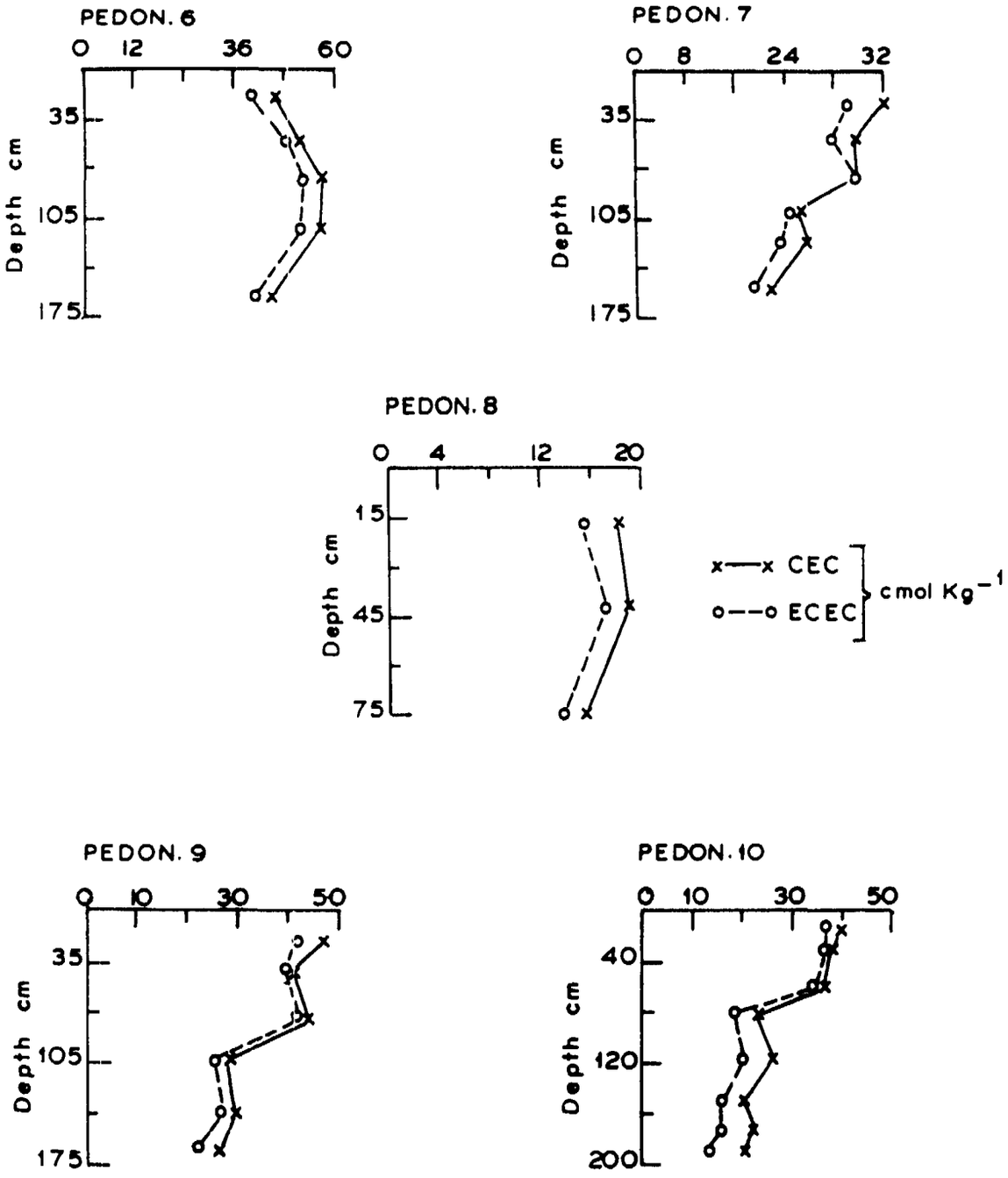
Table 14. Range and mean values of percent saturation of cations

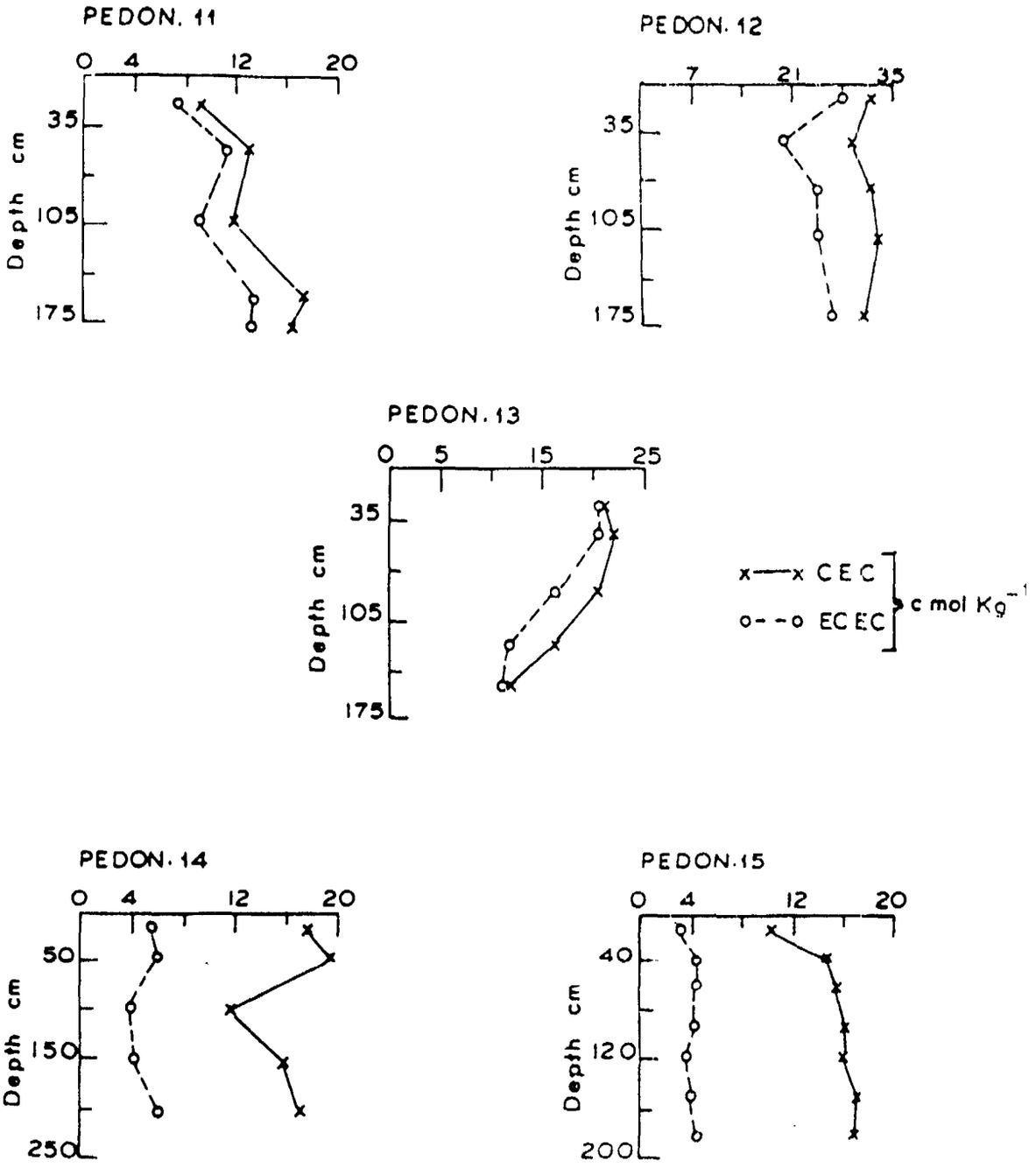
Pedons	Ca %		Mg %		Na %		K %		Ca/Mg		K/Na	
	R	M	R	M	R	M	R	M	R	M	R	M
Pedon 1	21.47-37.79	30.24	17.47-31.81	23.41	1.07-1.54	1.28	3.84-12.12	9.02	0.90-1.85	1.34	3.00-11.38	7.28
Pedon 2	27.32-35.98	31.34	20.31-26.12	23.60	0.64-0.77	0.70	1.33-12.57	5.68	1.26-1.45	1.35	1.92-16.25	7.67
Pedon 3	35.15-41.07	37.87	30.14-34.53	32.03	0.53-0.96	0.73	2.90-8.06	5.56	1.02-1.34	1.18	3.41-15.33	8.04
Pedon 4	49.16-56.70	53.93	10.15-20.31	16.43	0.62-0.97	0.82	1.37-6.77	2.87	2.50-4.13	3.01	1.61-7.56	3.34
Pedon 5	10.68-20.56	13.44	9.41-17.81	12.49	0.18-0.59	0.40	0.41-3.52	1.61	0.67-1.68	1.13	1.33-14.00	5.07
Pedon 6	52.70-64.32	57.50	23.08-34.76	28.71	2.49-3.02	2.79	1.37-1.46	1.41	1.70-2.79	2.31	0.46-0.56	0.51
Pedon 7	38.85-50.45	45.27	32.05-40.37	36.96	1.36-4.33	3.00	0.90-3.33	1.90	1.10-1.35	1.23	0.44-0.87	0.67
Pedon 8	44.97-49.51	46.96	23.36-32.62	27.96	3.43-4.02	3.75	3.81-7.66	5.83	1.41-2.12	1.72	1.00-1.90	1.55
Pedon 9	52.76-58.92	54.81	24.23-36.34	30.71	1.56-3.24	2.69	0.65-2.69	1.48	1.50-2.18	1.82	0.42-0.83	0.53
Pedon 10	24.76-37.17	31.00	28.29-35.61	32.22	3.82-19.53	10.23	2.65-7.53	4.24	0.79-1.09	0.96	0.15-0.93	0.55
Pedon 11	34.97-38.93	36.46	22.20-31.96	27.42	0.87-1.07	0.95	4.47-10.25	6.96	1.18-1.58	1.34	5.13-11.00	7.31
Pedon 12	34.83-48.25	42.71	21.76-32.12	26.37	1.02-1.65	1.34	1.46-3.33	2.58	1.50-2.06	1.64	0.89-3.27	2.10
Pedon 13	23.37-53.03	42.46	9.72-34.88	25.06	5.03-12.52	7.97	3.03-11.72	7.04	0.67-2.55	1.73	0.44-1.73	0.93
Pedon 14	6.49-12.13	9.63	8.35-12.21	10.86	0.53-0.86	0.72	3.63-6.65	5.05	0.53-1.18	0.91	4.67-12.44	7.32
Pedon 15	9.30-13.78	12.05	8.73-10.95	9.67	0.52-0.93	0.73	0.68-1.56	1.18	1.07-1.53	1.25	0.73-2.33	1.71

R = Range M = Mean

FIG. 3 DEPTHWISE DISTRIBUTION OF CEC AND ECEC




PEDON. 6
0 12 36 60
35
105
175
Depth cm
PEDON. 7
0 8 24 32
35
105
175
Depth cm
PEDON. 8
0 4 12 20
15
45
75
Depth cm
x—x CEC
o—o ECEC
cmol Kg⁻¹
PEDON. 9
0 10 30 50
35
105
175
Depth cm
PEDON. 10
0 10 30 50
40
120
200
Depth cm


PEDON. 11
0 4 12 20
35
105
175
Depth cm
PEDON. 12
7 21 35
35
105
175
Depth cm
PEDON. 13
0 5 15 25
35
105
175
Depth cm
x—x CEC
o- -o ECEC
c mol Kg⁻¹
PEDON. 14
0 4 12 20
50
150
250
Depth cm
PEDON. 15
0 4 12 20
40
120
200
Depth cm

4.7.2. Effective CEC (ECEC)

The highest ECEC of 4.09 cmol (p^+) kg^{-1} was observed in Pedon 6 while the lowest ECEC of 3.08 cmol (p^+) kg^{-1} was recorded in Pedon 1. The mean values of ECEC were less than 15 cmol (p^+) kg^{-1} in Pedons 1, 2, 4, 5, 11, 14 and 15. In Pedons 3, 7, 8, 10, 12, and 13 the mean values were between 15 and 30 cmol (p^+) kg^{-1}. The mean values were more than 30 cmol (p^+) kg^{-1} in Pedons 6 and 9.

As in the case of CEC, the values of ECEC did not show any trend in depthwise distribution (Fig.3).

4.7.3. Base saturation percentage

The base saturation ranged from 19.67 per cent in Pedon 15 to 94.88 per cent in Pedon 9. The mean values of base saturation were less than 50 per cent in Pedons 5,14 and 15. In Pedons 1, 2, 4, 10, 11 and 12 the mean values were 50 to 80 per cent. In Pedons 3, 6, 7, 8, 9 and 13 the mean values of base saturation were more than 80 per cent. In Pedons 14 and 15, base saturation was less than 30 per cent in all horizons.

4.7.4. Exchangeable bases

4.7.4.1. Exchangeable calcium

The exchangeable calcium content of the pedons varied from 1.01 cmol (p^+) kg^{-1} in Pedon 5 to 33.43 cmol (p^+) kg^{-1} in Pedon 6. The mean values of exchangeable calcium were more than 10 cmol (p^+) kg^{-1} in Pedons 6, 7, 9 and 12. The mean values were less than 10 cmol (p^+) kg^{-1} in the remaining pedons.

Among the cations, calcium dominated the exchange complex in almost all the pedons. The exchangeable calcium per cent values varied from 9.01 in Pedon 14 to 64.32 in Pedon 6. The exchangeable calcium per cent values were more than 40 in Pedons 4, 6, 7, 8, 9, 12 and 13. In Pedons

1, 2, 3, 10 and 11 the exchangeable calcium per cent values ranged from 30 to 40.

4.7.4.2. Exchangeable magnesium

The content of exchangeable magnesium ranged from 0.82 cmol (p^+) kg^{-1} in Pedon 5 to 18.01 cmol (p^+) kg^{-1} in Pedon 6. The mean values of exchangeable magnesium were 1-5 cmol (p^+) kg^{-1} in Pedons 1, 2, 4, 5, 8, 11, 14 and 15; 5 to 10 cmol (p^+) kg^{-1} in Pedons 3, 10, 12 and 13; more than 10 cmol (p^+) kg^{-1} in Pedons 6, 7 and 9.

Exchangeable magnesium per cent values varied from 8.35 in Pedon 14 to 40.37 per cent in Pedon 7. The mean values of exchangeable magnesium per cent were more than 30 in Pedons 3,7,9 an 10. In the remaining pedons the mean values were less than 30.

4.7.4.3. Exchangeable sodium

The exchangeable sodium content of the soils was observed to vary from 0.02 cmol (p^+) kg^{-1} in Pedon 2 to 7.52 cmol (p^+) kg^{-1} in Pedon 10. The mean values of exchangeable sodium content were more than 1 cmol (p^+) kg^{-1} in Pedons 6, 10 and 13. In all other pedons the mean values were less than 1 cmol (p^+) kg^{-1}.

The exchangeable sodium per cent ranged from 0.18 in Pedon 5 to 19.53 in Pedon 10. The mean values of exchangeable sodium per cent were less than 1 in Pedons 2,3,4,5,11,14 and 15; 1 to 10 in Pedons 1,6,7,8,9,12 and 13; more than 10 in Pedon 10.

4.7.4.4. Exchangeable potassium

The content of exchangeable potassium varied from 0.04 cmol (p^+) kg^{-1} in Pedon 5 to 2.18 cmol (p^+) kg^{-1} in Pedon 10. The mean values of exchangeable potassium content were more than 1 cmol (p^+) kg^{-1} in Pedons

8,10 and 13. In the remaining pedons the mean values were less than 1 cmol (p^+) kg^{-1}.

The exchangeable potassium per cent, varied from 0.41 per cent in Pedon 5 to 12.51 in Pedon 3. The mean values of exchangeable potassium per cent, were 1 to 5 in Pedons 4, 5, 6, 7, 9, 10, 12 and 15. In the rest of the pedons the mean values were between 5 and 10 per cent.

4.7.4.5. Ca/Mg ratio

The Ca/Mg ratio of the pedons varied from 0.53 in Pedon 14 to 4.13 in Pedon 4. The mean values of Ca/Mg ratio were less than 1 in Pedons 10 and 15 and more than 2 in Pedons 4 and 6. In all the other pedons the mean values were between 1 and 2.

4.7.4.6. K/Na ratio

The K/Na ratio ranged from 0.15 in Pedon 10 to 16.25 in Pedon 2. The mean values of the ratio were less than 1 in Pedons 6, 7, 9, 10 and 13; 1 to 5 in Pedons 4, 8, 12 and 15; more than 5 in Pedons 1, 2, 3, 5, 11 and 14.

4.8. Forms of acidity (Table 15; Annexure IIh)

4.8.1. Exchangeable acidity

Exchangeable acidity of the soils ranged from 0.10 cmol (p^+) kg^{-1} in Pedon 1 to 1.97 cmol (p^+) kg^{-1} in Pedon 12. The mean values of the exchangeable acidity were more than 1 cmol (p^+) kg^{-1} in Pedons 2, 3, 5, 10, 11 and 12. In the rest of the pedons the mean values were less than 1 cmol (p^+) kg^{-1}.

The exchangeable acidity increased with depth in Pedon 1. In Pedons 5 and 7 it increased upto 72 cm and 120 cm depth respectively and decreased thereafter. The depthwise distribution were variable in other pedons.

5. Range and mean values of forms of acidity

	Exch. acidity cmol (p$^+$) kg^{-1}		Total acidity cmol (p$^+$) kg^{-1}	
	R	M	R	M
	0.10-0.67	0.42	3.10-5.83	4.45
	1.15-1.53	1.32	5.41-10.23	7.36
	1.02-1.92	1.37	3.30-5.81	4.48
	0.21-0.33	0.27	1.07-3.14	2.01
	0.88-1.57	1.24	5.26-8.16	6.75
	0.50-0.74	0.63	7.75-14.70	11.44
	0.68-1.08	0.88	1.01-5.38	3.00
	0.64-0.79	0.69	1.47-3.10	2.43
	0.21-0.92	0.64	3.41-5.71	4.63
)	0.35-1.78	1.20	2.19-18.27	6.64
l	0.87-1.21	1.04	3.47-6.21	4.78
?	0.83-1.97	1.57	3.71-6.45	5.23
}	0.77-0.92	0.83	0.98-1.72	1.27
l	0.56-0.90	0.71	12.73-18.03	15.69
;	0.15-0.53	0.35	18.28-21.28	19.43

je M = Mean

4.8.2. Potential acidity

The potential acidity of the soils varied from 0.98 cmol (p^+) kg^{-1} in Pedon 12 to 21.28 cmol (p^+) kg^{-1} in Pedon 15. The mean values of potential acidity were 1 to 5 cmol (p^+) kg^{-1} in Pedons 1, 3, 4, 7, 8, 9, 11 and 13; 5 to 10 cmol (p^+) kg^{-1} in Pedons 2, 5, 10 and 12; more than 10 cmol (p^+) kg^{-1} in Pedons 6, 14 and 15.

The potential acidity increased with depth in Pedons 2 and 8. In Pedon 4 a reverse trend was observed. In Pedon 1 it increased upto 74 cm depth and decreased thereafter. In all other pedons the depthwise distribution was irregular.

4.9. Water soluble ions (Table 16; Annexure IIi)

4.9.1. Water soluble cations

4.9.1.1. Calcium

The water soluble calcium content was observed to vary from 2.07 mmol (p^+) kg^{-1} in Pedon 4 to 35.08 mmol (p^+) kg^{-1} in Pedon 10. The mean values of the water soluble calcium were more than 5 mmol (p^+) kg^{-1} in Pedons 1, 6, 7, 8 and 10. In the remaining pedons the mean values were less than 5.

The water soluble calcium content increased with depth in Pedon 2. The trend was reverse in Pedons 4 and 9. In Pedon 1 the water soluble calcium decreased upto 74 cm depth and increased thereafter. In Pedon 6 it increased upto 80 cm depth and decreased thereafter (Fig.4).

4.9.1.2. Magnesium

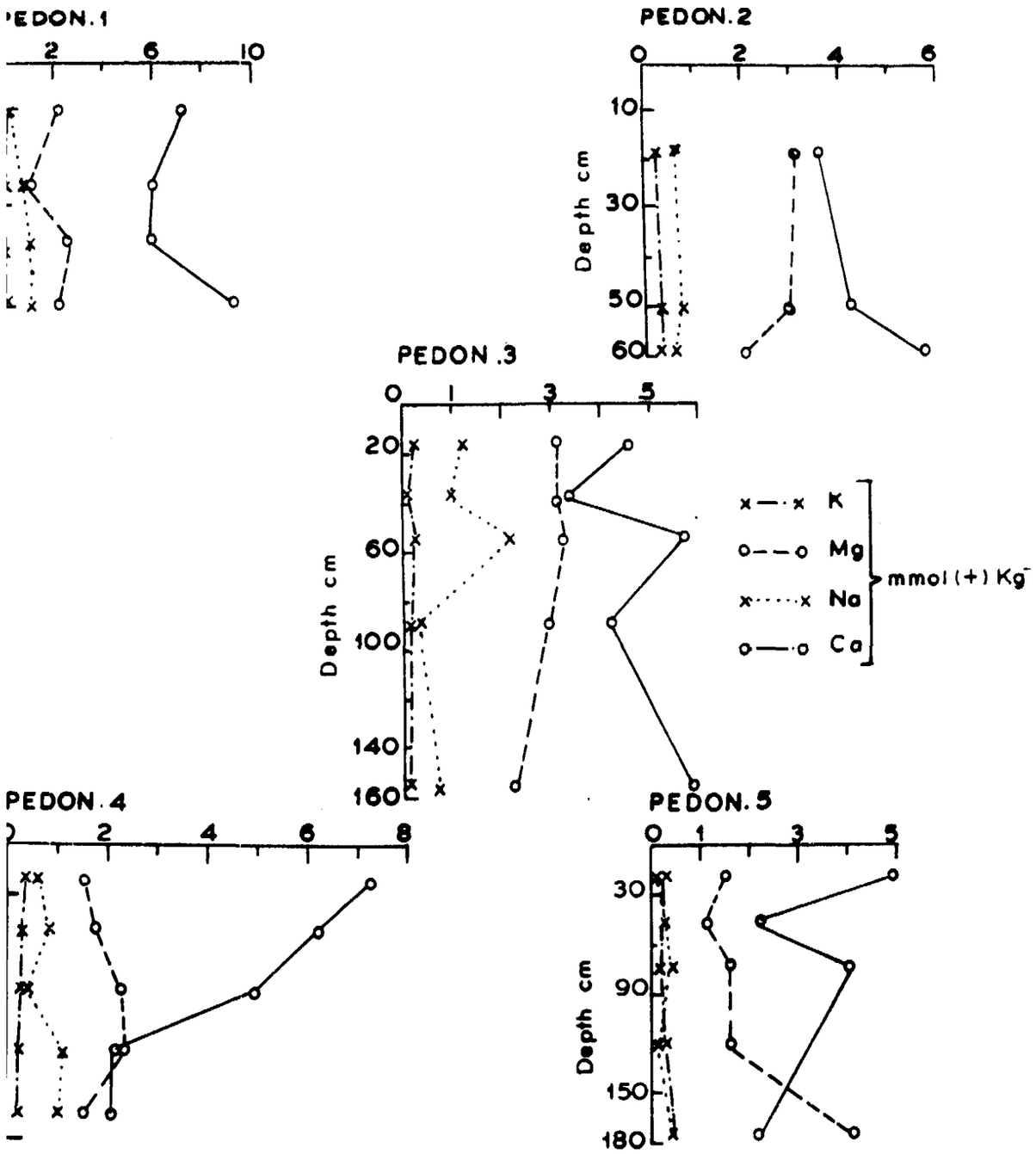
The lowest value of 1.07 mmol (p^+) kg^{-1} was recorded in Pedons 1 and 5. The highest value of 19.34 mmol (p^+) kg^{-1} was recorded in Pedon 10. The mean values of water soluble magnesium were more than 5 mmol (p^+) kg^{-1} in Pedon 10 and less than 2 mmol (p^+) kg^{-1} in Pedons 4 and 5. In all the

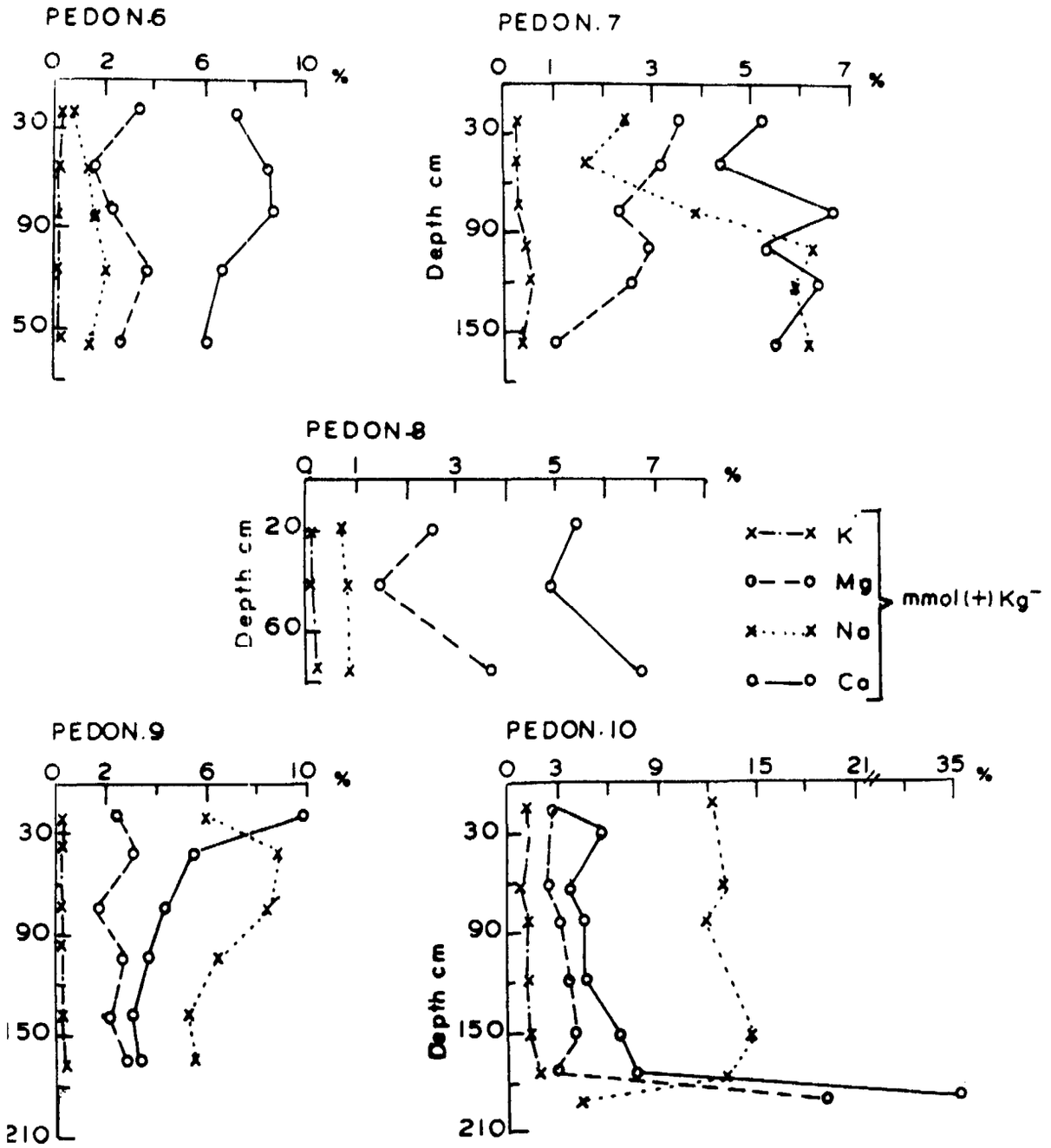
Table 16. Range and mean values of water soluble ions

Pedons	Ca^{++} (mmol (+) kg^{-1})		Mg^{++} (mmol (+) kg^{-1})		Na^{++} (mmol (+) kg^{-1})		K^{+} (mmol (+) kg^{-1})		HCO_3^{-} (mmol (-) kg^{-1})		Cl^{-} (mmol (-) kg^{-1})		SO_4^{--} (mmol (-) kg^{-1})	
	R	M	R	M	R	M	R	M	R	M	R	M	R	M
Pedon 1	5.90-9.35	7.19	1.07-2.71	2.05	0.31-1.17	0.88	0.13-0.28	0.18	3.77-5.91	4.68	3.08-4.02	3.42	0.23-0.48	0.34
Pedon 2	3.61-5.61	4.51	2.05-3.11	2.70	0.60-0.77	0.67	0.27-0.32	0.30	2.98-5.47	4.42	2.62-3.82	3.08	0.48-0.68	0.56
Pedon 3	3.25-5.80	4.69	2.21-3.28	2.92	0.32-2.22	1.09	0.13-0.28	0.19	3.39-6.67	4.82	2.81-3.87	3.33	0.43-0.68	0.52
Pedon 4	2.07-7.25	4.50	1.56-2.38	1.89	0.61-1.11	0.79	0.20-0.33	0.25	2.21-6.21	4.53	1.83-3.03	2.42	0.18-0.93	0.67
Pedon 5	2.15-4.85	3.27	1.07-4.02	1.94	0.10-0.32	0.21	0.18-0.43	0.27	1.03-2.77	1.98	2.16-4.11	2.88	0.38-0.97	0.72
Pedon 6	5.90-8.60	7.39	1.56-3.77	2.67	0.65-2.04	1.39	0.15-0.33	0.21	4.02-7.22	6.23	1.71-4.25	2.70	1.08-2.63	1.53
Pedon 7	5.20-6.65	5.57	0.98-3.52	2.55	1.65-6.22	4.36	0.23-0.56	0.35	5.04-10.78	7.50	2.28-7.28	4.23	0.47-3.71	1.96
Pedon 8	4.85-6.66	5.64	1.48-3.61	2.57	0.78-0.87	0.83	0.13-0.18	0.15	1.83-2.99	2.33	1.79-3.09	2.40	2.29-3.22	2.87
Pedon 9	3.12-9.71	4.91	1.48-3.20	2.45	5.35-8.91	6.79	0.23-0.36	0.27	6.96-9.28	8.11	2.26-8.36	4.83	0.88-1.67	1.12
Pedon 10	2.91-35.06	8.85	2.21-19.34	5.10	4.30-14.91	12.08	0.14-1.78	1.09	5.28-18.88	9.98	3.13-14.92	7.65	3.13-25.16	9.78
Pedon 11	3.85-6.80	5.13	2.62-3.12	2.92	0.41-1.26	0.87	0.10-0.46	0.19	2.17-3.71	3.07	3.01-5.73	4.38	0.51-0.91	0.74
Pedon 12	2.67-5.71	4.35	2.21-3.69	2.85	0.61-2.00	1.01	0.10-0.13	0.11	1.51-6.63	2.92	3.47-8.89	5.27	0.52-0.78	0.64
Pedon 13	3.35-5.11	4.31	1.48-2.71	2.10	3.43-8.52	6.61	0.23-0.50	0.39	3.22-8.27	5.84	2.18-7.21	4.24	0.48-0.72	0.58
Pedon 14	3.21-6.92	4.39	1.15-2.54	2.09	0.61-1.06	0.79	0.10-0.20	0.14	2.08-4.61	3.68	1.79-3.77	2.43	0.48-0.81	0.62
Pedon 15	2.15-5.73	4.48	1.15-2.62	2.05	0.41-0.74	0.58	0.05-0.13	0.09	1.37-3.72	2.85	1.93-3.96	3.21	0.32-0.91	0.55

R = Range M = Mean

DEPTHWISE DISTRIBUTION OF WATER SOLUBLE CATIONS




PEDON.6
0 2 6 10 %
30
90
50
PEDON.7
0 1 3 5 7 %
Depth cm
30
90
150
PEDON.8
0 1 3 5 7 %
Depth cm
20
60
K
Mg
Na
Ca
mmol(+) Kg⁻
PEDON.9
0 2 6 10 %
30
90
150
210
PEDON.10
0 3 9 15 21 35 %
Depth cm
30
90
150
210

other Pedons the mean values were between 2 and 3 mmol (p^+) kg^{-1}.

A decreasing trend with depth was observed in Pedon 2. In Pedons 3 and 4 the water soluble magnesium content increased upto 54 cm and 125 cm depths respectively and decreased thereafter. The depthwise distribution was irregular in the remaining pedons (Fig.4).

4.9.1.3. Sodium

The water soluble sodium content ranged from 0.10 mmol (p^+) kg^{-1} in Pedon 5 to 14.91 mmol (p^+) kg^{-1} in Pedon 10. The mean values of water soluble sodium were less than 1 mmol (p^+) kg^{-1} in Pedons 1, 2, 4, 5, 8, 11, 14 and 15; 1 to 5 mmol (p^+) kg^{-1} in Pedons 3, 6, 7 and 12; 5 to 10 in Pedons 9 and 13; and more than 10 mmol (p^+) kg^{-1} in Pedon 10.

In Pedons 1 and 8 the water soluble sodium content increased with depth. There was no trend in the distribution pattern in all other pedons (Fig.4).

4.9.1.4. Potassium

The water soluble potassium content varied from 0.05 mmol (p^+) kg^{-1} in Pedon 15 to 1.75 mmol (p^+) kg^{-1} in Pedon 10. The mean values of water soluble K was more than 1 only in Pedon 10. In all the remaining pedons the mean values were less than 0.5 mmol (p^+) kg^{-1}. Pedon 10 registered conspicuously lower water soluble potassium between 174 and 190 cm depth in comparison to other horizons. Pedon 15 recorded low water soluble potassium content. In all the pedons no trend in depthwise distribution was noticed (Fig.4).

4.9.2. Water soluble anions

Water soluble carbonate was recorded in very few samples. Hence it is not reported.

4.9.2.1. Bicarbonate

Pedon 5 recorded the lowest value of 1.03 mmol(-) kg^{-1}. The highest value of 18.88 mmol (p^+) kg^{-1} was recorded in Pedon 10. The mean values of the water soluble bicarbonate were more than 5 mmol(-) kg^{-1} in Pedons 6, 7, 9, 10 and 13. In other pedons the mean values were less than 5 mmol(-) kg^{-1}. Depthwise distribution of bicarbonate was irregular in all pedons (Fig.5).

4.9.2.2. Chloride

The water soluble chloride content of the soils ranged from 1.71 mmol(-) kg^{-1} in Pedon 6 to 14.92 mmol(-) kg^{-1} in Pedon 10. The mean values of the water soluble chloride content were more than 5 mmol(-) kg^{-1} in Pedons 10 and 12. The mean values were less than 5 in the remaining pedons.

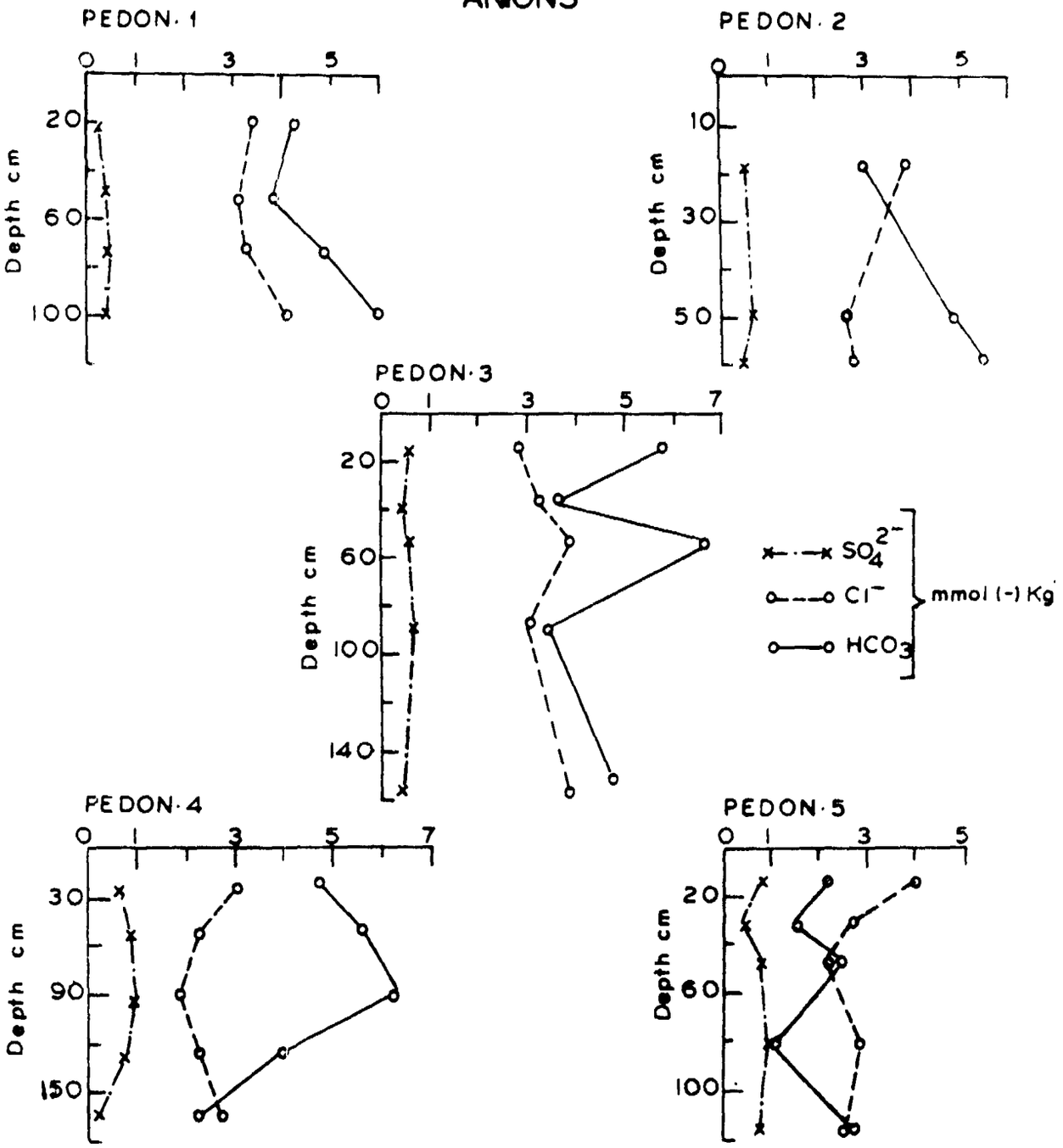
In Pedon 9, the water soluble chloride content decreased upto 139cm depth and then increased upto 164 cm. In Pedon 10, a general trend of increase with depth was observed. In the remaining pedons the depthwise distribution was irregular (Fig.5).

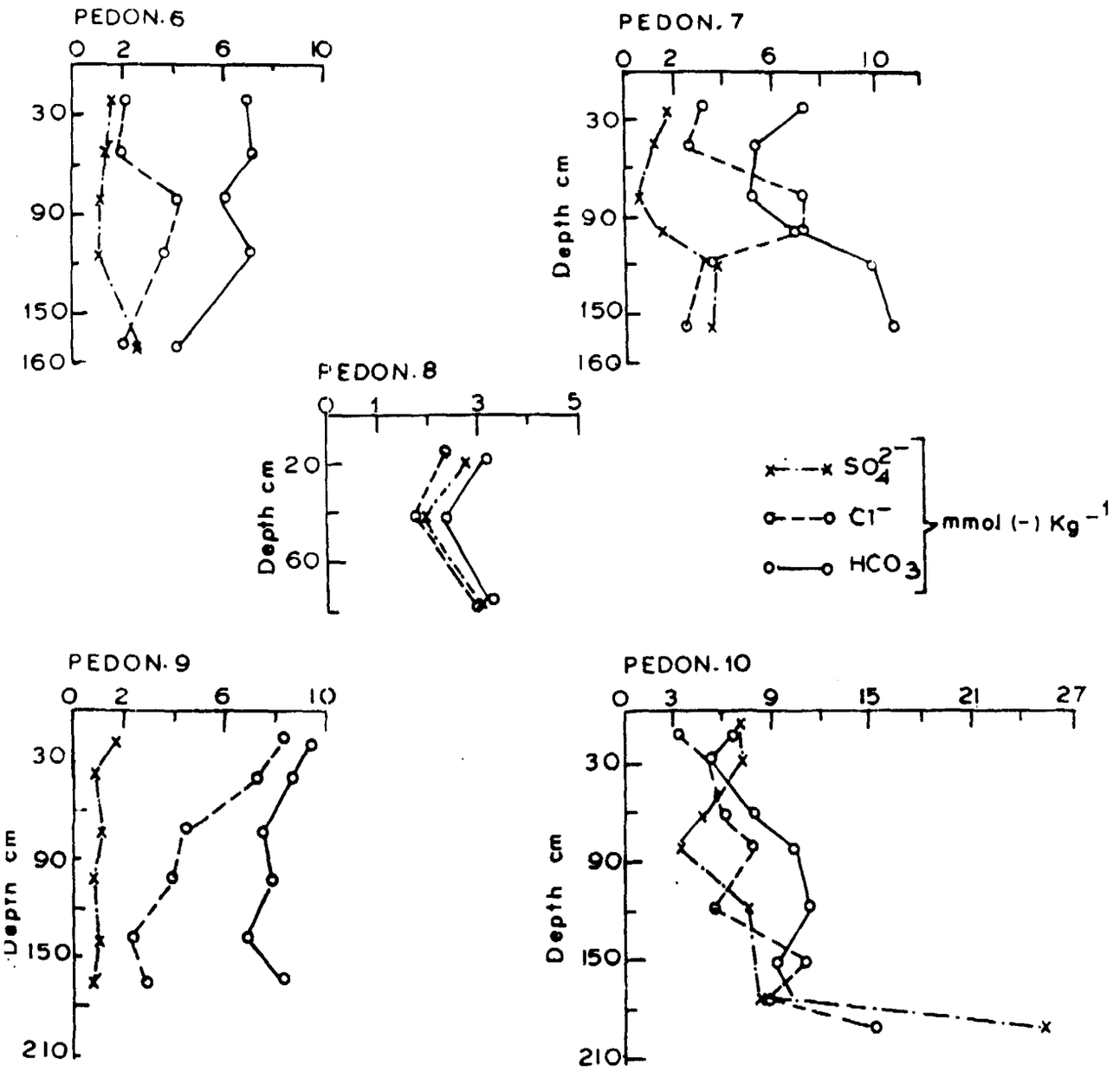
4.9.2.3. Sulphate

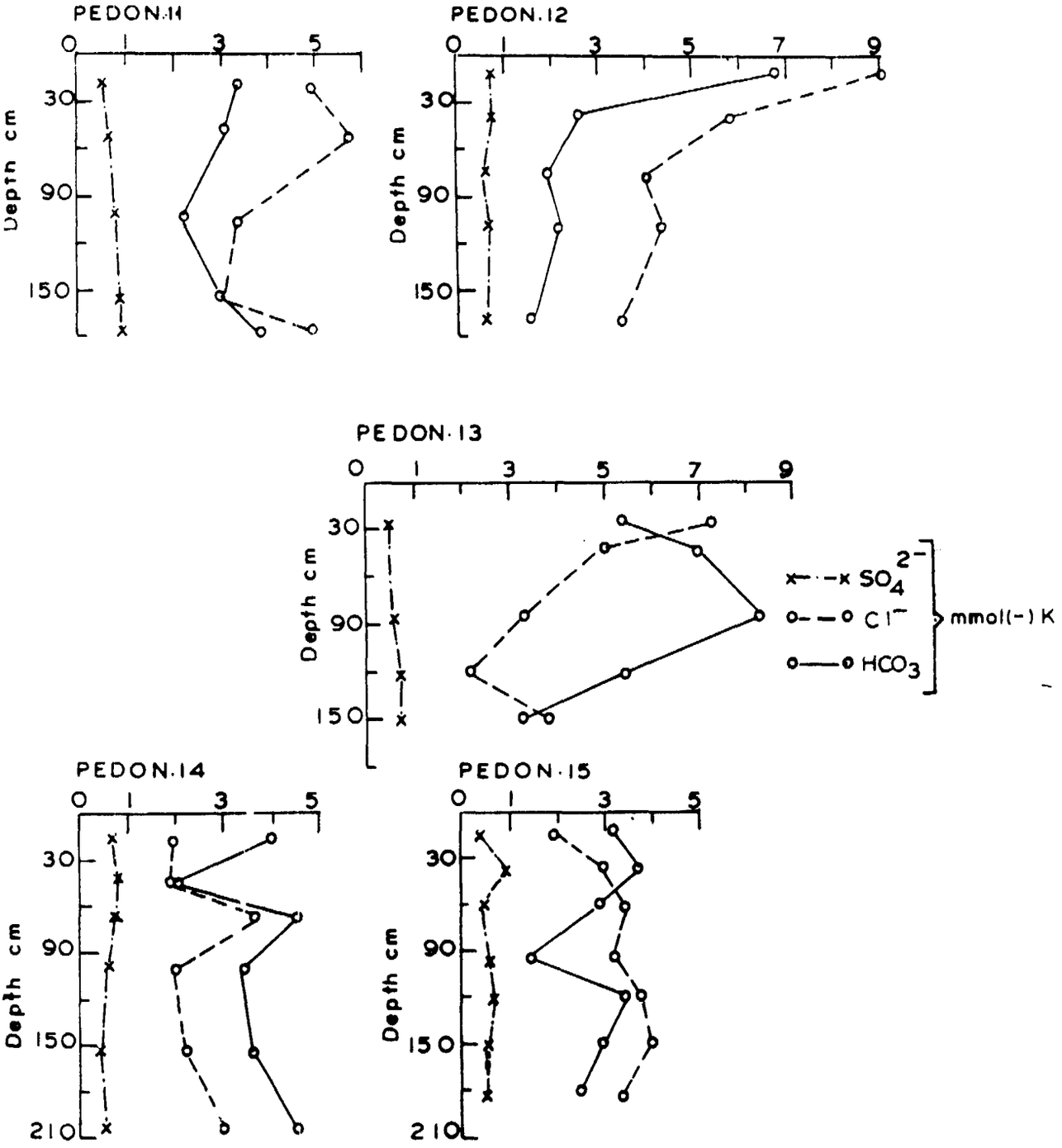
The water soluble sulphate content of the soils ranged from 0.13 mmol(-) kg^{-1} in Pedon 4 to 25.16 mmol(-) kg^{-1} in Pedon 10. The mean value of the water soluble sulphate content was more than 5 mmol(-) kg^{-1} in Pedon 10, and 1 to 5 mmol(-) kg^{-1} in Pedons 6,7,8 and 9. In the remaining pedons the mean values were less than 1 mmol(-) kg^{-1}.

In Pedons 11 and 13 the water soluble sulphate content was observed to increase with depth. In Pedon 6, it decreased upto 112 cm depth and increased thereafter. The depthwise distribution was irregular in other pedons (Fig.5).

FIG. 5 DEPTHWISE DISTRIBUTION OF WATER SOLUBLE ANIONS




PEDON. 6
0 2 6 10
30
90
150
160
PEDON. 7
0 2 6 10
Depth cm
30
90
150
160
PEDON. 8
0 1 3 5
Depth cm
20
60
SO_4^{2-}
Cl^-
HCO_3
mmol (-) Kg^{-1}
PEDON. 9
0 2 6 10
Depth cm
30
90
150
210
PEDON. 10
0 3 9 15 21 27
Depth cm
30
90
150
210


PEDON-11
PEDON-12
PEDON-13
PEDON-14
PEDON-15
Depth cm
SO_4^{2-}
Cl^-
HCO_3
mmol(-) K

4.10. Statistical relationship among soil properties (Table 17)

Correlation coefficients among particle size fractions, physico-chemical properties, moisture retention characteristics and chemical composition of the soil were worked out. Clay was positively correlated with CEC, moisture retention at 33 kPa and 1500 kPa tensions, CaO, MgO,K_2O,Na_2O and total copper. It was negatively correlated with sand, SiO_2, Fe_d, Fe_o and Fe_p.

Silt showed positive relationship with CEC, MgO, K_2O and Na_2O. The relationship of silt with other soil properties was not significant.

Sand was positively correlated with SiO_2 and negatively correlated with CEC, moisture retention at 33 kPa and 1500 kPa and K_2O.

Organic carbon had significant and positive relationship with total copper. pH_w was positively correlated with CaO, MgO, K_2O and Na_2O. The relationships among CEC, moisture retention at 33 kPa and 1500 kPa were positive and significant. CEC was negatively correlated with Fe_2O_3, Al_2O_3 and R_2O_3. SiO_2 showed negative relationship with Al_2O_3. Fe_2O_3 was positively correlated with Al_2O_3, total Cu, and Mn, and all the fractions of Iron. Total Cu and Mn and the fractions of Fe and Mn were positively correlated with each other.

4.11. Soil classification (Table 18)

Based on the morphological physical, chemical and exchangeable properties, the soils were classified upto soil family level (Soil Survey Staff, 1975 and 1994). Rainfall, PET (Potential Evapo-Transpiration) and temperature data for the locations of the pedons were collected and the moisture and temperature regimes were computed based on the guidelines given by Sehgal and Mandal (1994a) and Sehgal and Mandal (1994b) (Fig.6).

Table 17. Statistical relationship among soil properties

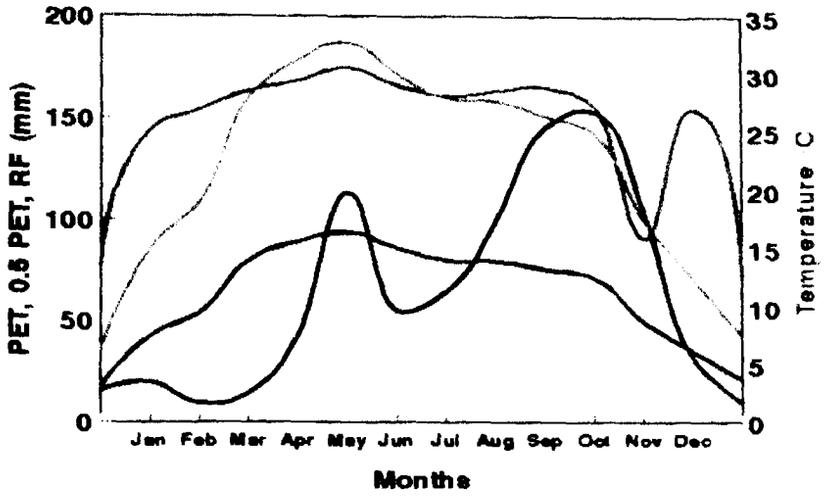
	Clay	Silt	Sand	OC	pHw	EC	CEC	33 kPa	1500 kPa	SiO_2	Fe_2O_3	Al_2O_3	R_2O_3	CaO	MgO	K_2O	Na_2O	Total Zn	Total Cu	Total Mn	Fe_d	Fe_o	Fe_p	Mn_d
Clay	1.000																							
Silt	0.415**	1.000																						
Sand	-0.653**	-0.542**	1.000																					
OC	-0.018	0.121	-0.214	1.000																				
pHw	0.405**	0.151	-0.047	0.108	1.000																			
EC	0.173	0.453	0.092	-0.065	0.184	1.000																		
CEC	0.688**	0.325**	0.687**	-0.023	0.627	0.098	1.000																	
33 kPa	0.568**	0.198	-0.923**	0.079	0.002	-0.311	0.819**	1.000																
1500 kPa	0.539**	0.209	-0.883**	0.001	0.208	0.297	0.813**	0.975**	1.000															
SiO_2	-0.027	-0.032	0.883**	-0.378**	0.384	0.417	0.017	-0.154	-0.118	1.000														
Fe_2O_3	0.298	-0.355	0.108	0.017	-0.406*	-0.366*	-0.252*	-0.119	-0.118	-0.471*	1.000													
Al_2O_3	0.584*	0.084	-0.298	0.440*	-0.463	-0.398*	-0.245*	-0.097	0.057	-0.845**	0.470**	1.000												
R_2O_3	0.201	-0.181	-0.073	0.342*	-0.508	-0.443	-0.283*	-0.089	-0.118	-0.824*	0.740**	0.942**	1.000											
CaO	0.575*	0.215	-0.063	-0.068	0.727**	0.131	0.468**	0.282*	0.277*	0.083	-0.478**	-0.219	-0.350**	1.000										
MgO	0.592*	0.584**	-0.173	-0.035	0.711**	0.147	0.544*	0.435**	0.370*	0.126	-0.456	-0.269*	-0.379*	0.616**	1.000									
K_2O	0.331*	0.817*	-0.538**	0.033	0.556**	0.296**	0.130	0.214	0.155	0.014	-0.239*	0.055	-0.049	0.106	0.358	1.000								
Na_2O	0.432**	0.706**	-0.299*	-0.187	0.578**	0.532*	0.416*	0.368**	0.389*	-0.281*	-0.278*	-0.330*	-0.358	0.325	0.414	0.556*	1.000							
Total Zn	0.226	0.544	-0.220	0.296	-0.174	0.414	0.294	-0.082	0.293	-0.033	0.200	-0.164	0.037	0.357	0.279	0.417	0.303	1.000						
Total Cu	0.459*	-0.102	-0.364	0.681*	0.743*	0.026	0.632*	0.290	0.193	-0.352	0.864**	-0.072	0.557	-0.037	0.060	-0.109	-0.250	0.088	1.000					
Total Mn	0.509	-0.188	0.278	0.109	0.383	-0.173	0.219	0.230	0.187	-0.355	0.822*	0.079	0.622*	-0.432	0.040	-0.425	-0.371	0.027	0.560	1.000				
Fe_d	-0.371**	-0.350	0.104	0.103	-0.644*	-0.365*	-0.443*	0.154	0.173	0.540**	0.894**	0.521*	0.738*	-0.572*	-0.650*	-0.336*	-0.490*	0.137	0.783*	0.691*	1.000			
Fe_o	-0.317*	-0.517	0.185	-0.188	-0.501*	-0.325*	-0.310*	0.218	0.228	-0.022	0.590**	0.103	0.304*	-0.490**	-0.579**	-0.464**	-0.434*	-0.192	0.781*	0.368	0.627**	1.000		
Fe_p	-0.328*	-0.118	0.005	0.073	-0.442*	-0.262*	-0.239*	0.183	0.206	-0.383	0.560**	0.461**	0.581*	-0.254*	-0.445	-0.301*	-0.252	-0.377	0.286	0.634	0.582*	0.358*	1.000	
Mn_d	0.201	-0.231	0.297	0.116	0.168	-0.218	0.049	-0.017	-0.023	-0.093	0.435	0.075	0.177	0.032	0.039	-0.108	-0.018	0.006*	0.565	0.990**	0.308*	0.336*	0.058	1.000

Table 18. Classification of soils under USDA system

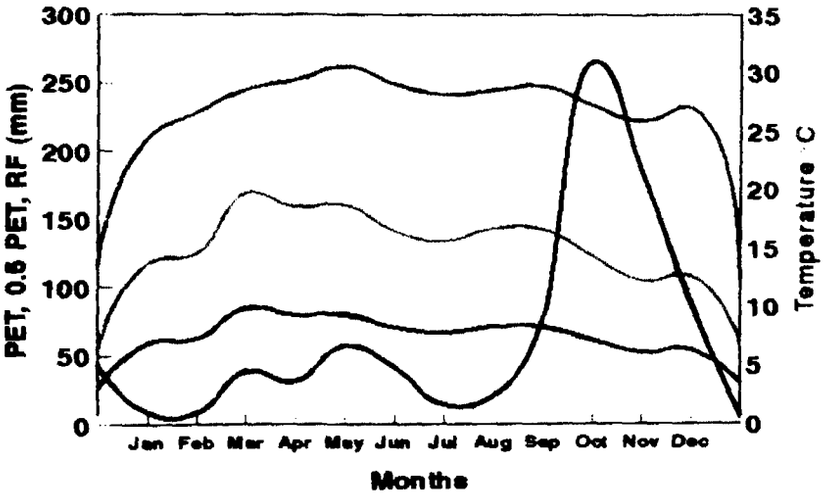
	Order	Suborder	Great group	Sub group	Family
Pedon 1	Inceptisol	Tropept	Ustropept	Typic Ustropept	Fine loamy, mixed (non-acid), isohyperthermic, Typic Ustropept
Pedon 2	Inceptisol	Tropept	Ustropept	Typic Ustropept	Fine loamy, mixed (non-acid), isohyperthermic, Typic Ustropept
Pedon 3	Inceptisol	Tropept	Ustropept	Typic Ustropept	Clayey skeletal, mixed (non-acid) isohyperthermic, Typic Ustropept
Pedon 4	Alfisol	Ustalf	Rhodustalf	Typic Rhodustalf	Coarse loamy over fine loamy, mixed, (non-acid) isohyperthermic, Typic Rhodustalf
Pedon 5	Alfisol	Ustalf	Rhodustalf	Typic Rhodustalf	Fine loamy, mixed, acid, isohyperthermic, Typic Rhodustalf
Pedon 6	Vertisol	Ustert	Haplustert	Typic Haplustert	Fine, montmorillonitic, calcareous, isohyperthermic, Typic Haplustert
Pedon 7	Inceptisol	Tropept	Ustropept	Vertic Ustropept	Fine loamy, mixed, calcareous, isohyperthermic, Vertic Ustropept
Pedon 8	Inceptisol	Tropept	Ustropept	Typic Ustropept	Coarse loamy, carbonitic, isohyperthermic, Typic Ustropept
Pedon 9	Inceptisol	Tropept	Ustropept	Vertic Ustropept	Fine loamy, mixed, isohyperthermic, Vertic Ustropept
Pedon 10	Inceptisol	Tropept	Ustropept	Aquic Ustropept	Fine, mixed, non-acid, isohyperthermic, Aquic Ustropept
Pedon 11	Alfisol	Ustalf	Haplustalf	Ultic Haplustalf	Fineloamy, mixed (acid), isohyperthermic, Ultic Haplustalf
Pedon 12	Alfisol	Ustalf	Rhodustalf	Typic Rhodustalf	Fine, mixed (acid), isohyperthermic, Typic Rhodustalf
Pedon 13	Alfisol	Ustalf	Haplustalf	Typic Haplustalf	Fine loamy, mixed, (non-acid) isohyperthermic, Typic Haplustalf
Pedon 14	Inceptisol	Tropept	Humitropept	Typic Humitropept	Loamy skeletal, mixed (acid) isohyperthermic, Typic Humitropept
Pedon 15	Ultisol	Humults	Haplohumults	Typic Haplohumult	Fine loamy, mixed, (acid) isothermic, Typic Haplohumult

Fig.6. CLIMATIC DATA

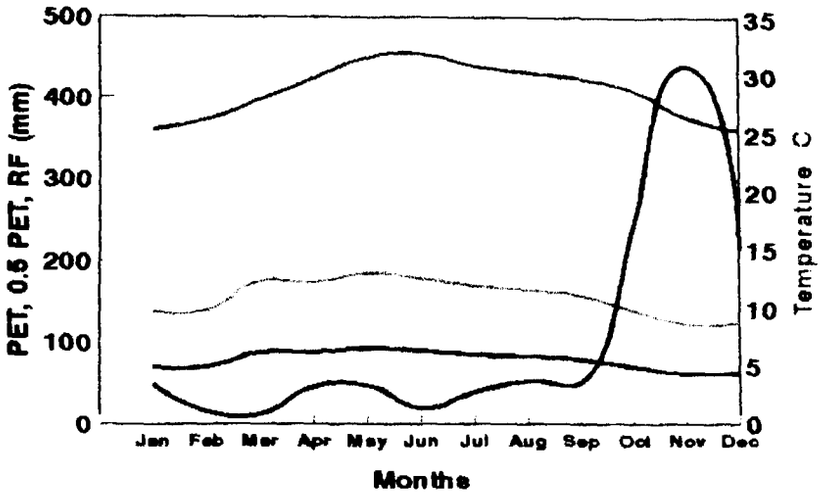
Palyur



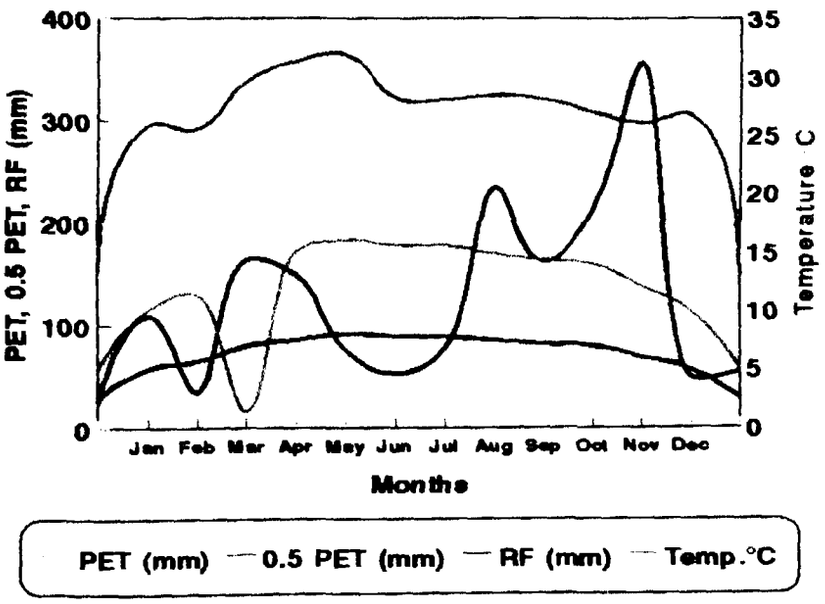
Bhavanisagar



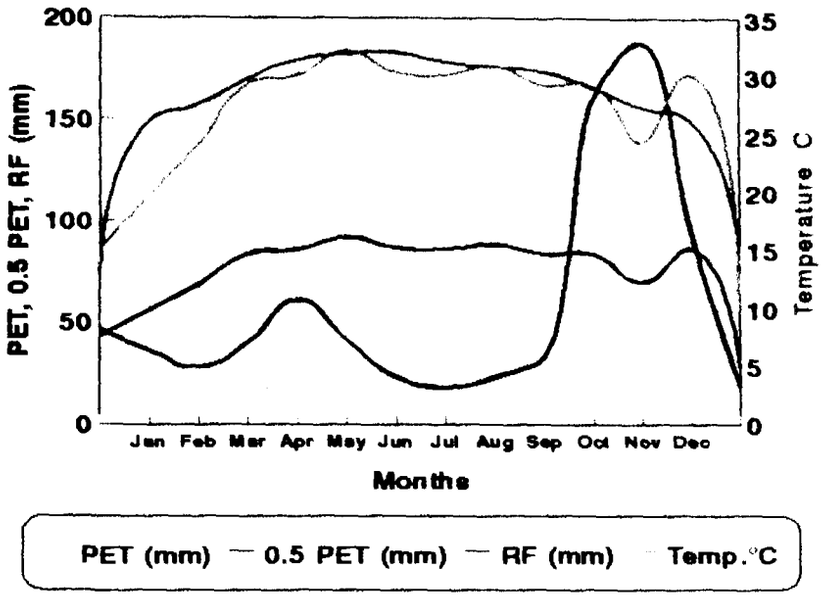
Thenkasi



Periyakulam



Sathankulam



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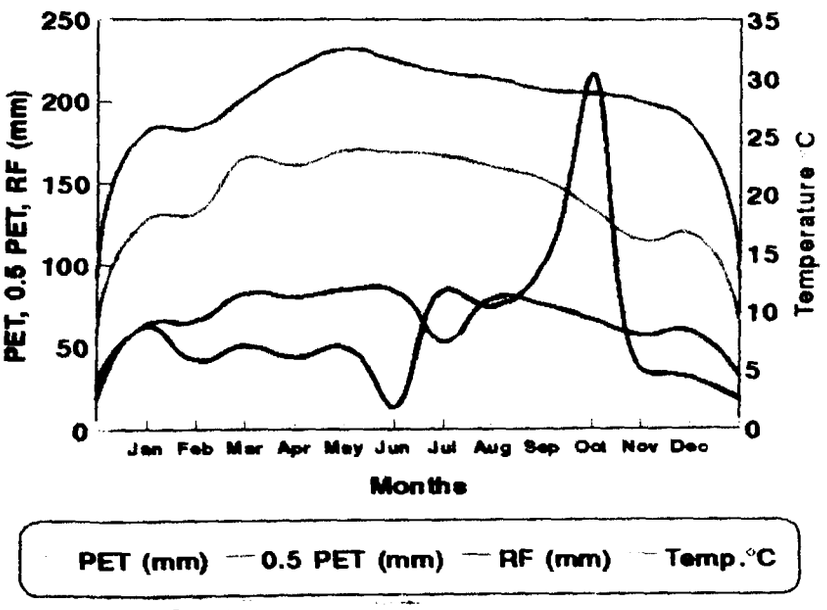

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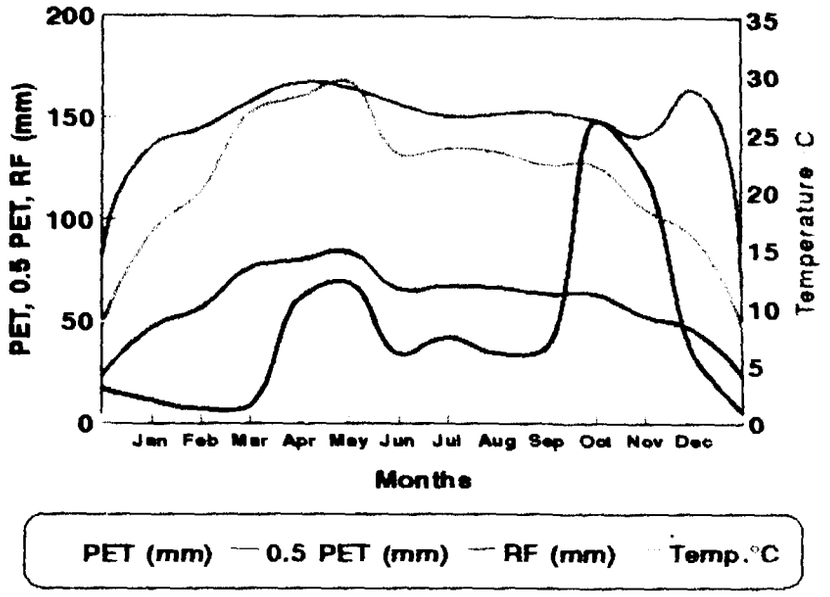
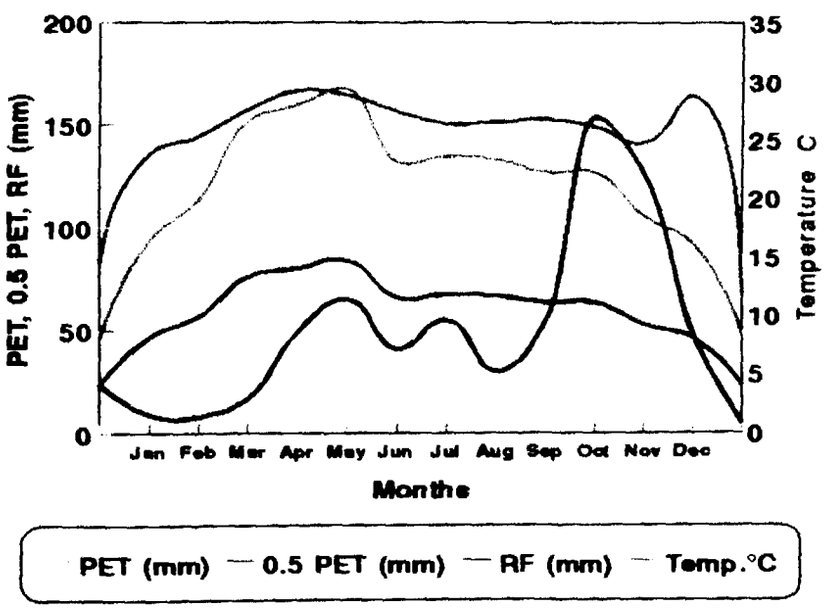
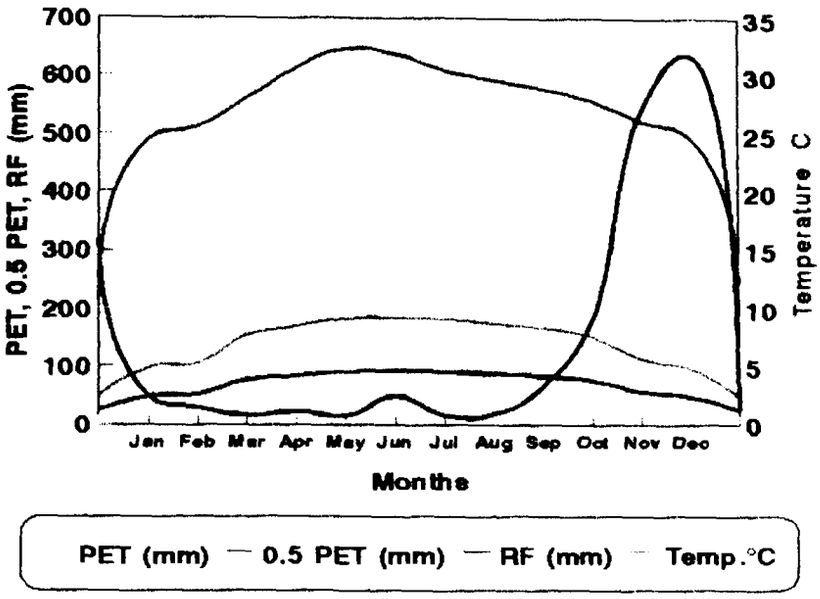


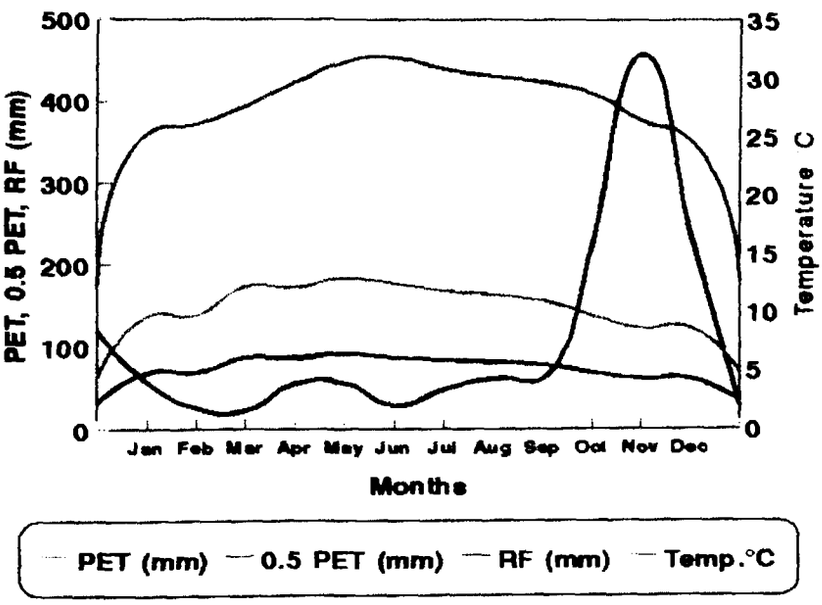
Palladam



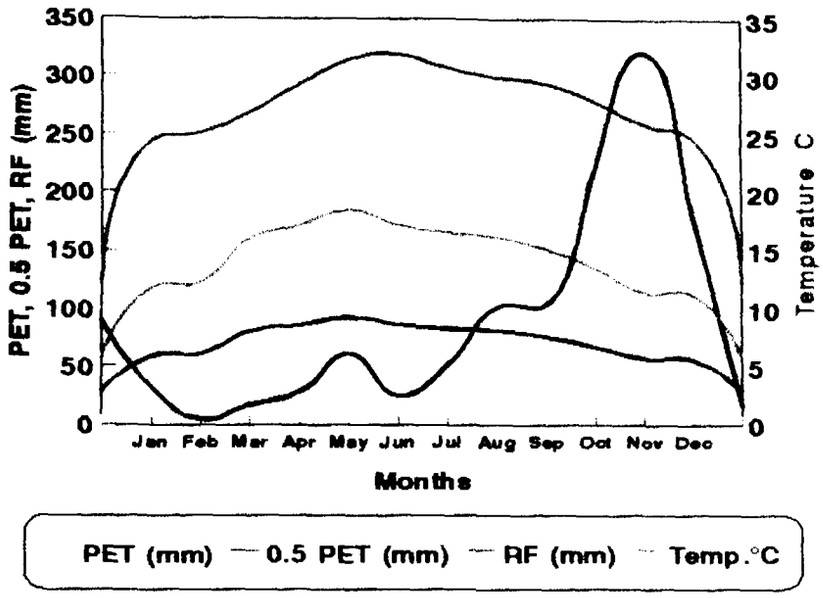
Aduthurai



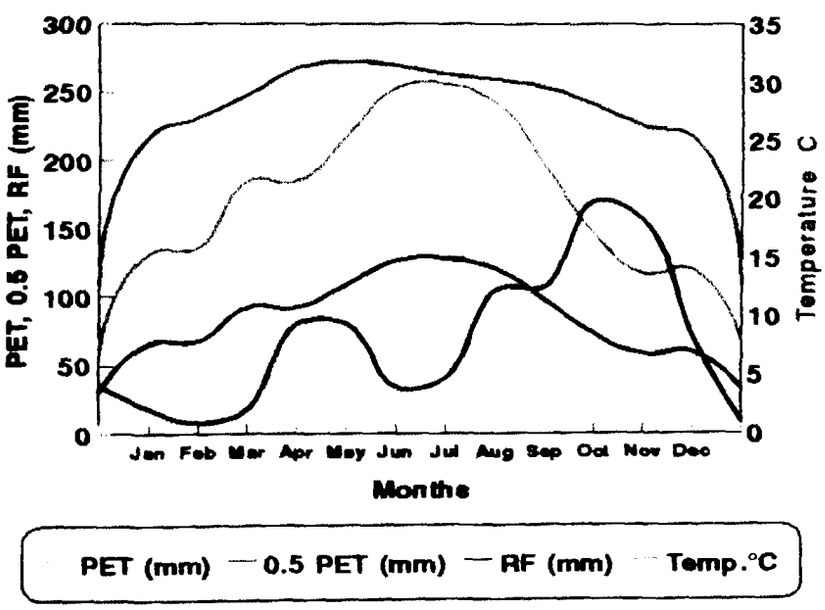
Sellur



Vridhachalam



Vamban



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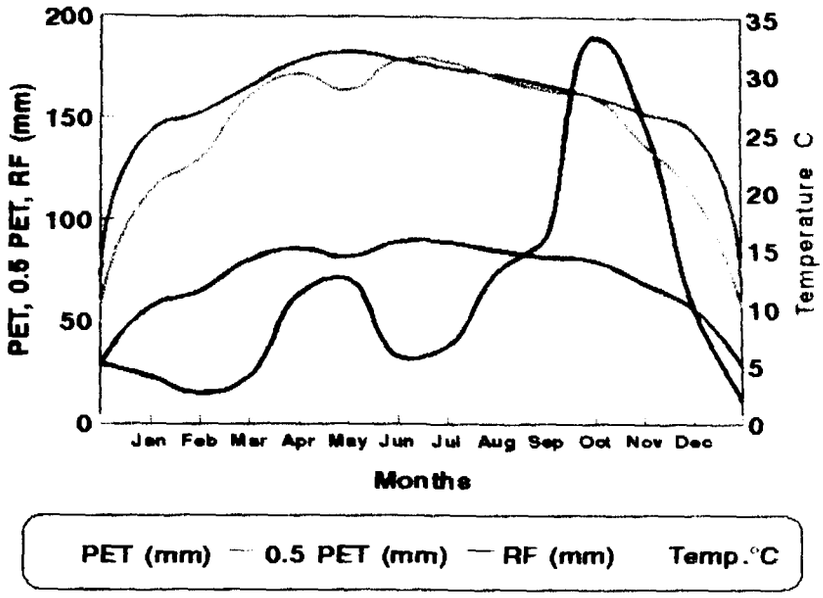
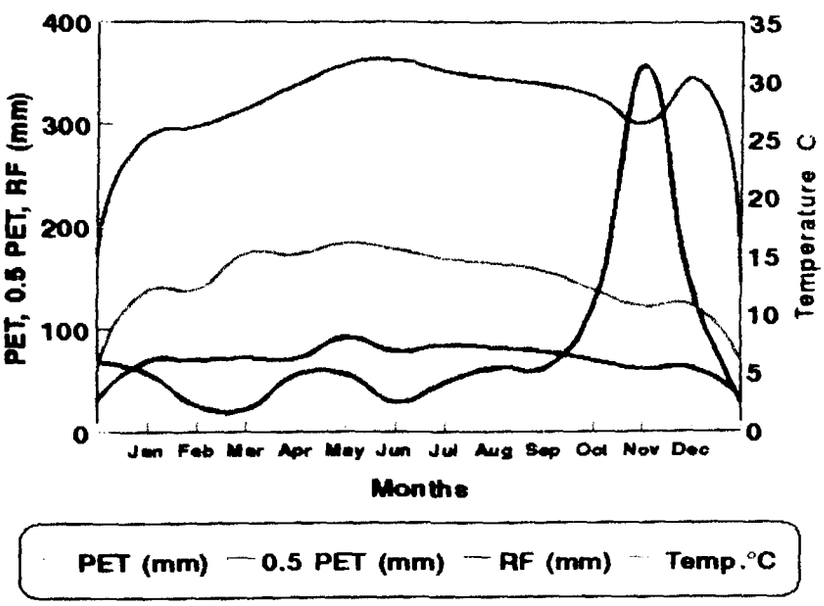


Pechiparai



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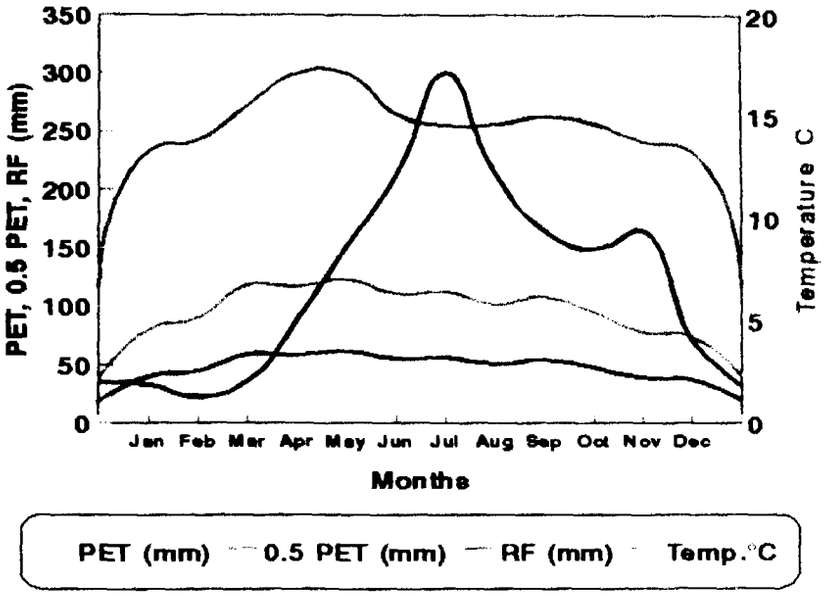

350
300
250
200
150
100
50
0
PET, 0.5 PET, RF (mm)
20
15
10
5
0
Temperature C
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Months
PET (mm)
0.5 PET (mm)
RF (mm)
Temp.°C

The temperature regime of Pedon 15 was computed as isothermic. All other pedons had isohyperthermic temperature regime. The moisture regime of Pedon 15 was udic. All other pedons had ustic moisture regime.

Pedons 1,2,3,7,8,9,10 and 14 were classified under Inceptisols. Pedons 4,5,11,12 and 13 were grouped under Alfisols. Pedon 6 was classified under Vertisol and Pedon 15 under Ultisol. The classification upto family level is given in Table (18).

4.12. Spectral reflectance

Soil reflectance is a cumulative property derived from inherent spectral behavior of combinations of mineral, organic and fluid water that comprise the soils. The spectral reflectance of soils differed markedly between soil groups as they have various chemical and physical properties including iron oxides, organic matter, moisture and texture. Surface soil reflectance always varies with subsoil reflectance. Hence an attempt was made to characterise the soils based on their spectral properties and to establish relationship between reflectance and soil properties.

4.12.1. Bandwise reflectance (Table 19; Annexure IIj)

4.12.1.1. Blue band reflectance

The reflectance in the blue band varied from 5.42 per cent in Pedon 15 to 39.01 in Pedon 4. The mean values of reflectance in blue band were less than 10 per cent in Pedons 3,8,9,12 and 14; 10 to 15 in Pedons 1,5,6,7,10,11,13 and 15; and more than 15 per cent in Pedons 2 and 4.

4.12.1.2. Green band reflectance

The reflectance in green band ranged from 7.02 per cent in Pedon 3 to 38.10 per cent in Pedon 4. The mean values of reflectance in the green band were less than 10 per cent in Pedons 8,9 and 12. In Pedons

Table 19. Range and mean values of percentage of spectral reflectance

Pedons	Blue		Green		Red		Infra Red	
	R	M	R	M	R	M	R	M
Pedon 1	8.10-16.55	12.20	10.21-18.71	13.91	12.28-12.93	16.16	17.28-24.00	19.39
Pedon 2	13.72-19.90	16.16	15.85-23.95	19.25	20.23-27.81	24.65	20.43-31.83	26.73
Pedon 3	6.28-13.60	8.74	7.02-18.18	11.46	10.83-19.65	15.71	12.72-27.20	20.43
Pedon 4	13.60-39.01	24.40	18.80-38.10	27.36	23.28-43.10	31.90	29.14-59.20	41.80
Pedon 5	5.91-12.84	10.09	8.09-18.62	14.50	10.42-23.04	16.83	15.87-26.86	21.58
Pedon 6	7.02-15.92	10.92	9.30-17.31	13.33	12.92-18.31	15.29	15.21-26.21	19.89
Pedo 7	10.98-17.21	13.72	11.84-21.50	15.81	17.26-26.71	21.11	19.41-37.60	25.59
Pedon 8	5.69-10.38	7.66	7.07-10.85	8.73	9.80-18.84	13.29	11.87-21.71	17.13
Pedon 9	6.68-13.38	9.45	8.57-18.91	12.28	9.94-20.64	15.23	10.21-35.93	19.58
Pedon 10	7.20-13.31	10.08	8.91-17.81	13.23	12.70-23.40	16.80	13.20-38.14	22.11
Pedon 11	6.47-13.37	10.89	7.11-14.94	12.86	10.84-28.99	19.80	16.85-37.50	25.82
Pedon 12	6.11-8.57	6.97	7.27-12.76	8.97	12.32-20.58	16.39	21.00-25.40	22.87
Pedon 13	10.31-21.30	14.40	13.18-23.91	17.90	15.17-28.62	21.83	29.99-47.21	35.25
Pedon 14	6.99-10.71	8.79	8.62-13.62	11.13	9.21-16.67	12.31	14.44-22.03	17.74
Pedon 14	5.42-14.29	10.52	7.17-16.32	11.47	9.50-20.63	14.56	11.70-25.21	19.95

R = Range M = Mean

1,3,5,7,9,10,11,14 and 15 the mean values were between 10 and 15 per cent. In Pedons 2,4 and 7 the mean values were more than 15 per cent.

4.12.1.3. Red band reflectance

The reflectance measured in red band varied from 9.21 per cent in Pedon 14 to 43.10 per cent in Pedon 4. The mean values of reflectance in red band were less than 15 per cent in Pedons 8,14 and 15; 15 to 20 per cent in Pedons 1,3,5,6,9,10,11 and 12; more than 20 per cent in Pedons 2,4,7 and 13.

4.12.1.4. Infrared band reflectance

The reflectance measured in the infrared band ranged from 10.21 per cent in Pedon 9 to 59.20 per cent in Pedon 4. The mean values of reflectance in this band were less than 20 per cent in Pedons 1,6,8,9,14 and 15. In Pedons 3,6,11 and 13 the mean values were between 20 and 25 per cent. The mean values were more than 25 per cent in Pedons 2,4,7,11 and 13.

4.13. Effect of physical and chemical properties of soils on spectral reflectance

Grouping of soils based on their physical and chemical properties and studying their effect on spectral reflectance is done by constructing reflectance curves in different spectral bands for different categories of soils. This will facilitate in soil map unit delineation and other field separation of soil differences.

4.13.1. Effect of clay

Soil with less than 18% clay recorded higher reflectance in all the four bands (blue, green, red and infrared bands) compared to those with 18 to 35 and more than 35 per cent clay. The reflectance of soil with 18 to 35

per cent and more than 35 per cent clay were almost similar in blue, green and red bands while they differed marginally in infrared band (Fig.7).

4.13.2. Effect of silt

The soils of present investigation were categorized into 3 classes (a) the soils with less than 5 per cent silt, (b) 5-10 per cent silt and (c) more than 10 per cent silt. The reflectance of the soils increased from blue, green, red and to infrared band. Significant differences occured in the infrared band for soils with varying amounts of silt, while they were more or less similar in the remaining bands (Fig.7).

4.13.3. Effect of sand

The reflectance was higher in all the four bands in the soils containing more than 75 per cent sand (Fig.7). The soils with more than 75 per cent sand could be discriminated from the other soils containing 50 to 75 per cent and less than 50 per cent sand because of their higher reflectance values. The reflectance curves of the soils with less than 50 per cent and 50-75 per cent were closer and hence the soil with low per cent sand could not be differentiated based on their spectral reflectance values.

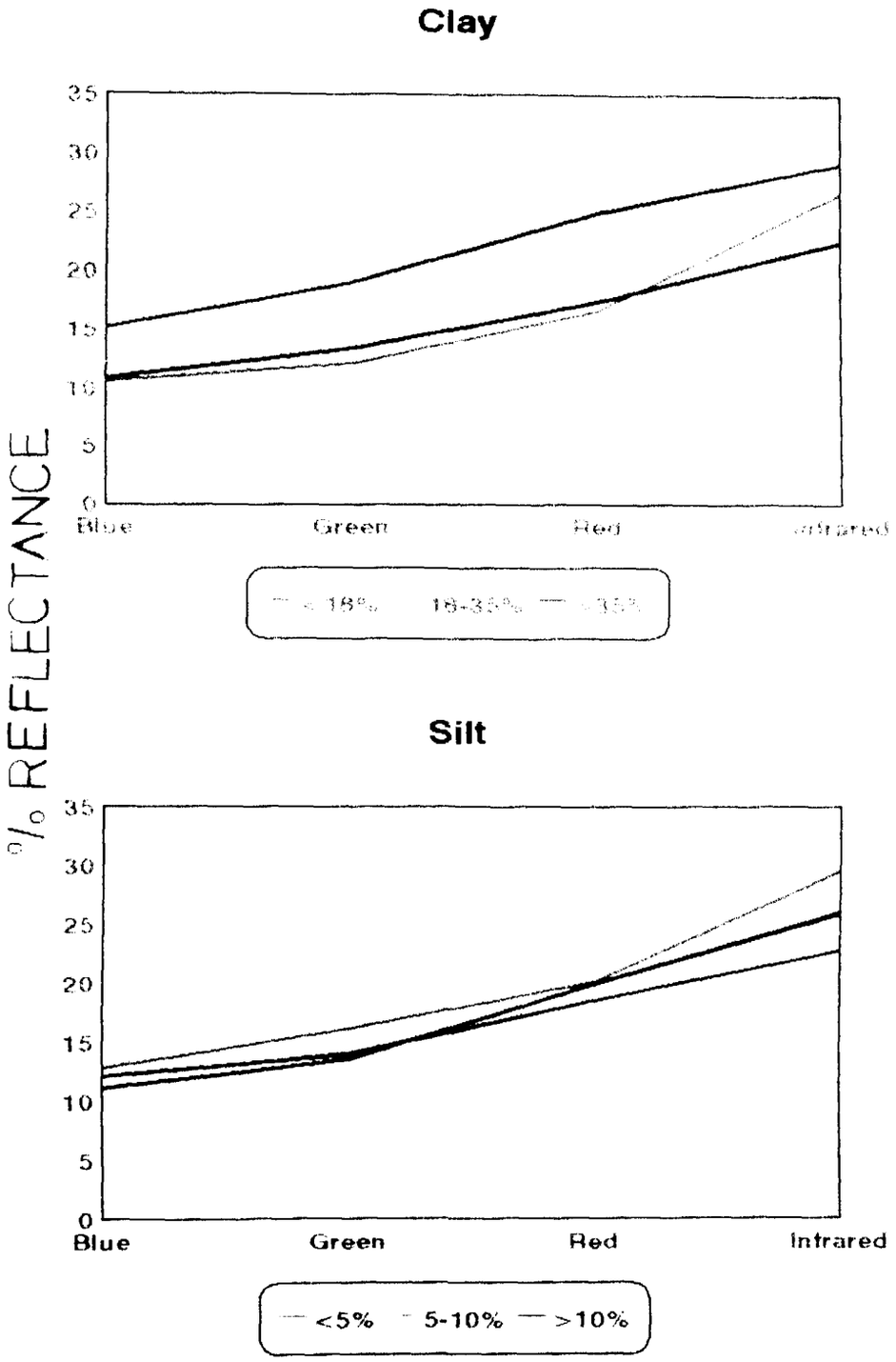
4.13.4. Effect of soil colour

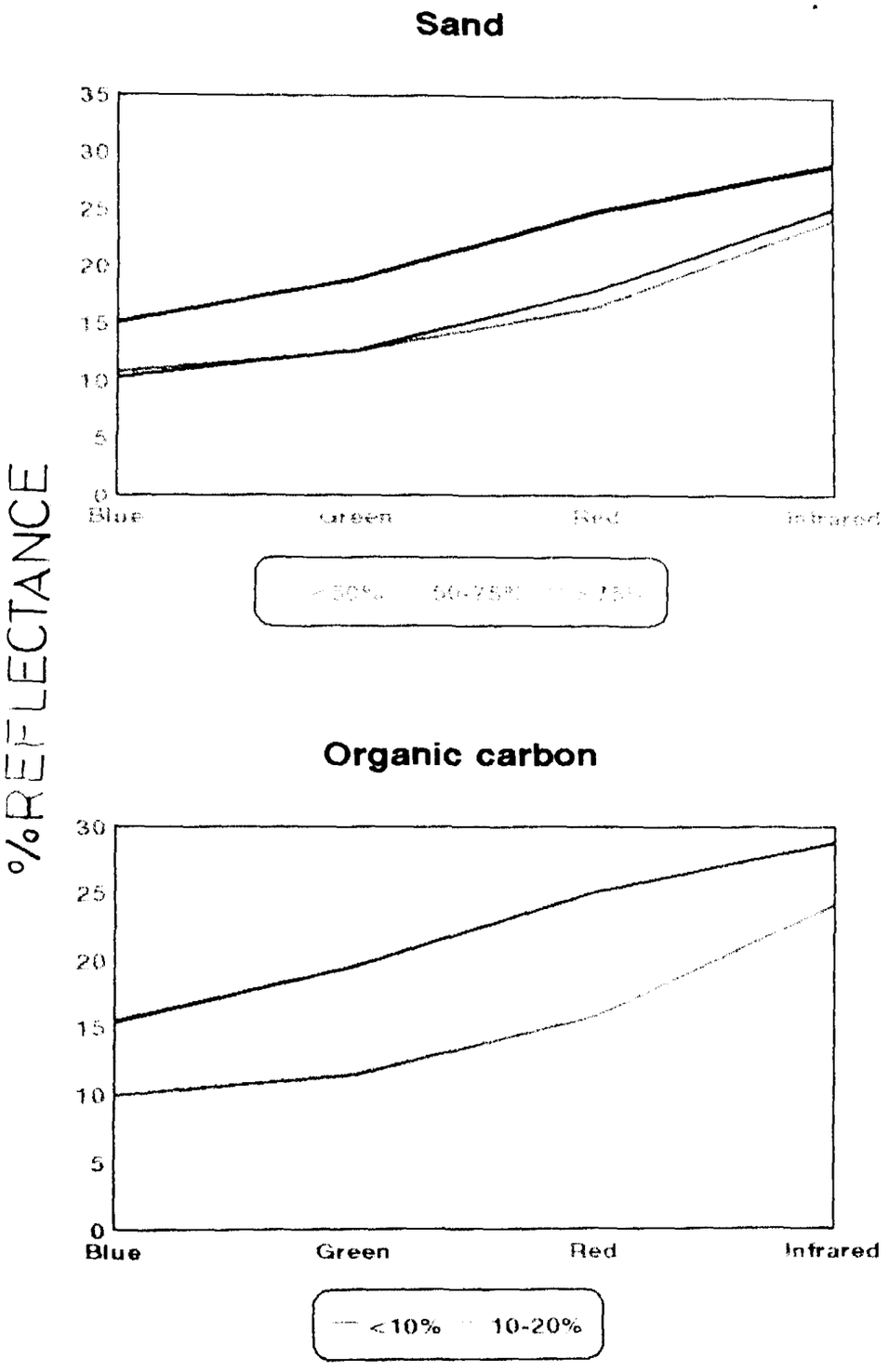
The soils in the present investigation possessed 10R, 2.5 YR, 5 YR, 7.5 YR and 10 YR hues. The reflectance recorded at the different bands of these soil showed that the soils with 7.5 YR hue have higher reflectance value compared to other group of soils. The reflectance curves were more closer in all the soils except those with 7.5 YR hues (Fig.7).

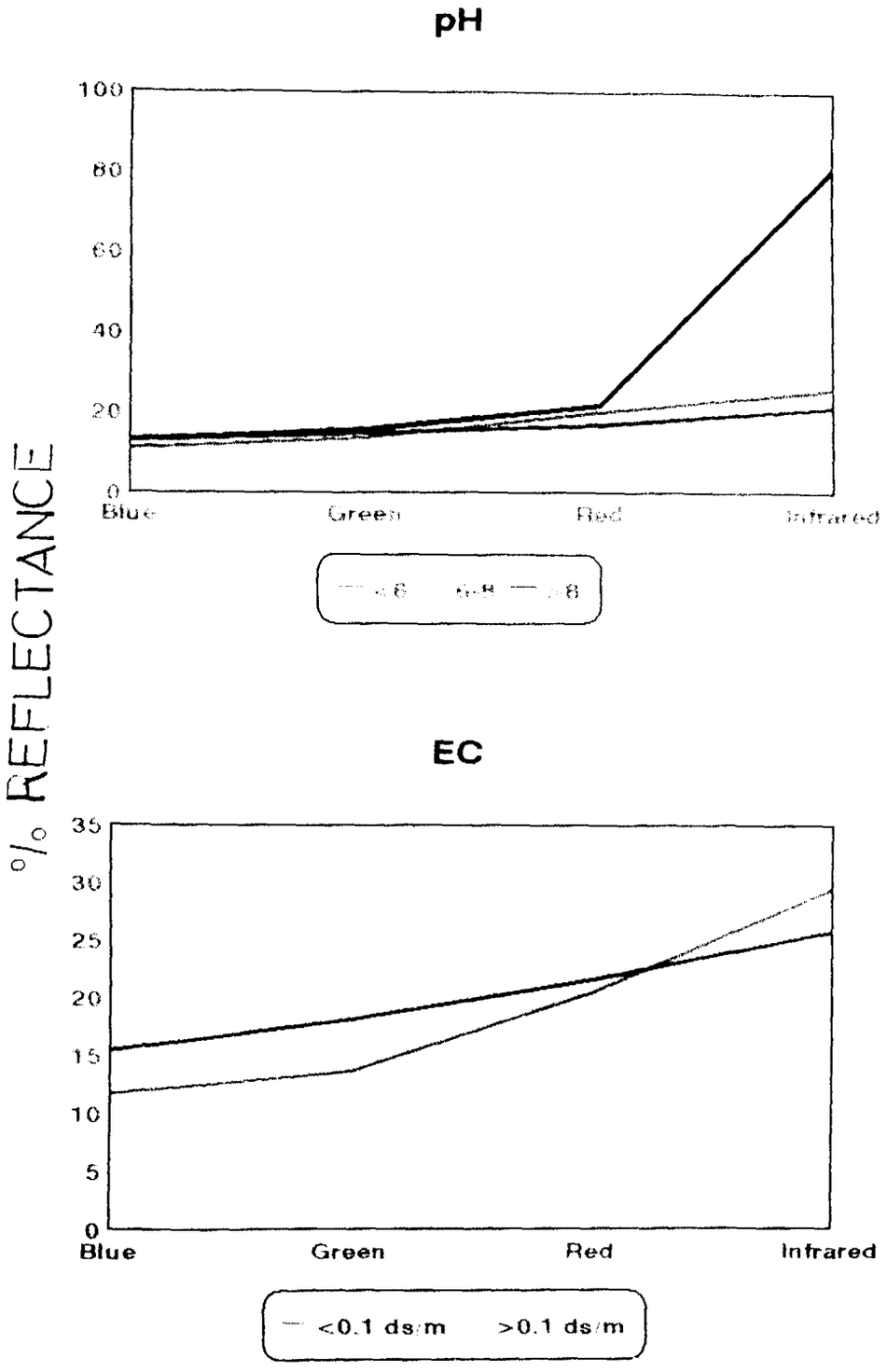
4.13.5. Effect of moisture retention at 33 kPa

The spectral reflectance of the soils with moisture retained at 33 kPa showed that the spectral reflectance increased from blue to infrared band.

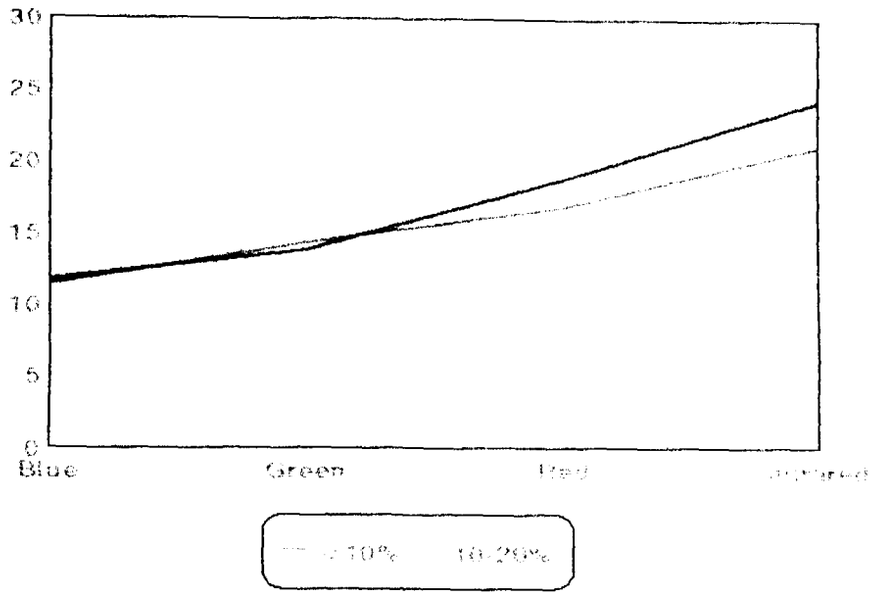
Fig.7. EFFECT OF SOIL PROPERTIES ON SPECTRAL REFLECTANCE



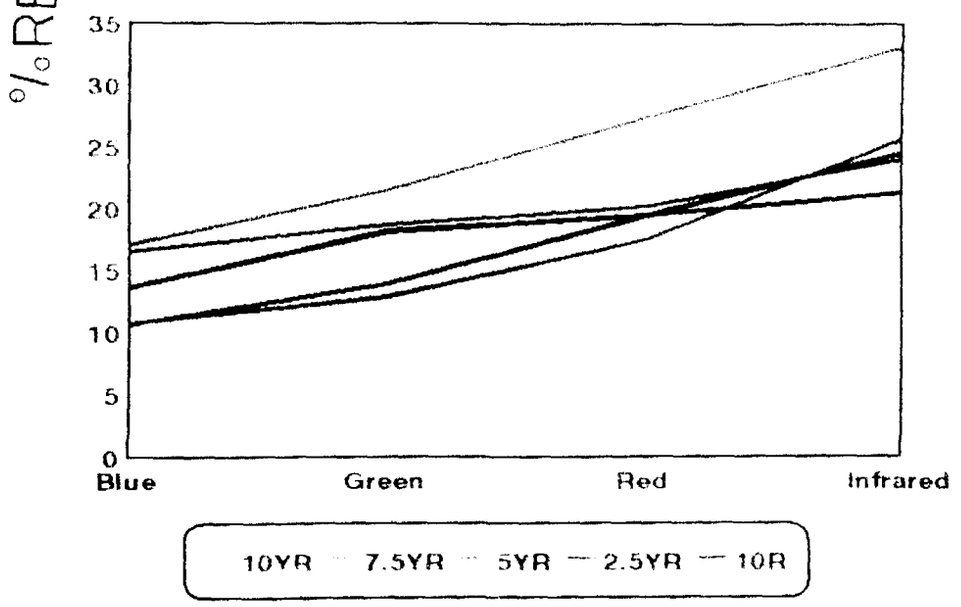

Sand
35
30
25
20
15
10
5
0
Blue
Green
Red
Infrared
%REFLECTANCE
Organic carbon
30
25
20
15
10
5
0
Blue
Green
Red
Infrared
<10%
10-20%

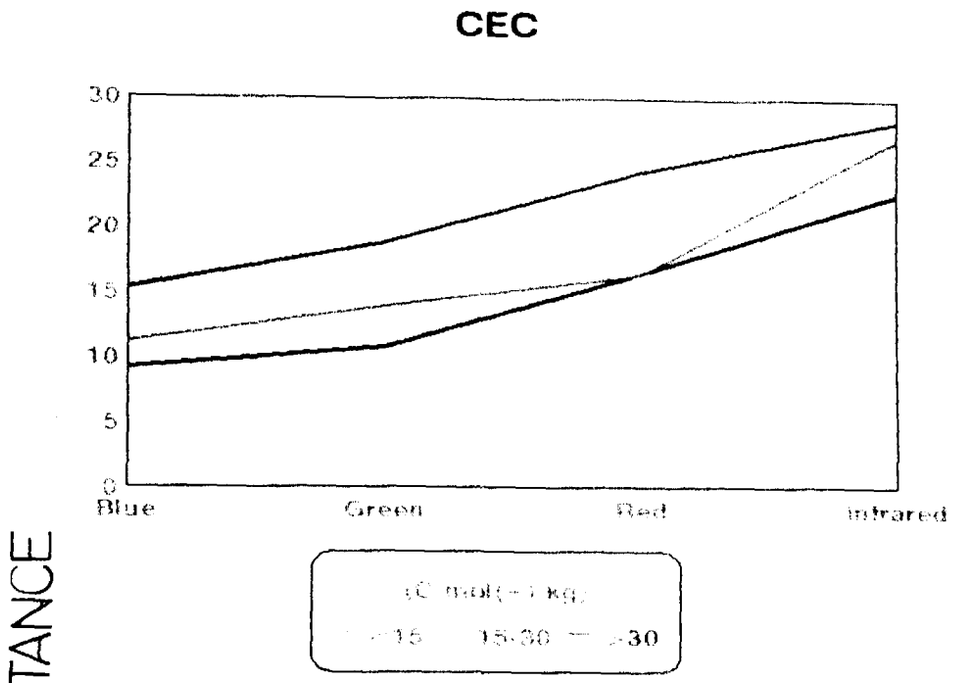

pH
100
80
60
40
20
0
Blue
Green
Red
Infrared
% REFLECTANCE
EC
35
30
25
20
15
10
5
0
Blue
Green
Red
Infrared
<0.1 ds/m
>0.1 ds/m

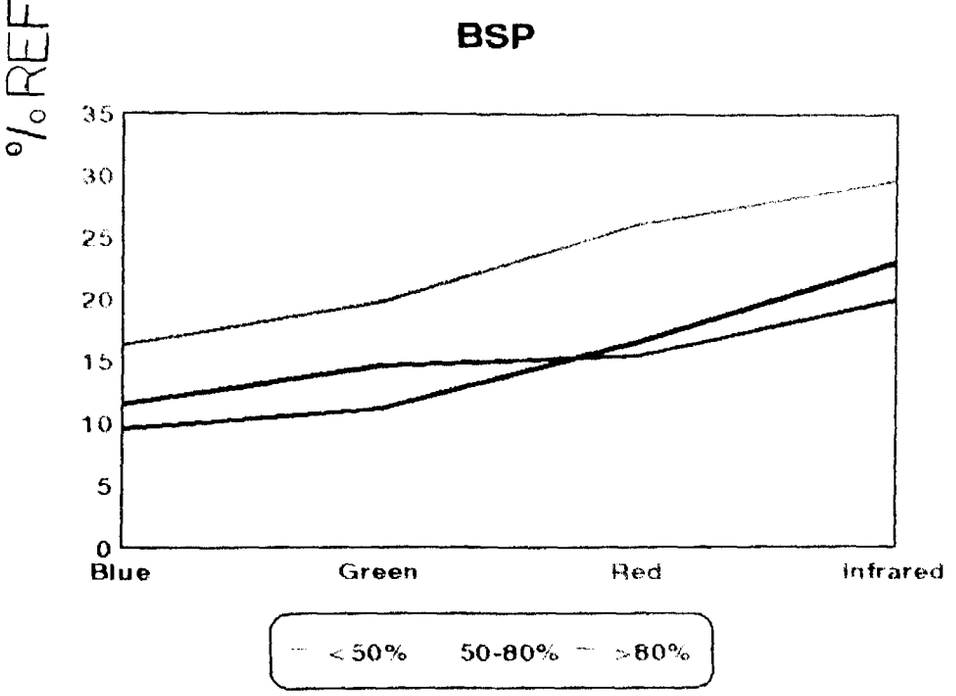
Free iron oxide



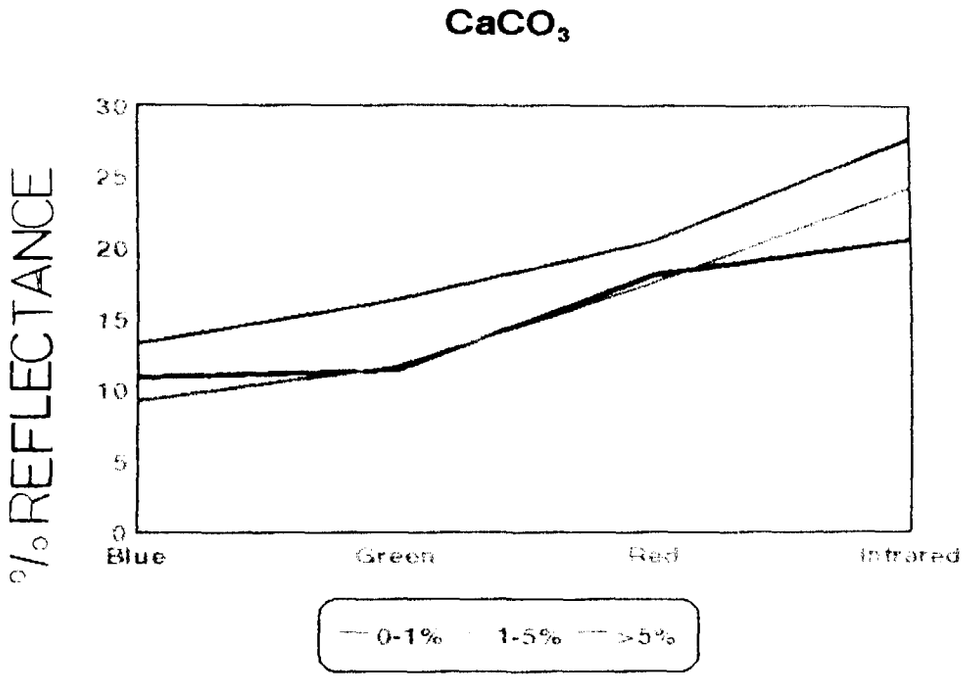
Colour







% REFLECTANCE


CaCO3
% REFLECTANCE
30
25
20
15
10
5
0
Blue
Green
Red
Infrared
0-1%
1-5%
>5%

However no regular trend was observed for differentiation of the soils based on their spectral values (Fig.7).

4.13.6. Effect of moisture retention at 1500 kPa

The reflectance of the soils with moisture retained at 1500 kPa showed significant difference of spectral reflectance. The values increased from blue to infrared band in all the soils. The reflectance in all the four bands was generally low in soils with higher moisture retention but was high in the soils having low moisture retention (Fig.7).

4.13.7. Effect of organic carbon

The soils were categorized into two groups based on the organic carbon content : (a) soils with low organic carbon (less than 0.4%). (b) soils with high organic carbon more than 0.4 per cent. The reflectance curves were distinctly different for the above two group of soils. The reflectance was lower in soils with high organic carbon and higher in soils with low organic carbon. This trend was observed in all the four spectral bands (Fig.7).

4.13.8. Effect of calcium carbonate

The influence of calcium carbonate content on the spectral reflectance could be seen from the Fig.7. The soils with low $CaCO_3$ equivalent (0 to 1) recorded higher reflectance value, compared to the soils in which the $CaCO_3$ equivalent were 1 to 5 or more than 5. The spectral reflectance curves were closer in blue, green, red bands and slightly wider at the infrared bands. The reflectance values of the soils, with different $CaCO_3$ content, increased generally from blue, green, red to infrared band.

4.13.9. Effect of soil reaction

The reflectance increased from blue to infrared band in the soils with different pH values. Soils with high pH (more than 8) registered higher

However no regular trend was observed for differentiation of the soils based on their spectral values (Fig.7).

4.13.6. Effect of moisture retention at 1500 kPa

The reflectance of the soils with moisture retained at 1500 kPa showed significant difference of spectral reflectance. The values increased from blue to infrared band in all the soils. The reflectance in all the four bands was generally low in soils with higher moisture retention but was high in the soils having low moisture retention (Fig.7).

4.13.7. Effect of organic carbon

The soils were categorized into two groups based on the organic carbon content : (a) soils with low organic carbon (less than 0.4%). (b) soils with high organic carbon more than 0.4 per cent. The reflectance curves were distinctly different for the above two group of soils. The reflectance was lower in soils with high organic carbon and higher in soils with low organic carbon. This trend was observed in all the four spectral bands (Fig.7).

4.13.8. Effect of calcium carbonate

The influence of calcium carbonate content on the spectral reflectance could be seen from the Fig.7. The soils with low $CaCO_3$ equivalent (0 to 1) recorded higher reflectance value, compared to the soils in which the $CaCO_3$ equivalent were 1 to 5 or more than 5. The spectral reflectance curves were closer in blue, green, red bands and slightly wider at the infrared bands. The reflectance values of the soils, with different $CaCO_3$ content, increased generally from blue, green, red to infrared band.

4.13.9. Effect of soil reaction

The reflectance increased from blue to infrared band in the soils with different pH values. Soils with high pH (more than 8) registered higher

reflectance in all the four bands compared to soils with neutral and acidic soil reaction. The reflectance curves were closer at blue and green bands while they were distinctly wider at red and infrared bands (Fig.7).

4.13.10. Effect of electrical conductivity

The reflectance was higher in the infrared band and decreased in red, green and blue bands for the soils with different EC values. Soils with low EC values (less than 0.1 dSm^{-1}) could be differentiated from the soils with high EC values (0.1-0.5 dSm^{-1}) in all the spectral bands except in the red band. Soils with high EC values showed lower reflectance in blue, green and red bands but a reverse trend was observed in the infrared band (Fig.7).

4.13.11. Effect of free iron oxide

The soils were grouped into two categories based on their free iron oxide content : (a) soils with more than 5 per cent free iron oxide and (b) soils with less than 5 per cent free iron oxide. The spectral reflectance of these two group of soil were closer in blue and green bands while they were distinctly different at the red and infrared bands.

4.13.12. Effect of CEC

Soils with high CEC values recorded low reflectance in all the four spectral bands compared to those with medium and low CEC values. The reflectance generally increased from blue, green, red to infrared band. The spectral reflectance curves were closer in the soils with high and medium CEC at red band but other wise the curves were wider and distinctly different in all the other bands including for the low CEC soils.

4.13.13. Effect of base saturation percentage

The reflectance values increased generally from blue, green, red to infrared band in the soils with different BSP values. The spectral reflectance

curve of the soils, with 50-80 per cent base saturation was distinctly different from the soils, with more than 80 and less than 50 per cent base saturation, in which they were closer to each other. The reflectance were different in blue, green and infrared bands for the soils with less than 50 and more than 80 BSP.

4.14. Spectral reflectance of soil by horizon

The spectral reflectance generally decreased with depth in Pedon 1 except for 50-74 cm and 74-100 cm depths at red and infrared bands. The reflectance of all the horizons increased from blue, green, red and infrared bands (Fig.8).

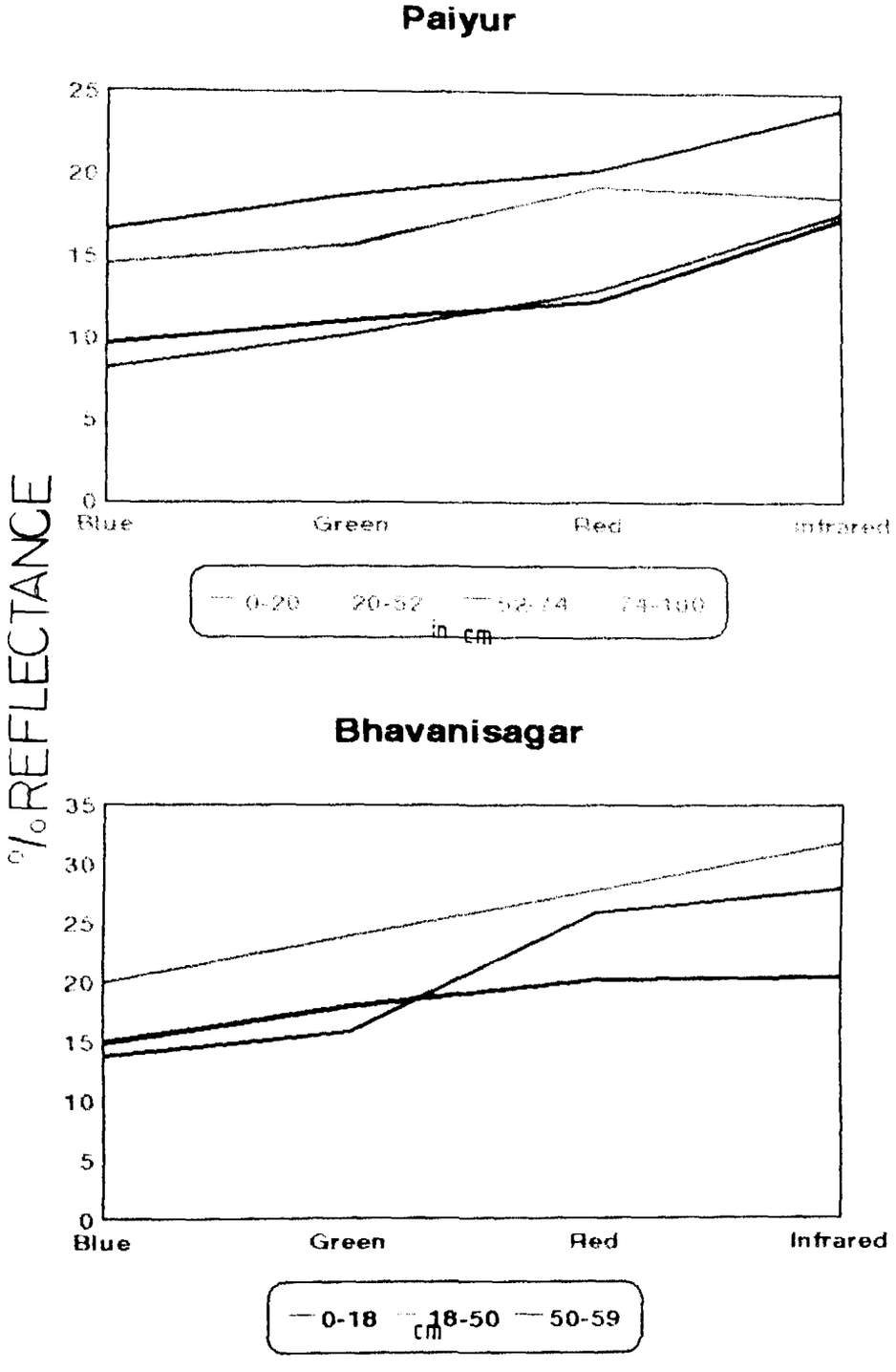
In the case of Pedon 2, the reflectance in all the bands was higher in the subsoil (18-50 cm depth) compared to the other two horizons (0-19 cm and 50-69 cm depths). The reflectance curves were distinctly different in the red and infrared bands for all the horizons.

Higher reflectance for Pedon 3 was noticed in the surface horizon (0-16 cm depth) in blue, green and red bands while in the infrared band the reflectance was high in the 30-50 cm depth. A regular decrease of reflectance with depth in blue band was noticed while no such trend was observed in other bands for the remaining layers (Fig.8).

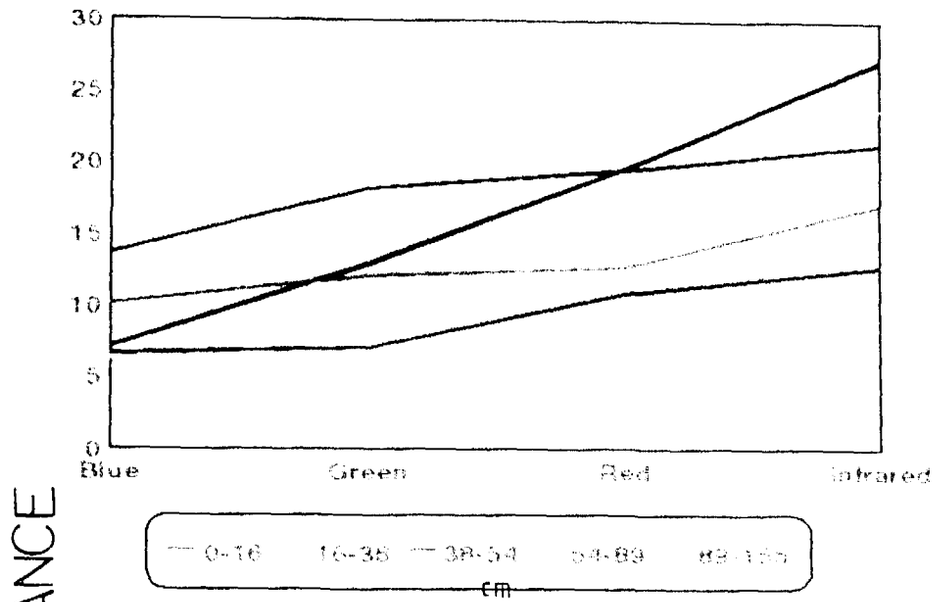
In Pedon 4, the reflectance measured in blue, green and infrared bands were higher in the 23 to 52 cm depth in comparison to the other horizons. The highest reflectance in the red band was noticed in the surface horizon. The reflectance in red band decreased with depth. The reflectance in the other three bands did not follow any pattern (Fig.8).

In Pedon 5, the highest reflectance in blue, red and infrared bands were recorded in the 48 to 72 cm depth. The highest reflectance in the green band was recorded in the surface horizon. The depthwise distribution

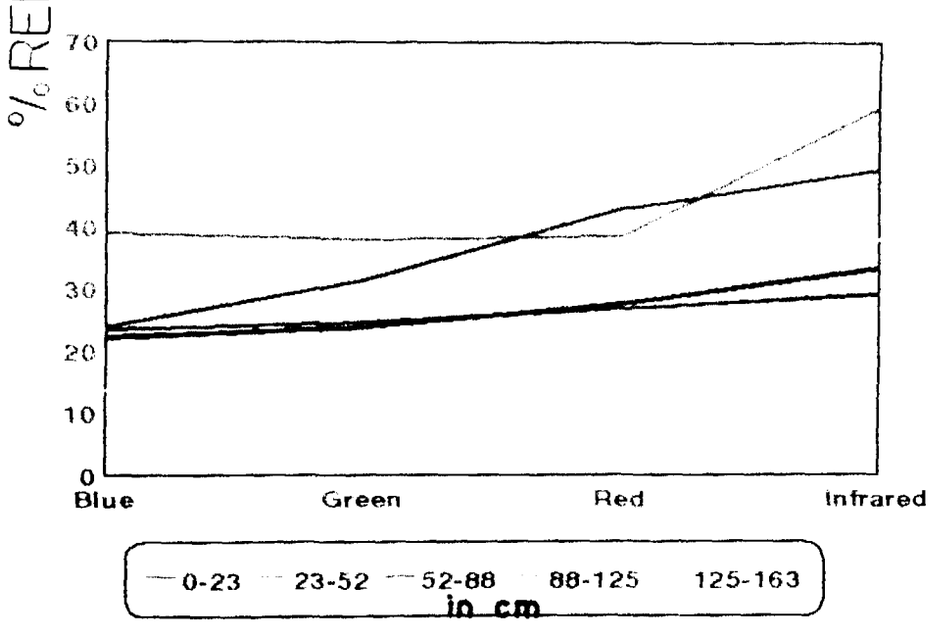
Fig.8. SPECTRAL REFLECTANCE OF SOIL BY HORIZON



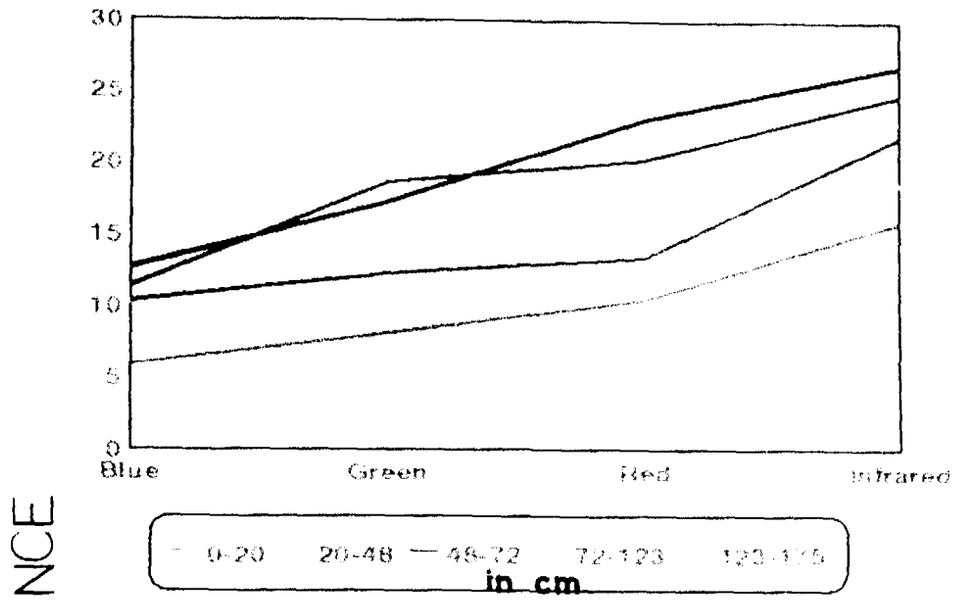
Thenkasi



Periyakulam

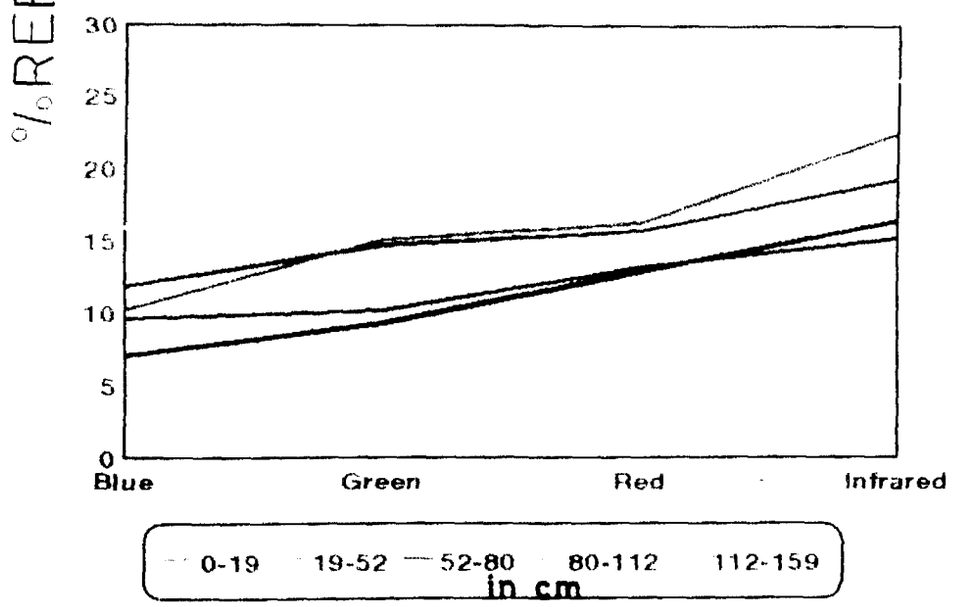


Sathankulam

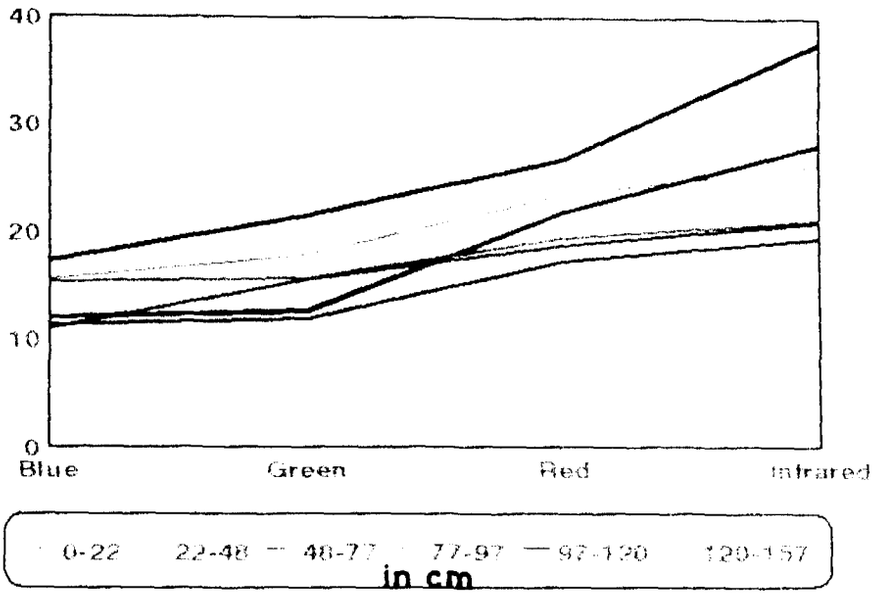


% REFLECTANCE

Aruppukkottai

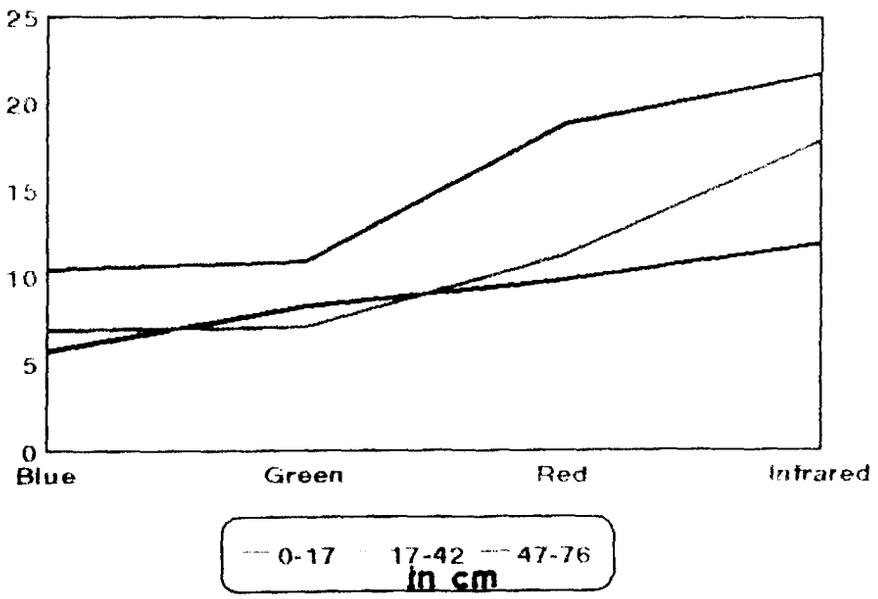


Coimbatore

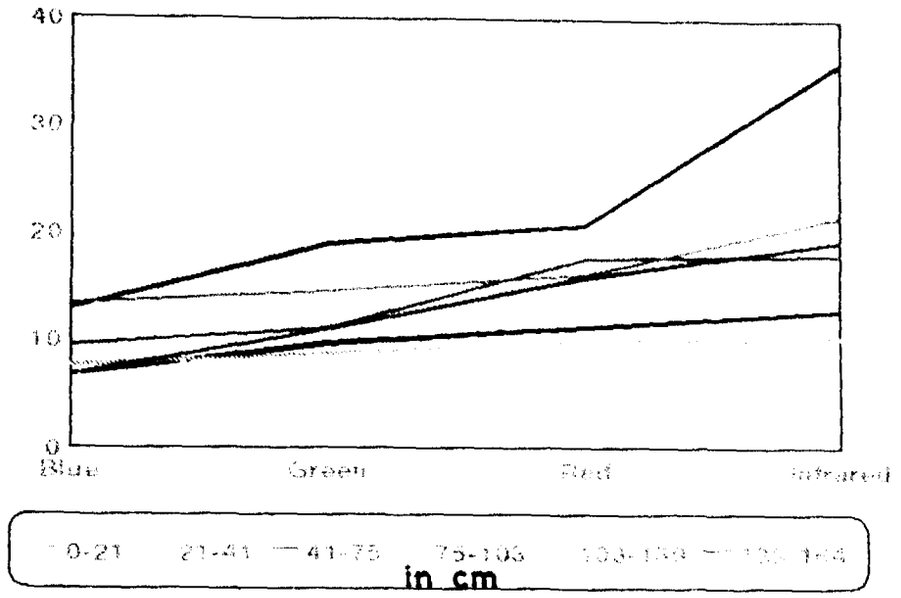


% REFLECTANCE

Palladam

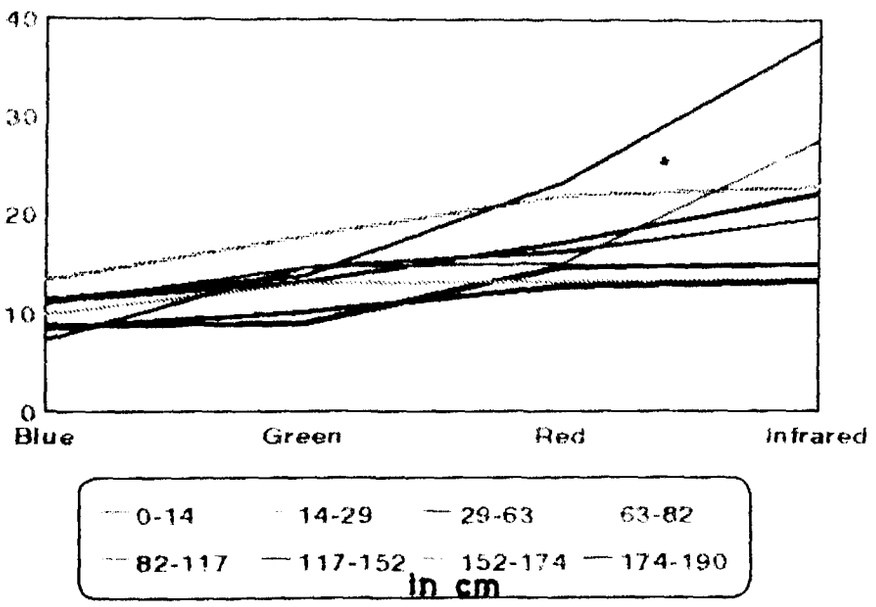


Aduthurai

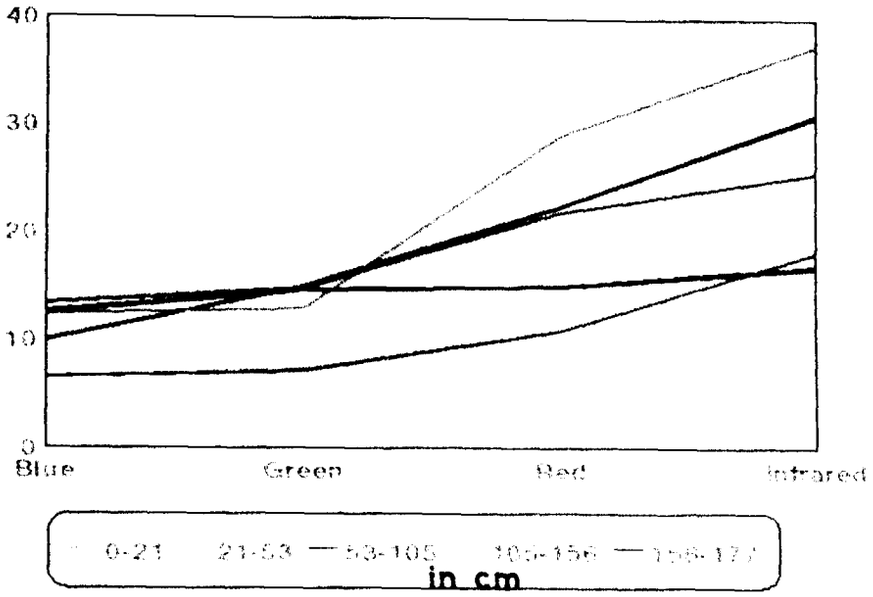


%REFLECTANCE

Sellur

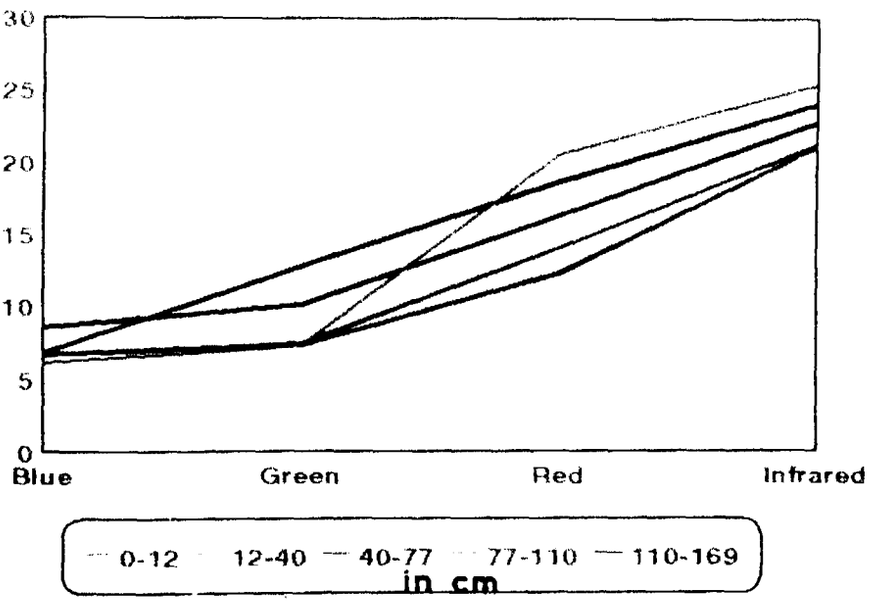


Vridhachalam

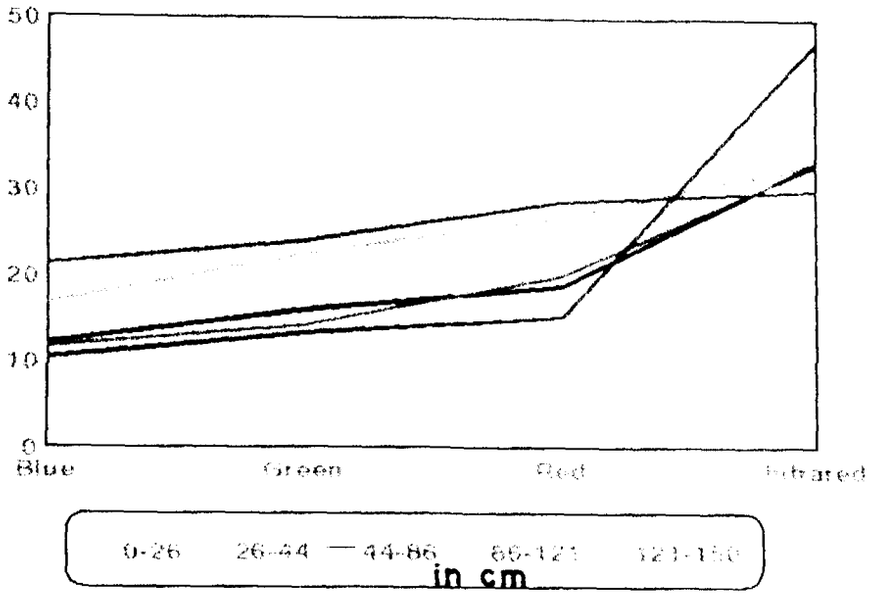


% REFLECTANCE

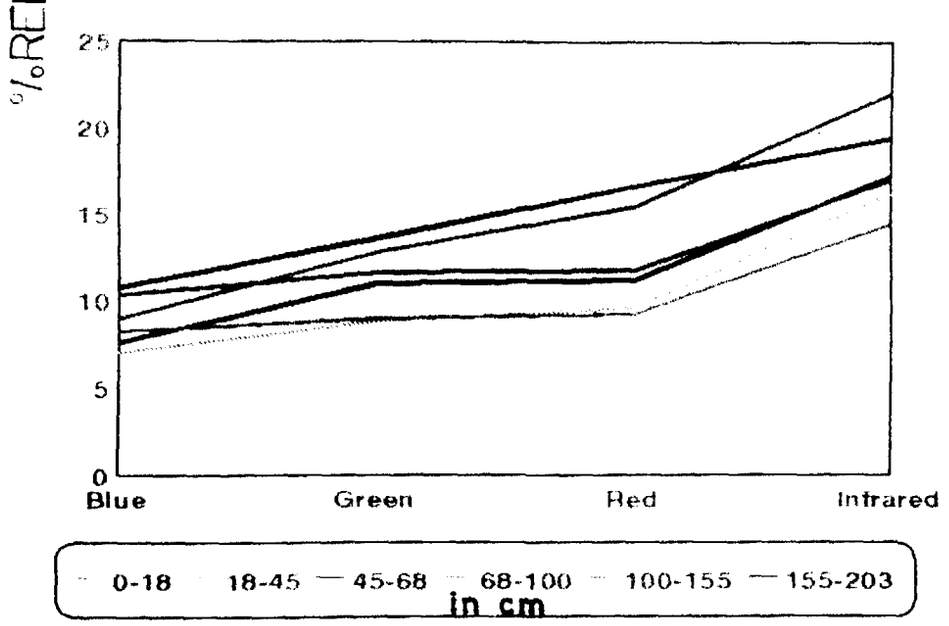
Vamban

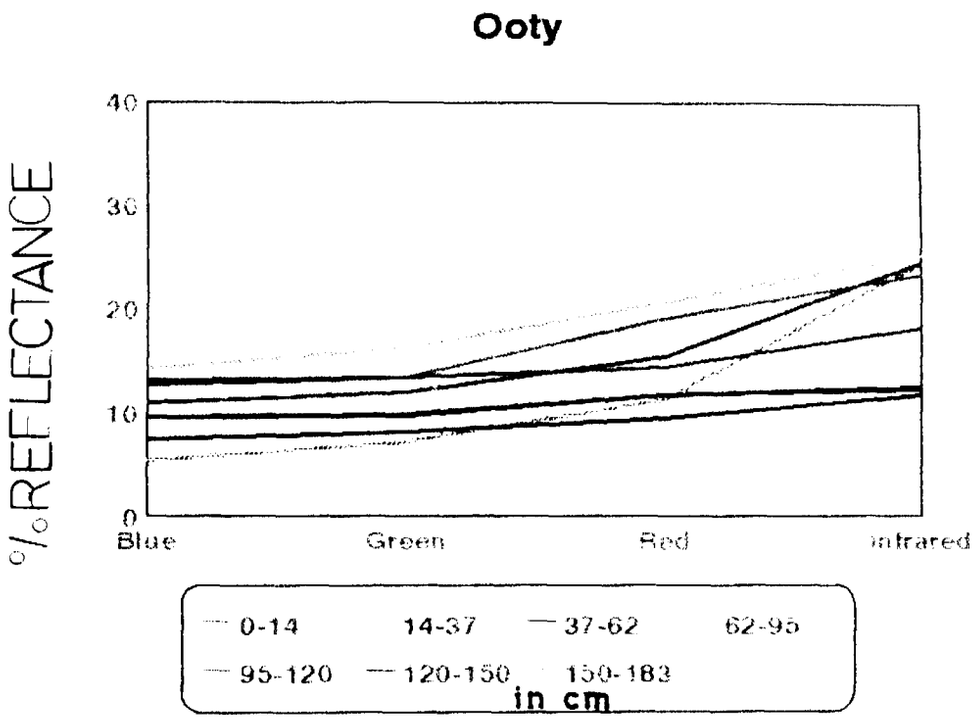


Madurai



Pechiparai




Ooty
%REFLECTANCE
40
30
20
10
0
Blue
Green
Red
Infrared
0-14
14-37
37-62
62-95
95-120
120-150
150-183
in cm

was irregular in all bands. A notable feature was that the second horizon i.e. 20-48 cm depth recorded the lowest reflectance in all bands (Fig.8).

In Pedon 6, the spectral reflectance in all bands increased with depth from the third horizon i.e. 52-80 cm depth and the highest values were recorded in the 112-159 cm depth (Fig.8).

In Pedon 7, the depthwise distribution was irregular. The highest reflectance in all the four bands was recorded in the 97-120 cm depth (Fig.8).

In Pedon 8, the spectral reflectance decreased with depth in all the bands except in blue band (Fig.8).

In Pedon 9, the reflectance measured in the green, red and infrared bands increased from the surface to 75 cm depth and decreased thereafter. The highest reflectance in the blue band was recorded in 21 to 41 cm depth. In case of green, red and infrared bands, the maximum reflectance was registered between 41 and 75cm depth (Fig.8).

In Pedon 10, the highest reflectance in blue and green bands were recorded in the 152 to 174 cm depth. The surface horizon (0-14 cm) was found to reflect high in red and infrared bands. The reflectance in blue band decreased upto 82 cm depth while the reflectance in red and infrared bands decreased upto 63 cm depth. The trend after these depths was variable (Fig.8).

In Pedon 11, the reflectance measured in the blue band decreased from the surface to 156 cm depth and reflectance in infrared band decreased from 21 cm to 177 cm depth. In the green and red bands the reflectance decreased from 21 cm to 156 cm depth. The highest reflectance in the blue and green band were recorded in the surface horizon (0-21 cm) and third horizon (53-105 cm)respectively. The highest reflectance in the red and infrared bands were recorded in the 21-53 cm depth (Fig.8).

In Pedon 12, the depthwise distribution of spectral reflectance was irregular in all four bands. The highest reflectance in the blue and green bands were noticed in the 110 to 169cm depth and 40 to 77 cm depth respectively. The horizon in 12 to 40 cm depth reflected high in the red and infrared bands (Fig.8).

In Pedon 13, the reflectance measured in the blue and green bands were found to increase from the surface to 121 cm depth. The depth function of reflectance in the red and infrared bands were irregular. The highest reflectance in the blue, green and red bands were measured at 85 to 121 cm depth. The surface horizon (0-26 cm) reflected high in the infrared band (Fig.8).

In Pedon 14, the depth functions of reflectance were irregular in all the four bands. The highest reflectance in the blue, green and red bands were noticed in the bottom most horizon (155-203 cm depth). The highest reflectance in the infrared band was noticed in the 68 to 100 cm depth (Fig.8).

In Pedon 15, the depthwise distribution was irregular in all the four bands. The highest reflectance was recorded at the 95 to 128 cm depth in all the bands. The lowest reflectance was registered in 150-183cm for blue and green bands. In case of red and infrared bands, the horizon in 37-62 cm depth recorded low reflectance (Fig.8).

4.15. Correlation studies between spectral reflectance and soil properties (Table 20)

Simple correlation between the spectral reflectance measured in the four bands and soil properties were worked out.

The spectral reflectance measured in the four bands were intercorrelated and the correlations were positive. The correlations between

able 20. Correlation coefficients (r) of spectral bands and soil parameters.

	Blue	Green	Red	Infra Red	pH_w	pH_{KCl}	EC	OC	$CaCO_3$	Clay	Silt	Sand	33kPa	1500kPa	CEC	BSP	Fe_2O_3	Free iron	SiO_2	Total acidity
lue	1.000	0.938**	0.823**	0.688**	0.265*	0.338**	-0.049	-0.076	-0.053	-0.485	-0.058	0.568*	-0.194	-0.211	-0.183	0.124	-0.124	-0.396*	0.531*	-0.449*
reen		1.000	0.870**	0.734**	0.270*	0.315**	-0.005	-0.162	-0.086	-0.352	-0.044	0.535*	-0.179	-0.188	-0.172	0.133	-0.115	-0.287	0.580*	-0.505**
ed			1.000	0.827**	0.277*	0.266*	-0.023	-0.197	-0.069	-0.407	-0.099	0.350*	-0.151	-0.166	-0.166	0.213	-0.122	-0.247	0.554**	-0.688**
ifra Red				1.000	0.281*	0.267*	-0.056	-0.137	-0.113	-0.454	-0.162	0.483*	-0.049	-0.061	-0.094	0.220	-0.039	-0.213	0.552*	-0.563**

spectral reflectance in all the four bands were positively and significantly correlated with pH_w, pH_{KCl}, sand and SiO_2 content. A significant negative correlation was observed with total acidity. The correlation between per cent base saturation and spectral reflectance was positive but not significant. Correlation between the spectral bands and EC, organic carbon, $CaCO_3$, clay silt, moisture retention at 33 kPa and 1500 kPa, CEC, total iron oxides and free iron oxides was negative but did not attain the level of significance.

Regression equations developed to predict soil properties from the spectral bands are presented in Table 21.

Table 21. Linear regression equations for predicting soil parameters from spectral reflectance data

Blue		
	pH_w	Y = 6.076 + 0.1 (X)
	pH_{KCl}	Y = 4.68 + 0.1 (X)
	Sand	Y = 54.42 + 1 (X)
	EC	Y = 0.308 - 0.004 (X)
	Total acidity	Y = 10.047 - 0.3 (X)
	S_iO_2	Y = 62.922 + 0.418 (X)
Green		
	pH_w	Y = 5.948 + 0.1 (X)
	pH_{KCl}	Y = 4.62 + 0.1 (X)
	Sand	Y = 54.19 + 1 (X)
	Total acidity	Y = 11.246 - 0.3 (X)
	S_iO_2	Y = 61.106 + 0.538 (X)
Red		
	pH_w	Y = 5.816 + 0.1 (X)
	pH_{KCl}	Y = 4.68 + 0.1 (X)
	Sand	Y = 52.31 + 1 (X)
	Total acidity	Y = 13.067 - 0.3 (X)
	S_iO_2	Y = 58.362 + 1.083 (X)
Infra Red		
	pH_w	Y = 5.862 + 0.048 (X)
	pH_{KCl}	Y = 4.74 + 0.043 (X)
	Sand	Y = 55.65 + 0.328 (X)
	Total acidity	Y = 12.324 - 0.216 (X)
	S_iO_2	Y = 61.456 + 0.323 (X)

Discussion

CHAPTER 5

DISCUSSION

The morphological characteristics as observed in the field and the results of the analysis of physical and chemical properties of the soils are discussed in this chapter.

5.1. Morphology

The morphological properties of the pedons varied widely depending on the pedogenic environment. Distinct differences were observed in the morphological properties like solum depth, colour, mottles, texture, structure, concretions and special features like slickensides and clay films. The differences in these properties were partly due to differences in parent materials and partly due to the pedogenic processes.

5.1.1. Solum depth

The solum depth was less than 1m in Pedons 2 and 8 and more than 1m in other pedons. The depth limitation in Pedons 2 and 8, were due to undulating topography. In addition to this, severe erosion in Pedon 8 was responsible to the solum depth of 76 cm. Prasad *et al.* (1989) also reported that, soil depth is related to the slope and degree of erosion. Another factor that could have influenced the solum depth of Pedon 8 was the calcareous parent material. Several workers have reported that abnormally shallow profiles result when they are developed on parent materials, excessively high in lime (Ehrlich *et al.*, 1967; Subbaiah and Manickam, 1992).

5.1.2. Colour

Soil colour often reflects the influence of texture and soil drainage, aeration and configuration of watertable. The hue component of the colour

can give a reasonably good idea of the iron oxide mineralogy of the soils (Richardson and Daniels, 1993).

The hue of Pedon 3 was 10R almost throughout the solum. This could be due to the presence of haematite, especially small haematite crystals. The 2.5YR colours of Pedons 1, 2, 4, 5 and 14 could also be attributed to the presence of haematite. The 5YR colour of Pedon 11 could be due to the presence of haematite in association with goethite. Childs and Wilson (1983) and Schwertmann (1993) reported similar observations.

Childs and Wilson (1983) stated that goethite is associated with 10YR colours. The 10YR colours of Pedons 13 and 15 were probably due to the presence of goethite.

The degree of oxidation or hydration, but not the total Fe_2O_3 are responsible for colour (Sahu *et al.*, 1983). In Pedons 1, 3, 5, 9, 10, 12 and 15, hues remained same almost throughout the solum. It is therefore inferred that the iron content could have varied within the pedons, but the iron oxide minerals have not undergone any transformation.

In Pedon 1, the surface horizon alone recorded 5YR colour while the rest of the horizons registered a hue of 2.5YR. This pedon has been subject to erosion (e_2) and the surface horizon had 95 per cent sand. The process of erosion could be the reason for the 5YR hue in the surface horizon.

The dark colour of Pedons 6 and 7 might be due to the formation of clay organic matter complex, iron sulphides and manganese oxides as suggested by Dudal (1965). The 10YR colour of Pedon 8 was probably due to the influence of calcareous parent material.

The 10YR colour of Pedons 9 and 10 could be attributed to their wetness and imperfect drainage. Singh *et al.* (1989) have reported similar findings. The dark colour of Pedon 15 could be due to the high organic

matter content. Schulze *et al.* (1993) reported that humic acid is responsible for the dark colour of the soil organic matter.

5.1.3. Structure

The structure was granular in the surface horizons of Pedons 1, 4, 5 and 8. In these pedons the texture varied from sandy to sandy loam. This was the cause for the granular structure. Pachrane *et al.* (1996) reported similar observations. The crumb structure of Pedon 15 could be attributed to the high organic carbon content. The subangular blocky structure of other pedons was probably due to the medium to heavy texture of these pedons. Sharma and Dev (1985b) attributed the development of blocky structure to alternate wet and dry conditions.

The structure in the subsurface horizons was angular blocky in Pedons 6 and 7. In the rest of the pedons, the structure was subangular blocky. The texture of the pedons could have influenced the structure. Tiwary *et al.* (1989) reported that, in soils with good base saturation particularly with reference to Ca, there was a tendency to form blocky structure, either angular or subangular.

5.1.4. Mottling

Mottles were observed in the surface and subsurface horizons in Pedons 9 and 10, and in the subsurface horizons of Pedons 13 and 15. Pedons 9 and 10 were examined in rice cultivated alluvial plains, where the soil is generally wet for a larger part of the year. Pedon 15, located in a hilly area, also remained wet for a substantial part of the year because of the high rainfall. These prolonged wet periods, should have resulted in mottle formation in these pedons as stated by Veneman *et al.* (1976) and Diwakar and Singh (1994).

In Pedon 13, the mottles could have formed due to fluctuating watertable levels. Zampella (1994) observed that a dual parameter approach taking into account soil features like mottling and vegetation could be used to determine water levels.

In Pedon 9 and 15, the mottles were dark with low chroma colours (10YR 2/1 and 10YR 3/1), suggesting the dominance of manganese. In Pedon 10 the mottles were brownish indicating the dominance of iron. In Pedon 13 the interesting feature was that while the soil matrix had a hue of 7.5 YR and 10 YR, the mottles possessed a hue of 2.5 YR. This might be due to alternate wetting and drying conditions after long periods of saturation.

5.1.5. Fe-Mn concretions

Several theories have been advanced with respect to the formation of Fe-Mn concretions (Aubert, 1963; Gallaher *et al.*, 1974; Sidhu *et al.*, 1976). Childs (1975) reported that, the formation of Fe-Mn concretions in soils, is primarily due to the ability of Fe and Mn to change their oxidation states in response to pH and Eh changes. Fe and Mn, originally present in highly insoluble forms, may become relatively soluble when pH and/or Eh changes occur enabling relocation in response to diffusion gradient and water movement. Secondary deposits occur in conditions where insoluble forms of Fe and Mn again become thermodynamically stable.

The presence of Fe-Mn concretions in Pedons 9 and 10, could be attributed to the redox conditions. These pedons were located in rice growing alluvial plains, where water stagnation is present for most part of the year. Zaydelman and Ogleznev (1971) reported that, waterlogging resulted in the increase of mobile iron and enhanced migration of manganese. These could have precipitated under the high pH in these pedons resulting in concretion formation.

Impeded internal drainage could have caused the formation of concretions in Pedon 7 and 12. In soils with impeded drainage, Fe and Mn are mobilized by reduction and afterwards concentrated in various forms among which concretions are the most frequent (Schwertmann and Fanning, 1976).

5.1.6. $CaCO_3$ nodules

The accumulation of calcium carbonate in sola is an important pedogenic process. Brewer (1964) suggested that the carbonate nodules are formed *in situ* by processes of diffusion and/or crystallisation in small voids due to local variations in chemical conditions. Pedons 6 and 7 desiccated during the summer months from March to June, and this was followed by wetting by monsoon rains, thus facilitating the movement of solutions from the voids into the soil material surrounding it. The high pH could have precipitated the $CaCO_3$ leading to the formation of nodules. Sehgal and Stoops (1972) reported similar views. The nodules thus formed at the lower horizons have moved up as a result of pedoturbation. Thiyagarajan (1985) reported similar observations.

The carbonate nodules observed in Pedon 8 is a result of the calcareous parent material, Ahmad (1983) stated that carbonate nodules are common in soils developed on basic igneous rocks and calcareous materials. In Pedon 8, insufficient rainfall was the cause of nodule formation. In Pedon 7 carbonate nodules as well as Fe-Mn concretions were observed. Both type of nodules can occur in the same profile (Simonson, 1954; Borden and Warkentin, 1974).

5.1.7. Special features

5.1.7.1. Surface cracks

Surface cracks were observed in Pedons 6, 7, 9 and 10, as a result of the shrink and swell properties of the soils, which inturn, are functions of

clay content, clay type, degree of hydration, rainfall distribution, natural vegetation and land use (Ahmad, 1983). The cracks observed in Pedons 6, 9 and 10, could be the result of the high clay content in their surface horizons. The influence of intensive cultivation could be an additional factor in Pedons 9 and 10 located in alluvial plains. In Pedons 6 and 7, the free iron oxides extracted by dithionite citrate-bicarbonate were low in the surface horizons than in the subsurface horizons. Davidson and Page (1956) found that removal of extractable Fe_2O_3 from the soil increased their property to swell. This could be the reason for the development of wide cracks in Pedons 6 and 7.

5.1.7.2. Slickensides

Slickensides are polished and grooved surfaces that are produced by one soil mass sliding past another. Large slickensides, below the depth of the apparent cracking zone, are attributed to stress phenomena (Mermut and Acton, 1985). Yaalon and Kalmar (1978) reported that, the depth of the soil at which the development of slickensides is active, is determined by the depth of cracking and of seasonal wetting. In the present study slickensides were observed in Pedons 6 and 7. In Pedon 6 prominent slickensides were observed in the 80 to 112 cm depth. In Pedon 7, slickensides were observed at a shallower depth, between 48 to 77 cm depth. This could be due to the comparatively lower annual rainfall in the location of Pedon 7. This is in agreement with the view of Ahmad (1983) who stated that, if the rainfall was lower, slickensides occurred closer to the surface. Vadivelu and Challa (1985) reported a positive correlation between mean annual rainfall and depth of occurrence of slickensides. They reasoned that, the amount of water available for wetting, and the nature of wetting seem to be the deciding factors for the depth of occurrence of slickensides.

Particularly, it is the difference in moisture percentage within a horizon, that causes shearing, resulting in slickenside formation. In high rainfall areas, it is quite likely that, upto a certain depth, there is uniformity in lateral wetting. Lateral wetting is irregular in very deep horizons as wetting of the soil mass between the cracks is never complete (Blokhuis, 1982). This irregular lateral wetting causes differential swelling that results in shearing and formation of slickensides.

5.1.7.3. Clay films

The presence of clay films is an evidence for illuviation. The illuvial materials are deposited on structural aggregates along root channels and on the surfaces of coarser particles. Voids in the soil matrix are often lined with colloidal weathering products (Eswaran, 1971). In the present study, clay films were observed in Pedons 4, 5, 11, 12, 13 and 15. In Pedon 15 the cutans were thick, whereas in Pedons 12 and 13 they were thin and patchy. Nettleton *et al.* (1969) suggested that if ped surfaces are not extremely stable and do not persist through many drying and wetting cycles, clay films will not develop to sufficient thickness.

5.2. Physical properties

5.2.1. Particle size distribution

The texture of the soils ranged from sand to clay. The textural differentiation in the soils can be explained by surface removal and deposition, sedimentary layering, *in situ* chemical weathering, clay illuviation and physical breakdown (Chittleborough *et al.*, 1984).

Among the different processes, erosion had played a major role in deciding the surface texture of many pedons. The sandy texture of Pedon 1, sandy loam texture of Pedons 8 and 11, were attributable to the influence of varying degrees of erosion. The sandy loam surface texture of Pedon 4

was probably a result of deposition of materials by streams. Based on the, on site observations, the sandy texture of Pedon 5 was considered a result of aeolian deposition. The sandy clay to clayey texture of Pedons 3, 13, 14 and 15 and the clayey texture of Pedons 6 were due to the influence of their parent material. The high clay content of Pedons 9 and 10 located in alluvial plains were attributable to the puddling operations under rice cultivation.

The texture of the subsurface horizons in all the pedons was due to the different stages of weathering and other soil forming processes. The increase in clay content in the subsurface horizons of Pedons 4, 5, 11, 12, 13 and 15 were due to illuviation. Different degrees of illuviation, though not intense, were responsible for the sandy clay to clayey texture, in Pedons 1, 2 and 3. Erosion had affected the subsurface texture also in Pedon 8 resulting in the sandy loam texture. Another factor that had resulted in the low clay content of Pedon 8 was its calcareous parent material. Low rainfall, and consequent insufficient leaching did not release the clay, cemented by aggregates of lime (Cady, 1960). The increase in clay content in Pedons 6 and 7 were due to argillopedoturbation (Thiyagarajan, 1985). The ratios of particle size fractions showed that the proportion of the fractions to each other varied widely, among and within the pedons.

The water dispersible clay content varied widely from 0.97 per cent in Pedon 1 to 41.26 per cent in Pedon 10. In general, it was observed that pedons with acidic or slightly acidic pH recorded low water dispersible clay values. Several authors have attributed the low content of water dispersible clay to the Zero Point of Net Charge (ZPNC). Eswaran and Sys (1979) reported that the water dispersible clay approaches minimum values close to the ZPNC, because in general, colloids flocculate at the ZPNC. Gallez *et al.* (1976) stated that the ZPNC of Low Activity Clay (LAC) soils range from 3 to 5. At pH lower than 5 Al plays a flocculating role by blocking permanent

charge sites. Dixit (1980) reported that, very low change in pH due to KCl addition is an indication that the soil carries very small surface charge or it lies at its ZPNC.

In this study, the pH of Pedons 5, 14 and 15 were 5 or less than 5 in most of their horizons. Probably Al had played a flocculating role resulting in low water dispersible clay as suggested by Gallez *et al.* (1976).

The pH ie., difference between pH_w and pH_{KCl} was less than 0.7 in Pedon 15. This could be an indication that the soil was close to its ZPNC, resulting in low water dispersible clay. The low water dispersible clay content of Pedon 15 could also be attributed to its Udic moisture regime. Sehgal *et al.* (1976) stated that soils developed in Ustic moisture regime are generally highly dispersed whereas soils developed on Udic moisture regime are generally flocculated and the water dispersible clay contents are low.

The low water dispersible clay contents of Pedons 1, 4, 5 and 11 were attributable to their sandiness.

The high values of water dispersible clay in Pedon 10 in some of its horizons could be a result of the high exchangeable sodium.

5.2.2. Coarse fragments

The coarse fragments in the pedons studied were mainly represented by quartz fragments, lime concretions and ferruginous concretions. Irregular quartz gravels were observed in Pedon 4. In Pedon 8, irregular quartz gravels were observed along with lime concretions. In Pedons 3 and 14, irregular quartz gravels were observed with ferruginous concretions. In Pedon 4, quartz gravels alone were present. In Pedon 6, lime concretions alone were present. In Pedons 9 and 12, irregular ferruginous gravels were observed. In Pedon 13, the ferruginous gravels were spherical. In Pedon 7, lime concretions as well as small ferruginous concretions were present.

The irregular nature of gravels suggested that they were formed *in situ* and not transported. Thiyagarajan (1985) reported similar observations.

5.2.3. Moisture retention characteristics

Simple correlation studies revealed that moisture retention at both 33 kPa and 1500 kPa were significantly and positively related to clay content and cation exchange capacity of the soils. The correlation with sand was significantly negative. Silt did not influence the moisture retention significantly.

The lowest mean value of moisture retention at 33 kPa was recorded in Pedon 5. This was the consequence of the low clay content of this pedon. Pedon 7 registered a comparatively lower clay content but higher moisture retention at 33 kPa than Pedons 2, 11, 13, 14 and 15. This indicated that Pedon 7 has dominantly 2:1 type of clay with higher water retention properties.

Moisture retained at 1,500 kPa was highest in Pedon 6 which can be attributed to its clay content. Loamy soils contain more available water, as compared to clay soil, due to the fact that the wilting point moisture in clay soils is high compared to loam (Mishra and Nanda, 1985). Though Pedon 6 was clayey textured, it recorded the highest available moisture capacity. Similar observations have been made by Ushakumari *et al.* (1987) for the soils of Kerala.

5.2.4. Bulk density

In a majority of the Pedons, the bulk density increased with depth. Plant roots create and stabilise channel voids. A decrease in root volume would lead to increased bulk density. Similarly a general decrease in faunal population would reduce void space volume leading to increase in bulk density (Blank and Fosberg, 1989). The low bulk density recorded in Pedon 15 was the result of the high organic matter content.

5.3. Physico-chemical properties

5.3.1. Soil reaction

The pH of the Pedons varied over a wide range. Sieg (1993) attributed such wide variation in pH among pedons to differences in parent material. Pedons 4,6,7,8 and 13 recorded pH values of around 8 in their sola. The high base saturation, restricted leaching and/or high $CaCO_3$ content might be the reasons for high pH. Virmani *et al.* (1982) reported similar observations. The low pH of Pedons 14 and 15 was probably due to the leaching of bases from their sola as they are located in hilly area (Mathan and Chirangivi Rao, 1982). The low pH of Pedons 1,5,11 and 12 could be attributed to the influence of parent material.

The increase in pH with depth observed in most of the Pedons could be a result of leaching of exchangeable bases from the surface horizons. Vadivelu (1985) reported similar view. Ohta *et al.* (1993) attributed such increase in pH to the increase in iron oxides with depth. In Pedon 10, the pH of the 3 Bg2 horizon (174 to 190 cm depth) was extremely low. The location of the pedon was very near to the sea. This low pH suggested the possibility of accumulation of sulphides (which on oxidation lead to a decrease in the pH). Bandhyopadhyay and Sarkar (1987) observed similar low pH in some coastal soils of West Bengal and attributed it to the accumulation of Fe and S. In the case of Pedon 10, though there was no evidence of accumulation of Fe, the high content of water soluble sulphate indicated the accumulation of S.

The pH measured in 1M KCl suspension was lower than the pH measured in soil water suspension. Kaswala and Deshpande (1983) considered such depression in pH in KCl, as an indication that, the cations surrounding the clay particles are more diffused. The low value of pH in KCl in comparison to pH in water, indicated that the soils have a net negative

charge and contain considerable amount of reserve acidity. Dolui *et al.* (1987) and Nayak *et al.* (1996) reported similar observations.

5.3.2. Electrical conductivity

The electrical conductivity of majority of the Pedons was less than 0.1 dSm^{-1}. Only Pedon 10 recorded EC values of more than 1 dSm^{-1} in its solum. This high EC was due to marine influence in this pedon. The EC increased from 0.38 dSm^{-1} in the surface horizon to 2.6 dSm^{-1} in the bottom most horizon.

5.3.3. Organic carbon

The organic carbon content was higher in Pedons 14 and 15. because of low temperature and concomitant slow rate of decomposition of organic matter in these soils (Sehgal *et al.*, 1985). The low organic carbon status of other Pedons could be attributed to high mean annual temperature. The organic carbon content decreased with depth in most of the Pedons.

5.4. Chemical properties

5.4.1. Elemental composition

5.4.1.1. Silica (SiO_2)

The correlation between SiO_2 and sand was positive and significant. The silica content was higher in Pedons 4,5 and 11 which had a higher content of sand. The relationship of SiO_2 with all other elements was either negative or non-significant. This was possibly due to, quartz being the main form of silica. The crystal structure of quartz does not contain anyother element in appreciable amounts. The highly negative correlation coefficient of silica with Al and K were probably due to the presence of micas and feldspars in the soils. In these minerals, trivalent Al replaces tetravatent Si in the tetrahedral network. The increase in the negative charge is balanced by the introduction of K in the crystal structure. Sidhu *et al.* (1977b) expressed similar views.

In the present study Pedon 15 recorded the lowest silica content, which was the result of the high rainfall in its location. Gowaikar and Datta (1977) observed a negative relationship between the amount of rainfall and SiO_2. Miller (1983) reported that mineral weathering and pedogenic processes in Ultisols resulted in an over all desilication. Such processes could have been active in Pedon 15.

An interesting feature in Pedon 14 was that quartz gravels were observed throughout the profile and yet the total silica content was comparatively low. Simultaneous enrichment in quartz and desilication through loss of combined silica are not incompatible processes in soils developed in quartz rich parent materials, because of the low solubility of quartz. This can be expected in environments where the losses of combined silica, bases and other constituents exceed the gain in water content of newly formed secondary minerals (Miller, 1983).

5.4.1.2. Iron (Fe_2O_3)

The wide variation observed in the total iron content of the pedons could be attributed to differences in parent material, and pedogenic processes involved.

The distribution of total iron within pedons was generally irregular. Guillet and Souchier (1982) reported that the behavior of iron in natural systems is to a large extent predicted by the fluctuation in the oxidation reduction potential, and pH environments. The irregular distribution of iron within the pedons could be attributed to variations in either or both of these factors. The total Fe_2O_3 content in Pedons 1,2,7,8 and 9 was almost uniform throughout the profile. Gotoh (1976) reported that in young soils, the amounts of total Fe_2O_3 was nearly uniform throughout the profile. The process of soil development with time gives rise to accumulation of different quantities of Fe_2O_3 in certain horizons resulting in a net loss from the upper

horizons. This explained the accumulation of total iron in the subsurface horizons of Pedons 1,4,5,11,14 and 15.

Gotoh (1976) also reported that, in the oldest profiles total Fe_2O_3 was least in surface and increased sharply downwards. Such a trend was observed in Pedon 15. The increase in iron content with depth in Pedon 15 may be due to vertical migration of iron either independently or along with other soil components. Similar reports were made by De Kimpe *et al.* (1984). Another factor that could have led to the increase in iron content with depth in Pedon 15, is the distribution of organic carbon which was high in the surface horizon and decreased with depth. The high organic carbon could have resulted in the microbial reduction of iron to Fe^{2+} and its subsequent movement out of the surface horizon and accumulation in the subsurface horizons. Schwertmann (1990) reported similar observations.

5.4.1.3. Free iron oxides

The free iron oxide content of the pedons varied from less than 1 per cent in Pedons 6 and 7 to more than 5 per cent in other pedons. These differences were due to the degree of weathering and mineralogical composition of the parent materials. The low free iron oxide content in Pedons 6 and 7 could be attributed to their vertic properties. Same view was expressed by Zhu *et al.* (1990).

5.4.1.4. Alumina

Alumina was positively correlated with clay, suggesting that pedogenic processes responsible for clay formation are also responsible for the content of alumina in soils. Manickam (1977) reported similar observations. The alumina content of pedons was negatively correlated with SiO_2 and the relationship was highly significant. Sand content also was negatively correlated with alumina, but did not attain high level of significance. Diwakar and Singh (1994) attributed such relationship to the fact that alumina

occurred in the forms of several alumina-silicates rather than aluminum oxides and hydroxides. The variations of Al_2O_3 within the pedons might be due to mobilisation and the clay content (Sinha, 1957).

5.4.1.5. Sesquioxides

The sesquioxide content of the pedons varied over a wide range. The highest sesquioxide content was recorded in Pedon 15. Mineral weathering and pedogenic processes in Ultisols resulted in an over all desilication and a conservation or enrichment with respect to sesquioxides (Miller, 1983). Verma *et al.* (1987) reported that sesquioxide content was higher in soils developed under high rainfall. The increase of sesquioxides with depth implies that there is intense weathering of parent material under conditions of high rainfall.

5.4.1.6. Calcium

The total calcium content was higher in Pedons 6 and 7, which could be due to the enrichment of $CaCO_3$. Thiyagarajan (1985) expressed similar views. Calcium is known to occur in crystal lattices of feldspars associated with sodium and potassium (Dutil, 1982). In this study, the CaO content was positively correlated with Na_2O content, suggesting the influence of the parent material on Ca content. The total calcium content increased with depth in Pedon 8, as the soil had developed from calcareous parent material.

5.4.1.7. Magnesium

The correlation between total Ca and Mg was positive and significant. Soils with high content of total Ca also registered high total Mg. The wide variation among the pedons in the total Mg content and also within pedon variations might be due to difference in parent material (Vadivelu, 1985). Pedons 14 and 15 recorded comparatively low total Mg content. High rainfall in the location of the pedons could have resulted in high weathering leading to low total Mg content. Pedons 9 and 10 located in alluvial plains registered

relatively high total Mg. Mokwunye and Melsted (1972) reported similar observations.

5.4.1.8. Potassium

In primary minerals, K is not an exchangeable cation in the thermodynamic sense, since its activation energy varies from 15 to 22 Kcal/ mol, thus various weathering processes must occur inorder to release it (Robert and Trocme, 1982). The very low content of K_2O recorded in Pedon 14 and 15 could be due to small amounts of feldspars (Bhaskar and Subbaiah, 1996). Pedons 10 and 13 had comparatively higher contents of K_2O and Na_2O. Walia and Rao (1996) considered high contents of K_2O and Na_2O as an indication of the presence of orthoclase feldspars. Jackson (1964) reported that the distribution of K in soils is related more to the condition of weathering of potash feldspars and micas than to the composition of the parent materials.

5.4.1.9. Sodium

Pedon 10 recorded more than 0.5 percent in all its horizons due to its proximity to the sea coast. The Na_2O content of Pedon 6 was found to increase with depth. Biswas *et al.* (1966) and Thiyagarajan (1985) have reported similar observations.

5.4.2. Molar ratios

Relative accumulation of iron is an index to understand the stage of weathering. Lower the SiO_2/Fe_2O_3, SiO_2/R_2O_3 and Al_2O_3/Fe_2O_3 ratios, more weathered is the soil (Sharma *et al.* 1996). Under this criteria, Pedon 15 can be considered as comparatively more weathered than rest of the pedons as the silica: sesquioxide ratio was low in this pedon. Norfleet and Smith (1989) reported that increase in rainfall increases the probability of removal of silica from soils. This could be the reason for the low silica: sesquioxide ratio in Pedon 15.

Mayalagu and Subramanian (1993) considered lower ratios of SiO_2/Fe_2O_3, SiO_2/R_2O_3 and Al_2O_3/Fe_2O_3 as an indication of better pedon development. Based on their views, Pedons 3,14 and 15 have undergone better development.

Gupta and Tripathi (1992) considered the molecular ratios of SiO_2/Al_2O_3 ranging from 3.5 to 5.6 and SiO_2/R_2O_3 ranging from 2.6 to 3.9 as an indication of the presence of 2:1 type of claymineralS. This inference did not seem to be true for Pedons 14 and 15. The low CEC and ECEC values of these Pedons do not indicate the presence of 2:1 type of clay minerals. The molor ratios have their limitation in providing information on the stage of weathering (Jackson and Sherman, 1953).

The molar SiO_2/Al_2O_3 proved that the SiO_2 content was much higher than Al_2O_3 in Pedons 4,10 and 11. This can be construed to mean that the process of silication was operating in these soils. Mishra and Ghosh (1995) expressed similar views. Ghabru and Ghosh (1980) reported that high SiO_2/R_2O_3 and SiO_2/Al_2O_3 ratios indicate podsolic type of weathering. In the present study, in Pedon 10, the values of these ratios were comparatively higher, but the profile did not show any features to assume that it had undergone podsolic type of weathering.

Singh *et al.* (1995) considered lower K_2O/Na_2O ratios of clay to mean that the clays were more weathered. It appears that this inference drawn for clay, does not hold good if the fine earth (<2mm) fractions are considered as a whole. This is because, in Pedon 15 which is considered more weathered based on molar ratios involving SiO_2, the K_2O/Na_2O ratio was comparatively high.

5.4.3. Nutrient composition

5.4.3.1. Nitrogen

Nitrogen *per se* does not have any pedogenetic role. It does not form a part of any mineral and its content in soil is almost invariably decided by the organic matter status of the soil (apart from what is added as plant nutrient). In this study the highest total nitrogen content was recorded in Pedon 15. Pedon 15 had a comparatively cooler, isothermic temperature regime which has favoured the build up of organic matter and as a result high total N. All other Pedons had an isohyperthermic temperature regime which does not permit any organic matter accumulation. The total N generally decreased with depth. This is in agreement with the findings of Aggarwal *et al.* (1990).

5.4.3.2 Phosphorus

Phosphorus can serve as a useful indicator in investigations of pedogenetic processes and has several desirable properties which other elements do not possess. In unweathered parent material, phosphorus is generally present as apatite and consequently the quantity of phosphorus in solution is governed by weathering of apatite (Smeck, 1973). Pedons 4,6,7 and 8 with a high pH (mean values more than 8) recorded high total P. Sieg (1993) reported similar findings.

The total P was very low in Pedon 2. Probably this pedon was low in apatite minerals. Walker (1965) reported that, as annual rainfall increases, the amount and extractability of P decreases. This has not been the case in this study where Pedon 15 recorded higher rainfall than other pedons, but still registered a higher content of total P. The intensive application of phosphatic fertilizers to the vegetabale crops could have been the cause for this.

In most of the pedons, the highest total P content was recorded in the B horizons. Smeck and Runge (1971) attributed the accumulation of P in the B horizons to different modes of mobilisation. The upper accumulation may indicate a zone of frequent wetting and drying or chemical precipitation by iron, whereas the lower maximum is a result of precipitation by calcium. Fenton (1983) stated that the accumulation of P between 1 and 2 m depth is due to downward movement from the surface in percolating water, and lack of removal by plants.

In general, the minimum total P content was recorded in the layer of maximum clay content. Runge and Riecken (1966) reported similar results.

5.4.3.3. Citric acid soluble P

The citric acid soluble P is used to identify the anthropic epipedon, which has more than 250 ppm of CSP. None of the pedons recorded 250 ppm of CSP in the upper horizon. Pedons 7 and 10 recorded 205 and 200 ppm respectively in their surface horizons. Interestingly, the horizons at 103-139 cm depth and 139-164cm depth of Pedon 9, recorded 645 and 411 ppm respectively. This pedon was located in a rice cultivating alluvial plain. Application of higher doses of phosphatic fertilizers and the puddling operations could have led to the concentration of phosphorus in these depths. The total P contents were also higher in these depths. Kosse (1990) stated that "anthropedogenic" processes like deep working and intensive fertilization leads to enrichment of plant nutrients, particularly phosphorus and potassium in "anthric" soils. Hence the higher content of CSP in Pedons 7,9 and 10 could be attributed to such "anthropedogenic" processes. These processes were not as intense in other pedons which registered lower CSP.

5.4.3.4. Bray P

The Bray P content was comparatively higher in Pedons 1,10 and 11

and very low in Pedons 2 and 8. Mayalagu (1982) attributed such high P_2O_5 to human addition of fertilizer P. The low Bray P content of Pedon 8 could be the result of its calcareousness. Roberts *et al.* (1985) stated that the extractable P is influenced by the $CaCO_3$ equivalent and dithionite extractable iron content of the soils. In all pedons except Pedons 3,5 and 15, the surface horizons recorded the highest Bray P. The total amount of P sorbed and the distribution of P within the soil is dependent upon the reactivity of the organic matter coatings, and solution parameters that affect their reactivity. Structural alteration of organic matter coatings could result *in the exposure of more P adsorption sites resulting in reduction in percent* extractable Bray P (Evans Jr. and Sorensen, 1985). In Pedon 15 the highest Bray P was recorded beyond the 95cm depth. This could be due to the high rainfall. Though phosphorus can be considered essentially immobile over short time spans, it is mobile enough to provide a useful index of flow patterns in a landscape during the long time span involved in soil development (Smeck, 1973).

5.4.3.5. Olsen P

Pedons 1, 10 and 15 had a comparatively higher content of Olsen P. As in the case of Bray P, this could be attributed to human addition. O'Halloran *et al.* (1985) attributed the variation in Olsen P, to more pronounced effects of microbial activity, plant growth and soil properties. In Pedon 15 the high organic carbon could have sustained a higher level of microbial activity resulting in high Olsen P. The relatively higher P in Pedon 15 might be another indication of its weathered nature. Roberts *et al.* (1985) stated that, increased weathering action caused by increased moisture resulted in greater plant available P. The distribution of Olsen P within the pedons was similar to that of Bray P. In most of the pedons the surface horizons recorded higher Olsen P than the sub-surface horizons.

5.4.3.6. Total zinc

The total zinc content differed over a wide range. Pedons 5, 11 and 12 recorded low total zinc content. Pedon 13, located in a lateritic land form recorded comparatively higher total zinc. The variation in total zinc has to be attributed to the parent materials. Aubert and Pinto (1977) stated that the influence of parent material on total zinc content of soil was major, compared to the pedogenic processes. They also reported that the zinc content was low in sandstone and high in basic igneous rocks. The acidic pH, high sand content and low zinc content of Pedon 5 is a reflection on the nature of its parent material. Pedons 2, 4, 6 and 15 registered a relatively higher total zinc content.

Randhawa and Singh (1995) reported that total zinc in alluvium derived soils of Punjab varied from 20 to 78 ppm. The alluvial soils of Tamil Nadu (Pedons 9 and 10) appear to have a comparatively higher total zinc, ranging from 39 to 102 ppm.

The depthwise distribution of zinc was irregular in all pedons except Pedon 8. Hazra *et al.* (1993) attributed such irregular distribution of zinc in soil profile to variations in the contents of clay, crystalline Fe_2O_3 and Al_2O_3.

5.4.3.7. Total copper

Pedons 3 and 15 had comparatively higher total copper than all other pedons. Aubert and Pinto (1977) reported that variations in copper content of soils are mostly due to different contents of parent rocks in which the soils have formed and to a lesser degree to the types of soils corresponding to different climatic zones. Dwivedi and Shanker (1982) also reported that distribution of copper in soils is primarily due to the parent material.

Total copper content was highly dependent on clay rather than coarser fractions of the soils. This was evident from the positive correlation of total

copper with clay and significantly negative correlation with sand. Appavu and Sree Ramulu (1991) and Randhawa and Singh (1996) reported similar findings.

The total copper content was significantly correlated with the organic carbon indicating that a major fraction of total copper was associated with organic carbon. Paramasivam and Gopalaswamy (1994), and Raghupathi and Vasuki (1993) also reported similar observations.

5.4.3.8. Total manganese

The wide variation observed in the total manganese content could be due to the Mn bearing minerals in the parent material. Prasad and Sahu (1989) reported similar observations. The behaviour of Mn in oxidising and reducing environments is analogous to that of Fe (Miller, 1983). This explained the similar pattern of accumulation of total Mn and Fe in Pedons 1, 3, 4, 5 and 6, and more particularly in the Bc1 and Bc2 horizons of Pedon 3, and Ack horizon of Pedon 6.

Jarvis (1984) stated that the distribution of Mn in soil profiles is influenced by two major processes. a) leaching and subsequent removal of divalent Mn in the soil and b) precipitation of very insoluble hydrous oxides of Mn^{3+} or Mn^{4+}. The position of equilibria between the mobile and immobile forms is controlled by drainage, redox conditions and pH. In neutral and slightly alkaline soils, most of the Mn is generally in an oxidised insoluble form. Under acidic conditions the equilibria shifts to mobile Mn^{2+}. The increase in total Mn with depth in Pedons 1, 2 and 5 could be attributed to the slightly acidic pH recorded in these pedons. The increase in total Mn with depth in Pedon 4, though it recorded high pH, could be due to the well drained nature of the profile which is due to the total sand content of more than 80 per cent in the upper horizons of this pedon. Imperfect drainage

and alkaline pH could be the reasons for the high total Mn content in the surface horizons of Pedons 9 and 10.

Miller (1983) reported that at the onset of reducing conditions Mn is reduced before Fe, and upon return of oxidising condition, is oxidised later than Fe. Environments that are reducing for Mn can remain oxidising for Fe. It can be inferred from this, that under a given condition Mn remains more mobile than Fe. This inturn, can be taken to mean that the Mn maxima should occur at depths, beyond those in which Fe maxima occurs. In this study such a trend has been observed in Pedons 2, 7, 8, 10, 11 and 13. A notable exception to this trend is Pedon 14, in which the Fe maximum is at the bottom most horizon (155 to 203 cm depth) whereas the maximum total Mn was recorded in the surface horizon. In this pedon, ferruginous concretions were observed throughout the profile. Perhaps Mn was preferentially used in concretion formation in this pedon. Polteva and Sokholova (1967) reported that, other conditions being equal, the intensity of segregation of iron and manganese into concretions varies with that of soil formation as a whole, especially with the rate and depth of weathering and decomposition of primary and secondary minerals, which result in the release of free iron and manganese hydroxides. Dobrovolskii and Tereshina (1976) reported that, the Fe-Mn concretions they studied were distinguished by wide variation in composition of concretion forming element. The Fe:Mn ratio in the concretions varied from 0.8 to 5.8. A detailed study of the composition of concretions could have provided a better picture about the movement of Fe and Mn in Pedon 14.

5.4.4. Fraction of Fe and Mn

5.4.4.1. Fractions of iron

The Fe_d content was the highest and Fe_p content the lowest among the fractions of iron. Their contribution to total iron also varied among the

pedons. It is generally considered that sodium dithionite will extract iron from both crystalline and amorphous sources whereas iron extracted by ammonium oxalate is essentially amorphous in nature (Blume and Schwertmann, 1969; McKeague and Day, 1966). Pyrophosphate extracts organic Fe and amorphous gel hydroxides (Lutwick and Dormaar, 1973).

Generally dithionite extracted more Fe than oxalate. Ogunsola and Omueti (1990) reported that the low contribution of oxalate Fe to total Fe suggested that iron oxides are essentially crystalline.

Concentration of gel and organic iron (Fe_p) were low. Perhaps the gel and organic forms of Fe in these soils cannot reach very large proportions and the equilibrium is far toward the formation of well crystallised iron oxides, with aged amorphous forms present in some soils. This is in agreement with the observations of Lutwick and Dormaar (1973) and Paterson (1995).

Fe_d/Fe_t per cent ranged from 7.67 in Pedon 7 to 92.05 in Pedon 15. More of the iron remains in silicates in the younger soils than in the older soils (Arudino *et al.*, 1984). Based on this criterion, Pedons 6, 7, 8, 9, 10 can be considered relatively young as the mean values of Fe_d/Fe_t per cent were less than 50 in these pedons.

Higher contents of Fe_d is an indication of higher degree of weathering (Van Ranst *et al.*, 1990). Advanced soil age results in a higher Fe_d/Fe_t ratio of more than 0.8 i.e. more than 80 per cent of the silicate bound iron has been turned into Fe III oxides (Schwertmann, 1990). In Pedon 15, the Fe_d/Fe_t per cent was more than 80 in most of the horizons indicating that the soil is highly weathered. Smeck *et al.* (1994) considered a Fe_d/Fe_t ratio of less than 63 per cent to mean that a significant part of primary minerals are still present in the soils. Such a conclusion can be drawn for Pedons 4,

6, 7, 8, 9, 10 and 13 where the ratios of Fe_d/Fe_t were less than 63 per cent.

Nagatsuka (1972) suggested that the ratio of $(Fe_d-Fe_o)/Fe_t$ may be used as a relative measure of the degree of weathering, accompained by ageing or crystallisation of free iron oxides, for soils from different materials. This ratio was high in Pedon 15 proving the highly weathered nature of that pedon. In Pedons 6, 7, 9 and 10 this ratio was low, reinforcing the view that they are relatively unweathered.

Elless and Rabenhorst (1994) stated that, if residual iron levels i.e. Fe_t-Fe_d are similar to that of Fe_d levels, chlorite could be present in the soils. This condition exists in Pedons 4 and 13, but in this case it could be erroneous to assume that chlorite is present in these pedons. Miller and Donahue (1992) stated that acidic soil with some leaching of silica and basic cations and a high Mg content is essential for the formation of chlorite. These conditions were not present in Pedons 4 and 13. The observation of Elless and Rabenhorst (1994) does not apply in these pedons.

In most of the pedons, Fe_d maximum occurred in the horizon of maximum accumulation of total iron. This is in line with the findings of Stonehouse and St.Arnaud (1971) who stated that the Fe_d maximum usually occurs in the uppermost portion of the B horizon, and almost always corresponds to the horizon of maximum clay and total iron accumulation.

The Fe_o/Fe_d ratio was higher in the sub-surface horizons in all the pedons except Pedon 8, indicating the presence of higher amounts of amorphous iron in the subsurface horizons than the surface layers. Michalyna (1971) and Barrett and Schaetzel (1992) have reported similar findings.

5.4.4.2. Fractions of Mn

The differentiation of Mn_d within pedons was more marked in most of

the pedons as compared with total iron. With the exception of Pedon 10, the Mn_d constituted a relatively high proportion of total Mn. This is in agreement with the report of Gotoh (1976).

In Pedons 3, 4, 6, 11 and 15 the Mn_d maxima occurred in the same horizons in which Fe_d maxima occurred. Buol *et al.* (1980) reported that in well drained soil profiles Mn^{2+} remains in a soluble form longer than Fe^{3+} and hence Mn_d maximum always occurs deeper. This explained the Mn occurring at lower depths than Fe_d maxima. Pedons 9, 10 and 13 were not well drained, nevertheless the Mn_d maxima occurred deeper. All the three pedons were located in rice growing areas. The ponding of water in the field could have facilitated the movement of Mn to deeper horizons.

5.5. Exchange properties

5.5.1. Cation exchange capacity

The CEC of Pedons 1, 4, 5, 11 and 15 were low. Pedons 4 and 5 had a low clay content. This could have resulted in the low CEC, as the CEC was significantly correlated with clay content. In Pedons 1 and 11, the low CEC recorded despite comparatively higher clay content in lower horizons is probably due to the influence of 1:1 type of clay minerals or the formation of complexes of clays and sesquioxides which lead to the blocking of exchange sites. Walia and Chamuah (1996) expressed similar views. The relatively low CEC in Pedon 15 is an indication of the type of clay mineral in that pedon. Long periods of weathering and leaching could result in the formation of minerals with low CEC such as kaolinite and gibbsite in Ultisols (Gamble and Daniels, 1972).

The higher CEC of Pedons 6, 9 and 12 could be attributed to their higher clay content. In comparison to these pedons, Pedon 7 had relatively low clay content but still recorded high CEC. This increase in CEC with low

clay content is suggestive of the contribution of non-clay fractions towards CEC. There are evidences that the sand and silt fractions of soils sometimes exert a considerable influence on exchange properties of some soils. The arid or semi arid climate might be one condition for the occurrence of such exchange sand (Barticevic *et al.*, 1976).

5.5.2. Effective CEC

Pedon 6 recorded the highest ECEC, which is to be expected considering the fact that this pedon recorded the highest CEC and also the highest percent base saturation. In Pedons 14 and 15, the ECEC values were less than 15 cmol (p$^+$) kg^{-1} soil, though the CEC values were from 15 to 30 cmol (p$^+$) kg^{-1} soil. These pedons were located in hilly regions with high rainfall which could have leached the bases from the solum resulting in low ECEC. The low ECEC values of these pedons could also be due to the dominating influence of kaolinite and other oxides which result in low soil reactive properties. Okusami (1990) reported similar observations.

The ECEC values were low in Pedons 1, 2, 4 and 11. In these pedons, the CEC itself was low because of their low clay content. Compared to the CEC values, ECEC was not drastically reduced in these pedons. In Pedon 5, the ECEC values were very low, compared to its CEC values. This pedon had a high sand content, acidic pH and low base saturation. These factors could have contributed to the low ECEC in this pedon. Norfleet and Smith (1989) considered low ECEC values as an indication of the presence of substantial amount of low activity clays.

5.5.3. Base exchange properties

The influence of the parent materials and, pedogenic processes was evident in the base saturation which varied widely among the pedons. The per cent base saturation was very low in Pedon 15, where the high rainfall

has leached the bases from the solum. With little or no weatherable minerals a low base saturation can develop in relatively short periods in ultisols (Miller, 1983). The low base saturation in Pedon 14 was also attributable to the high rainfall. The very low base saturation in Pedon 5 was the consequence of its high sand content.

Pedons 6, 7, 8, 9 and 13 registered a very high base saturation. Rao *et al.* (1995) considered a high base saturation as a reflection of restricted internal water movement. This accounted for the high base saturation of Pedons 6, 7, 9 and 13. Sieg (1993) reported that soils developed from calcareous parent materials have high base saturation. This explained the high base saturation of Pedon 8, developed over calcareous parent material.

In most of the pedons Ca dominated the exchange complex followed by Mg, K and Na. Kaswala and Deshpande (1983) and Sahu and Bala (1995) reported similar findings. Hydrated ions (Na) are adsorbed less intensively than unhydrated ions (K) and multivalent ions are adsorbed most intensively in the exchange complex (Zonn, 1986). In general, the contents of Ca and Mg were high in the top soils. This was assumed to be due to biological accumulation in top soils, through litter supply and their relatively low mobility in the sola. This is in agreement with the views of Ohta *et al.* (1993).

Among the pedons, the contents of exchangeable bases were high in Pedons 6, 7 and 9. Ohta and Effendi (1992) considered the presence of larger amounts of exchangeable Ca, Mg and K as a reflection on the presence of higher content of weatherable minerals. In this study, the Fe_d/Fe_t ratios have shown that Pedons 6 and 7 are relatively unweathered, which implies that they have a high weatherable mineral content. Exchangeable Na was high in Pedon 10 and the exchangeable sodium percent was more than 15, in the 16 to 63 cm depth, in this pedon. The proximity of this pedon to the seacoast could have been the cause for this. Kaswala and Deshpande (1983)

also attributed the high exchangeable Na in coastal soils to the presence of soluble salts carried over from the sea.

Distribution of Ca, Mg, Na and K could also have been affected by groundwater table fluctuations. Sharma and Dev (1985) reported similar findings.

The ratio of exchangeable Ca/Mg is considered to give an idea about the stage of weathering of the soil. A low Ca/Mg is an indication of greater weathering (Joffe, 1940). The Ca/Mg ratio was wider in Pedons 4, 6 and 9 and in the lower horizons of Pedons 8, 12 and 13. Wider Ca/Mg could be due to low and moderately weathered nature of these pedons. High Ca/Mg ratios in the upper horizons compared to the lower horizons in most of the pedons suggested that vegetation played an active role in cycling Ca to the upper horizons. This is in agreement with the observations of Singhal and Sharma (1985).

Pedon 15 had a relatively narrow Ca/Mg ratio indicating its weathered nature. Barshad (1964) attributed the diminishing of exchangeable Ca/Mg ratios with soil development, to the interchange of exchangeable hydrogen for octahedral magnesium. This displaced Mg is an important source for replenishment of exchangeable Mg. Apart from Pedon 15, some other pedons (1, 3, 5, 7, 10 and 11) which are not considered highly weathered also had narrow Ca/Mg ratio. Ahmad (1983) stated that in soils developed from basic igneous rocks, metamorphic rocks and marine sediments, exchangeable magnesium could be as high as exchangeable calcium. These factors could have resulted in low Ca/Mg ratio in these pedons.

5.5.4. Forms of acidity

The exchangeable acidity estimated in the present study with 1M KCl extract was considerably lower than potential acidity, measured in

$BaCl_2$-TEA extract. Adhikari and Si (1991) and Ananthanarayana and Hanumantharaju (1994) have reported similar findings. According to Peech *et al.* (1962) the $BaCl_2$-TEA extraction is a measure of the pH dependent acidity. In this extraction, acidity results from replacement of hydrogen and aluminium ion and from dissociation of acidic groups neutralised by free triethanol-amine, which is bufferred at pH 8.2. The barium ion in addition to replacement of hydrogen ions also increases the extent of hydrolysis of adsorbed aluminium and degree of dissociation of hydrogen on clay surfaces. Exchange acidity is the acidity (H+Al) released upon exchange by an unbufferred KCl solution (ISRIC, 1992).

The exchangeable acidity was generally lower in surface horizons in comparison to the subsurface horizons (except in Pedons 4 and 15). Nayak *et al.* (1996) reported similar observations. The exchangeable acidity was relatively higher in Pedons 2, 3, 5, 11 and 12. Kumar *et al.* (1995) attributed variations in exchangeable acidity to the nature of the parent material and base saturation.

Cation exchange capacity did not show any significant relationship with exchangeable acidity. pH in water and 1M KCl had a negative correlation with exchange acidity, indicating that mostly the exchange acidity was responsible for lowering the pH in most of the soils. Organic carbon did not show any significant correlation with exchangeable acidity indicating that organic matter has probably no role in contributing to exchange acidity, in most of the pedons. Das *et al.* (1991) have reported similar observations.

Potential acidity was relatively higher in Pedons 6, 14 and 15. The high potential acidity in Pedons 14 and 15 could probably be due to, apart from other factors, their high organic matter content. The functional groups of organic matter like-COOH and phenolic-OH could have contributed to total acidity. Das *et al.* (1991) reported similar observations. Besides organic

matter, free iron oxides and clay content also contribute to total acidity (Nayak *et al.*, 1996). The free iron oxide contents of Pedons 14 and 15 were relatively higher. This could also have contributed to the total acidity in these pedons. In Pedon 6, the free iron oxide and organic carbon contents were low. The high total acidity in this pedon was probably due to its high clay content. The lower total acidity of other pedons might be attributed to the variation in the organic carbon, clay and free iron oxide content of these pedons.

In Pedon 15, though potential acidity was high, the exchangeable acidity was found to be very low. Nayak *et al.* (1996) stated that KCl extractable Al^{3+} is low in soils at an advanced stage of weathering. Kumar *et al.* (1995) attributed such relatively low exchangeable acidity to organic matter complexing the acid forming cations.

5.6. Water soluble ions

5.6.1. Cations

Water soluble cations and anions for most of the soils were within 3 mmol and electrical neutrality was maintained. Water soluble cations were generally in the order Ca > Mg > Na > K.

In Pedons 9, 10, 13 and in the lower horizons of Pedon 7 (beyond 77 cm depth) water soluble Na was more than Mg. Anbazhagan (1994) has reported high water soluble Na than Mg in some soils of Thanjavur district of Tamil Nadu. In Pedon 10, this could be attributed to the closeness of the location of the pedon to the sea. In Pedon 7, $CaCO_3$ nodules were observed in the lower horizons. This involves the precipitation of Ca in insoluble forms. Mg also could have been rendered insoluble resulting in the apparent increase in Na. In Pedon 10, in the 3Bg2 horizon (174 to 190 cm) the water soluble Na and K decreased drastically while Ca and Mg increased. The

extremely low pH in this depth could have caused this. Qian *et al.* (1994) reported that Na in solution was high in soil under conventional tillage than no tillage. Pedon 9 located in the Cauvery delta area is under rice cultivation with the inevitable intense cultural operations. Perhaps, this has led to the high water soluble Na in this pedon.

5.6.2. Anions

Among the water soluble anions, the content of HCO_3^- was the highest followed by Cl^- and SO_4^{2-}. In Pedons 8 and 10, the contents of SO_4^{2-} were higher than Cl^-. The differences in depthwise distribution of the water soluble anions could be attributed to the differences in internal drainage among the pedons. The higher content of anions in lower horizons of Pedon 10 was due to marine influence.

5.7. Soil classification

The soils were classified according to USDA Soil Taxonomy (Soil Survey Staff, 1975 and 1994). The morphological, physical, chemical and exchangeable properties of soils and climatic parameters like moisture and temperature regimes were considered for soil classification.

5.7.1. Inceptisol

Pedons 1, 2, 3, 7, 8, 9, 10 and 14 were classified under Inceptisols based on the presence of cambic subsurface horizon. The suborder Tropept was coined for all the pedons based on the warmer isotemperature (isohyperthermic regime). The great group was Ustropept for Pedons 1, 2, 3, 7, 8, 9 and 10 as they had Ustic moisture regime. Pedon 14 belonged to the great group 'Humitropept' as it had base saturation of less than 50 per cent in the horizons between 25 and 100 cm and more than 12 kg m^{-2} organic carbon in the upper 100 cm depth. Pedons 1, 2, 3 and 8 were placed under the subgroup Typic Ustropept as they had the soil

characteristics of the central concept of Ustropepts. Challa *et al.* (1993) also classfied some red soils under Typic Ustropepts.

Association of vertic characters with Pedons 7 and 9 made them to be grouped under Vertic Ustropepts. Singh *et al.* (1989) reported similar conclusions. Pedon 10 was grouped under Aquic Ustropepts as it possessed reduced mottles with chroma less than 2 within a metre depth. Vadivelu (1985) reported similar findings. Pedon 14 had the soil characters of central concept of Humitropepts. Hence it was classified as Typic Humitropepts. This is in agreement with the findings of Gangopadhyay *et al.* (1989).

Considering the percentage of particle size fractions in the soil control section, fine loamy class for Pedons 1, 2 and 7, clayey skeletal for Pedon 3, loamy skeletal for Pedon 14, fine particle size class for Pedons 9 and 10 were proposed. The mineralogy class was carbonitic for Pedon 8, as it contained more than 40 per cent carbonates and it was montmorillonitic in case of Pedon 9. The other pedons had mixed mineralogy in the fine loamy and fine particle size classes. As the pH was more than 5.5 (1:1 soil:water extract) in the control section of 25 and 50 cm from mineral surface, all pedons except Pedon 14 were grouped under nonacid class. Acidic class was given to Pedon 14 as pH value of less than 5.5 was registered in the soil reaction control section.

5.7.2. Alfisols

Pedons 4, 5, 11, 12 and 13 were grouped under Alfisols, as they had argillic horizon and clay films in the solum. The suborder was Ustalfs for all the pedons, since Ustic moisture regime was registered in them. Rhodustalfs was the great group for Pedons 4, 5 and 12 while it was Haplustalfs in the case of Pedons 11 and 13, as redder hue of 2.5YR/10R was observed in the first group of pedons but it was not observed in the second category of pedons. All pedons except Pedon 13 were included under

the subgroup Typic, as they possessed soil characteristics of the central concept of their respective great groups. Pedon 13 was included in Ultic subgroup as the argillic horizon had less than 75 per cent base saturation. These are in agreement with the views of Tiwary *et al.* (1989), Hameed Khan and Hanuman Ram (1977) and Rakhunde *et al.* (1993).

Fine loamy textural class for Pedons 5, 11 and 13, fine class for Pedon 12 and coarse loamy over fine loamy class for Pedon 4 were proposed based on the particle size fractions in their control section. Mixed mineralogy was proposed for all the pedons. Based on the pH values in 1:1 soil water extract, acid reaction class for Pedons 5, 11 and 12 and non-acid class for Pedons 4 and 13 were given.

5.7.3. Ultisols

Pedon 15 was grouped under Ultisols as it contained argillic horizon and less than 35 per cent base saturation in the solum. The suborder was Humults as more than 12 kg m^{-2} organic carbon was present between the mineral surface and a depth of 100 cm. The clay per cent did not decrease with increasing depth by 20 per cent from the maximum clay content 41 per cent. The CEC of more than 16 cmol (p^+) kg^{-1} clay and ECEC of more than 12 cmol (p^+) kg^{-1} clay were observed in argillic horizon. Hence, the great group was named after Haplohumult. The soil possessed the characteristics of central concept of Haplohumult and hence it was included under Typic subgroup. Based on the particle size, mineralogy, soil reaction and temperature regimes, fine loamy mixed acid and isothermic classes were coined in the soil family name.

5.7.4. Vertisols

Pedon 6 was the only soil which was grouped under Vertisols as it had more than 30 per cent clay in the upper 50 cm depth, intersecting

slickensides in the upper 1m depth and cracks which open and close periodically. The suborder was Ustert as Ustic moisture regime was computed from climatic parameters and AWC. pH values of more than 5 was noticed in the soil. Further salic, gypsic, calcic and petrocalcic horizons were absent. Hence the pedon was grouped under Haplustert. It was included under Typic subgroup, as it had the characteristics of central concept of Haplustert.

5.8. Spectral reflectance characteristics of soils

Recent advances in remote sensing capabilities with high altitude air craft and satellites have demonstrated the possibility of its large scale use in agricultural resource inventories and management. Such studies emphasize the need to accurately define soil spectral reflectance, as an aid in the interpretation of multispectral imagery or other remotely sensed data. Measurements of soil reflectance in the different regions of electromagnetic spectrum is important not only for differentiating variable soil conditions but also for normalising soil background effects in vegetation studies by remote sensing techniques. A variety of soil parameters and conditions, either individually or combined, contribute to the spectral reflectance of soils. Hence, the characterization of soil reflectance has important implications for soil genesis, survey and classification. With this background the spectral reflectance study was carried out and the results are discussed.

5.8.1. Bandwise reflectance

The different soils formed due to the influence of various soil forming factors and soil forming processes, have affected both the amount of light energy reflected by the soil and the spectral distribution of this energy. The reflectance was generally low in blue band and increased to the green, red and infrared bands, in almost all the soils. Sinha (1987) and Govardhan (1991) reported similar observations.

The increase in reflectivity of the soils in the red and infrared regions did not mean that shortwave blue and green radiation is absorbed by soils in larger absolute amounts than longwave radiation. The total amount of energy absorbed by the soils of various agro-climatic zones is determined, not only by the reflectivity, but also by the intensity of solar radiation that reaches the soil and the spectral composition. This radiation, whose maximum shifts toward the yellow portion of the spectrum as the height of the sun above, the horizon increases. The last factor causes corresponding changes in the actual spectral composition of the reflected light. Studies have shown that radiation with a wavelength of more than 550 mi comprised the main portion of energy absorbed by the soil (Obukhov and Orlov, 1964).

5.8.2. Effect of soil properties on spectral reflectance

The influence of individual soil parameters on reflectance was examined by grouping the soils based on their physical and chemical properties and by constructing the reflectance curves in different spectral bands.

Soils with less than 18 per cent clay reflected high in all the four bands. The reflectance in the blue, green and red bands were almost similar for soils with 18 to 35 per cent clay and soils with more than 35 per cent clay. Considering the influence of sand, it was observed that soils with more than 75 per cent sand recorded high reflectance in all the four bands. From these facts, it is reasonable to assume that decreasing particle size, decreases the soil reflectance. This could be attributed to the increased moisture content and organic matter content, that lower soil reflectance. This is confirmed by the negative correlation between clay content and soil reflectance in all the four bands, while a positive correlation was observed between sand and soil reflectance in all the four bands. Baumgardner *et al.*(1985) reported a linear relationship between the increasing sand content

and increasing reflectance. Montgomery *et al.* (1972) stated that silt content is the single most significant parameter in explaining the spectral variations in soil. In this study, spectral reflectance in soils with varying contents of silt was almost uniform except in the infrared band. The low silt content of the soils in this study could be a reason for such a trend.

Soils that registered a hue of 7.5 YR reflected high in all the bands. There was no discernible trend in the reflectance spectra of soils with hues other than 7.5 YR. Several authors emphasize the role of soil texture, water, organic matter, carbonate or iron oxide content on soil colour (Shields, *et al.*, 1968; Barron and Torrent, 1986). Variations in these factors could be a cause for these observations. Escadafal *et al.*(1989) also reported that soils with 7.5 YR hue reflected highly in all the bands, compared to soils with other hues.

The influence of moisture on spectral reflectance was more evident in the moisture retained at 1500 kPa. In this, the soils that contained less than 10 per cent moisture reflected very high in all the bands, while soils that had more than 20 per cent moisture reflected least in all bands. Several workers have reported that presence of soil moisture considerably reduces the spectral reflectance (Curran, 1985; Sinha, 1987). There was no recognisable pattern in spectral reflectance among soils that retained different level of moisture at 33 kPa. Myers (1983) observed that, the absolute magnitude of reflectance with the addition of water varies considerably because of differences associated with texture, structure, roughness, organic matter, mineral content and illumination geometry.

$CaCO_3$ was observed to decrease the soil reflectance. Soils with less than 1 percent $CaCO_3$ showed high reflectance in all the bands. Abdel-Hamid (1993) reported positive correlations between $CaCO_3$ and soil reflectance. In this study a negative relationship was observed. Soils which

recorded high values of $CaCO_3$ were darker in colour with 10 YR hues (Pedons 6,7 and 8). Perhaps the dark soil colour has contributed to the negative relationship.

Soils with pH values of more than 8 reflected high in all the bands, while soils with pH of less than 6 reflected least in the red and infrared bands. Soils with base saturation of 50 to 80 per cent reflected high in all the bands. In comparison to soils with per cent base saturation of more than 50, the spectral reflectance in soils with base saturation of less than 50 per cent was marginally higher in blue and green bands, and marginally lower at red and infrared bands. pH and BSP by themselves could not have influenced the spectral reflectance of soils. Factors that affect these properties should be the reason for such variation in the spectral reflectance. Soil is a complex mixture of different components. Their spectral signatures are determined by a large number of state variables (Desmet *et al.*, 1988).

Soils with high EC values showed lower reflectance in the blue, green and red bands but a reverse trend was observed in the infrared band. Al-Mahawili (1983) reported similar observations.

Iron compounds have a substantial effect on the reflectance of soils. The reflectance of an iron compound is strongly dependent in its degree of oxidation or hydration (Curran *et al.*, 1990). In the present study soils containing higher amount of free iron oxides reflected low in the red and infrared bands. Obukhov and Orlov (1964) reported that soils with an elevated content of iron are easily distinguished by the inflection characteristic for pure Fe_2O_3, and the intensity of reflection in the region from 500 to 640 mμ is inversely proportional to the iron content. Coleman *et al.* (1991) reported that iron oxide was best predicted by using blue, green, red and thermal infrared bands. In this study,the reflectance in the blue and green band was almost similar in soils irrespective of their free

iron content. This indicates that the blue and green bands may not accurately predict the free iron content. The effect of various iron compounds or the spectral reflectance is not proportional to the relative content and is manifested differently in different soils (Karmanov, 1981).

Soils with low CEC values (<15 cmol (p^+) kg^{-1}) recorded higher spectral reflectance than soils with high CEC values (30 cmol (p^+) kg^{-1}) in all bands. Statistically spectral reflectance in all the four bands were negatively correlated with CEC. Although there is no physical basis for this relationship, it seems that cation exchange capacity is acting as a natural integrating factor for clay type and content, as well as for organic matter content - soil parameters which exhibit inherent spectral behavior (Myers, 1983).

Soils with higher organic carbon content recorded low reflectance in all the bands. Organic matter has a profound influence on soil colour by imparting dark colour. This was the reason for such a trend. Sinha (1987) reported similar findings.

Though remote sensing is primarily concerned with surface soil, the spectral reflectance of soil from lower horizons can be of interest as agricultural and engineering tasks lead to soil reorganisation and soil from lower horizons is brought to the surface. The curves for the spectral reflection of deep horizons are more complex. Changes in the spectral reflection by these horizons reflect the genetic characteristics of the soil profile (Obhukhov and Orlov, 1964).

In the present study, the spectral reflectance of soils by horizon followed different patterns in different pedons. This is to be expected, as the soil properties which contribute to the spectral reflectance follow different patterns between and within pedons. Curran *et al.* (1990) also confirmed that soils with varying properties will display different reflectance characteristics at different depths.

Summary and Conclusion

CHAPTER 6

SUMMARY AND CONCLUSIONS

The seven agroclimatic zones in Tamil Nadu vary widely not only in their climatic parameters but also in their soil characteristics. It was felt that, if comprehensive informations are generated about the major soils of these zones, it will be of much help for researchers in formulating suitable management practices, for the optimum use of these soils. This study was carried out towards this objective.

Fifteen pedons were identified in the seven agroclimatic zones and seventy eight horizonwise soil samples were collected.

The soil samples were analysed for their textural composition, moisture retention characteristics, physico-chemical properties, elemental composition, fractions of iron and manganese, exchange properties, forms of acidity, water soluble ions and spectral reflectance properties. Using all these analytical data an attempt was made to understand the factors and processes that were responsible for the formation of these soils.

6.1. Morphology

The solum depth varied from very shallow (<1m) in Pedons 2 and 8, to very deep (>2m) in Pedons 4, 5, 7, 9, 10, 11, 14 and 15. The hue of the soil colour varied from 10R to 10YR. Vertic properties like surface cracks were observed in Pedons 6, 7, 9 and 10, and slickensides in Pedons 6 and 7. Calcium carbonate nodules were observed in Pedons 6, 7 and 8. The occurrence of these nodules in Pedons 6 and 7 was attributed to the influence of climate and soil characteristics. The variation in the depth of occurrence of the nodules was due to the difference in the intensity of rainfall and pedoturbation. The carbonate nodules found in Pedon 8 were

due to the influence of the calcareous parent material. Iron and manganese concretions were observed in Pedons 7, 9, 10 and 12 because of impeded internal drainage.

Pedons 6 and 8 had weakly developed B horizons suggesting that the pedons are still in a juvenile stage. Only Pedon 4 showed lithological discontinuity with two contrasting materials present in the solum.

6.2. Physical properties

The texture of the pedons varied very widely. Erosion had played a major role in determining the texture of the surface horizons of many pedons. Based on onsite observations the texture of Pedon 5 was considered a result of aeolian deposit. The high clay content of Pedons 9 and 10 were attributed to the puddling operations under rice cultivation. Illuvial accumulation of clay was observed in Pedons 4, 5, 12, 13 and 15. Argillopedoturbation had taken place in Pedons 6 and 7. Water dispersible clay content varied because of variations in Zero Point of Net Charge (ZPNC).

The moisture retention characteristics varied considerably and were positively correlated with clay content. Pedon 15 recorded comparatively lower bulk density because of its higher organic content.

6.3. Physico-chemical properties

Pedons 5, 12, 14 and 15 recorded pH values of less than 6 while Pedons 4, 6, 7, 8 and 13 recorded pH values of more than 7.5. In Pedon 10 the upper horizons were neutral to slightly alkaline, while the bottom most horizon was highly acidic indicating the accumulation of sulphides. Addition of 1M KCl was found to decrease the pH resulting in positive ΔpH values in all the pedons. This implied that the soil had net negative charge. The magnitude of pH varied widely among the pedons. The EC values were

above 1 dSm^{-1} in Pedon 10 because of marine influence. All other pedons registered low EC values. Pedons 14 and 15 had comparatively higher organic carbon due to high rainfall and cooler climates respectively.

6.4. Elemental composition

Silica, alumina and iron dominated elemental composition of the soils. Silica content was high in Pedons 4 and 15 because of their high sand content. In Pedons 14 and 15, the silica content was low, because of the high mean annual rainfall. Alumina was negatively correlated with silica. The variations in the elemental composition were due to variations in parent material and age. The free iron oxides were very low in Pedons 6 and 7 and very high in Pedon 15. The distribution of iron within pedons were largely irregular as a result of changes in pH and Eh. Molar ratios indicated that Pedon 15 had undergone a relatively higher degree of weathering.

6.5. Nutrient composition

The total nitrogen content was highest in Pedon 15 possibly as a result of high organic matter and cooler climate. In most of the pedons the maximum total P was observed in the middle horizons due to precipitation by iron or calcium. Anthropic epipedon was not identified in any of the pedons. In Pedon 9 more than 250 ppm of citric acid soluble P was recorded in two of the subsurface horizons, indicating the influence of anthropedogenic processes in the past. Generally, Bray P and Olsen P were high in the surface horizons. The contents of total Zn, Cu and Mn varied due to the influence of parent materials, among the pedons.

The fractions of iron studied were in the order $Fe_d > Fe_o > Fe_p$. The higher content of Fe_d in comparison to the other two fractions implied that the crystalline iron content was higher than amorphous and organic/gel

hydroxide forms. The Fe_d/Fe_t ratio was very high in Pedon 15 suggesting the highly weathered nature of the soil. The ratio was very low in Pedons 6 and 7 indicating that they were relatively unweathered. Mn_d constituted a larger properties of Mn_t in all the pedons.

6.6. Exchange properties

Cation exchange capacity was highly correlated with clay. Pedon 6 which recorded the highest clay content also registered the highest CEC. Pedon 7 despite its relatively low clay content recorded high CEC which was attributed to contributions from non-clay fractions. The ECEC values were very low in Pedons 5 and 15 suggesting the presence of low activity clays. In all the pedons the exchangeable bases were of the order Ca^{2+} > Mg^{2+} > K^+ > Na^+. Base saturation was very high in Pedons 6, 7 because of impeded internal drainage and very low in Pedons 14 and 15 because of high rainfall in their locations.

6.7. Forms of acidity

Exchangeable acidity was very low in comparison to potential acidity in all pedons. Exchangeable acidity was negatively correlated with pH, indicating that exchange acidity was mainly responsible for lowering the pH in most of the soils. The high potential acidity in Pedon 6 was attributed to its high clay content, while the high potential acidity in Pedons 14 and 15 were due to their high free iron and organic carbon content.

6.8. Water soluble ions

Among the cations Ca^{2+} was dominant in all the pedons. In Pedons 9, 10 and 13 the water soluble Na^+ was more than Mg^{2+}. This was attributed to the intensive cultivation of rice in these pedons. Proximity to sea coast was an additional factor in Pedon 10. Among the anions, generally HCO_3

content was dominant. In the lower horizons of Pedon 10, SO_4^{2-} dominated due to marine influence.

6.9. Soil classification

The soils were classified as per the USDA Soil Taxonomy. Among the pedons 8 were classified under Inceptisol, 5 under Alfisol, one each under Vertisol and Ultisol. Inadequacy of the classification systems was felt in Pedon 14 in which other parameters indicated that the pedon was highly weathered, but the absence of argillic/nitric horizon caused it to be included in Inceptisol.

6.10. Spectral reflectance

The spectral reflectance increased from the blue band to the infrared band. The red and infrared bands were useful in differentiating soils. It was possible to discriminate soils with varying contents of organic carbon, clay, CEC and moisture at 1500 kPa using the spectral data. Soils with 7.5YR hue were also discriminated from the soils with other hues. Sand, SiO_2, free iron, pH_w, pH_{KCl} and total acidity were correlated with the spectral data. Regression equations were developed to predict pH_w, pH_{KCl}, sand total acidity and SiO_2 using the spectral data.

In this study, an attempt was made to understand the soil forming factors and processes that had influenced soil formation and the spectral properties of reference soils of Tamil Nadu. Adequate information was generated on these soils. Studies on charge characteristics, sand and clay mineralogical composition, micromorphology and spectral variability of spectral reflectance of soils could strengthen the findings of the present study and provide a comprehensive picture on the reference soils of Tamil Nadu.

References

REFERENCES

Abdel-Hamid,M.A. 1993. Surface soil reflectance as a criteria of soil classification related to some physical and chemical soil properties. **Egypt. J. Soil Sci., 33** : 149-162.

Adhikari,M. and S.K.Si. 1991. Studies on different forms of iron and aluminium and their release in relation to acidity of some acid soils. **J. Indian Soc. Soil Sci., 39** : 252-255.

Aggarwal,R.K., Praveen Kumar and B.K.Sharma. 1990. Distribution of nitrogen in some Aridisols. **J. Indian Soc. Soil Sci., 38**: 430-433.

Ahmad,N. 1983. Vertisols. **In** : Pedogenesis and Soil Taxonomy II The Soil Orders. (Eds). L.P.Wilding, N.E.Smeck and G.F.Hall. Elsevier, Amsterdam, pp.91-123.

Al-Mahawili,S.M.H.1983. MS thesis. Purdue University, West Lafayette, Indiana as cited by Baumgardner,M.F., L.F.Silva,L.L.Biehl and E.R.Stoner (1985). Reflectance properties of soils. Adv. Agronomy. Academic Press Inc. London. pp.2-29.

Ananthanarayana,R. and T.H.Hanumantharaju. 1994. Nature of soil acidity and lime requirement in the agro-climatic zones of Shimoga District, Karnataka. **J. Indian Soc. Soil Sci., 42** : 361-364.

Anbazhagan,S. 1994. Studies on profile development in relation to toposequence in lateritic soils of Thanjavur district and strategies for resource management. M.Sc.(Ag.) Thesis Submitted to Tamil Nadu Agricultural University, Coimbatore, India.

Appavu,K. and U.S.Sree Ramulu. 1991. Distribution of copper in soil. **Madras agric. J., 78** : 182-185.

Arshad,M.A., R.J.St.Arnaud and P.M.Wang. 1972. Dissolution of trioctahedral layer silicates by ammonium oxalate, sodium dithionite-bicarbonate and potassium pyrophosphate. **Can. J. Soil Sci., 52** : 22-26.

Arudino,E., E.Barbaris, F.Garraro and M.G.Forro. 1984. Estimating relative ages from iron oxide/total iron ratios of soils in the Waster P.O. Valley, Italy. **Geoderma, 33** : 39-52.

Aubert,G. 1963. Soils with ferruginous or ferralitic crusts of tropical regions. **Soil Sci.**, 235-243.

Aubert,H. and M.Pinto. 1977. Trace elements in soils. Elsevier Scientific Publishing Company, Amsterdam.

Bandhyopadhyay,A.K. and D.Sarkar. 1987. Occurrence of acid saline soils in coastal area in Sundarban area of West Bengal. **J. Indian Soc. Soil Sci., 35** : 542-544.

Barrett,L.R. and R.J.Schaetzel. 1992. An examination of podzolisation near Lake Michigan using Chronofunctions. **Can. J. Soil Sci., 72** : 527-541.

Barron,V. and J.Torrent. 1986. Use of the Kubelka Munk theory to study the influence of iron oxides on soil colour. **J. Soil Sci. 37** : 499-510.

Barshad,I. 1964. Chemistry of soil development. **In** : Chemistry of the soil. Ed.F.E.Bear, Reinhold, New York, pp.1-70.

Barticevic,D.E., G.Martinez and S.Aomine. 1976. Cation Exchange Capacity of the sand fraction of some Chilean soils. **Soil Sci. Plant Nutr., 22** : 247-255.

Bascomb,C.L. 1968. Distribution of pyrophosphate extractable iron and organic carbon in soils of various groups. **J. Soil Sci., 19** : 251-268.

Baumgardner,M.F., L.F.Silva, L.L.Biehl and E.R.Stoner. 1985. Reflectance properties of soils. **Adv. Agronomy. 32:** 2-39.

Beckman,G.G., C.H.Thompson and G.D.Hubble. 1974. Genesis of red and black soils on basalt on the Darlingdowns, Queensland, Australia. **J. Soil Sci., 25** : 265-280.

Bhargava,D.S. and D.W.Mariam. 1992. The effect of variation in suspended sediment properties on reflectance measurement. **Photonirvachak, 20** : 139-152.

Bhaskar,B.P. and G.V.Subbaiah. 1995. Genesis, characterisation and classification of laterites and associated soils along the East Coast of Andhra Pradesh. **J. Indian Soc. Soil Sci., 43** : 107-112.

Bhattacharyya,T., T.K.Sen, R.S.Singh, D.C.Nayak and J.L.Sehgal. 1994a. Morphology and classification of Ultisols with Kandic horizon in North Eastern region. **J. Indian Soc. Soil Sci., 42** : 301-306.

Bhattacharyya,T., R.Srivastava, J.P.Sharma and S.L.Sehgal. 1994b. Classification of saline sodic Vertisols in the coastal plains of Gujarat. **J. Indian Soc. Soil Sci., 42** : 306-309.

Biswas,T.D., M.R.Narayana and A.B.Vasudeva Rao. 1966. Characteristics of catenary soils on granite-gneiss parent rock in Kurnool district of Andhra Pradesh. **J. Indian Soc. Soil Sci., 14** : 183-195.

*Blakemore,L.C., P.L.Searle and B.K.Daly. 1987. **Methods for chemical analysis of soils.** N.Z. Soil Bureau Ser. Rep. 80 Soil Bureau, Lower Hutt, New Zealand.

Blank,R.R. and M.A.Fosberg. 1989. Cultivated and adjacent virgin soils in North Central South Dakota : I Chemical and Physical Comparison. **Soil Sci. Soc. Am. J., 53** : 1484-1490.

Blockheim,J.G. 1980. Solution and use of chronofunctions in studying soil development. **Geoderma, 24** : 71-85.

Blokhuis,W.A. 1982. Morphology and genesis of Vertisols. **In:** Vertisols and Rice Soils of the Tropics. Symposia papers II. Trans. 12th Int. Cong. Soil Sci. New Delhi, pp.23-47.

Blume,H.P. and U.Schwertmann. 1969. Genetic evaluation of profile distribution of aluminium, iron and manganese oxides. **Soil Sci. Soc. Am. Proc., 33** : 438-444.

Borden,R.W. and B.P.Warkentin. 1974. An irrigation rating for some soils in Antigua,W.I. **Tropical Agric., 51** : 501-510.

Bray,R.H. and L.T.Kurtz. 1945. Determination of total, organic and available forms of phosphorus in soils. **Soil Sci., 59** : 39-45.

Bremner,J.M. and C.S.Mulvaney. 1982. Nitrogen-Total **In** : Methods of Soil Analysis Part 2. Chemical and Microbiological Properties. Ed.A.L.Page. Soil Science Society of America, Madison, Wisconsin, USA, pp.595-622.

Brewer,R. 1964. Fabric and Mineral Analysis of Soils. Wiley, New York, p.470.

Buol,S.W., F.D.Hole and R.J.McCracken. 1980. Soil genesis and classification. The Iowa State University Press, Ames. Iowa, USA.

Cady,J.G. 1960. Mineral occurrence in relation to profile differentiation. **In** : Trans. 7th International Congress of Soil Science, **4** : 418-424.

Chakravarty,D.N. and J.P.Barua. 1983. Characterisation and classification of the soils of citrus growing belts of Hill Districts of Assam. **J. Indian Soc. Soil Sci., 31** : 287-295.

Challa,O., S.N.Deshmukh, K.M.Nair and J.Prasad. 1993. Red and lateritic soils in part of Western Maharashtra, their characteristics, classification and management. **In** : Red and Latertic Soils of India. (Eds). J.Sehgal, V.A.K.Sarma, R.K.Batta, K.S.Gajbhiye, S.R.Nagabhushna and K.R.Venugopal, NBSS & LUP, ICAR, Nagpur, pp.111-116.

Chapman,H.D.1965. Cation exchange capacity. In : Methods of soil analysis. Ed. C.A.Black. **Am. Soc. Agron.** Madison. Wisconsin, USA. pp.891-901.

Chatterji,S., Dipak Sarkar and Rajvir Sharma. 1995. Water retention characteristics of some typical soils of the Sundarbans, West Bengal. **J. Indian Soc. Soil Sci., 43**:120-121.

Childs,C.W. 1975. Composition of iron-manganese concretions from some New Zealand Soils. **Geoderma, 13** : 141-152.

Childs,C.W. and A.D.Wilson. 1983. Iron oxide minerals in soils of the Ha'Pai group Kingdom of Tongu. **Aust. J. Soil Res., 21** : 489-503.

Chittleborough,D.J., R.H.Walker and J.M.Oades. 1984. Textural differentiation in chronosequences from eastern Australia II. Evidence from particle size distribution. **Geoderma. 32** : 203-226.

Coleman,T.L., P.A.Agbu, O.L.Montgomery, T.Gao and S.Prasad.1991. Spectral band selection for quantifying selected properties in highly weathered soils. **Soil Sci., 151** : 355-361.

Contractor,R.M. and V.P.Badanur. 1996. Effect of forest vegetation on properties of a Vertisol. **J. Indian Soc. Soil Sci., 44** : 510-511.

Couto,W., C.Sanzonowicz and A.O.Barcellos. 1985. Factors affecting oxidation-reduction processes in an oxisol with a seasonal water table. **Soil Sci. Soc. Am. J., 49** : 1245-1248.

Crocker,R.L. 1967. The plant factor in soil formation. **In** : Selected papers in soil formation and classification. (Ed). J.V.Drew. SSSA Special Publication No.1 SSSA, Madison, Wisconsin, USA, p.190.

Curran,P.J.1985. Principles of remote sensing. English language book society/Longman, Essex, England. p.33.

Curran,P.J., G.M.Foody, K.Ya, Kondratyev, V.V.Kozoderov and P.P.Fedchenko. 1990. Remote sensing of soils and vegetation in the USSR. Taylor and Francis. New York. pp.1-201.

Daniels,R.B., J.F.Brasfield and J.F.Riecken. 1962. Distribution of sodium hydrosulfite extractable manganese in some Iowa soil profiles. **Soil Sci. Soc. Am. Proc., 26** : 75-78.

Das,A.N., B.K.Laskar, G.K.De and N.C.Debnath. 1991. Nature of acidity of some acid soils of West Bengal. **J. Indian Soc. Soil Sci., 39** : 246-251.

Das,P.K., G.C.Sahu., and S.S.Khanna. 1992. Nature of acidity and exchange chemistry of some laterite soils of Orissa **J. Indian Soc. Soil Sci., 40** : 425-430.

Dasog.G.S., J.Vishwanath, S.I.Tolanur and T.Satyanarayana. 1990. Properties and genesis of Vertisols formed on three parent rocks in Northern Karnataka, India. **In** : Trans. 14th International Congress of Soil Science, Kyoto, Japan. Vol.5 pp.392-393.

Davidson,S.E and J.B.Page. 1956. Factors influencing swelling and shrinkage in soils. **Soil Sci. Soc. Am. Proc., 20** : 320-324.

De Kimpe,C.R., M.R.Laverdiers, J.Dejon and P.Lasalle. 1984. Effects of acidic and basic parent materials on formation of soils in Quebec (Canada). **Geoderma, 33** : 101-118.

Desmet,A., H.Eernes and R.Gombeer. 1988. Influence of some soil factors on the reflectance of baresoils. **Pedologie. 38** : 227-247.

Dhaliwal,S.S., P.S.Sidhu and H.S.Jassal. 1993. Mineralogy and elemental association of flood plain soils. **J. Indian Soc. Soil. Sci., 41** : 754-778.

Digar,S. and N.K.Barde. 1982. Morphology, genesis and classification of red and laterite soils. Review of soil Research in India. Part II **In** : 12th International congress of Soil Science. New Delhi, India, pp. 498-507.

Digar,S., A.K.Haldar and A.L.Das. 1973. Classification of the soils of the Machkand Catchment according to U.S taxonomy. **J. Indian Soc. Soil Sci., 21** : 491-497.

Diwakar,D.P.S. and R.N.Singh. 1993. Tal land soils of Bihar-V; Occurrence and genesis of concretion and nodules. **J. Indian Soc. Soil Sci., 41** : 111-115.

Diwakar,D.P.S. and R.N.Singh. 1994. Characterization, classification and productivity potential of Vertisols and associated soils of Bihar. **Agropedology, 4** : 19-30.

Dixit,S.P. 1980. Surface charge characteristics of soil colloids of some different soils types. **J. Plant Nut. Soil Sci., 143:** 422-431.

Dobrovolskii,G.V. and T.V.Tereshina. 1976. Biological origin of manganese - iron concretions in the soils of the Southern Taiga. **Moscow Univ. Soil Sci. Bull., 31** : 1-8.

Dolui,A.K., S.Dey and A.K.Nayak. 1987. Charge characteristics of two soil profiles. **J. Indian Soc. Soil Sci., 35**:353-356.

Dubey,D.D., O.P.Sharma and G.P.Verma. 1985. Sand mineralogy of some salt affected soils of Western Madhya Pradesh. **J. Indian Soc. Soil Sci., 33** : 461-464.

Dudal,R. 1965. Dark clay soils of tropical and subtropical regions. Agric. Devel. Paper 83, FAO, Rome, Italy.

Dutil,P. 1982. Lime in soils: Calcium and Magnesium. **In:** Constituents and properties of soils. (Eds). M.Bonneau and B.Souchier Academic Press, New York. p.418.

Dwivedi,K.N. and H.Shanker. 1982. Distribution of copper in soils of Uttar Pradesh. **Indian J. Agric. Chem., 15**:53-71.

Ehrlich,W.H., H.M.Rie and J.H.Ellis. 1967. Influence of the composition of parent materials on soil formation in Manitoba. **In :** Selected papers in soil formation and classification. (Ed). J.V.Drew. SSSA Special Publication series No. 1, Soil Science Society of America, Madison, Wisconsin, USA. pp. 228-244.

Elahi,S.F., M.F.Hossain and A.S.M.M.Kamal. 1996. Characteristics of some soils developed on Madhupur clay in Bangladesh. **J. Indian Soc. Soil Sci., 44** : 482-488.

Elless,M.P. and M.C.Rabenhorst. 1994. Hematite in the shales of Triassic culpeper Basin of Maryland. **Soil Sci., 158** : 150-154.

Escadafal,R., M.C.Girard and D.Courault. 1989. Munsell soil colour and soil reflectance in the visible spectral bands of Landsat MSS and TM data. **Remote Sens. Environ. 27** : 37-46.

Eswaran,H.1971. Electron scanning studies of the fabric of fracture surfaces. **Soil Sci. Soc. Am. Proc., 35** : 787-790.

Eswaran,H. and C.Sys. 1979. Argillic horizon in LAC(*) soils formation and significance to classification. **Pedologie, 26:** 175-190.

Evans,Jr.A. and R.C.Sorensen. 1985. Effect of ionic strength and solution pH on P extractability and leaching in coarse texture soils. **Can. J. Soil Sci., 65** : 101-108.

FAO. 1990. Guidelines for soil description. Soil Resources Management and Conservation Service. Land and Water Development Division. Food and Agriculture Organisation, Rome.

Fenton,T.E. 1983. Mollisols. **In :** Pedogenesis and Soil Taxonomy II The Soil Orders (Eds). L.P.Wilding, N.E.Smeck and G.F.Hall Elsevier, Amsterdam. p.145.

Gallaher,R.N., H.F.Perkins and K.H.Tan. 1974. Classification, composition and mineralogy of iron glabules in a southern coastal plain soil. **Soil Sci., 117** : 155-164.

Gallez,A., A.S.R.Juo. and A.J.Herbillon. 1976. Surface and charge characteristics of selected soils in the tropics. **Soil Sci. Soc. Am. J., 40** : 601-608.

Gamble,E.E. and R.B.Daniels. 1972. Iron and silica in water, acid ammonium oxalate and dithionite extracts of some North Carolina coastal plain soils. **Soil Sci. Soc. Am. Proc., 36** : 939-943.

Gangopadhyay,S.K., P.K.Das, S.Nath and S.K.Banerjee. 1989. Pedogenic characteristics of the soils supporting different forest vegetation in the foot hill region. **J. Indian Soc. Soil Sci., 37**: 775-781.

Ghabru,S.K. and S.K.Ghosh. 1980. Morphology, genesis and classification of two soil profiles from the Dhanlodhor range of middle siwaliks. **J. Indian Soc. Soil Sci., 28** : 154-162.

Gile,L.H. 1975. Causes of soil boundaries in an arid region. I. Age and parent materials. **Soil Sci. Soc. Am. Proc., 39**: 316-323.

Gordon,F.R. and D.M.A.Smith. 1984. Lateritic soils near Worsteg. Fourth Australia Newzealand Conference on Geomechanies. Baston Australia. pp. 273-277.

Gotoh,S. 1976. Distribution of total and extractable forms of iron, magnesium and aluminum in development of rice soils of Saga Bider lands. **Soil Sci. Plant Nutr., 22** : 335-344.

Govardhan,V.1991. Spectral reflectance characterization of different soils of Deccan plateau. **Photonirvachak. 19** : 175-185.

Govindan,K. 1996. Satellite Remote sensing for soil resource and land degradation studies in Lower Gundar Basin. M.Sc.(Ag.) Thesis submitted to Tamil Nadu Agricultural University, Coimbatore, India.

Gowaikar,A.S. and N.P.Datta. 1971. Influence of moisture regime on the genesis of laterite soils in South India. **J. Indian Soc. Soil Sci., 19** : 279-291.

Guillet,B. and B.Souchier. 1982. Amorphous and crystaline oxyhydroxides and oxides in soils. **In** : Constituents and properties of soils (Eds). M.Bonneau and B.Souchier. Academic Press, New York. p 273.

Gupta,R.P. and C.Dakshinamurthi. 1980. Procedures for physical analysis of soils and collection of agrometeorological data. Division of agricultural physics, IARI, New Delhi.

Gupta,R.D. and B.R.Tripathi. 1992. Genesis of soils in wet temperate and sub alpine/moist-alpine climatic zones of the North West Himalayas. **J. Indian Soc. Soil Sci., 40** : 505-512.

Gupta,R.D. and B.R.Tripathi. 1993. Characterization of rice growing and adjacent virgin soils. I Morphology, genesis and classification. **J. Indian Soc. Soil Sci., 41** : 720-724.

Hall,F.G. 1983. Pedology and Geomorphology. **In** : Pedogenesis and Soil Taxonomy I. Concepts and interactions. (Eds). L.P.Wilding, N.E.Smeck and G.F.Hall. Elsevier Science Publishers, Amsterdam. p.127.

Hameed Khan,H. and Hanuman Ram. 1977. Morphology, chemistry and classification of two red soil series. **Madras agric. J., 64**: 580-585.

Hazra,G.C., J.K.Saha, P.K.Mete and B.Mandal. 1993. Distribution of zinc fractions in red and lateritic soils of Birbhum, West Bengal. **J. Indian Soc. Soil Sci., 41** : 472-476.

Hesse,P.R. 1971. A Textbook of Soil Chemical analysis. John Murray, New York.

Hole,F.D. 1981. Effects of animals on soil. **Geoderma, 25**:75-112.

Holmes,R.S. 1945. Determination of total Cu, Zn, Co and Pb in soils and soil solution. **Soil Sci., 59** : 77-84.

Humphreys,G.S. 1994. Bioturbation, biofabrics and the biomantle : an example from Sydney basin. **In** : Soil micromorphology studies in management and genesis. Proc. of Nineth International Working meeting on Soil Micromorphology, Townsville, Australia. 1992. (Eds). A.J.Voase, G.S.Humphreys. Elsevier Science Publishers, Amsterdam. pp.421-436.

ISRIC. 1992. Procedures for soil analysis. (Ed). L.P.Van Reeuhijk. International Soil Reference and Information Centre, Wageningen, The Netherlands.

Jackson,M.L. 1958. Soil Chemical Analysis. Prentice Hall of India.

Jackson,M.L. 1964. Chemical composition of soils. **In** : Chemistry of soil. (Ed). F.E.Bear. Oxford and IBH Publishing Co., Calcutta.

Jackson,M.L. and G.D.Sherman. 1953. Chemical weathering of minerals in soils. **Adv. Agronomy. 5** : 221-318.

Jarvis,S.C. 1984. The forms of occurrence of manganese in some acidic soils. **J. Soil Sci., 35** : 421-429.

Jenny,H. 1941. Factors of soil formation. McGraw-Hill Book Company, New York. p.52.

Joffe,J.S. 1940. Lysimeter studies : The translocation of cations in the profile of a gray brown podzolic soils. **Soil Sci. Soc. Am. Proc., 5** : 187-190.

Kailash Kumar, K.V.P.Rao and L.J.Singh. 1995. Forms of acidity in some acid Inceptisols under different land use in Manipur. **J. Indian Soc. Soil Sci., 43** : 338-342.

Kaistha,B.P. and R.D.Gupta. 1994. Morphology and characteristics of a few Entisols and Inceptisols of North Western Himalayan region. **J. Indian Soc. Soil Sci., 42** : 100-104.

Karale,R.L., R.V.Tamhane and S.C.Das. 1969. Soil genesis as related to parent material and climate. **J. Indian Soc. Soil Sci., 17** : 227-239.

Karmonov,L.A. 1981. Effect of various iron compounds on the spectral reflectance and colour of soils. **Soviet Soil Sci., 13** : 53-60.

Kaswala,R.R. and S.R.Deshpande. 1983. Physico-chemical and mineralogical characteristics of some coastal and inland soil series of South Gujarat. I. Physico-chemical characteristics. **J. Indian Soc. Soil Sci., 31** : 281-286.

Kosse,A. 1990. The Anthric major soil grouping in the IRB. **In:** Trans. 14th International Congress of Soil Science, Kyoto, Japan. Vol.V. p.357.

Krishnan,P., J.D.Alexander, B.J.Butler and J.W.Hummel. 1980. Reflectance techniques for predicting soil organic matter. **Soil Sci. Soc. Am. J., 44** : 1282-1285.

Kudrat,M., M.L.Manchanda, J.Prasad, P.D.Saxena and H.D.Tayal. 1995. Morphology, physico-chemical characteristics and classification of lateritic soils of a part of Ajoy catchment in West Bengal. **Agropedology, 5** : 9-14.

Kumar,S. and S.Kumar. 1993. Pedogenesis and classification of some salt affected and associated normal soils of Gangetic alluvial tract in Western Uttar Pradesh. **Agropedology, 3** : 49-58.

Kumar,K., K.V.P.Rao and L.J.Singh. 1995. Forms of acidity in some acid Inceptisols under different Land Use in Manipur. **J. Indian Soc. Soil Sci., 43** : 338-342.

*Laboratory for Soil and Crop Testing. 1979. Phosphate P-citric acid. Working procedure No.F3/A15-025 Lab for Soil and Crop Testing. Ooterbuk, Netherlands.

Lal,R. 1981. Physical properties. **In** : Characterization of soils in relation to their classification and management for crop production examples from some areas of the humid tropics. (Ed). D.J.Greenland, Clarendon Press, Oxford. p.214.

Landey,R.J., L.R.Hirekerur and P.Krishnamoorthy. 1982. Morphology, genesis and classification of black soils. Review of soil research in India. Part II 12th International Congress of Soil Science. New Delhi, India. pp. 484-497.

Loganathan,S. and K.K.Krishnamoorthy. 1979. A study of calcium in relation to other cations of soils. **Andhra Agric. J., 26** : 1-2.

Lutwick,L.E. and J.T.Dormaar. 1973. Fe status of Brunisolic and related soil profiles. **Can. J. Soil Sci., 53** : 185-197.

Mac Vicar,C.N., R.W.Fitzpatrick and M.E.Soleczyk. 1984. Highly weathered soils in the East Coast hinterland of South Africa with thick humus rich A1 horizons. **J. Soil Sci., 35** : 103-115.

Manickam,T.S. 1977. Studies on laterite soils of Tamil Nadu, India. Ph.D. Thesis submitted to Tamil Nadu Agricultural University, Coimbatore, India.

Mason,B. 1966. Principles of Geochemistry. Wiley. New York. p.281.

Mathan,K.K. and K.Chirangivi Rao. 1982. Magnesium as a function of Pedogenic factors. **Madras agric. J., 67** : 300-308.

Mathan,K.K., K Sankaran, N.Kanakabushini and K.K.Krishnamoorthy. 1978. Cumulative effect of manures and fertilizers on the mechanical fraction of soils. **Madras agric. J., 65** : 641-644.

Mathan,K.K., B.Raj Kannan and R.Natesan. 1991. Moisture retention characteristics and available water capacities of certain soil series. **Madras agric. J., 80** : 256-260.

Mathews,H.R., R.L.Cunningham and G.W.Peterson. 1973. Application of multispectral remote sensing to soil survey research in south eastern Pennsylvania. **Soil Sci. Soc. Am. J., 37** : 88-93.

Mayalagu,K. 1982. Distribution of total and available N, P and K in the major soil series profiles of black soils of Coimbatore district, Tamil Nadu. **Madras agric. J., 69** : 825-829.

Mayalagu,K. and K.Subramanian. 1993. Pedogenesis related chemical constituents in Kodaikanal hilly tracts along three aspects catenas. **Indian J. Agric. Chem., 26** : 5-15.

McKeague,J.A. and J.H.Day. 1966. Dithionite and oxalate extractable Fe and Al as aids in differentiating various classes of soils. **Can. J. Soil Sci., 46** : 13-22.

*Mehra,G.P. and M.L.Jackson. 1960. Iron oxide removal from soils and clays by a dithionite-citrate-bicarbonate system bufferred with sodium bicarbonate. **In** : Proc 7th Natl. Conf. on clays and clay minerals, Pergamon Press, New York. pp.317-327.

Menon,P.K.R. and A.Mariakulandai. 1957. The soils of Madras state. **Madras agric. J., 44** : 313-325.

Mermut,A.R. and D.F.Acton. 1985. Surficial rearrangement and cracking in swelling clay soils of the glacial Lake Regina Basin in Saskatchewan. **Can. J. Soil Sci., 65** : 317-327.

Michalyna,W. 1971. Distribution of various forms of aluminium, iron and manganese in the orthic gray wooded, gleyed orthic gray wooded and related Gleysols in Manitoba. **Can. J. Soil Sci., 51** : 23-36.

Miller,B.J. 1983. Ultisols. **In** : Pedogenesis and soil taxonomy II. The soil orders (Eds). L.P.Wilding, N.E.Smeck and G.F.Hall. Elsevier, Amsterdam. pp.201-237.

Miller,R.W. and R.L.Donahue. 1992. Soils : An Introduction to Soils and Plant Growth. Prentice Hall of India, p.96.

Mishra,D.P. and S.S.K.Nanda. 1985. Available water of different textural classes in the Hirakud Command area (Orissa). **J. Indian Soc. Soil Sci., 33** : 372-379.

Mishra,B.B. and S.K.Ghosh. 1995. Characterisation of soils developed from mica-rich parent materials in two toposequences. **J. Indian Soc. Soil Sci., 43** : 92-98.

Mishra,B.B., S.K.Ghosh and S.K.Srivastava. 1993. Spectral reflectance of soils derived from mica-rich parent materials in two different toposequences in relation to soil properties. **J. Indian Soc. Soil Sci., 41** : 516-521.

Mohr,T.C.J., F.A.Van Barren and J.Van Schuylenborgh. 1972. Tropical soils. Mouton Ichitar Bani. Van Hueva. The Hague. p.255.

Mokwunye,A.U. and S.W.Melsted. 1972. Magnesium forms in selected temperate and tropical soils. **Soil Sci. Soc. Am. Proc., 36** : 762-764.

Mongia,A.D. and A.K.Bandhyopadhyay. 1992. Physicochemical changes occurring in soils of tropical forest after clearfelling for high value plantation crops. **J. Indian Soc. Soil Sci., 40** : 420-424.

*Montgomery,O.L., M.F.Baumgardner and W.A.Weismiller. 1972. An investigation of the relationship between spectral reflectance and the chemical, physical and genetic characteristics of the soils. LARS Information Note.082776. Purdue Univ., West Lafayette. Indiana, USA.

Murthy,R.S. 1978. Rice soils of India. **In** : Soils and Rice. International Rice Research Institute, Los Banos, Philippines. pp.3-17.

Murthy,R.S., L.R.Hirekerur, S.B.Deshpande and B.V.Venkata Rao. 1982. Benchmark Soils of India. National Bureau of Soil Survey and Land Use Planning (ICAR), Nagpur.

Myers,V.I. 1983. Remote sensing applications in agriculture. **In** : Manual of Remote Sensing. Vol.I. Theory, Instruments and Techniques. (Eds). R.N.Colwell, D.S.Simoneth and F.T.Ulaby. American Society of Photogrammetry. Falls Church, Virginia, USA. pp.2111-2228.

Myers,V.I., L.R.Ussery and W.J.Rippert. 1963. Photogrammetry for detailed detection of drainage and salinity problems. **Trans. ASAE, 6** : 322-334.

Nagatsuka,S. 1972. Studies on genesis and classification of soils in warm-temperate region of South West Japan. Part 3. Some features in distribution and mode of existence of free iron and aluminium oxides in the soil profile. **Soil Sci. Plant Nutr., 18** : 147-154.

Nahon,D., A.Beauvais and J.J.Trescases. 1985. Manganese concentration through chemical weathering of metamorphic rocks under lateric conditions. **In** : The chemistry of weathering (Ed). J.I.Drever. D.Reidel Publications Co., Dordrecht, West Germany. pp.277-291.

Natarajan,A. 1995. Mineralogy and genesis of typical lateritic soils in Peninsular India. Ph.D. Thesis submitted to University of Agricultural Sciences, Bangalore, India.

Natarajan,S. and M.Y.Gajbe. 1983. Report on soil and land use survey of North Mewat and adjacent areas - Haryana. Soil Survey Division. Indian Photo Interpretation Institute, Dehradun.

Nayak,D.C., T.K.Sen, G.S.Chamuah and J.L.Sehgal. 1996. Nature of soil acidity in some soils of Manipur. **J. Indian Soc. Soil Sci., 44** : 209-214.

Nettleton,W.D., K.W.Flach and B.R.Brasher. 1969. Argillic horizons without clay skins. **Soil Sci. Soc. Am. Proc., 33** : 121-125.

Norfleet,M.L. and B.R.Smith. 1989. Weathering and mineralogical classification of selected soils of the Blue ridge mountain of South Carolina. **Soil Sci. Soc. Am. J., 53** : 1771-1778.

Obukhov,A.I. and D.S.Orlov. 1964. Spectral reflectivity of the major soil groups and possibility of using diffuse reflection in soil investigation. **Soviet Soil Sci., 2** : 174-184.

Ogunsola,O.A. and J.A.I.Omueti. 1990. The physical, chemical and mineralogical characteristics of soils overlaying limestone areas in southern Nigeria. **In** : Trans. 14th International Congress of Soil Science, Kyoto, Japan. Vol.VIII, p.426.

O'Halloran,I.P. and R.G.Kachanoski and J.W.B.Stewart. 1985. Spatial variability of soil phosphorus as influenced by soil texture and management. **Can. J. Soil Sci. 65** : 475-487.

Ohta,S. and S.Effendi. 1992. Ultisols of "Lowland *Dipterocarp* Forest" in East Kalimantan, Indonesia. I. Morphology and physical properties. **Soil Sci. Plant Nutr., 38** : 207-216.

Ohta,S., S.Effendi, N.Tanaka and S.Miura. 1993. Ultisols of lowland *Dipterocarp* Forest in East Kalimantan, Indonesia. III Clay minerals, Free oxides and Exchangeable cations. **Soil Sci. Plant Nutr., 39** : 1-12.

Okusami,T.A. 1990. The properties, clay mineralogy and soil classification of dominant red soils in the humid rain forest of South West Nigeria. **In** : Trans. 14th International Congress of Soil Science, Kyoto, Japan, Vol.VII. p.479.

*Olsen,S.R., C.V.Cole, F.S.Watanabe and L.A.Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circ. U.S. Dept. Agric., 939.

Pachrane,T.K., D.K.Pal and S.B.Deshpande. 1996. Genesis and transformation of clay minerals in the formation of ferruginous Inceptisols and Vertisols in the Saptadhara Watershed of Nagpur district, Maharashtra. **J. Indian Soc. Soil Sci., 44** : 300-309.

Palaniappan,SP., S.Natarajan and T.M.Thiyagarajan. 1993. Agroecology and soils of Tamil Nadu, India. **In** : Agroecology of rice based cropping systems : Proceedings of the International Workshop on Agro-ecological Zonation of rice Zhejiang Agricultural University, China, 14-17, April 1993. p.138.

Paramasivam,P. and A.Gopalaswamy. 1994. Distribution of micronutrients in Lower Bhavani Project command area soil profiles. **Madras agric. J., 81** : 545-547.

Paterson,E. 1995. Precipitation of iron in a poorly drained alluvial soil. **Commun. Soil Sci. Plant Anal., 26** : 1203-1212.

Patgiri,D.K., M.Das and T.C.Baruah. 1993. Effect of mechanical composition and organic matter on soil water retention. **J. Indian Soc. Soil Sci., 41** : 544-545.

Peech,M. 1965. Hydrogen ion activity. **In** : Methods of Soil Analysis. Ed.C.A.Black. **Am. Soc. Agron.** Madison, Wisconsin, USA.

Peech,M., R.I.Cowan and J.H.Baker. 1962. A critical study of $BaCl_2$-TEA and NH_4OAC methods for determining exchangeable H content of soils. **Soil Sci. Soc. Am. Proc., 26** : 37-40.

Piper,C.S. 1966. Soil and Plant Analysis. Inter-science Publishers, Inc., New York.

Polteva,R.N. and T.A.Sokholova. 1967. Investigations of concretions in a strongly podzolic soil profile. **Soviet Soil Sci., 7** : 884-893.

Prabhuraj,D.K. and A.S.P.Murthy. 1994. Forms of acidity in some acid soils. **J. Indian Soc. Soil Sci., 42** : 455-456.

Prasad,S.N. and B.P.Sahu. 1989. Distribution of manganese in relation to soil properties in some typical soil profiles. **J. Indian Soc. Soil Sci., 37** : 567-570.

Prasad,K.K., R.L.Karale and T.D.Biswas. 1977. Studies on soil genesis from complex geological rocks in an area around Junagarh. **J. Indian Soc. Soil Sci., 25** : 207-220.

Prasad,A., N.G.Totey, A.K.Singh, R.Kulkarni, P.K.Khatri, A.K.Bharmik, J.S.Chouhan and V.K.Dahia. 1989. Profile development in relation to topography. **J. Indian Soc. Soil Sci., 37** : 790-797.

Qian,P., J.D.Wolt and D.D.Tyler. 1994. Soil solution composition as influenced by tillage and time of nitrogen fertilization. **Soil Sci., 158** : 141-149.

Raghupathi,H.B. and N.Vasuki. 1993. Relationship of available copper with total copper in some vertisols. **J. Indian Soc. Soil Sci., 41**: 569-571.

Rakhunde,S.B., B.V.Khaladkar and S.M.Khairnar. 1993. Soils of Southern Sindhudurg district, Maharashtra - Their Characterisation and Classification. **In** : Red and latertic soils of India. (Eds). J.Sehgal, V.A.K.Sarma and K.R.Venugopal, NBSS JLUP, Nagpur, pp.68-72.

Ramu,S. 1994. Remote sensing for characterisation and rehabilitation of gypsum mined soils. M.Sc.(Ag.) Thesis Submitted to Tamil Nadu Agricultural University, Coimbatore, India.

Randhawa,H.S. and S.P.Singh. 1995. Distribution of zinc fractions in alluvium derived soils of Punjab. **J. Indian Soc. Soil Sci., 43** : 124-126.

Randhawa,H.S. and S.P.Singh. 1996. Copper fractions in soils of Punjab. **J. Indian Soc. Soil Sci., 44** : 243-246.

Rao,C.S., G.V.Subbaiah and K.P.Tomar. 1995. Characterisation and classification of black soils of Telugu Ganga Project area in Nellore District (Andhra Pradesh). **In** : Proc. Indian National Science Academy Part B, Biological Sciences, **61** : 191-198.

Ravikumar,V., Mahendra Singh, D.S.Ruhal and Rajendra Singh. 1987. Forms of potassium in some soils of central Haryana. **Haryana agric. Univ. J. Res., 17** : 356-362.

Raychaudhuri,S.P., B.B.Roy, S.P.Gupta and M.L.Dewan. 1963. Blacksoils of India. National Institute of Sciences of India, New Delhi.

Richards,L.A. 1965. Diagnosis and improvement of saline and alkali soils. Agric. Hand Book No.60, USDA.

Richardson,J.L. and R.B.Daniels. 1993. Stratigraphic and hydraulic influences on soil colour development. **In** : Soil colour: SSSA Special Publication No.31, (Eds). J.M.Bingham and E.S.Ciolkosz, Soil Science Society of America, Madison, Wisconsin, USA. pp.109-125.

Robert,M. and S.Trocme. 1982. Potassium. **In** : Constituents and properties of soils. (Eds). M.Bonneau and B.Souchier. Academic Press, New York, p.428.

Roberts,T.L., J.W.B.Stewart and J.R.Bettany. 1985. The influence of topography on the distribution of organic and inorganic soil phosphorus across a narrow environmental gradient. **Can. J. Soil Sci., 65** : 651-665.

Ruhe,R.V. 1967. Geomorphic surface and the nature of soils. **In** : Selected papers in soil formation and classification. SSSA Special Publication No.1. (Ed). J.V.Drew. Soil Science Society of America, Madison, Wisconsin, USA. pp.270-285.

Runge,E.C.A. and F.Riecken. 1966. Influence of natural drainage on the distribution and forms of phosphorus in some Iowa prairie soils. **Soil Sci. Soc. Am. Proc., 30** : 624-630.

Rutherford,G.K. and R.A.Kemp. 1983. Soil genesis on the canadian shield near Machesney lake, Eastern Ontario. **Can. J. Soil Sci., 63** : 45-55.

Sahu,G.C. and N.Bala. 1995. Characterization and classification of soils on valley plains of middle Andaman Island. **J. Indian Soc. Soil Sci., 43** : 99-103.

Sahu,G.C. and S.S.Dash. 1993. Characterisation and classification of salt affected coastal soils of Astaranga, Orissa. **J. Indian Soc. Soil Sci., 41** : 138-144.

Sahu,G.C., N.Panda and S.K.Nanda. 1983. Genesis and morphology of some red and laterite soils of Orissa. **J. Indian Soc. Soil Sci., 31** : 254-262.

Sarkar,D., C.J.Thampi and A.K.Haldar. 1993. Characterisation and classification of soils of Mahsani island of the Sunderbans, West Bengal. **J. Indian Soc. Soil Sci., 41** : 511-516.

Schulze,D.G., J.L.Nagel, G.E.Van Scoyoe, T.L.Henderson, M.F.Baumgardner and D.E.Stott. 1993. Significance of soil organic matter in determining soil colours. **In** : Soil Colour: SSSA Special Publication No.31. (Eds). J.M.Bingham and E.J.Golkosz. Soil Science Society of America, Madison, Wisconsin, USA. pp.71-90.

Schwertmann,U. 1990. Pedogenic significance of iron oxide minerals in highly weathered tropical soils. **In** : Trans. 14th International Congress of Soil Science. Kyoto, Vol.VII, p.91.

Schwertmann,U. 1993. Relations between iron oxides soil colour and soil formation **In** : Soil Color : SSSA Special Publication No.31. (Eds). J.M.Bingham and E.J.Ciolkosz. Soil Science Society of America, Madison, Wisconsin, USA. pp.51-69.

Schwertmann,U. and D.S.Fanning. 1976. Iron-manganese concretions in hydrosequences of soils in Loess in Bavaria. **Soil Sci. Soc. Am. J., 40** : 731-738.

Sehgal,J.L. and G.Stoops. 1972. Pedogenetic calcite accumulation in arid and semi-arid regions of the Indo-Gangetic alluvial plain of erstwhile Punjab (India). Their morphology and origin. **Geoderma, 8** : 59-72.

Sehgal,J. and D.K.Mandal. 1994a. Soil moisture regimes in India. National Bureau of Soil Survey and Land Use Planning, ICAR, Nagpur. pp.1-6.

Sehgal,J. and D.K.Mandal. 1994b. Soil temperature regimes in India. National Bureau of Soil Survey and Land Use Planning, ICAR, Nagpur. pp.1-4.

Sehgal,J.L., R.Gombeer and J.D.Hoore. 1976. Clay migration in the formation of argillic horizons in soils developed under varying moisture regimes. **J. Indian Soc. Soil Sci., 24**:20-28.

Sehgal,J.L., C.Sys, G.Stoops and R.Tavernier. 1985. Morphology, genesis and classification of two dominant soils of the warm temperate and humid region of the Central Himalayas. **J. Indian Soc. Soil Sci., 33**: 846-857.

Seshagiri Rao,M., R.K.Chatterjee and N.G.Raghu Mohan. 1992. Free iron oxides in soils of Alfisols-Vertisols Toposequence. **J. Indian Soc. Soil Sci., 40** : 606-607.

Shankaranarayana,H.S. and V.A.K.Sarma. 1982. Soils of India. **In:** Benchmark soils of India. Morphology characteristics and classification for resource management. (Eds). R.S.Murthy, L.R.Hirekerur, S.B.Deshpande and B.V.Venkata Rao. NBSS & LUP. pp.41-70.

Shanwal,A.K. and S.K.Ghosh. 1987. Soils on surfaces differing in age in Yamuna alluvial plain, India. **Pedologie, 37** : 169-186.

Sharma,P.K. and G.Dev. 1985a. Physiography - Soil relationship in a transect in North-East Punjab. **J. Indian Soc. Soil Sci., 33** : 604-612.

Sharma,P.K. and G.Dev. 1985b. Genesis of soils on different geomorphic surfaces in a riverine plain in Punjab. **J. Indian Soc. Soil Sci., 33** : 613-626.

Sharma,S.S., K.L.Totawat and R.L.Shyampura. 1996. Characterisation and classification of soils in a toposequence order Basaltic Terrain. **J. Indian Soc. Soil Sci., 44** : 470-473.

Shields,J.A., E.A.Paul, R.J.St.Arnaud and W.K.Head. 1968. Spectrophotometric measurement of soil colour and its relation to moisture and organic matter. **Can. J. Soil Sci. 48** : 271-280.

Sidhu,P.S. and S.S.Bhangu. 1993. Distribution of water soluble and exchangeable potassium in benchmark soils of Punjab. **J. Indian Soc. Soil Sci., 41** : 678-682.

Sidhu,P.S., J.L.Sehgal and M.K.Sinha. 1976. Trace element content of Fe-Mn concretions in soils of Punjab. **J. Indian Soc. Soil Sci., 24** : 330-331.

Sidhu,P.S., G.F.Hall and J.L.Sehgal. 1977a. Nature of distribution of carbonate in the semi arid region of Punjab. **J. Indian Soc. Soil Sci., 25** : 161-169.

Sidhu,P.S., J.L.Sehgal and N.S.Randhawa. 1977b. Elemental distribution and associations in some alluvium derived soils of the Indo-Gangetic plain of Punjab (India). **Pedologie, 27**: 225-235.

Sidhu,P.S., Rajkumar and B.D.Sharma. 1994. Characterisation and classification of Entisols in different soil moisture regimes of Punjab. **J. Indian Soc. Soil Sci., 42** : 633-640.

Sieg,C.H. 1993. A classification of soils in Bur Oak Woodlands in the foothills of the black hills, South Dakota. **Soil Sci., 155** : 131-147.

Simonson,R.W. 1954. Morphology and classification of regur soils of India. **J. Soil Sci., 5** : 275-288.

Simonson,R.W. 1993. Soil colour standards and terms for field use - History of their development. **In** : Soil Colour : SSSA special Publication No.31. (Eds). J.M.Bingham and E.J.Ciolkosz. Soil Science Society of America, Madison, Wisconsin, USA. pp.1-20.

Singh,S. 1956. The formation of dark coloured clay-organic complexes in black soils. **J. Soil Sci., 7** : 43-58.

Singh,R.A.1980. Soil physical analysis. Kalyani publishers, New Delhi.

Singh,B., R.J.Gilkes. 1996. Nature and properties of iron rich globules and mottles from South-West Australian soils. **Geoderma, 71** : 95-120.

Singh,N.N. and B.B.Mishra. 1996. Pedogenetic characterization of some typical soils of Gandak command area of Bihar for evaluation of land suitability. **J. Indian Soc. Soil Sci., 44**: 136-142.

Singh,G.N., H.P.Agrawal and M.Singh. 1989. Genesis and classification of soils in an alluvial pedogenic complex. **J. Indian Soc. Soil Sci., 37**: 343-354.

Singh,O.P., B.Datta and C.N.Rao. 1991a. Pedochemical characterisation and genesis of soils in relation to altitude in Mizoram. **J. Indian Soc. Soil Sci., 39** : 739-750.

Singh,K., A.R.Bhandari and K.P.Tomar. 1991b. Morphology, genesis and classification of soils of North West Himalayas. **J. Indian Soc. Soil Sci., 39** : 139-146.

Singh,R.N., D.P.S.Diwakar and A.K.Singh. 1993. A comparative study of acid soils developed on granite gneiss and Mahananda alluvium. **J. Indian Soc. Soil Sci., 41** : 125-132.

Singh,S.K., K.Das, R.L.Shyampura, J.D.Giri, R.S.Singh and J.L.Sehgal. 1995. Genesis and taxonomy of black soils from basalt and basaltic alluvium in Rajasthan. **J. Indian Soc. Soil Sci., 43** : 430-436.

Singhal,R.M. and S.D.Sharma. 1985. Study of the soils of Doon Valley forests. **J. Indian Soc. Soil Sci., 33** : 627-634.

Sinha,S.D. 1957. Studies on a black soil from Padegaon. **J. Indian Soc. Soil Sci., 5** : 91-101.

Sinha,A.K.1987. Variations in soil spectral reflectance related to soil moisture, organic matter and particle size. **Photonirvachak. 15** : 7-11.

Sinha,S.D., R.P.Verma and A.B.Lal. 1962. A study of the morphology of some of the red soils of Ranchi district in relation to topography of the land. **J. Indian Soc. Soil Sci., 10** : 35-42.

Sivarajasingham,S. 1962. Laterites. **Adv. Agronomy. 16** : 7-60, Academic Press, New York.

Smeck,N.E. 1973. Phosphorus : An indicator of pedogenetic weathering processes. **Soil Sci., 115** : 199-206.

Smeck,N.E. and E.C.A.Runge. 1971. Phosphorus availability and redistribution in relation to profile development in an Illinois landscape segment. **Soil Sci. Soc. Am. Proc. 35** : 952-959.

Smeck,N.E., J.Torrent and V.Barron. 1994. Genesis and native phosphorus distribution in some Palexeralfs of Southern Spain. **Soil Sci. Soc. Am. J., 58** : 1718-1723.

Snedcor,G.W. and W.C.Cochran. 1967. Statistical methods. Oxford and IBH Publishing House, Calcutta.

Soil Conservation Service. 1992. Soil survey laboratory methods manual. Soil Survey Investigations Report No.42, USDA, Washington, USA.

Soil Survey Staff. 1975. Soil Taxonomy. Agric. Handbook. No.436, USDA. Washington. USA.

Soil Survey Staff. 1994. Keys to Soil Taxonomy. Soil Management Support Services Technical Monograph No.19 (5th Edn). Blaksberg, Virginia, USA.

Srinivasan,T.R., Y.P.Balu and R.V.Tamhane. 1969. Placement of black soils of India in the comprehensive soil classification system-7th approximation. **J. Indian Soc. Soil Sci., 17** : 323-332.

Srivastava,A.K. and O.P.Srivastava. 1994. Soluble cations and anions in relation to pH and EC in Typic Natraqualf. **Madras agric. J., 81** : 429-432.

Stanford,S. and I.English. 1949. Use of flame photometer in rapid soil tests of K and Ca. **Agron. J., 41** : 446-447.

Stonehouse,H.B. and R.J.St.Arnaud. 1971. Distribution of iron, clay and extractable iron and aluminium in some Saskatchewan soils. **Can. J. Soil Sci., 51** : 283-292.

Subbaiah,G.V. and T.S.Manickam. 1987. Characterisation of Vertisol clays of Andhra Pradesh by dehydration methods. **Andhra. agric. J., 34** : 168-172.

Subbaiah,G.V. and T.S.Manickam. 1992. Genesis and morphology of Vertisols developed on different parent materials. **J. Indian Soc. Soil Sci., 40** : 150-156.

Subhas Chandra Bose,M., B.Rajendra Prasad and R.N.Pillai. 1987. Forms of potassium in the soils of Telugu-Ganga Project Area of Chitoor district. **Andhra agric. J., 34** : 429-434.

Swaify,S.A., S.Ahmed and L.D.Swindale. 1970. Effects of adsorbed cations on physical properties of tropical red and tropical black earths. II. Liquid limit, degree of dispersion and moisture retention. **J. Soil Sci., 21** : 186-198.

Swindale,L.D. 1991. Research for implementation of a land use policy in India. **J. Indian Soc. Soil Sci., 39** : 14-32.

Thirumagal Jothi,T. 1996. Characterisation and classification of soils of Kottakaraiyar Watershed through Remote Sensing Techniques. M.Sc.(Ag.) Thesis submitted to Tamil Nadu Agricultural University, Coimbatore, India.

Thiyagarajan,T.M. 1985. Characterisation of Vertisols in the dryland tracts of Tamil Nadu. Ph.D. Thesis submitted to Tamil Nadu Agricultural University, Coimbatore, India.

Thomas,G.W. 1982. Exchangeable cations. **In** : Methods of Soil Analysis. Part 2. Chemical and Microbiological Processes. Soil Science Society of America. Madison, Wisconsin, USA, pp.159-164.

Tiwari,S.C., B.K.Tiwari and R.R.Mishra. 1992. Variation in some physico-chemical characteristics of pineapple orchard soils of north eastern India. **J. Indian Soc. Soil Sci., 40** : 204-209.

Tiwari,R.C., S.G.Misra, S.K.Ojha and P.C.Misra. 1969. Testing the fertility status of black and red soils from south east Utter Pradesh. **J. Indian Soc. Soil Sci., 17**:167-170.

Tiwary,J.R. and B.B.Mishra. 1992. Clay mineralogy of some red soils developed on Rajmahal trap of Bihar. **J. Indian Soc. Soil Sci., 40**: 833-836.

Tiwary,J.R., P.P.Jha and B.B.Mishra. 1989. Characteristics and classification Red, Black and Yellow soils of Rajmahal Trap of Bihar. **J. Indian Soc. Soil Sci., 37** : 518-523.

Usha Kumari,K., K.Leela and A.Sharda. 1987. Infiltration and moisture retention of five major soil groups of Kerala. **Agric. Res. J. Kerala, 25** : 167-176.

Vadivelu,S. 1985. Pedogenesis characterisation and categorization of alluvium derived rice soils of Tamil Nadu. Ph.D. Thesis submitted to Tamil Nadu Agricultural University, Coimbatore, India.

Vadivelu,S. and C.Challa. 1985. Depth of slickenside occurrence in vertisols. **J. Indian Soc. Soil Sci. 33** : 452-455.

Van Ranst,E., M.Doube and F.De.Coninck. 1990. Soil development in Basalt and Tuff in West Cameroon. **In** : Trans. 14th International Congress of Soil Science. Kyoto, Vol.VII, pp.112-116.

Veneman,P.L.M., M.J.Vepraskas and J.Bouma. 1976. The physical significance of mottling in a Wisconsin toposequence. **Geoderma, 15** : 103-118.

Vepraskas,M.J. and J.Bouma. 1976. Model experiments on mottle formation simulating field conditions. **Geoderma, 15** : 217-230.

Verma,T.S., B.R.Tripathi and S.D.Verma. 1987. A comparative study on the nature and properties of soil in relation to climate and parent material. **J. Indian Soc. Soil Sci., 35**: 89-91.

Vinayak,A.K., J.L.Sehgal and P.K.Sharma. 1981. Pedogenesis and taxonomy of some alluvium-derived sodic soils in Punjab. **J. Indian Soc. Soil Sci., 29** : 71-80.

Virmani,S.M., K.L.Sahrawal and J.R.Burford. 1982. Physical and chemical properties of vertisols and their management. **In** : Vertisols and Rice soils of the tropics. Symposia papers II Trans. 12th Int. Congr. Soil Sci. New Delhi, pp.80-93.

Walia,C.S. and G.S.Chamuah. 1992. Soil profile development in relation to land use. **J. Indian Soc. Soil Sci., 40** : 220-222.

Walia,C.S. and G.S.Chamuah. 1996. Characterization of some Inceptisols of Arunachal Hills. **J. Indian Soc. Soil Sci., 44** : 179-182.

Walia,C.S. and Y.S.Rao. 1996. Genesis, characteristics and taxonomic classification of some red soils in Bundelkhand region of Uttar Pradesh. **J. Indian Soc. Soil Sci., 44** : 476-481.

Walker,T.W. 1965. The significance of phosphorus in pedogenesis. **In** : Experimental Pedogenesis. Wiiliam Clowes and Sons Ltd, London, pp.295-316.

Wieder,M. and D.H.Yaalon. 1974. Effect of matrix in carbonate nodule crystallisation. **Geoderma, 11** : 95-121.

Wieder,M. and D.H.Yaalon. 1982. Micromorphologic fabrics and development stages of carbonate nodular forms related to soil characteristics. **Geoderma, 28** : 203-220.

Wilding,L.P., N.E.Smeck and G.F.Hall. 1983. Pedogenesis and Soil Taxonomy II The Soil Orders. Elsevier, Amsterdam.

Yaalon,D.H. 1960. Some implications of fundamental concepts of pedology in soil classification. Trans. 7th Int. Congress Soil Science. Madison Wisconsin. pp.119-123.

Yaalon,D.H. 1983. Climate, time and soil development. **In** : Pedogenesis and Soil Taxonomy. I. Concepts and interaction. (Eds). L.P.Wilding, N.E.Smeck and G.F.Hall, Elsevier, Amsterdam, p.238.

Yaalon,D.H. and D.Kalmar. 1978. Dynamics of cracking and swelling clay soils : Displacement of skeletal grains, optimum depth of slickensides and rate of intra-pedonic turbation. **Earth Surface Processes, 3** : 31-42.

Zampella,R.A. 1994. Morphologic and color pattern indicators of watertable levels in sandy pinelands soils. **Soil Sci., 157** : 312-317.

Zaydelman,F.R. and A.K.Ogleznev. 1971. Determination of the degree of waterlogging of soil from the properties of concretions. **Soviet Soil Sci., 3** : 619-625.

Zhu,H., Binhua and J.Chen. 1990. A study on the characteristics of Vertisol in Fujian province, China. **In** : Trans. 14th International Congress of Soil Science. Kyoto. Japan, Vol.V. pp.394-395.

Zonn,S.V. 1986. Tropical and Subtropical Soil Science. **Mir Publishers**, Moscow, p.422.

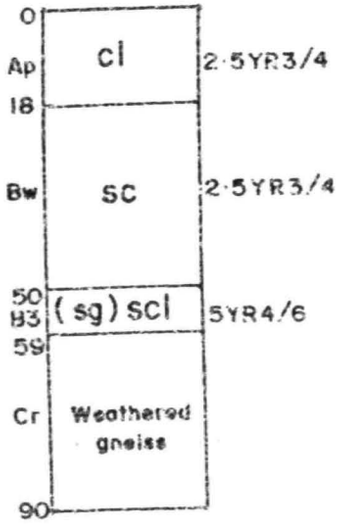
* Originals not seen.

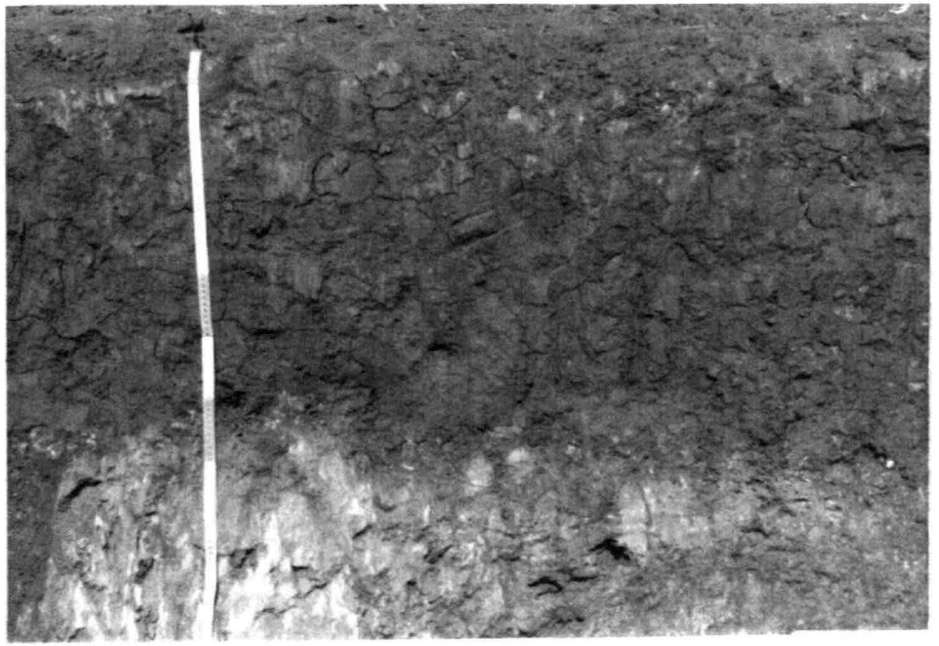
Annexures

ANNEXURE I

PEDON 1	:	VANNAPPATTI SERIES
Village	:	Paiyur
Taluk	:	Krishnagiri
District	:	Dharmapuri
Latitude	:	12°21'N
Longitude	:	78°18'E
Elevation	:	490 MSL
Land form	:	Undulating Plain
Slope	:	1-3%
Natural vegetation	:	Neem, Tamarind, Calotropis, Prosopis
Land use	:	Millets, Groundnut, Mango

Horizon	Depth (cm)	Description
Ap	0-20	Reddish brown (5YR 4/3) moist; sand; weak fine granular; loose moist; few fine pores; few very fine roots; very rapid permeability; clear wavy boundary
Bw1	20-52	Dark red (2.5YR 3/6) moist; sandy clay; moderate medium to coarse sub angular blocky; sticky and plastic; firm moist; few fine pores; few very fine roots; moderately rapid permeability; clear smooth boundary.
Bw2	52-74	Red (2.5YR 4/6) moist; (gravelly) sandy clay; moderate, medium sub angular blocky; sticky and plastic; firm moist; many irregular quartz gravels; few fine pores; few very fine roots; clear wavy boundary.
Bc	74-100	Dark reddish brown (2.5YR 3/4) moist; (very gravelly) sandy loam; weak medium sub angular blocky; slightly sticky; slightly firm moist; abundant irregular quartz gravels; few fine pores; few very fine roots; diffuse wavy boundary.
	100+	Weathered gneiss.


0
Ap
cl
2·5YR3/4
18
Bw
SC
2·5YR3/4
50
B3
(sg) SCl
5YR4/6
59
Cr
Weathered gneiss
90

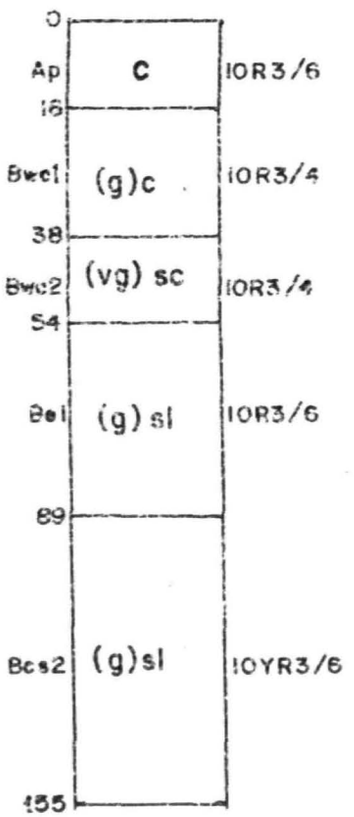


PEDON 2 : IRUGUR SERIES

Village	:	Bhavanisagar
Taluk	:	Gobichettipalayam
District	:	Periyar
Latitude	:	11°N
Longitude	:	78°28'E
Elevation	:	260 MSL
Land form	:	Peneplain with undulating topography
Slope	:	1-3%
Natural Vegetation	:	Prosopis, Calotrophis, Neem
Land Use	:	Groundnut, Turmeric, Paddy

Horizon	**Depth (cm)**	**Description**
Ap	0-18	Dark reddish brown (2.5YR 3/4) moist and dry; clay loam; strong coarse sub angular blocky; sticky and plastic; firm moist, very hard dry; common fine pores; few very fine roots; moderate permeability; clear smooth boundary.
Bw	18-50	Dark reddish brown (2.5YR 3/4) moist and dry; sandy clay; strong, coarse sub angular blocky; sticky and plastic; firm moist, very hard dry; common fine pores; few, very fine roots; few termite channels; moderate permeability; gradual wavy boundary.
B3	50-59	Yellowish red (5YR 4/6) moist and dry; (slightly gravelly) sandy clay loam; moderate coarse sub angular blocky; sticky and slightly plastic; firm moist; hard dry; common irregular quartz gravels; few, fine pores; few, very fine roots; diffuse irregular boundary.
	59-90	Weathered gneiss.
	90+	Granite

Pedon- 3


0
Ap
C
10R3/6
16
Bwc1
(g)c
10R3/4
38
Bwc2
(vg) sc
10R3/4
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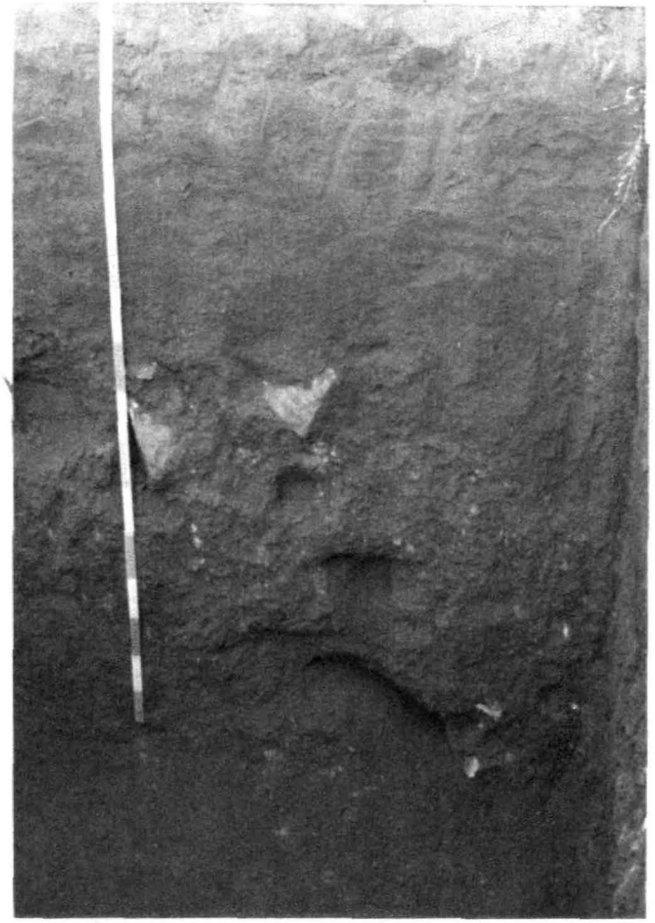
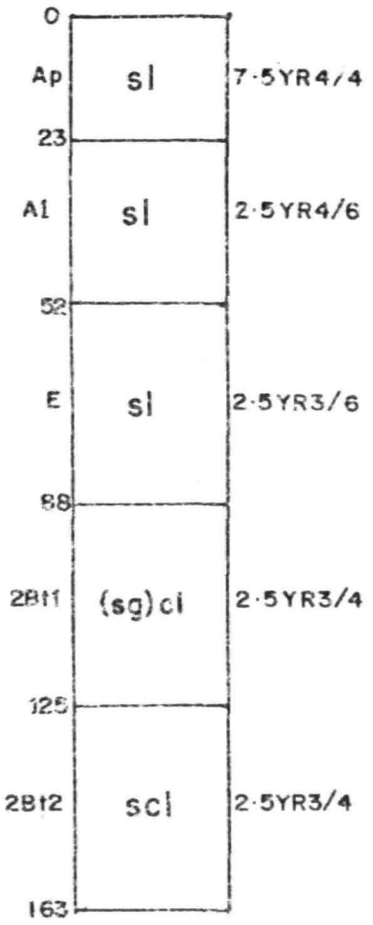
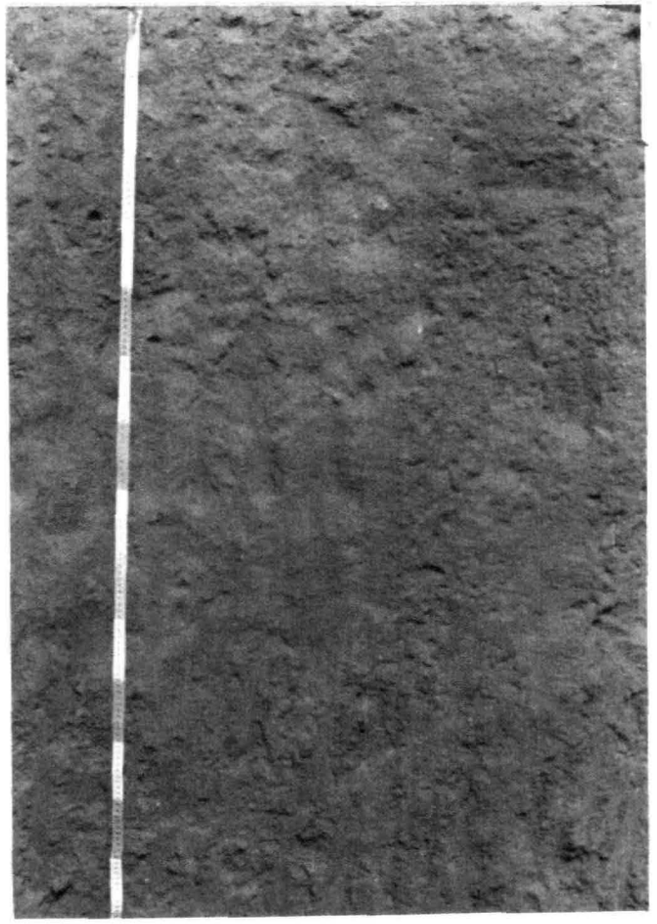
Bc1
(g) sl
10R3/6
89
Bcs2
(g)sl
10YR3/6
155



Bc1	54-89	Dark red (10R 3/6) moist; (gravelly) sandy loam; massive to weak fine granular; friable moist, slightly hard dry; dominant irregular quartz gravels, few stones and many irregular ferruginous gravels; few medium and fine pores; few fine roots; few termite channels; rapid permeability; gradual wavy boundary.
Bc2	89-155	Dark red (10R 3/6); (gravelly) sandy loam; massive to weak medium granular; friable moist, slightly hard dry; dominant round irregular ferruginous gravels, few irregular quartz gravels; few medium and fine pores; few fine roots; very few termite channels.
	155 +	Weathered gneiss.

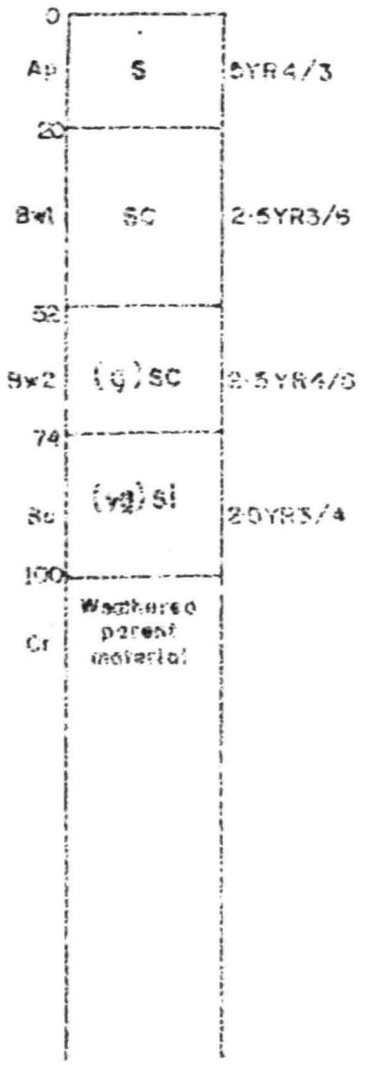
Poden- 4

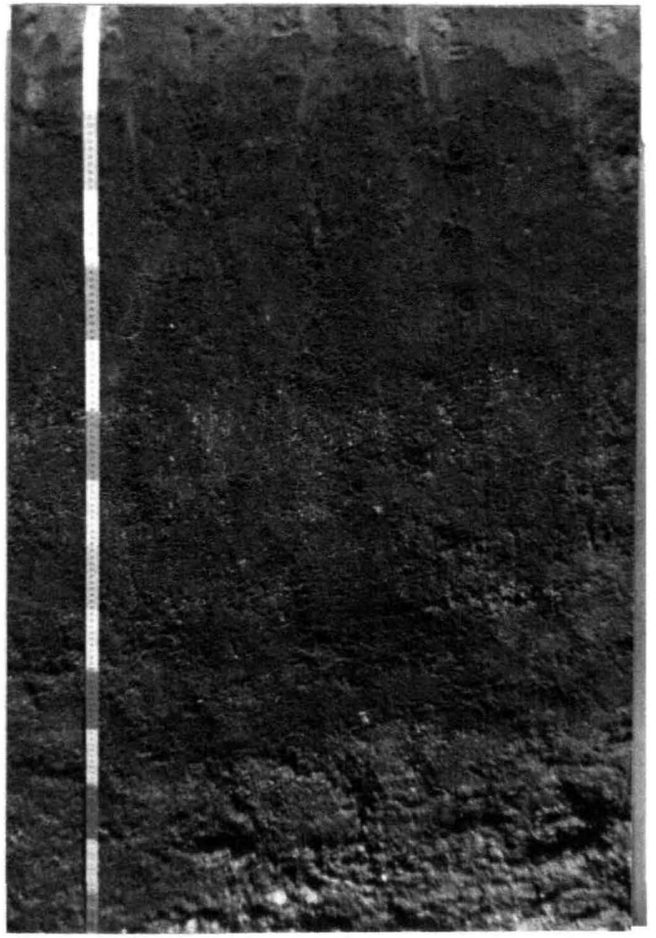

0
Ap
sl
7·5YR4/4
23
A1
sl
2·5YR4/6
52
E
sl
2·5YR3/6
88
2B11
(sg)cl
2·5YR3/4
125
2B12
scl
2·5YR3/4
163



Region 1

Vanniapatti series





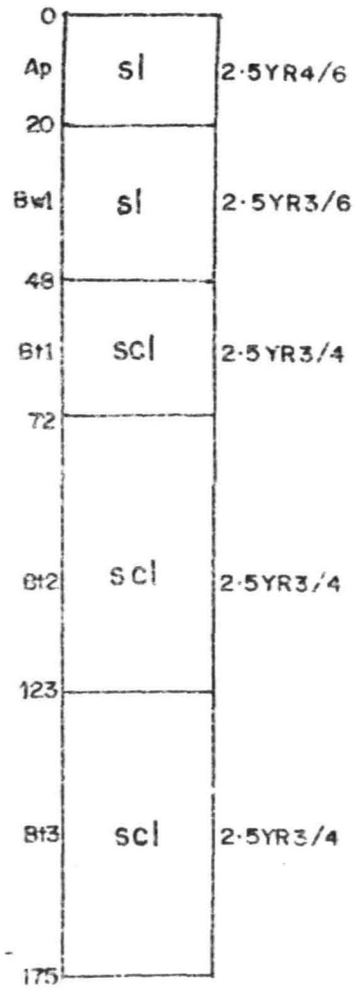
PEDON 4	:	PALAVIDUTHI SERIES
Village	:	Periyakulam
Taluk	:	Periyakulam
District	:	Madurai
Latitude	:	10°N
Longitude	:	77°01'E
Elevation	:	260 MSL
Land form	:	Peneplain with undulating topography
Slope	:	1-3%
Natural Vegetation	:	Tamarind, Neem Acacia
Land Use	:	Fruit trees and vegetables.

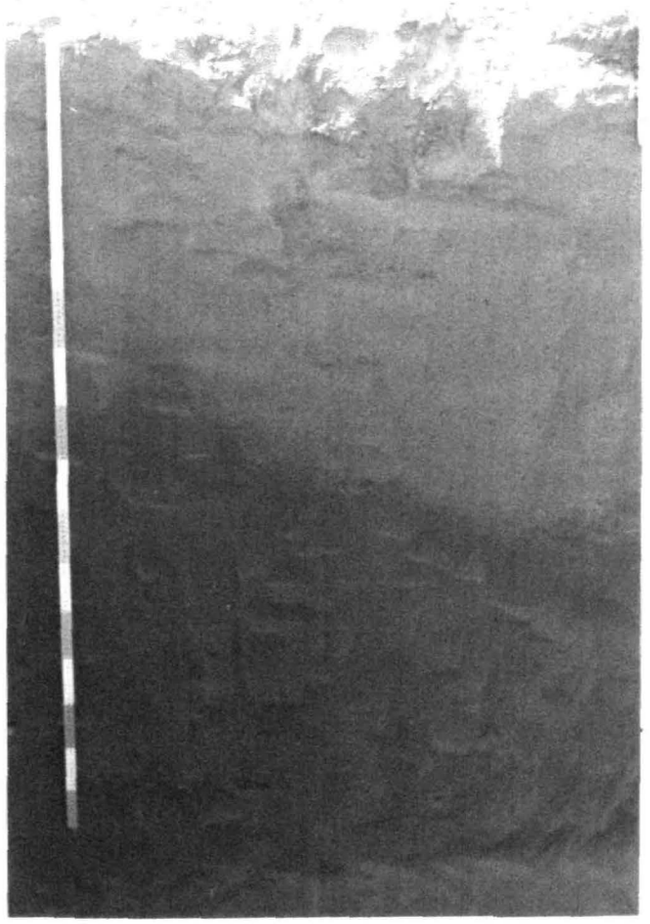
Horizon	Depth (cm)	Description
Ap	0-23	Dark brown (7.5YR 4/4) moist and dry; sandy loam; massive to weak medium granular; loose moist, slightly hard dry; very few small irregular quartz gravels; few common pores; few very fine roots; very rapid permeability clear smooth boundary.
A1	23-52	Red (2.5YR 4/6) dry and moist; sandy loam; weak, medium, subangular blocky to weak medium granular; loose moist, slightly hard dry; few large quartz gravels; common very fine pores; few very fine roots; very rapid permeability; clear wavy boundary.
E	52-88	Dark red (2.5YR 5/6) moist and red (2.5YR 4/6) dry; sandy loam; massive to moderate medium, subangular blocky; friable moist, hard dry; very few large quartz gravels; few medium common fine pores; few very fine roots; rapid permeability; abrupt smooth boundary.

2Bt1	88-124	Dark reddish brown (2.5YR 3/4) moist and dry; (slightly gravelly) clay loam; strong, coarse, columnor breaking to strong coarse subangular blocky; sticky and slightly plastic; slightly firm moist, very hard dry; few large quartz gravels; strongly cemented iron pan; patchy, moderate clay films on ped faces; few coarse and many fine pores; few fine and very fine roots; few termite channels; moderate permeability; abrupt smooth boundary.
2Bt2	125-163	Dark reddish brown (2.5YR 3/4) moist and dark red (2.5YR 3/6) dry; sandy clay loam; strong coarse subangular blocky; sticky and slightly plastic; slightly firm moist, very hard dry; common thick clay films; few coarse and many fine pores; few fine and very fine roots; few termite channels; moderate permeability.

Pedon - 5

Udangudi series





PEDON 5 : UDANGUDI SERIES

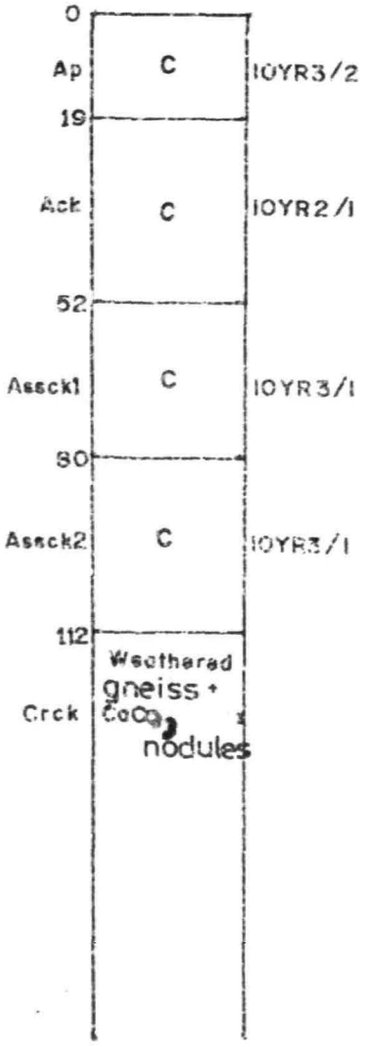
Village	:	Sathankulam
Taluk	:	Tuticorin
District	:	V.O.Chidambaranar
Latitude	:	9°55'N
Longitude	:	77°07'E
Elevation	:	183 m
Land form	:	Sand dunes with sandy plains
Slope	:	0-1%
Natural Vegetation	:	Palmyra, Virali, *Acacia sp.*
Land Use	:	Cultivable waste

Horizon	Depth (cm)	Description
Ap	0-20	Red (2.5YR 4/6) moist, and (2.5YR 4/8) dry; sandy loam; weak, coarse subangular blocky, breaking to weak fine granular; slightly sticky; friable moist, slightly hard dry; common, medium, few fine pores; few, medium roots; very rapid permeability; clear smooth boundary.
Bw1	20-48	Dark red (2.5YR 3/6) moist and red (2.5YR 4/6) dry; sandy loam; weak moderate subangular blocky to weak, fine granular; slightly sticky; friable moist, slightly hard dry; few medium and fine pores; very rapid permeability; abrupt smooth boundary.
Bt1	48-72	Dark reddish brown (2.5YR 3/4) moist and dark red (2.5YR 3/6) dry; sandy clay loam; weak, medium subangular blocky to weak, fine granular; slightly sticky; friable moist, slightly hard dry; few medium common fine pores; patchy, fine clay films on ped faces; few medium roots; rapid permeability; abrupt smooth boundary.

Bt2	72-123	Dark reddish brown (2.5YR 3/4) moist; sandy clay loam; massive to weak fine granular; slightly sticky; friable moist, slightly hard dry; patchy, medium clay films; few termite channels; few medium and common fine pores; few medium roots; moderately rapid permeability; abrupt smooth boundary.
Bt3	123-175	Dark reddish brown (2.5YR 3/4); sandy clay loam; massive to weak, medium subangular blocky; slightly sticky; loose moist; common thick clay films; few, medium coarse fine pores; few very fine roots; moderately rapid permeability.

Pedon - 6

Pilomedu series



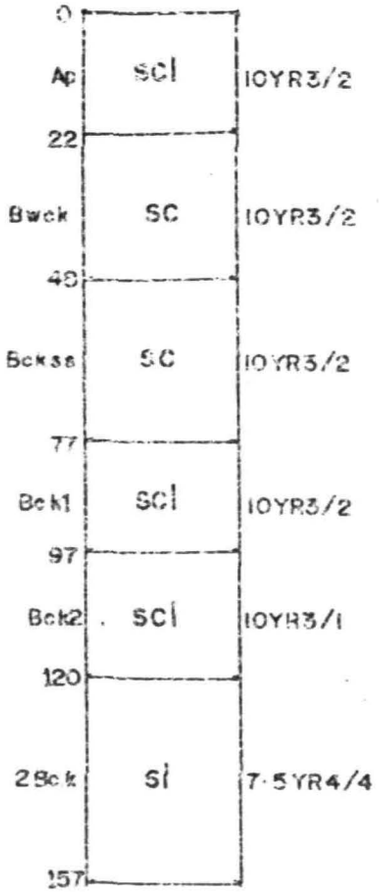
PEDON 6	:	PILAMEDU SERIES
Village	:	Aruppukkottai
Taluk	:	Aruppukkottai
District	:	Kamarajar
Latitude	:	9°31'N
Longitude	:	77°57'E
Elevation	:	50 MSL
Land form	:	Gently sloping plain
Slope	:	0-1%
Natural Vegetation	:	Prosopis, Acacia, Tamarind
Land Use	:	Cotton, Sunflower, Millets

Horizon	Depth (cm)	Description
Ap	0-19	Very dark grayish brown (10YR 3/2) moist and dry; clay; weak, medium subangular blocky and weak medium crumb; sticky and plastic; slightly firm moist, slightly hard dry; few, large hard irregular lime concretions; slightly calcareous; few, very fine and fine pores; few, medium and fine roots; slow permeability; clear wavy boundary.
Ack	19-52	Black (10YR 2/1) moist and very dark gray (10YR 3/1) dry; clay; moderate, coarse subangular blocky; sticky and plastic; firm moist and hard dry; few, large hard irregular lime concretions; calcareous; distinct, non intersecting sickensides; few, fine and very fine pores; very fine medium roots; slow permeability; gradual wavy boundary.

Assck1	52-80	Very dark gray (10YR 3/4) moist and dry; clay; strong, medium to coarse angular blocky; very sticky, very plastic; very firm moist, extremely hard dry; frequent, large hard irregular lime concretions; calcareous; distinct intersecting sickensides; few, fine and common very fine pores; very fine medium roots; slow permeability; abrupt wavy boundary.
Assck2	80-112	Very dark gray (10YR 3/1) moist and dark gray (10YR 4/1) dry; clay; strong, coarse angular blocky; sticky and plastic; very firm moist, very hard dry; very frequent, hard irregular large lime concretions; calcareous; prominent intersecting slickensides; few, fine and common, very fine pores; very few, very fine roots; slow permeability; abrupt smooth boundary.
Crck	112+	Weathered gneiss and $CaCO_3$ nodules.

P · N · Palayam series

Pedon - 7



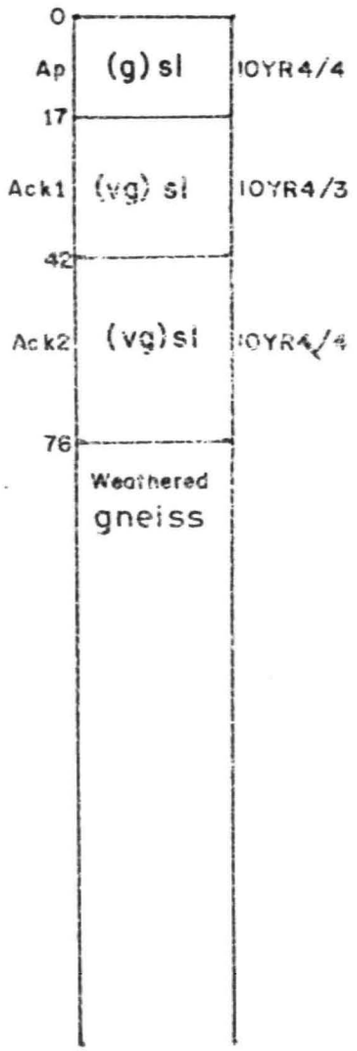
PEDON 7	:	P.N.PALAYAM SERIES
Village	:	Coimbatore
Taluk	:	Coimbatore
District	:	Coimbatore
Latitude	:	11°N
Longitude	:	77°E
Elevation	:	MSL
Land form	:	Peneplain with flat topography
Slope	:	0-1%
Natural Vegetation	:	Prosopis, Neem, Euphorbia, Nuna
Land Use	:	Sunflower, Millets

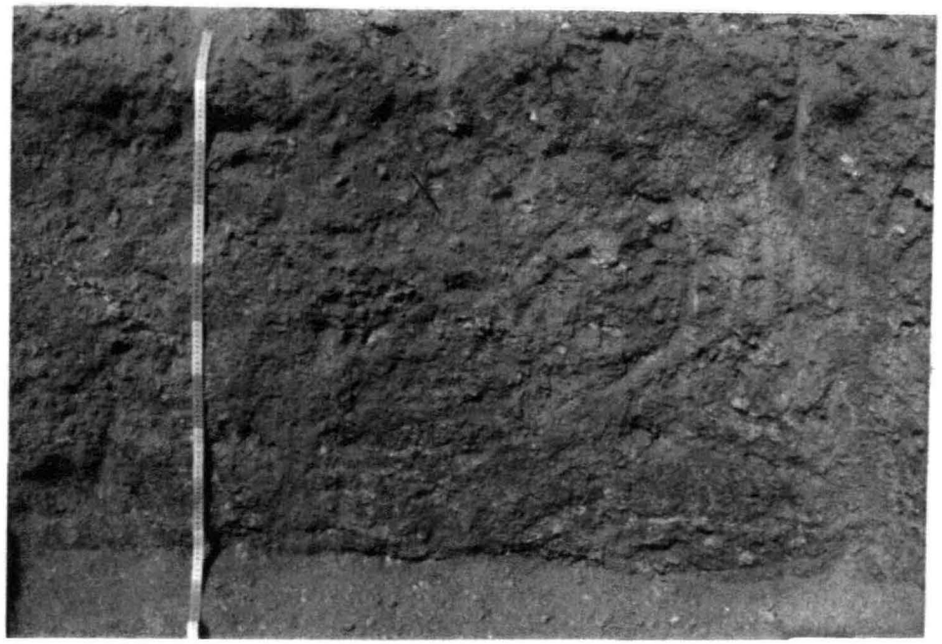
Horizon	Depth (cm)	Description
Ap	0-22	Very dark grayish brown (10YR 3/2) moist and dark brown (10YR 3/3) dry; sandy clay loam; weak, fine subangular blocky; sticky and plastic; slightly firm moist, slightly hard dry; very few, small round to irregular hard lime concretions; strongly calcareous; many fine pores; few, medium coarse fine roots; moderately slow permeability. abrupt smooth boundary.
Bwck	22-48	Very dark grayish brown (10YR 3/2) moist and dry; sandy clay; moderate, medium subangular blocky; sticky and plastic; firm moist, hard dry; very few, small round to irregular lime concretions; strongly calcareous; many, fine pores; few, fine roots; moderately rapid permeability; abrupt smooth boundary.
Bckss	48-77	Very dark gray brown (10YR 3/2); sandy clay; strong, coarse angular blocky; sticky and plastic; very firm moist, very hard dry; frequent,

		powdery and hard lime concretions; strongly calcareous; distinct pressure faces and indistinct slickensides; very few, medium and few, fine pores; few, fine roots; moderately slow permeability; gradual wavy boundary.
Bck1	77-97	Very dark grayish brown (10YR 3/2) and brown (10YR 5/3) moist and dry; Grayish brown (10YR 5/2) rubbed; sandy clay loam; strong coarse angular blocky; sticky and plastic; slightly firm moist, slightly hard dry; frequent, powdery and hard round to irregular lime concretions; strongly calcareous; indistinct pressure faces; common, fine pores; few, fine roots; moderately slow permeability; gradual wavy boundary.
Bck2	97-120	Very dark gray (10YR 3/1) and brown (10YR 5/3) moist and dry; grayish brown (10YR 5/2) rubbed; moderately fine subangular blocky; few, medium prominent very dark brown (10YR 2/2) mottlings; frequent, powdery and hard round to irregular lime concretions; strongly calcareous; common, fine pores; few, fine roots; moderately rapid permeability; gradual smooth boundary.
2Bck	120-157	Darkbrown (7.5YR 4/2) moist, brown (2.5YR 5/4) dry; few medium prominent very dark brown (10YR 2/2) mottlings; sandy loam; moderate, medium subangular blocky; slightly sticky, slightly plastic; slightly firm moist, hard dry; frequent powdery and hard round to irregular lime concretions; very few, small, round ferruginous concretions; strongly calcareous; common, fine pores; very few, very fine roots; moderately rapid permeability.

Palladam series

Pedon - 8



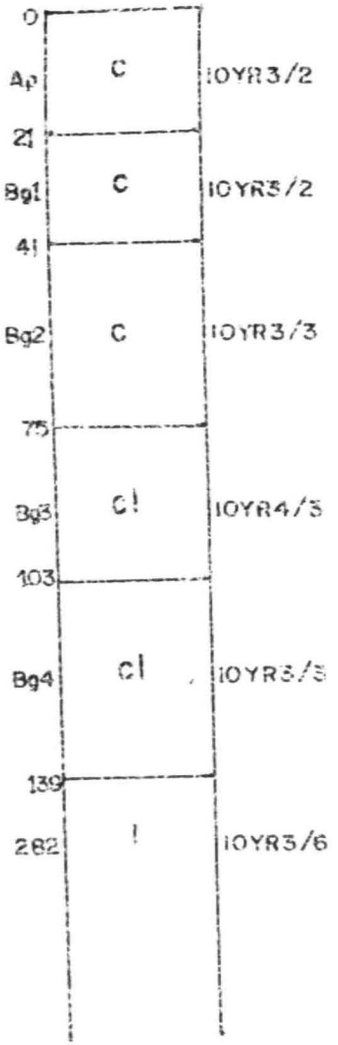


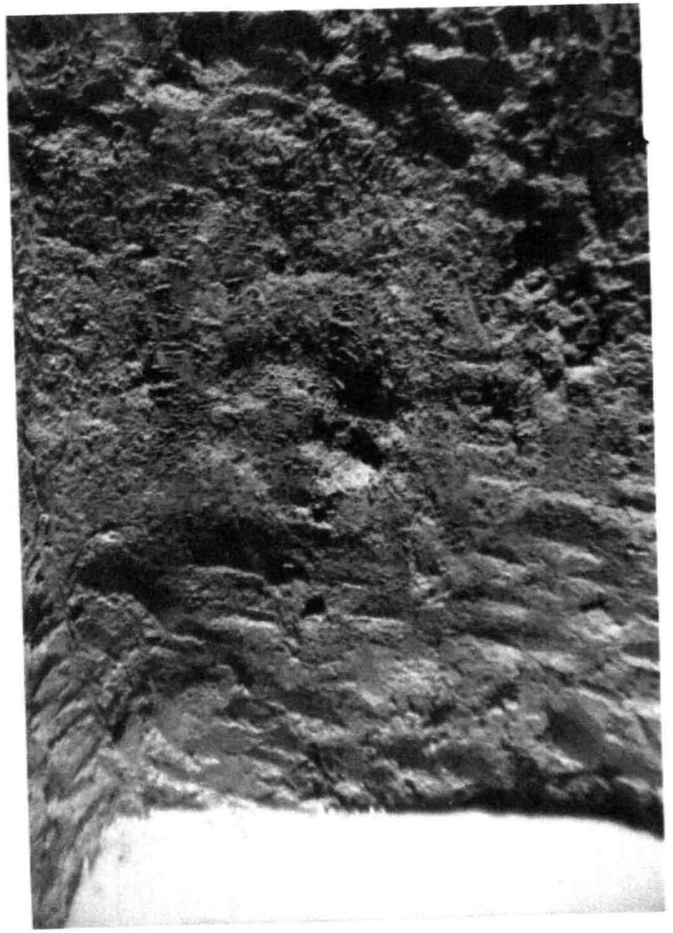
PEDON 8 : PALLADAM SERIES

Village	:	Palladam
Taluk	:	Palladam
District	:	Coimbatore
Latitude	:	10°59'N
Longitude	:	77°17'E
Elevation	:	427 MSL
Land form	:	Undulating Plain
Slope	:	3-5%
Natural Vegetation	:	*Acacia sp* ; Cassia; Prosopis
Land Use	:	Pasture and minor millets

Horizon	Depth (cm)	Description
Ap	0-17	Dark yellowish brown (10YR 4/4) moist and yellowish brown (10YR 5/4) dry; (gravelly) sandy loam; weak, fine subangular blocky to weak, fine granular; very friable moist, loose dry; few, irregular quartz gravels: few, hard large irregular lime concretions; strongly calcareous; few, very fine pores; common, fine roots; very rapid permeability; clear wavy boundary
Ak	17-42	Dark brown (10YR 4/3) moist and brown (10YX 5/3) dry; (very gravelly) sandy loam; weak, fine granular; slightly sticky; very friable moist, loose dry; very few, irregular small quartz gravel and frequent, hard large irregular lime concretions; strongly calcareous; few, very fine pores; few, fine roots; very few, medium weathered rock fragments; very rapid permeability; diffuse wavy boundary.

Ak2	42-76	Dark yellowish brown (10YR 4/4) and yellowish brown (10YR 5/4); weak, medium granular; slightly sticky; very friable most, loose dry; very few, round to irregular quartz graves; very frequent hard large irregular lime concretions; very few, medium weathered rock fragments;strongly calcareous; few, very fine pores; few, fine roots; very rapid permeability; diffuse wavy boundary.


0
Ap
C
10YR3/2
21
Bg1
C
10YR3/2
41
Bg2
C
10YR3/3
75
Bg3
C!
10YR4/3
103
Bg4
C!
10YR3/3
139
282
!
10YR3/6

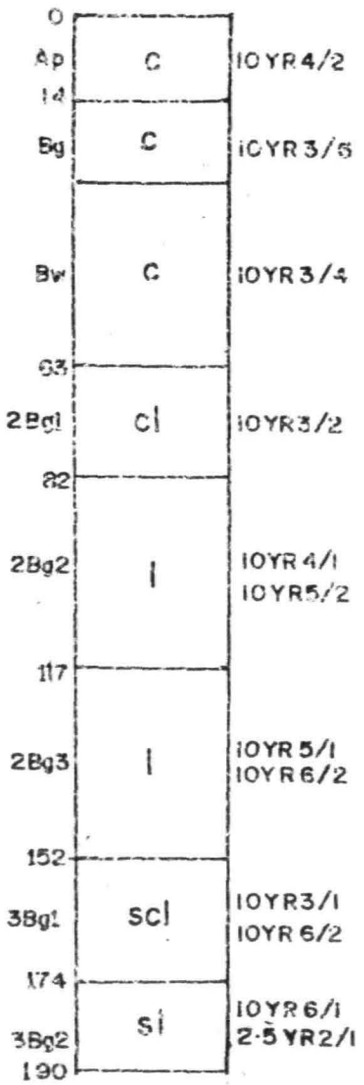


PEDON 9	:	PADUGAI SERIES
Village	:	Aduthurai
Taluk	:	Tiruvidaimarudur
District	:	Thanjavur
Latitude	:	11°N
Longitude	:	79°30'E
Elevation	:	20 MSL
Land form	:	Delta plain
Slope	:	0-1%
Natural Vegetation	:	Bamboo, Neem, Vahai
Land Use	:	Rice

Horizon	Depth (cm)	Description
Ap	0-21	Very dark grayish brown (10YR 3/2) moist and dark brown (10YR 3/3) dry; clay; massive, to weak, fine subangular blocky; sticky and slightly plastic; very firm moist, very hard dry; few, medium and fine pores; common, fine, few, medium roots; moderate permeability; clear, smooth boundary.
Bg1	21-41	Very dark grayish brown (10YR 3/2) moist; clay; strong, coarse subangular blocky; sticky and plastic; firm moist; few, fine distinct black (10YR 2/1) mottles; very few, small round Fe-Mn concretions; slightly calcareous; few shells; many fine and very fine, medium pores; very few, fine and very fine roots; moderate permeability; clear smooth boundary.
Bg2	41-75	Dark brown (10YR 3/3) moist; clay; moderate, coarse subangular blocky; sticky and plastic;

		firm moist; common, fine to medium distinct black (10YR) mottles; very few, small ferruginous concretions; few, medium common, fine pores; very few, very fine roots; moderately slow permeability; clear, smooth boundary.
Bg3	75-103	Dark brown (10YR 3/3) moist; clay; strong, coarse subangular blocky; sticky and plastic; firm moist; common, fine faint black (10YR 2/1) mottles; very few, small ferruginous concretions; few, medium common fine pores; few, brick bits; very few, very fine roots; slightly calcareous; moderately slow permeability; clear, smooth boundary.
Bg4	103-139	Dark brown (10YR 3/3) clay loam; coarse subangular blocky; sticky and plastic; firm moist; common, medium black (10YR3/1) mottles; few, small ferruginous concretions; few medium, and very few, fine pores; few, brick bits; very few, very fine roots; slightly calcareous; slow permeability; abrupt smooth boundary.
2B2	139-194	Dark yellowish (10YR 3/4) moist; loam; moderate, medium subangular blocky; sticky and plastic; slightly firm moist; distinct pressure faces; few, fine and very fine pores; slow permeability;

Pedon-10


0
Ap
C
10YR4/2
14
Bg
C
10YR3/5
Bw
C
10YR3/4
63
2Bg1
cl
10YR3/2
82
2Bg2
l
10YR4/1
10YR5/2
117
2Bg3
l
10YR5/1
10YR6/2
152
3Bg1
scl
10YR3/1
10YR6/2
174
3Bg2
sl
10YR6/1
2.5YR2/1
190

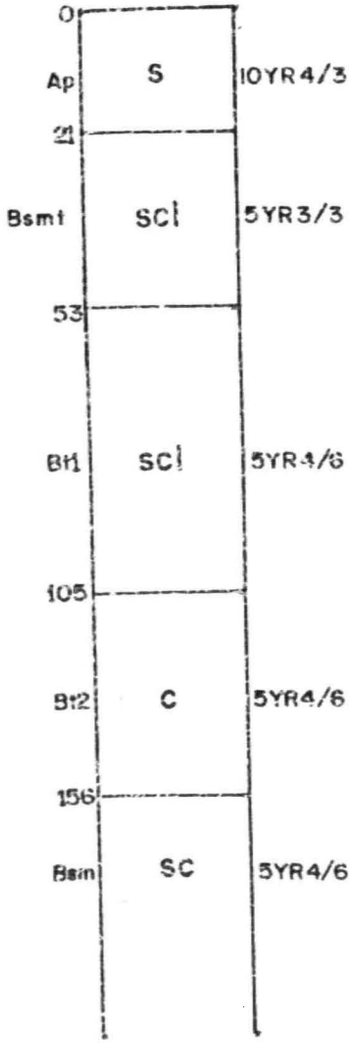
PEDON 10	:	KOHUR SERIES
Village	:	Sellur
Taluk	:	Nagappattinam
District	:	Nagai Quaid-E-Milleth
Latitude	:	10°46'N
Longitude	:	79°51'E
Elevation	:	9 MSL
Land form	:	Marine land
Slope	:	0-1%
Natural Vegetation	:	Ipomoea, Thespesia
Land Use	:	Paddy

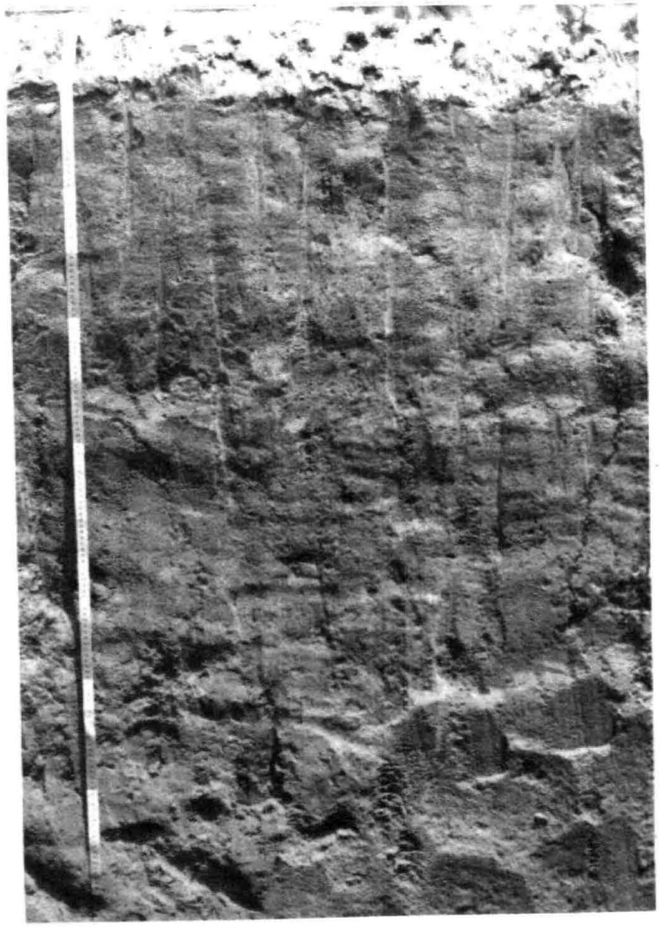
Horizon	Depth (cm)	Description
Ap	0-14	Dark grayish brown (10YR 4/2) moist and dark gray (10YR 4/1); clay; massive to strong, coarse subangular blocky; sticky and plastic; very firm moist, extremely hard dry; many, fine prominent yellowish brown (10YR 5/6) mottles; few medium, and common, fine pores; common, fine and very fine, few, medium roots; moderately rapid permeability; clear, smooth boundary
Bg	14-29	Dark yellowish brown (10YR 3/4) moist and dark brown (10YR 3/3) dry; clay; massive to strong, coarse subangular blocky; sticky and plastic; slightly firm moist, extremely hard dry; few, small round ferruginous gravels; few medium, common fine pores; few, fine and very fine roots; moderately slow permeability; clear, wavy boundary.
Bw	29-63	Dark yellowish brown (10YR 3/4) moist; clay; strong, coarse prismatic; sticky and plastic; very firm moist; indistinct slickensides and distinct pressure faces; slightly calcareous; few, medium and fine pores; few, coarse medium and fine roots; moderately slow permeability; abrupt wavy boundary.

2Bg1	63-82	Very dark gray brown (10YR 3/2); massive to strong, medium sub angular blocky; clayloam; sticky and plastic; very firm moist; few, medium distinct, very dark brown (10YR 5/6) mottles; few, medium and fine pores; very few, very fine roots; moderately slow permeability; abrupt, smooth boundary.
2Bg2	82-117	Dark gray (10YR 4/1) and grayish brown (10YR 5/2) moist; loam; massive, weak medium subangular blocky; slightly sticky; friable moist; few, coarse prominent very dark brown (10YR 2/2) and yellowish brown (10YR 5/6) mottles; few medium, common fine and very fine pores; moderate permeability; abrupt, smooth boundary.
2Bg3	117-152	Gray (10YR 5/1) and light brownish gray (10YR 6/2) moist; loam; massive; slightly sticky; friable moist; common, fine to coarse prominent very dark brown (10YR 2/2) and yellowish brown (10YR 5/6) mottles; few medium, common fine pores; moderately slow permeability; abrupt, smooth boundary.
3Bg1	152-174	Very dark gray (10YR 3/1) and light brownish gray (10YR 6/2) moist; sandy clay loam; massive; sticky and plastic; slightly firm moist; many, coarse prominent mottles; very dark brown (10YR 2/2) and yellowish brown (10YR 5/6) mottles; few medium, common fine and very fine pores; moderately slow permeability; abrupt and wavy boundary.
3Bg2	174-190	Gray (10YR 6/1) and black (2.5YR 2/0) moist; sandy loam; massive; slightly sticky; slightly plastic; slightly firm moist; many shells of marine origin; few, coarse prominent mottles; very dark brown (10YR 2/2) and yellowish brown (10YR 5/6) mottles; few, medium fine and common very fine pores; slow permeability.

Vallam series

Pedon - II

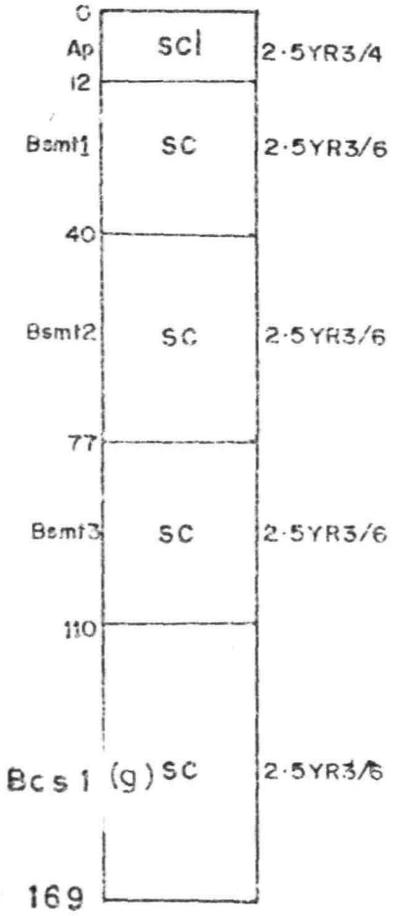


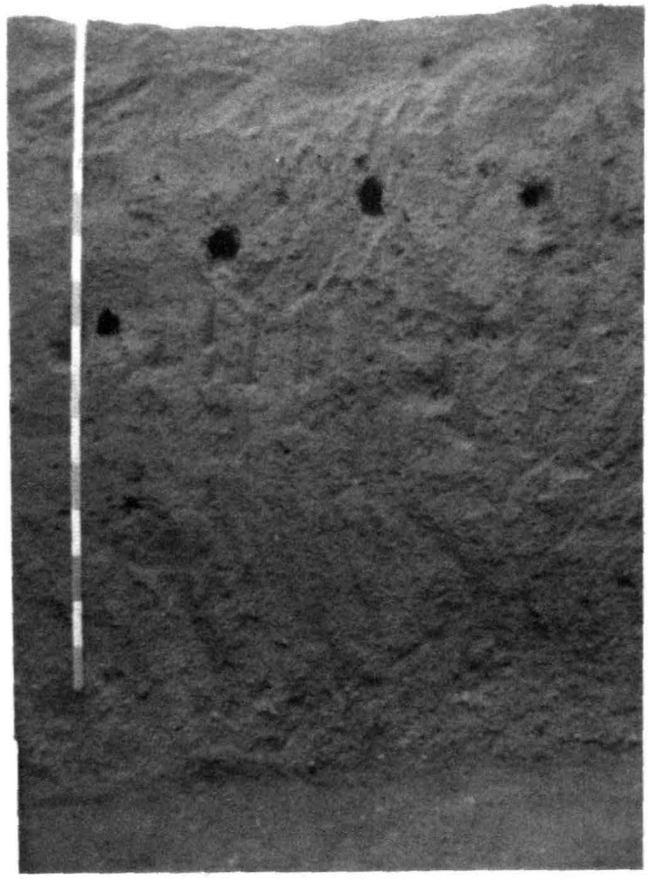


		roots; moderately rapid permeability; abrupt, smooth boundary.
Bt2	105-156	Yellowish red (5YR 4/6) moist and dry; clay; massive to moderate, medium subangular blocky; patchy, thin clay films on ped faces; frequent termite channels; few coarse, many fine pores; few, very fine roots; moderately rapid permeability; clear, wavy boundary.
Bsm	156-177	Yellowish red (5YR 4/6) moist and dry;sandy clay; massive to weak fine subangular blocky; slightly sticky, slightly plastic; slightly firm moist, slightly hard dry; few, medium and fine pores; few, very fine roots; moderately rapid permeability.

Vayalogam series

Pedon - 12





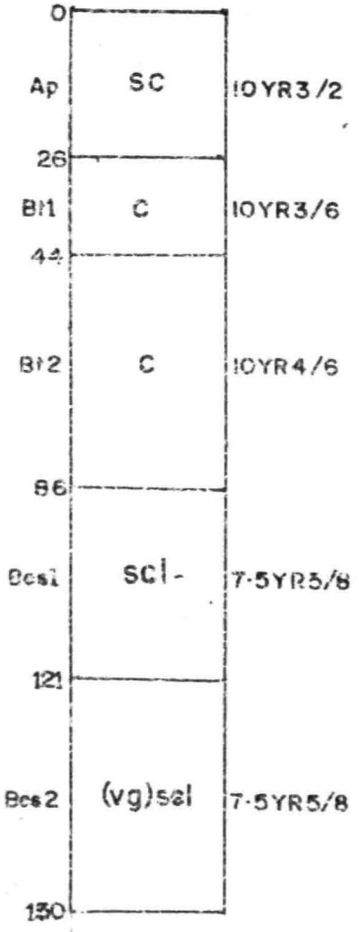
PEDON 12	:	VAYALOGAM SERIES
Village	:	Vamban
Taluk	:	Alangudi
District	:	Pudukkottai
Latitude	:	10° 23'N
Longitude	:	78°52'E
Elevation	:	100 MSL
Land form	:	Lateritic
Slope	:	0-1%
Natural Vegetation	:	Neem, Agave
Land Use	:	Pulses, Groundnut, Cashew

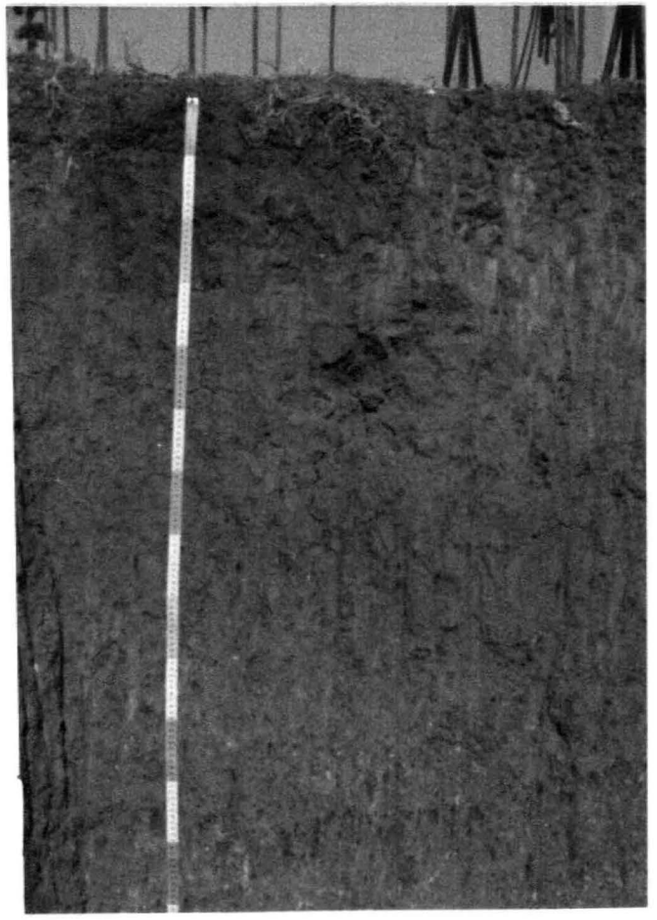
Horizon	Depth (cm)	Description
Ap	0-12	Dark reddish brown (2.5YR 3/4) moist and dark red (2.5YR 3/4) dry; sandy clay loam; massive to moderate, coarse subangular blocky; sticky and slightly plastic; slightly firm moist, slightly hard dry; few medium, common fine pores; few, medium and fine pores; moderate permeability; clear, wavy boundary.
Bsmt1	12-40	Dark red (2.5YR 3/6) moist and red (2.5YR 4/8) dry; sandy clay; massive to weak, medium subangular blocky; sticky and slightly plastic; slightly firm moist, slightly hard dry; few, medium and common fine and very fine pores; few, fine and very fine root;' thin patchy, clay films on ped faces; rapid permeability; abrupt, smooth boundary.
Bsmt2	40-77	Dark red (2.5YR 3/6) moist and red (2.5YR 4/6) dry; sandy clay; massive to weak, fine subangular blocky; sticky and slightly plastic;

		slightly firm moist, slightly hard dry; thick patchy, clay films on ped faces; few, coarse medium, and coarse fine and very fine pores; very few, very fine roots; few termite channels; rapid permeability; abrupt, smooth boundary.
Bsmt3	77-110	Dark red (2.5YR /6) moist and dry; gravelly sandy clay; massive to weak fine granular; slightly sticky; friable moist, slightly hard dry; dominant large and small, round, ferruginous and dominant quartz gravels; fine ferruginous stones; few medium and fine pores; very few, very fine roots; moderately rapid permeability.
Bcs1	110-169	Dark red (2.5YR 3/6) moist and dry; (gravelly) sandy clay; massive to weak, fine granular; slightly sticky; friable moist, slightly hard dry; dominant, large and small round ferruginous and dominant, quartz gravels; few, ferruginous stones; few, medium and fine pores; very few, very fine roots; moderately rapid permeability;

Pedon - 13

Madukkur series





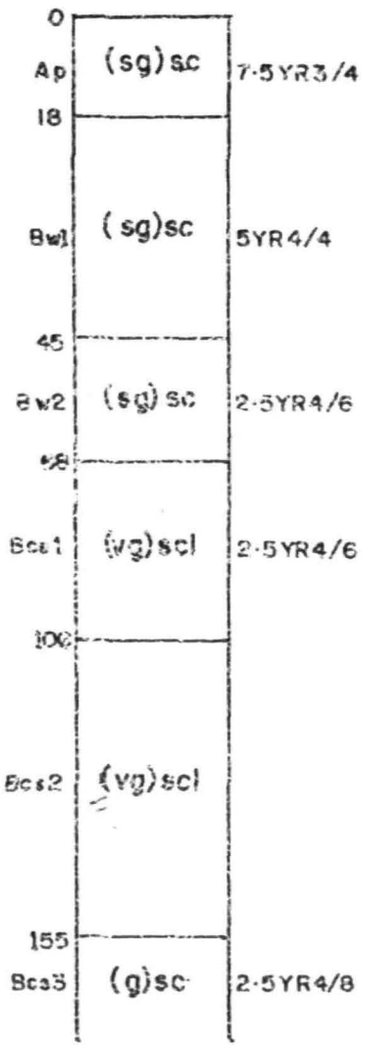
PEDON 13 : MADUKKUR SERIES

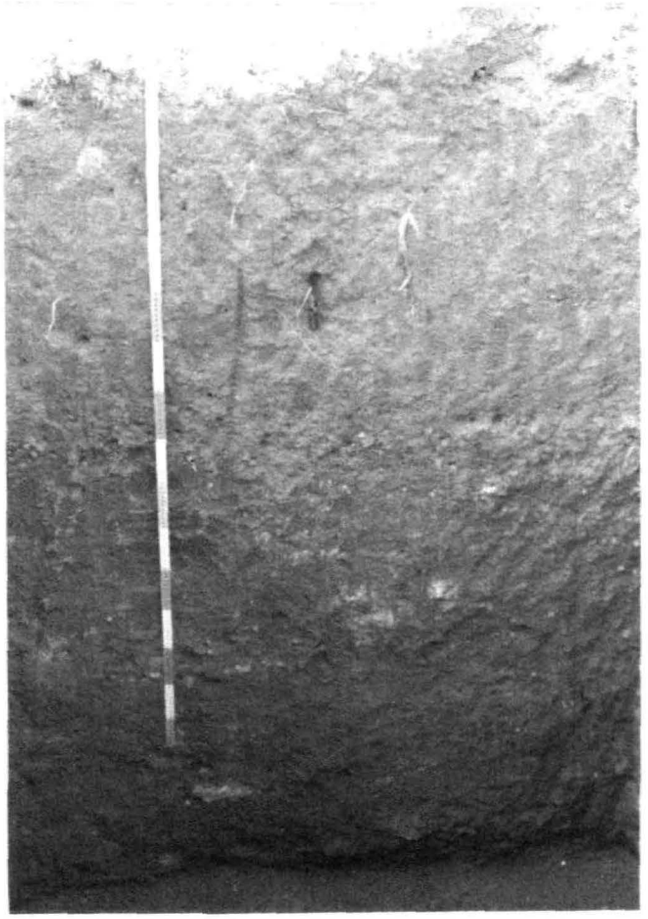
Village	:	Madurai
Taluk	:	Madurai
District	:	Madurai
Latitude	:	9°55'N
Longitude	:	78°07'E
Elevation	:	133 MSL
Land form	:	Lateritic landform
Slope	:	0-1%
Natural Vegetation	:	Prosopis, Tamarind, Bamboo, Neem
Land Use	:	Paddy

Horizon	Depth (cm)	Description
Ap	0-26	Very dark grayish brown (10YR 3/2) moist, dark brown (10YR 3/3) dry; sandy clay; moderate, medium subangular blocky; sticky, plastic; firm moist, hard dry; few medium, common fine pores; many fine, common medium roots; moderate permeability; clear, wavy boundary.
Bt1	26-44	Dark yellowish brown (10YR 3/6) moist (10YR 4/6) dry; clay; massive to strong, coarse subangular blocky; slightly sticky; slightly firm moist, extremely hand dry; few, fine faint dark reddish brown (2.5YR 2.5/4) mottlings; very few, coarse, medium and spherical, ferruginous corrections; few medium, common fine pores; very few, very fine roots; moderately slow permeability; clear, smooth boundary.
Bt2	44-86	Dark yellowish brown (10YR 4/6) moist and yellowish brown (10YR 5/6) dry; clay; strong,

Pedon-14

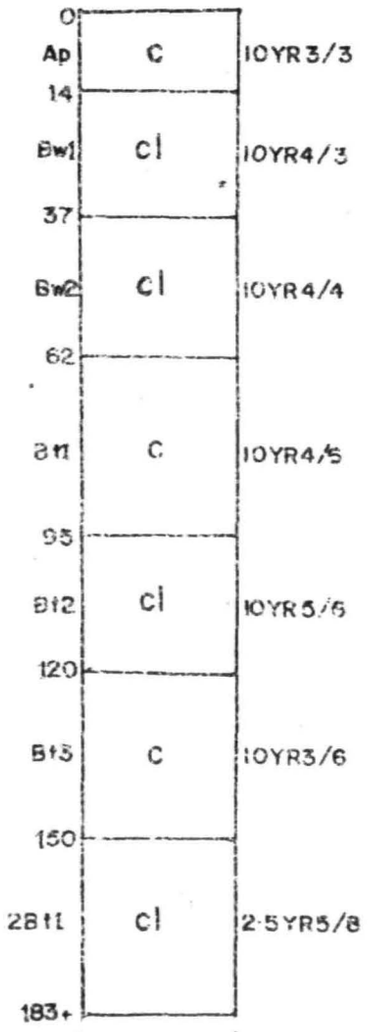
Pechiparai series

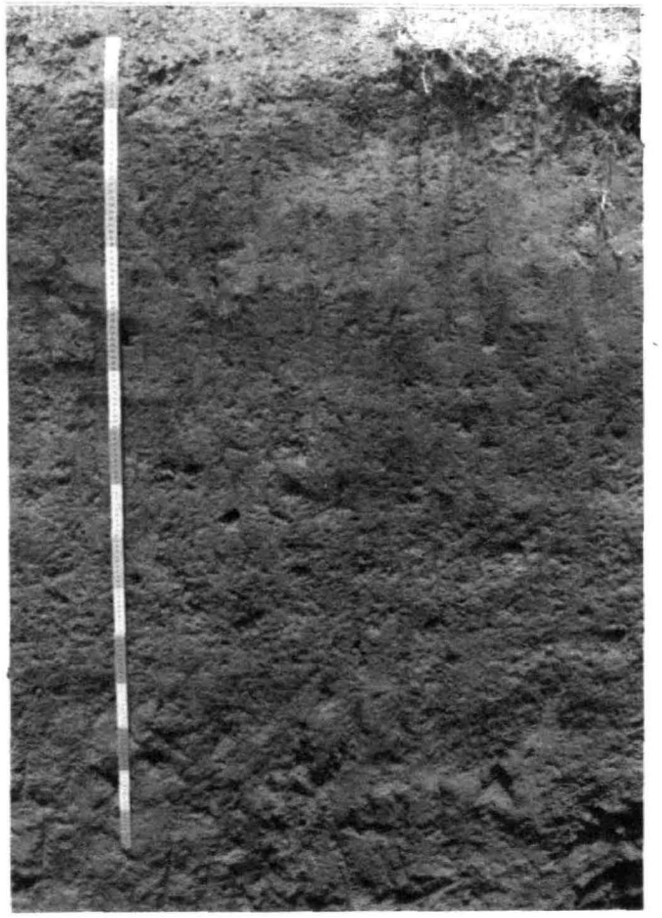




Ooty series

Pedon -15





PEDON 15 : **OOTY SERIES**

Village	:	Ooty
Taluk	:	Udhagamandalam
District	:	Nilgiris
Latitude	:	11°37'N
Longitude	:	76° 27'E
Elevation	:	2090 MSL
Land form	:	Mountains with rolling topography
Slope	:	15-30%
Natural Vegetation	:	Eucalyptus, Pine. Shola forest
Land Use	:	Tea, Cold Vegetables like Potato, Cauliflower, Cabbage.

Horizon	Depth (cm)	Description
Ap	0-14	Dark brown (10YR 3/3) moist; clay; weak, fine subangular blocky to weak, fine crumb; sticky and slightly plastic; slightly firm moist; few, very fine pores; few coarse, common fine roots; rapid permeability; clear, wavy boundary.
Bw1	14-33	Dark brown (10YR 4/3) moist; clay loam; weak, medium subangular blocky to weak, fine crumb; slightly sticky, slightly plastic; friable moist; few, very fine pores; few fine, many very fine roots; clear, smooth boundary.
Bw2	37-62	Dark yellowish brown (10YR 4/4) moist; clay loam; weak, medium subangular blocky to weak, fine crumb; slightly sticky, slightly plastic; friable moist; few, very fine pores; very few, very fine roots; rapid permeability; clear, smooth boundary.

Bt1	62-95	Dark yellowish brown (10YR 4/6); clay; moderate, medium subangular blocky to weak fine subangular blocky; sticky and slightly plastic; slightly firm moist; few, medium distinct very dark gray (10YR 3/1) mottles; common, thick cutans on ped faces; very frequent, earthworm channels; few coarse, and few fine pores; very few, fine and very fine roots; rapid permeability; clear, wavy boundary.
Bt2	95-120	Yellowish brown (10YR 5/6); clay loam; moderate, medium subangular blocky; slightly sticky, slightly plastic; few, fine distinct very dark gray (10YR 3/1) mottles; common, thick cutans on ped faces; frequent earthworm channels; few fine pores; very few, very fine roots; moderate permeability; gradual, wavy boundary.
Bt3	120-150	Red (10R 4/6) and dark red (10R 5/6); clay; moderate, coarse subangular blocky; sticky, slightly plastic; firm moist; common thick cutans on ped faces; few coarse and few fine pores; very few, very fine roots; moderate permeability; clear, wavy boundary.
2Bt1	150-183	Dark red (2.5YR 3/6) and red (2.5YR 5/8) moist; clay loam; massive to strong, coarse subangular blocky; slightly sticky, slightly plastic; slightly firm moist; common thick cutans on ped faces; few medium, few fine pores; very few, very fine roots; moderately rapid permeability.

Annexure IIa. Particle size fractions

Horizon	Depth (cm)	Gravel %	Clay %	Silt %	Sand fractions %					WDC %	Silt/ Clay	Sand/ Silt	CS/ FS	Aggre -gation index
					VCS	CS	MS	FS	VFS					
Pedon 1. Palyur														
Ap	0-20	-	3.40	1.56	16.36	30.64	17.70	23.56	6.78	0.97	0.46	60.92	1.30	0.42
Bw1	20-52	-	35.90	2.42	12.16	16.02	10.42	16.56	6.52	10.26	0.07	25.49	0.97	0.71
Bw2	52-74	12	30.76	2.83	23.02	14.41	8.79	15.07	5.12	8.31	0.09	23.47	0.96	0.73
Bc	74-100	70	15.83	7.14	21.18	28.69	10.39	14.04	4.36	6.14	0.45	10.79	1.90	0.55
Pedon 2. Bhavanisagar														
Ap	0-18	-	28.04	20.61	5.43	3.81	8.61	24.19	9.31	16.72	0.74	2.49	0.16	0.40
Bw	18-50	-	30.08	14.90	16.04	10.98	9.76	14.40	3.84	14.26	0.50	3.69	0.76	0.53
B3	50-59	11	27.38	10.27	18.11	15.72	5.69	14.87	7.96	8.07	0.38	6.07	1.06	0.71
Pedon 3. Thenkasi														
Ap	0-16	-	42.01	2.29	10.71	13.59	11.25	15.11	5.04	6.04	0.05	24.32	0.90	0.86
Bwc1	16-38	20	50.04	2.27	18.30	6.29	6.53	10.49	6.08	8.21	0.05	21.01	0.60	0.84
Bwc2	38-54	60	31.10	2.46	39.51	6.47	7.28	9.26	3.91	11.28	0.08	27.01	0.70	0.64
Bc1	54-89	30	14.04	2.10	38.06	11.57	9.22	18.42	6.59	5.14	0.15	39.93	0.63	0.63
Bc2	89-155	35	17.45	5.46	32.16	13.11	9.83	17.73	4.97	3.19	0.31	14.12	0.74	0.82
Pedon 4. Periyakulam														
Ap	0-23	-	11.21	6.28	12.86	21.54	16.85	21.84	9.47	9.21	0.56	13.13	0.99	0.18
A1	23-52	-	10.14	5.42	9.58	26.00	19.40	22.28	7.18	3.87	0.53	15.58	1.17	0.62
E	52-88	-	9.26	6.28	14.45	17.52	14.96	29.43	8.10	1.87	0.68	13.45	0.60	0.80
2Bt1	88-125	8	26.78	11.28	6.25	12.24	9.76	23.22	13.27	6.95	0.42	5.49	0.53	0.74
2Bt2	125-163	-	27.63	5.16	5.82	13.11	13.22	23.59	11.47	5.29	0.19	13.03	0.56	0.81
Pedon 5. Sathankulam														
Ap	0-20	-	10.38	8.33	1.97	17.09	23.22	34.18	4.46	1.28	0.80	9.76	0.50	0.88
Bw1	20-48	-	11.08	7.95	2.47	17.61	24.33	30.96	5.60	2.03	0.72	10.18	0.57	0.82
Bt1	48-72	-	26.91	2.83	1.84	12.97	20.54	32.58	2.38	3.11	0.11	24.83	0.40	0.88
Bt2	72-123	-	20.30	2.95	2.02	10.76	19.81	37.20	6.92	2.83	0.15	26.01	0.29	0.86
Bt3	123-175	-	25.84	3.26	3.11	11.70	18.38	29.05	8.66	3.28	0.13	21.75	0.40	0.87

Contd...

Annexure II a. Contd...

Horizon	Depth (cm)	Gravel %	Clay %	Silt %	Sand fractions %					WDC %	Silt/ Clay	Sand/ Silt	CS/ FS	Aggre -gation index
					VCS	CS	MS	FS	VFS					
Pedon 6. Aruppukkottai														
Ap	0-19	-	36.51	9.50	3.12	5.71	10.78	26.71	7.66	27.31	0.26	5.68	0.21	0.25
Ack	19-52	-	45.50	13.82	2.14	3.37	12.14	17.34	5.69	31.46	0.30	2.94	0.19	0.31
Assck1	52-80	-	50.71	14.07	2.23	3.00	7.53	16.13	6.33	30.78	0.28	2.50	0.19	0.39
Assck2	80-112	-	57.67	13.34	3.24	3.51	6.95	11.38	3.91	34.25	0.23	2.17	0.31	0.41
Crck	112-159	-	31.11	14.94	4.50	9.08	8.55	23.84	7.98	25.78	0.48	3.61	0.38	0.17
Pedon 7. Coimbatore														
Ap	0-22	-	22.00	6.19	2.36	5.46	23.09	33.60	7.30	13.70	0.28	11.60	0.16	0.38
Bwck	22-48	-	30.90	5.25	2.26	3.34	20.09	30.64	7.52	14.90	0.17	12.16	0.11	0.52
Bckss	48-77	-	31.20	8.10	0.93	3.88	22.59	26.42	6.68	14.50	0.26	7.49	0.15	0.53
Bck1	77-97	-	25.52	15.53	1.24	3.84	18.41	29.59	6.92	12.90	0.61	3.80	0.13	0.49
Bck2	97-120	-	24.46	4.08	2.70	5.47	18.17	40.25	8.52	18.10	0.17	17.52	0.14	0.26
2Bck	120-157	-	18.21	9.64	3.21	7.45	24.03	29.16	8.30	13.70	0.53	7.48	0.26	0.25
Pedon 8. Palladam														
Ap	0-17	42	16.58	3.04	25.66	15.59	12.11	18.83	8.21	10.41	0.18	26.44	0.83	0.38
Ak1	17-42	65	16.41	4.43	23.53	15.18	11.78	20.31	8.38	13.81	0.27	17.87	0.75	0.16
Ak2	42-76	70	10.27	3.86	30.75	12.12	10.22	17.70	15.08	6.41	0.38	22.25	0.68	0.38
Pedon 9. Aduthurai														
Ap	0-21	-	44.52	14.87	9.00	5.96	8.23	13.89	3.53	18.70	0.33	2.73	0.43	0.58
Bg1	21-41	-	36.21	12.17	12.52	7.28	12.88	13.21	5.73	20.41	0.34	4.24	0.55	0.44
Bg2	41-75	-	34.21	10.43	14.56	8.54	6.41	17.35	8.50	19.27	0.30	5.31	0.49	0.44
Bg3	75-103	-	35.21	9.37	16.99	8.00	6.32	19.81	4.30	10.87	0.27	5.91	0.40	0.69
Bg4	103-139	-	25.86	13.21	14.56	10.76	9.59	16.07	9.95	14.83	0.51	4.61	0.67	0.43
2B2	139-164	-	22.45	13.73	13.20	10.00	8.56	19.90	12.16	14.10	0.61	4.65	0.50	0.37
Pedon 10. Sellur														
Ap	0-14	-	53.71	10.96	0.50	1.01	3.22	15.14	15.46	20.14	0.20	3.22	0.07	0.63
Bg	14-29	-	52.56	11.01	0.88	1.37	3.61	14.68	15.89	41.26	0.21	3.31	0.09	0.21
Bw	29-63	-	50.08	20.08	1.15	0.95	1.27	11.83	14.64	30.08	0.40	1.49	0.08	0.40
2Bg1	63-82	-	35.63	21.03	16.27	5.71	1.71	7.20	12.45	28.27	0.59	2.06	0.79	0.21
2Bg2	82-117	-	17.52	20.64	18.77	0.49	2.29	6.13	34.16	8.27	1.18	3.00	0.56	0.53
2Bg3	117-152	-	15.61	25.91	12.42	0.78	0.93	7.05	37.30	3.01	1.66	2.26	0.11	0.81
3Bg1	152-174	-	22.53	10.60	10.04	1.67	1.55	8.32	45.29	3.96	0.47	6.31	0.2	0.18
3Bg2	174-190	-	14.26	12.81	10.19	1.70	2.79	13.12	45.13	1.26	0.90	5.69	0.13	0.91

Contd

Annexure IIa. Contd...

Horizon	Depth (cm)	Gravel %	Clay %	Silt %	Sand fractions %					WDC %	Silt/ Clay	Sand/ Silt	CS/ FS	Aggre -gation index
					VCS	CS	MS	FS	VFS					
Pedon 11. Vridhachalam														
Ap	0-21	-	5.90	2.56	1.46	28.46	30.21	27.46	3.95	1.87	0 43	35 76	1.03	0.68
Bsmt	21-53	-	27.40	5.17	0.75	16.23	22.86	23.80	3.79	10.28	0.19	13.04	0.68	0.62
Bt1	53-105	-	23.47	7.59	1.11	20.64	25.50	18.77	2.92	8.46	0.32	9.08	1.10	0.64
Bt2	105-156	-	35.92	5.08	1.04	15.12	16.79	21.69	4.36	14.39	0.14	11.61	0.70	0.60
Bsm	156-177	-	35.62	2.81	1.08	15.40	19.69	21.53	3.87	13.38	0.08	21 91	0.72	0 38
Pedon 12. Vamban														
Ap	0-12	-	33.80	4.38	8.75	10.44	10.63	24.27	7.75	13.80	0.13	14 11	0.43	0.59
Bsmt1	12-40	-	38.84	4.04	10.21	8.30	8.78	21.66	8.17	9.40	0.10	14 14	0.38	0.76
Bsmt2	40-77	-	40.70	4.44	6.85	10.45	10.08	20.13	7.38	7.20	0.11	12.36	0.52	0.82
Bsmt3	77-110	-	44.84	2.91	8.65	7.54	8.06	19.00	9.00	10.20	0.06	17.96	0.40	0.77
Bcs1	110-169	-	39.83	3.54	30.20	4.51	4.61	11.02	6.29	14.80	0.09	16.00	0.41	0.63
Pedon 13. Madural														
Ap	0-26	-	31.92	8.77	12.92	13.84	7.94	15.82	8.79	18.28	0.27	6.76	0.87	0.43
Bt1	26-44	-	36.94	6.19	6.72	11.80	10.29	19.12	8.94	10.91	0.17	9.19	0.62	0.71
Bt2	44-86	-	35.19	6.81	11.00	12.24	10.51	17.59	6.66	9.47	0.19	8.52	0.70	0.73
BcS1	86-121	-	20.56	6.03	21.56	16.25	8.01	21.69	5.90	6.18	0.29	12.17	0.75	0.70
BcS2	121-150	52	20.18	3.35	53.25	9.15	3.98	7.05	3.24	9.46	0.17	22.82	1.30	0.53
Pedon 14. Pechiparai														
Ap	0-18	10	33.47	5.63	14.99	16.18	9.89	15.59	4.25	7.08	0.17	10.82	1.04	0.79
Bw1	18-45	12	33.92	7.57	21.92	14.81	6.41	11.69	3.72	9.41	0 22	7.73	1.27	0.73
Bw2	45-68	14	32.69	2.69	34.66	14.34	4.66	7.95	3.00	9.81	0.08	24.02	1.80	0.70
Bcs1	68-100	50	20.43	9.04	44.28	10.33	4.00	8.42	3.48	4.51	0.44	7.80	1.23	0.78
Bcs2	100-155	58	20.98	10.09	41.96	13.20	4.68	6.32	2.89	3.12	0.48	6.83	2.09	0.85
Bcs3	155-203	40	31.45	5.57	26.15	12.85	7.35	11.23	5.50	4.89	0.18	11.31	1.14	0.85
Pedon 15. Ooty														
Ap	0-14	-	37.12	14.81	8.11	8.55	11.40	13.69	6.12	6.21	0.40	3 25	0.62	0.83
Bw1	14-37	-	31.01	10.98	8.09	16.07	11.03	17.82	5.00	4.17	0.35	5 28	0.90	0.87
Bw2	37-62	-	30.21	10.08	12.32	15.54	9.93	16.21	5.71	7.28	0.33	5.92	0.96	0.76
Bt1	62-95	-	38.94	13.83	8.07	10.09	9.52	12.63	6.92	8.81	0.36	3 42	0.80	0.77
Bt2	95-120	-	31.14	12.81	10.46	9.94	11.66	15.18	8.81	6.54	0.41	4 38	0.65	0 79
Bt3	120-150	-	41.12	11.84	6.98	8.05	8.75	16.49	6.77	10.21	0.29	3 97	0.49	0 75
2Bt1	150-183	-	31.81	10.21	6.38	11.63	11.85	19.07	9.05	6.64	0.32	5 68	0.61	0 79

Annexure IIb. Moisture retention characteristics

Horizon	Depth (cm)	B.D (Mg/m^3)	33 kPa (%)	1500 kPa (%)	AWHC (%)	Air dry moisture
Pedon 1. Paiyur						
Ap	0-20	1.63	4.68	2.12	2.56	0.98
Bw1	20-52	1.46	28.68	15.32	13.36	1.32
Bw2	52-74	1.57	24.30	13.62	10.68	1.46
Bc	74-100	1.69	14.28	6.94	7.34	1.16
Pedon 2. Bhavanisagar						
Ap	0-18	1.38	18.63	10.28	8.35	3.21
Bw	18-50	1.45	13.66	7.22	6.44	4.38
B3	50-59	1.56	11.69	5.84	5.85	4.29
Pedon 3. Thenkasi						
Ap	0-16	1.24	29.65	13.37	16.28	3.87
Bwc1	16-38	1.36	28.04	12.10	15.94	4.29
Bwc2	38-54	1.45	27.68	14.03	13.65	5.61
Bc1	54-89	1.47	10.69	4.78	5.91	3.83
Bc2	89-155	1.47	14.16	8.10	6.06	2.76
Pedon 4. Periyakulam						
Ap	0-23	1.33	17.83	9.32	8.51	2.13
A1	23-52	1.38	14.63	7.92	6.71	2.08
E	52-88	1.38	10.68	4.12	6.56	2.43
2Bt1	88-125	1.41	21.93	10.63	11.30	3.21
2Bt2	125-163	1.45	23.38	12.83	10.55	3.93
Pedon 5. Sathankulam						
Ap	0-20	1.47	9.21	6.33	2.88	1.01
Bw1	20-48	1.59	7.83	5.17	2.66	1.08
Bt1	48-72	1.64	9.08	6.15	2.93	1.21
Bt2	72-123	1.67	8.17	4.32	3.85	0.99
Bt3	123-175	1.72	9.88	4.75	5.13	0.93
Pedon 6. Aruppukkottai						
Ap	0-19	1.27	37.90	18.63	19.27	5.32
Ack	19-52	1.31	41.28	20.72	20.56	6.31
Assck1	52-80	1.38	42.33	22.63	19.70	7.38
Assck2	80-112	1.54	43.21	23.90	19.31	7.73
Crck	112-159	1.57	34.34	18.81	15.51	4.93

Contd...

Annexure IIb. Contd...

Horizon	Depth (cm)	B.D (Mg/m^3)	33 kPa (%)	1500 kPa (%)	AWHC (%)	Air dry moisture
Pedon 7. Coimbatore						
Ap	0-22	1.29	36.67	16.17	20.50	4.08
Bwck	22-48	1.47	38.08	19.21	18.87	5.12
Bckss	48-77	1.48	39.87	16.78	23.09	5.78
Bck1	77-97	1.57	33.05	13.92	19.13	4.90
Bck2	97-120	1.57	29.20	14.44	14.76	3.88
2Bck	120-157	-	28.31	13.14	15.17	3.71
Pedon 8. Palladam						
Ap	0-17	1.41	13.48	6.92	6.56	1.08
Ak1	17-42	1.58	14.18	7.10	7.08	1.97
Ak2	42-76	1.66	8.29	3.98	4.31	1.70
Pedon 9. Aduthurai						
Ap	0-21	1.23	39.61	20.68	18.93	3.28
Bg1	21-41	1.39	34.82	19.33	15.49	4.31
Bg2	41-75	1.44	33.22	15.71	17.51	5.26
Bg3	75-103	1.50	35.38	18.48	16.90	5.43
Bg4	103-139	1.53	42.35	22.94	19.41	4.08
2B2	139-164	-	29.21	15.30	13.91	3.19
Pedon 10. Sellur						
Ap	0-14	1.18	43.62	19.34	24.28	3.28
Bg	14-29	1.27	41.92	22.33	19.59	3.86
Bw	29-63	1.34	40.64	20.28	20.36	6.02
2Bg1	63-82	1.47	34.68	17.79	16.89	5.03
2Bg2	82-117	1.52	18.66	10.42	8.24	4.21
2Bg3	117-152	1.55	14.38	8.66	5.72	4.83
3Bg1	152-174	-	19.32	10.66	8.66	4.73
3Bg2	174-190	-	13.78	7.70	6.08	5.93
Pedon 11. Vridhachalam						
Ap	0-21	1.34	4.28	2.22	2.06	1.09
Bsmt	21-53	1.45	21.69	10.29	11.40	2.12
Bt1	53-105	1.48	20.18	9.72	10.46	4.28
Bt2	105-156	1.54	31.62	16.33	15.29	4.76
Bsm	156-177	1.57	29.68	14.39	15.29	4.53

Contd...

Annexure IIc. Physico-chemical properties of soils

Horizon	Depth (cm)	pH			pH	EC (dSm^{-1})	O.C (%)	$CaCO_3$ Equiv.	Gypsum (%)
		1:1	1:2.5	1:2.5 1 M Kcl					
Pedon 1. Paiyur									
Ap	0-20	5.80	5.90	5.72	0.18	0.043	0.10	-	-
Bw1	20-52	5.93	6.10	5.40	0.70	0.068	0.19	0.08	-
Bw2	52-74	6.05	6.27	5.53	0.74	0.080	0.15	0.13	-
Bc	74-100	6.13	6.33	5.48	0.85	0.068	0.15	0.23	-
Pedon 2. Bhavanisagar									
Ap	0-18	6.00	6.10	4.65	1.45	0.351	0.25	0.12	-
Bw	18-50	5.90	6.35	4.85	1.50	0.412	0.20	0.21	-
B3	50-59	6.20	6.85	4.96	1.89	0.383	0.17	0.35	-
Pedon 3. Thenkasi									
Ap	0-16	5.95	6.15	4.70	1.45	0.048	0.28	0.21	-
Bwc1	16-38	6.00	6.45	4.50	1.95	0.063	0.25	0.10	-
Bwc2	38-54	6.43	7.05	4.63	2.42	0.073	0.25	0.17	-
Bc1	54-89	6.76	7.33	5.82	1.51	0.048	0.19	0.21	-
Bc2	89-155	6.38	6.57	5.18	1.39	0.038	0.15	0.21	-
Pedon 4. Periyakulam									
Ap	0-23	7.71	8.11	7.45	0.66	0.081	0.25	-	-
A1	23-52	7.72	8.15	7.50	0.65	0.072	0.20	-	-
E	52-88	7.51	8.11	7.68	0.43	0.060	0.17	-	-
2Bt1	88-125	7.32	7.91	7.38	0.53	0.072	0.13	-	-
2Bt2	125-163	7.42	7.84	7.43	0.41	0.053	0.13	-	-
Pedon 5. Sathankulam									
Ap	0-20	5.00	5.00	3.63	1.37	0.043	0.17	-	-
Bw1	20-48	4.33	4.93	3.24	1.69	0.062	0.13	-	-
Bt1	48-72	5.00	5.10	3.15	1.95	0.032	0.13	-	-
Bt2	72-123	4.50	4.95	3.15	1.80	0.073	0.10	-	-
Bt3	123-175	5.20	5.50	4.48	1.02	0.203	0.10	-	-

Contd...

Annexure IIc. Contd...

Horizon	Depth (cm)	pH			pH	EC (dSm^{-1})	O.C (%)	$CaCO_3$ Equiv.	Gypsum (%)
		1:1	1:2.5	1:2.5 1 M Kcl					
Pedon 11. Vridhachalam									
Ap	0-21	6.30	6.62	5.10	1.52	0.062	0.38	-	-
Bsmt	21-53	5.08	6.22	5.10	1.12	0.120	0.23	-	-
Bt1	53-105	4.95	6.30	5.05	1.25	0.073	0.23	-	-
Bt2	105-156	4.95	6.50	5.20	1.30	0.078	0.23	-	-
Bsm	156-177	4.63	6.50	5.15	1.35	0.093	0.06	-	-
Pedon 12. Vamban									
Ap	0-12	6.00	6.90	5.90	1.00	0.154	0.53	-	-
Bsmt1	12-40	4.85	5.65	3.50	2.15	0.088	0.30	-	-
Bsmt2	40-77	4.61	5.15	3.22	1.93	0.082	0.17	-	-
Bsmt3	77-110	5.13	5.65	3.40	2.25	0.073	0.15	-	-
Bcs1	110-169	5.95	6.40	4.32	2.08	0.052	0.09	-	-
Pedon 13. Madurai									
Ap	0-26	7.90	8.60	7.21	1.39	0.321	0.42	-	-
Bt1	26-44	7.41	8.41	7.31	1.10	0.210	0.26	-	-
Bt2	44-86	7.52	8.32	7.22	1.10	0.280	0.20	-	-
BcS1	86-121	7.50	8.30	7.09	1.21	0.131	0.20	-	-
BcS2	121-150	7.60	8.30	7.01	1.29	0.242	0.23	-	-
Pedon 14. Pechiparai									
Ap	0-18	4.40	4.80	4.10	0.70	0.062	1.57	-	-
Bw1	18-45	4.62	5.05	4.00	1.05	0.053	1.09	-	-
Bw2	45-68	4.62	4.93	3.92	1.01	0.043	0.87	-	-
Bcs1	68-100	4.80	5.12	4.07	1.05	0.032	0.33	-	-
Bcs2	100-155	5.05	5.15	4.38	0.77	0.021	0.33	-	-
Bcs3	155-203	5.10	5.36	4.49	0.87	0.033	0.12	-	-
Pedon 15. Ooty									
Ap	0-14	4.80	5.00	4.30	0.70	0.051	2.60	-	-
Bw1	14-37	4.61	4.93	4.35	0.58	0.021	1.50	-	-
Bw2	37-62	4.52	4.63	4.40	0.23	0.053	1.18	-	-
Bt1	62-95	4.63	4.75	4.20	0.55	0.028	0.89	-	-
Bt2	95-120	4.73	5.03	4.40	0.63	0.083	0.52	-	-
Bt3	120-150	4.85	5.08	4.50	0.58	0.033	0.29	-	-
2Bt1	150-183	4.73	4.88	4.63	0.25	0.038	0.29	-	-

Annexure IId. Chemical composition of the soils

Horizon	Depth (cm)	SiO_2	Total Fe_2O_3	Al_2O_3	R_2O_3	CaO	MgO	K_2O	Na_2O	Free Fe_2O_3
Pedon 1. Paiyur										
Ap	0-20	79.10	2.79	10.21	13.00	1.09	0.80	0.194	0.320	1.79
Bw1	20-52	65.62	5.42	15.98	21.40	0.88	0.32	0.293	0.384	4.40
Bw2	52-74	62.11	5.31	19.84	25.15	1.23	1.19	0.388	0.338	3.52
Bc	74-100	68.33	5.87	18.81	24.68	1.50	1.43	0.594	0.394	3.55
Pedon 2. Bhavanisagar										
Ap	0-18	63.11	7.62	15.82	23.44	1.93	0.96	0.599	0.390	5.45
Bw	18-50	67.10	7.71	14.90	22.61	1.78	1.82	0.622	0.447	5.23
B3	50-59	76.53	7.31	10.81	18.12	1.68	1.19	0.558	0.351	4.30
Pedon 3. Thenkasi										
Ap	0-16	63.31	10.28	15.21	25.49	1.16	1.36	0.317	0.233	7.22
Bwc1	16-38	64.10	10.35	14.81	25.16	1.22	1.11	0.299	0.394	7.35
Bwc2	38-54	64.91	9.34	16.66	26.00	1.37	0.71	0.289	0.339	6.79
Bc1	54-89	61.92	14.63	15.98	30.61	0.77	0.96	0.139	0.283	12.56
Bc2	89-155	63.50	12.17	19.20	31.37	1.50	0.63	0.171	0.386	8.92
Pedon 4. Periyakulam										
Ap	0-23	82.80	5.51	10.31	15.82	7.40	1.24	0.130	0.355	2.97
A1	23-52	81.40	8.11	9.21	17.32	5.07	3.48	0.155	0.446	3.30
E	52-88	80.10	6.28	10.83	17.11	4.31	1.29	0.113	0.373	3.15
2Bt1	88-125	69.30	9.11	18.28	27.39	4.77	1.38	0.148	0.461	4.66
2Bt2	125-163	65.80	9.24	20.14	29.38	4.86	1.16	0.229	0.528	5.15

Contd..

Annexure IId. Contd...

Horizon	Depth (cm)	SiO_2	Total Fe_2O_3	Al_2O_3	R_2O_3	CaO	MgO	K_2O	Na_2O	Free Fe_2O_3
Pedon 5. Sethankulam										
Ap	0-20	76.10	6.13	14.31	20.44	0.92	0.48	0.177	0.393	4.45
Bw1	20-48	72.30	6.62	17.38	24.00	1.02	0.23	0.188	0.284	4.60
Bt1	48-72	73.40	7.12	16.29	23.41	1.23	0.32	0.152	0.233	4.83
Bt2	72-123	72.30	6.68	18.21	24.89	1.13	0.48	0.100	0.176	5.03
Bt3	123-175	78.20	8.28	10.97	19.25	0.90	0.71	0.199	0.455	4.90
Pedon 6. Aruppukkottai										
Ap	0-19	69.20	4.27	12.73	17.00	8.20	2.55	0.166	0.361	0.77
Ack	19-52	71.40	6.88	15.43	22.31	8.79	3.53	0.317	0.376	0.99
Assck1	52-80	66.50	3.79	12.86	16.65	8.30	1.29	0.177	0.383	0.83
Assck2	80-112	58.70	1.89	11.83	13.72	7.25	4.48	0.192	0.400	0.66
Crck	112-159	58.80	2.13	14.21	16.34	22.51	3.98	0.236	0.685	0.49
Pedon 7. Coimbatore										
Ap	0-22	69.50	4.47	13.85	18.32	9.33	3.53	0.391	0.528	0.34
Bwck	22-48	68.30	3.79	14.26	18.05	6.73	5.42	0.443	0.448	0.61
Bckss	48-77	63.00	4.69	18.21	22.90	5.71	6.98	0.469	0.422	0.47
Bck1	77-97	63.90	3.87	10.91	14.78	7.23	4.51	0.528	0.514	0.40
Bck2	97-120	65.40	4.40	13.21	17.61	6.38	3.62	0.430	0.505	0.44
2BcK	120-157	65.70	4.13	14.26	18.39	7.24	4.11	0.448	0.477	0.86
Pedon 8. Palladam										
Ap	0-17	79.40	4.25	11.33	15.58	4.73	2.70	0.366	0.444	2.62
Ak1	17-42	66.20	5.64	18.31	23.95	8.57	1.99	0.407	0.386	2.42
Ak2	42-76	66.41	5.18	19.25	24.43	11.57	2.70	0.507	0.397	2.27

Contd..

Annexure IId. Contd...

Horizon	Depth (cm)	SiO_2	Total Fe_2O_3	Al_2O_3	R_2O_3	CaO	MgO	K_2O	Na_2O	Free Fe_2O_3
Pedon 9. Aduthurai										
Ap	0-21	70 10	6.43	15 13	21 56	2 62	2 95	0 442	0 828	1 69
Bg1	21-41	76.21	6.42	10 28	16.70	2 46	1 44	0 383	0.892	2 33
Bg2	41-75	75 30	6.15	11 21	17.36	2 41	3 03	0.387	0.644	2 19
Bg3	75-103	71 22	6 86	12 81	19 69	3 48	2 80	0 322	0 555	2 06
Bg4	103-139	74 20	5.58	16 31	21 89	4 02	1 99	0 436	0.551	1 70
2B2	139-164	69.70	5.18	17.21	22 39	3.79	2 55	0 443	0 420	1 83
Pedon 10. Sellur										
Ap	0-14	66.24	5.87	14.31	20 18	3 39	2 39	0.567	0.551	2 23
Bg	14-29	70.20	7.45	16.28	23.73	3 51	3 18	0 617	0.758	1.76
Bw	29-63	68.21	6.76	14.92	21.68	3.64	1 76	0.734	0.974	1.86
2Bg1	63-82	71.83	4.42	10.56	14.98	2 91	2 79	0 636	0.688	0 63
2Bg2	82-117	86.40	2.96	7.41	10.37	3 48	2 01	0 454	0.679	0 47
2Bg3	117-152	86.21	2.33	6.81	9 14	4 02	2 11	0.376	0 555	0.93
3Bg1	152-174	85.83	3.45	7.01	10.46	5 22	2 87	0 436	0 820	1 54
3Bg2	174-190	78.92	2.90	10 8	13.70	4 73	1 03	0 323	0 550	0 99
Pedon 11. Vridhachalam										
Ap	0-21	80.31	2.17	7 31	9 48	0 98	0 63	0 130	0 253	1 19
Bsmt	21-53	76.32	5.16	11 78	16 94	1 09	0 56	0 240	0 339	3 73
Bt1	53-105	75.12	5.31	11.09	16 40	0.78	0 71	0 201	0 281	5 31
Bt2	105-156	76 13	5.69	12.08	17.77	1 09	0 56	0 219	0 332	3 50
Bsm	156-177	62 10	5.48	20 98	26.46	1.26	0 56	0 232	0 277	3 52

Contd

Annexure IId. Contd...

Horizon	Depth (cm)	SiO_2	Total Fe_2O_3	Al_2O_3	R_2O_3	CaO	MgO	K_2O	Na_2O	Free Fe_2O_3
Pedon 12. Vamban										
Ap	0-12	71.70	7.45	14.28	21.73	2.31	2.39	0.306	0.292	5.73
Bsmt1	12-40	70.82	8.02	12.26	20.28	1.51	0.88	0.275	0.389	5.77
Bsmt2	40-77	74.70	7.82	11.37	19.19	1.67	0.20	0.202	0.397	5.36
Bsmt3	77-110	71.63	7.41	12.14	19.55	1.74	0.32	0.175	0.339	5.15
Bcs1	110-169	70.54	8.98	13.24	22.22	1.25	0.35	0.182	0.359	7.15
Pedon 13. Madurai										
Ap	0-26	69.52	5.19	13.21	18.40	6.95	1.46	0.323	0.528	2.16
Bt1	26-44	70.81	6.69	15.16	21.85	4.58	2.67	0.383	0.441	3.66
Bt2	44-86	69.54	5.78	16.28	22.06	5.08	0.80	0.873	0.685	3.69
Bcs1	86-121	61.30	5.96	20.28	26.24	3.18	2.95	0.783	0.693	2.45
Bcs2	121-150	68.52	6.19	17.23	23.42	2.69	1.76	0.666	0.837	3.27
Pedon 14. Pechiparai										
Ap	0-18	50.61	9.82	20.10	29.92	0.78	1.03	0.131	0.346	7.59
Bw1	18-45	46.72	8.52	25.12	33.64	1.12	0.56	0.118	0.279	6.72
Bw2	45-68	52.11	8.94	24.31	33.25	1.19	0.40	0.140	0.335	7.08
Bcs1	68-100	51.90	11.28	20.28	31.56	1.12	0.63	0.107	0.292	9.71
Bcs2	100-155	51.72	8.34	21.24	29.58	1.46	0.40	0.096	0.332	8.34
Bcs3	155-203	49.83	11.55	19.26	30.81	1.46	0.32	0.078	0.346	10.04
Pedon 15. Ooty										
Ap	0-14	57.31	6.01	25.14	31.15	1.02	0.88	0.371	0.280	5.08
Bw1	14-37	57.52	6.25	27.31	33.56	1.16	0.96	0.399	0.233	5.22
Bw2	37-62	61.60	6.65	20.81	27.46	1.32	0.71	0.367	0.225	5.03
Bt1	62-95	58.32	6.74	22.89	29.63	1.43	0.96	0.611	0.311	5.33
Bt2	95-120	50.81	7.89	27.38	35.27	1.57	0.56	0.597	0.319	6.38
Bt3	120-150	53.81	9.31	22.78	32.09	1.12	0.88	0.582	0.361	8.18
2Bt1	150-183	39.51	10.61	29.94	40.55	1.32	0.23	0.217	0.373	9.77

Annexure IIe. Molar ratios

Horizon	Depth (cm)	SiO_2 / R_2O_3	SiO_2 / Al_2O_3	SiO_2 / Fe_2O_3	Al_2O_3 / Fe_2O_3	CaO+MgO / Al_2O_3	CaO / MgO	K_2O+Na_2O / Al_2O_3	K_2O / Na_2O
Pedon 1. Paiyur									
Ap	0-20	11.19	13.15	57.24	5.73	0.39	0.98	0.072	0.40
Bw1	20-52	5.73	6.97	32.17	4.62	0.12	1.96	0.059	0.50
Bw2	52-74	4.54	5.31	31.08	5.85	0.26	0.74	0.049	0.76
Bc	74-100	5.14	6.16	31.14	5.05	0.34	0.75	0.069	0.99
Pedon 2. Bhavanisagar									
Ap	0-18	5.19	6.77	22.01	3.25	0.38	1.44	0.082	1.01
Bw	18-50	5.74	7.64	23.13	3.03	0.53	0.70	0.095	0.92
B3	50-59	8.39	12.01	27.81	2.32	0.56	1.02	0.109	1.05
Pedon 3. Thenkasi									
Ap	0-16	4.93	7.06	16.37	2.32	0.36	0.61	0.048	0.90
Bwc1	16-38	5.08	7.34	16.46	2.24	0.34	0.79	0.066	0.50
Bwc2	38-54	4.87	6.61	18.47	2.79	0.26	1.39	0.052	0.56
Bc1	54-89	4.15	6.57	11.25	1.71	0.24	0.58	0.039	0.32
Bc2	89-155	4.00	5.61	13.87	2.47	0.22	1.71	0.043	0.29
Pedon 4. Periyakulam									
Ap	0-23	10.16	13.63	39.94	2.93	1.61	4.29	0.071	0.24
A1	23-52	9.60	15.00	26.68	1.78	1.96	1.05	0.098	0.23
E	52-88	9.16	12.55	33.90	2.70	1.03	2.40	0.068	0.20
2Bt1	88-125	4.88	6.43	20.22	3.14	0.67	2.49	0.050	0.21
2Bt2	125-163	4.29	5.54	18.93	3.41	0.58	3.01	0.055	0.29
Pedon 5. Sathankulam									
Ap	0-20	7.09	9.02	32.99	3.66	0.20	1.38	0.059	0.30
Bw1	20-48	5.68	7.06	29.03	4.11	0.14	3.19	0.039	0.44
Bt1	48-72	5.98	7.65	27.40	3.58	0.19	2.76	0.034	0.43
Bt2	72-123	5.46	6.74	28.77	4.27	0.18	1.69	0.022	0.37
Bt3	123-175	8.16	12.10	25.10	2.08	0.31	0.91	0.088	0.29

Contd

Annexure IIe. Contd...

Horizon	Depth (cm)	SiO_2 / R_2O_3	SiO_2 / Al_2O_3	SiO_2 / Fe_2O_3	Al_2O_3 / Fe_2O_3	CaO+MgO / Al_2O_3	CaO / MgO	K_2O+Na_2O / Al_2O_3	K_2O / Na_2O
Pedon 6. Aruppukkottai									
Ap	0-19	7.60	9.22	43.07	4.67	1.68	2.31	0.061	0.30
Ack	19-52	6.11	7.85	27.58	3.51	1.61	1.79	0.063	0.55
Assck1	52-80	7.39	8.78	46.63	5.31	1.43	4.62	0.064	0.30
Assck2	80-112	7.64	8.42	82.55	9.80	2.07	1.16	0.073	0.32
Crck	112-159	6.41	7.02	73.37	10.45	3.59	4.06	0.097	0.23
Pedon 7. Coimbatore									
Ap	0-22	7.05	8.52	41.32	4.85	1.87	1.90	0.940	0.49
Bwck	22-48	6.94	8.13	47.90	5.89	1.85	0.89	0.085	0.65
Bckss	48-77	5.05	5.87	35.70	6.08	1.56	0.59	0.066	0.73
Bck1	77-97	8.12	9.94	43.88	4.42	2.25	1.15	0.129	0.68
Bck2	97-120	6.91	8.40	39.50	4.70	1.57	2.92	0.098	0.56
2BcK	120-157	6.60	7.82	42.28	5.41	1.65	1.27	0.089	0.62
Pedon 8. Palladam									
Ap	0-17	9.59	11.89	49.65	4.18	1.36	1.26	0.100	0.54
Ak1	17-42	5.13	6.14	31.20	5.08	1.12	3.07	0.059	0.69
Ak2	42-76	5.00	5.85	34.07	5.82	1.45	3.08	0.063	0.84
Pedon 9. Aduthurai									
Ap	0-21	6.18	7.86	28.97	3.69	0.81	0.64	0.122	0.35
Bg1	21-41	8.99	12.58	31.55	2.51	0.79	1.23	0.183	0.25
Bg2	41-75	8.44	11.40	32.54	2.85	1.07	0.57	0.133	0.40
Bg3	75-103	7.02	9.43	27.50	2.92	1.05	0.89	0.098	0.38
Bg4	103-139	6.33	7.71	35.34	4.58	0.76	1.45	0.084	0.52
2B2	139-164	5.76	6.87	35.76	5.20	0.78	1.07	0.068	0.69

Contd..

Annexure IIe. Contd...

Horizon	Depth (cm)	SiO_2 / R_2O_3	SiO_2 / Al_2O_3	SiO_2 / Fe_2O_3	Al_2O_3 / Fe_2O_3	CaO+MgO / Al_2O_3	CaO / MgO	K_2O+Na_2O / Al_2O_3	K_2O / Na_2O
Pedon 10. Sellur									
Ap	0-14	6.22	7.85	29.97	3.82	0.85	1.02	0.106	0.68
Bg	14-29	5.64	7.32	25.04	3.42	0.89	0.79	0.118	0.54
Bw	29-63	6.02	7.76	26.81	3.46	0.74	1.49	0.161	0.50
2Bg1	63-82	9.87	12.50	43.19	3.74	1.17	0.75	0.173	0.61
2Bg2	82-117	15.79	19.81	77.58	3.92	1.54	1.25	0.217	0.44
2Bg3	117-152	17.63	21.48	98.33	4.58	1.86	1.37	0.194	0.45
3Bg1	152-174	15.80	20.77	66.10	3.18	2.39	1.31	0.259	0.35
3Bg2	174-190	10.56	12.40	72.31	5.83	1.11	3.30	0.117	0.38
Pedon 11. Vridhachalam									
Ap	0-21	15.67	18.64	98.35	5.28	0.44	1.26	0.076	0.34
Bsmt	21-53	8.59	10.99	39.30	3.58	0.29	1.40	0.070	0.48
Bt1	53-105	8.80	11.49	37.59	3.27	0.29	0.78	0.061	0.47
Bt2	105-156	8.27	10.76	35.78	3.33	0.28	1.40	0.065	0.43
Bsm	156-177	4.31	5.02	30.12	6.00	0.18	1.62	0.034	0.55
Pedon 12. Vamban									
Ap	0-12	6.39	8.52	25.58	3.00	0.72	0.69	0.057	0.69
Bsmt1	12-40	6.91	9.80	23.46	2.39	0.41	1.23	0.076	0.47
Bsmt2	40-77	7.76	11.15	25.39	2.28	0.31	6.01	0.076	0.34
Bsmt3	77-110	7.20	10.01	25.68	2.57	0.33	3.90	0.062	0.34
Bcs1	110-169	6.31	9.04	20.87	2.31	0.24	2.57	0.059	0.33

Contd..

Annexure IIe. Contd...

Horizon	Depth (cm)	SiO_2 / R_2O_3	SiO_2 / Al_2O_3	SiO_2 / Fe_2O_3	Al_2O_3 / Fe_2O_3	CaO+MgO / Al_2O_3	CaO / MgO	K_2O+Na_2O / Al_2O_3	K_2O / Na_2O
Pedon 13. Madurai									
Ap	0-26	7.09	8.93	35.59	3.99	1.24	3.44	0.092	0.40
Bt1	26-44	6.18	7.93	28.13	3.55	1.00	1.23	0.075	0.57
Bt2	44-86	5.91	7.24	31.96	4.41	0.69	4.56	0.127	0.84
Bcs1	86-121	4.32	5.13	27.34	5.33	0.65	0.77	0.098	0.74
Bcs2	121-150	5.49	6.75	29.41	4.36	0.65	1.51	0.122	0.52
Pedon 14. Pechiparai									
Ap	0-18	3.26	4.27	13.69	3.21	0.20	0.78	0.035	0.25
Bw1	18-45	2.59	3.15	14.57	4.62	0.14	1.53	0.024	0.28
Bw2	45-68	2.95	3.64	15.49	4.26	0.13	2.02	0.029	0.27
Bcs1	68-100	3.20	4.34	12.22	2.82	0.18	1.66	0.029	0.24
Bcs2	100-155	3.30	4.13	16.48	3.99	0.17	2.62	0.031	0.19
Bcs3	155-203	3.17	4.39	11.46	2.61	0.18	3.27	0.034	0.15
Pedon 15. Ooty									
Ap	0-14	3.36	3.87	25.34	6.55	0.16	0.83	0.034	0.87
Bw1	14-37	3.12	3.57	24.45	6.84	0.17	0.87	0.030	1.13
Bw2	37-62	4.14	4.98	24.41	4.90	0.20	1.33	0.037	1.07
Bt1	62-95	3.64	4.32	22.99	5.32	0.22	1.07	0.051	1.29
Bt2	95-120	2.66	3.15	17.11	5.44	0.16	2.02	0.043	1.23
Bt3	120-150	3.18	4.01	15.36	3.83	0.19	0.92	0.054	1.06
2Bt1	150-183	1.83	2.24	9.89	4.42	0.10	4.12	0.028	0.38

Annexure IIf. Nutrient composition of soils

Horizon	Depth (cm)	Total N (%)	Total P (ppm)	CSP (ppm)	Bray P (ppm)	Olsen P (ppm)	Total Fe (%)	Total Zn (ppm)	Total Cu (ppm)	Total Mn (ppm)
Pedon 1. Paiyur										
Ap	0-20	0.034	916	81	23	13	1.95	36	50	180
Bw1	20-52	0.077	752	17	3	7	3.79	65	61	246
Bw2	52-74	0.062	379	31	Tr	Tr	3.71	16	65	308
Bc	74-100	0.040	553	74	4	1	4.08	80	61	322
Pedon 2. Bhavanisagar										
Ap	0-18	0.066	356	3	1	3	5.33	92	85	399
Bw	18-50	0.061	298	19	1	Tr	5.39	69	85	432
B3	50-59	0.012	767	31	Tr	Tr	5.11	73	108	462
Pedon 3. Thenkasi										
Ap	0-16	0.071	695	60	4	3	7.19	68	106	443
Bwc1	16-38	0.122	972	5	4	3	7.24	82	130	587
Bwc2	38-54	0.053	283	11	5	4	6.53	15	127	563
Bc1	54-89	0.042	514	10	3	Tr	10.23	59	125	2313
Bc2	89-155	0.032	654	24	2	Tr	8.51	60	86	1891
Pedon 4. Periyakulam										
Ap	0-23	0.035	1050	52	6	6	3.85	91	65	341
A1	23-52	0.033	1130	8	4	3	5.67	93	74	473
E	52-88	0.030	960	3	5	4	4.39	75	63	477
2Bt1	88-125	0.040	790	4	2	3	6.37	115	78	575
2Bt2	125-163	0.041	1930	5	2	2	6.46	60	98	663
Pedon 5. Sathankulam										
Ap	0-20	0.042	320	4	3	4	4.29	36	58	223
Bw1	20-48	0.036	934	19	6	5	4.63	31	56	254
Bt1	48-72	0.036	1127	3	7	6	4.98	30	57	314
Bt2	72-123	0.034	828	3	3	5	4.67	46	50	392
Bt3	123-175	0.035	784	62	1	Tr	5.79	34	63	408

Contd

Annexure IIf. Contd...

Horizon	Depth (cm)	Total N (%)	Total P (ppm)	CSP (ppm)	Bray P (ppm)	Olsen P (ppm)	Total Fe (%)	Total Zn (ppm)	Total Cu (ppm)	Total Mn (ppm)
Pedon 6. Aruppukkottai										
Ap	0-19	0.057	820	51	6	4	2.99	35	74	882
Ack	19-52	0.041	1060	5	2	1	4.81	125	92	1563
Assck1	52-80	0.028	3070	4	3	1	2.65	50	57	327
Assck2	80-112	0.044	890	4	2	1	1.32	53	62	981
Crck	112-159	0.019	1050	3	3	3	1.49	90	60	854
Pedon 7. Coimbatore										
Ap	0-22	0.035	1080	205	5	4	3.13	72	69	622
Bwck	22-48	0.039	1120	68	3	6	2.65	80	62	582
Bckss	48-77	0.060	980	92	1	1	3.28	73	57	543
Bck1	77-97	0.043	1270	149	1	1	2.71	67	54	731
Bck2	97-120	0.030	1430	52	3	1	3.08	91	53	809
2BcK	120-157	0.019	1520	92	1	2	2.89	65	66	672
Pedon 8. Palladam										
Ap	0-17	0.043	2294	41	2	3	2.97	43	73	334
Ak1	17-42	0.044	532	29	1	Tr	3.94	58	86	357
Ak2	42-76	0.034	394	32	1	Tr	3.62	64	98	378
Pedon 9. Aduthural										
Ap	0-21	0.109	740	30	4	5	4.50	80	91	413
Bg1	21-41	0.047	786	4	3	2	4.49	53	82	563
Bg2	41-75	0.043	715	13	1	2	4.30	73	82	428
Bg3	75-103	0.030	875	58	2	4	4.81	50	77	464
Bg4	103-139	0.028	1256	645	1	1	3.90	86	82	383
2B2	139-164	0.028	822	411	1	1	3.62	69	84	421

Contd...

Annexure III. Contd...

Horizon	Depth (cm)	Total N (%)	Total P (ppm)	CSP (ppm)	Bray P (ppm)	Olsen P (ppm)	Total Fe (%)	Total Zn (ppm)	Total Cu (ppm)	Total Mn (ppm)
Pedon 10. Sellur										
Ap	0-14	0.102	980	200	14	6	4.10	102	84	371
Bg	14-29	0.060	732	53	7	6	5.21	75	85	465
Bw	29-63	0.048	334	39	3	5	4.73	77	86	513
2Bg1	63-82	0.021	925	38	4	5	3.09	58	61	226
2Bg2	82-117	0.018	778	91	7	6	2.07	41	51	93
2Bg3	117-152	0.021	903	62	7	4	1.63	56	48	113
3Bg1	152-174	0.029	654	45	3	4	2.41	43	51	185
3Bg2	174-190	0.030	378	66	5	4	2.03	39	46	103
Pedon 11. Vridhachalam										
Ap	0-21	0.044	317	82	23	13	1.52	48	54	277
Bsmt	21-53	0.049	228	22	10	10	3.61	52	57	234
Bt1	53-105	0.052	641	19	1	Tr	4.27	41	71	241
Bt2	105-156	0.042	923	19	1	1	3.98	39	70	266
Bsm	156-177	0.043	833	25	Tr	Tr	3.83	52	82	278
Pedon 12. Vamban										
Ap	0-12	0.101	352	6	7	11	5.21	51	72	372
Bsmt1	12-40	0.078	193	3	4	8	5.61	46	70	351
Bsmt2	40-77	0.062	632	3	2	Tr	5.47	37	67	460
Bsmt3	77-110	0.065	672	4	2	1	5.18	42	76	583
Bcs1	110-169	0.065	794	2	2	7	6.28	63	74	383
Pedon 13. Madurai										
Ap	0-26	0.150	990	21	5	8	3.63	121	66	574
Bt1	26-44	0.043	830	4	4	2	4.66	86	56	527
Bt2	44-86	0.038	700	4	2	Tr	4.04	81	80	549
Bcs1	86-121	0.034	790	3	3	Tr	4.17	105	113	583
Bcs2	121-150	0.050	676	2	1	1	4.33	26	51	736

Contd..

Annexure IIf. Contd...

Horizon	Depth (cm)	Total N (%)	Total P (ppm)	CSP (ppm)	Bray P (ppm)	Olsen P (ppm)	Total Fe (%)	Total Zn (ppm)	Total Cu (ppm)	Total Mn (ppm)
Pedon 14. Pechiparai										
Ap	0-18	0.198	930	12	4	7	6.87	43	74	265
Bw1	18-45	0.162	256	5	2	Tr	5.96	68	75	151
Bw2	45-68	0.118	504	8	Tr	Tr	6.25	53	65	222
Bcs1	68-100	0.104	693	30	Tr	Tr	7.89	41	76	178
Bcs2	100-155	0.091	1431	19	Tr	Tr	6.91	58	89	154
Bcs3	155-203	0.066	372	22	Tr	Tr	8.08	50	100	193
Pedon 15. Ooty										
Ap	0-14	0.239	773	24	4	6	4.20	76	91	211
Bw1	14-37	0.153	814	21	2	2	4.37	82	96	153
Bw2	37-62	0.127	796	18	1	Tr	4.65	79	91	218
Bt1	62-95	0.107	753	22	5	Tr	4.71	95	99	262
Bt2	95-120	0.081	928	27	8	10	5.52	101	126	193
Bt3	120-150	0.066	1465	30	7	16	6.51	96	124	182
2Bt1	150-183	0.054	1154	38	7	18	7.42	93	116	231

Annexure IIg. Fractions of Fe and Mn

Horizon	Depth (cm)	Fe_d (%)	Fe_o (%)	Fe_p (%)	Per cent to Total Fe			Fe_o/Fe_d	Mn_d (ppm)	Mn_d/Mn_t	$\frac{Fe_d-Fe_o}{Fe_t}$
					Fe_d	Fe_o	Fe_p				
Pedon 1. Palyur											
Ap	0-20	1.25	0.200	0.021	64.10	10.26	1.08	0.16	55	30.56	0.53
Bw1	20-52	3.08	0.590	0.043	81.53	15.57	1.13	0.19	104	42.28	0.66
Bw2	52-74	2.46	0.540	0.038	66.31	14.56	1.02	0.22	108	35.06	0.52
Bc	74-100	2.48	0.370	0.029	60.78	9.07	0.71	0.15	152	47.20	0.52
Pedon 2. Bhavanisagar											
Ap	0-18	3.81	0.240	0.008	71.48	4.50	0.15	0.06	178	44.61	0.67
Bw	18-50	3.66	0.304	0.012	67.90	5.64	0.22	0.08	206	47.69	0.62
B3	50-59	3.01	0.331	0.015	58.90	6.48	0.29	0.11	243	52.59	0.52
Pedon 3. Thenkasi											
Ap	0-16	5.05	0.981	0.018	70.24	13.64	0.25	0.19	296	66.81	0.57
Bwc1	16-38	5.14	1.720	0.038	70.99	23.76	0.52	0.33	378	64.40	0.47
Bwc2	38-54	4.75	1.583	0.041	72.74	24.24	0.63	0.33	401	71.23	0.48
Bc1	54-89	8.78	1.08	0.061	85.83	10.56	0.60	0.12	1875	81.06	0.75
Bcs2	89-155	6.24	1.78	0.053	73.33	20.92	0.62	0.29	1792	94.76	0.52
Pedon 4. Periyakulam											
Ap	0-23	2.08	0.401	0.063	54.03	10.42	1.64	0.19	141	41.35	0.44
A1	23-52	2.31	0.536	0.087	40.74	9.45	1.53	0.23	172	36.36	0.31
E	52-88	2.20	0.516	0.059	50.11	11.75	1.34	0.23	170	39.81	0.38
2Bt1	88-125	3.26	0.813	0.120	51.18	12.76	1.88	0.25	348	60.52	0.38
2Bt2	125-163	3.60	0.687	0.072	55.73	10.63	1.11	0.19	367	53.73	0.45
Pedon 5. Sathankulam											
Ap	0-20	3.11	1.120	0.038	72.50	26.10	0.89	0.36	115	51.57	0.46
Bw1	20-48	3.22	1.180	0.047	69.55	25.49	1.02	0.37	125	49.21	0.44
Bt1	48-72	3.38	1.430	0.041	67.87	28.71	0.82	0.42	153	48.73	0.39
Bt2	72-123	3.52	1.020	0.063	75.37	21.84	1.35	0.29	242	61.73	0.54
Bt3	123-175	3.43	1.390	0.053	59.24	24.01	0.92	0.41	276	67.65	0.35

Contd...

Annexure IIg. Contd...

Horizon	Depth (cm)	Fe_d (%)	Fe_o (%)	Fe_p (%)	Per cent to Total Fe			Fe_o/Fe_d	Mn_d (ppm)	Mn_d/Mn_t	$\frac{Fe_d-Fe_o}{Fe_t}$
					Fe_d	Fe_o	Fe_p				
Pedon 6. Aruppukkottai											
Ap	0-19	0.54	0.112	0.038	18.06	3.75	1.27	0.21	467	52.95	0.14
Ack	19-52	0.69	0.143	0.042	14.35	2.97	0.87	0.21	505	32.31	0.11
Assck1	52-80	0.58	0.138	0.027	21.89	5.21	1.02	0.24	123	37.61	0.17
Assck2	80-112	0.46	0.117	0.032	34.85	8.86	2.42	0.25	482	49.13	0.26
Crck	112-159	0.34	0.108	0.018	22.82	7.25	1.21	0.32	363	42.51	0.16
Pedon 7. Coimbatore											
Ap	0-22	0.24	0.041	0.006	7.67	1.31	0.19	0.17	225	36.17	0.06
Bwck	22-48	0.43	0.093	0.012	16.23	3.51	0.45	0.22	203	34.88	0.13
Bckss	48-77	0.33	0.063	0.008	10.06	1.92	0.24	0.19	217	39.96	0.08
Bck1	77-97	0.28	0.059	0.008	10.33	2.18	0.30	0.21	322	44.04	0.08
Bck2	97-120	0.44	0.108	0.021	14.29	3.51	0.68	0.25	363	44.87	0.11
2Bck	120-157	0.60	0.130	0.031	20.76	4.50	1.07	0.22	308	45.98	0.16
Pedon 8. Palladam											
Ap	0-17	1.83	0.146	0.004	61.62	4.92	0.13	0.08	108	32.34	0.57
Ak1	17-42	1.69	0.135	0.004	42.89	3.43	0.10	0.08	102	28.57	0.39
Ak2	42-76	1.59	0.111	0.008	43.92	3.07	0.22	0.07	158	41.80	0.41
Pedon 9. Aduthurai											
Ap	0-21	1.18	0.021	0.008	26.22	0.47	0.18	0.02	218	52.78	0.26
Bg1	21-41	1.63	0.550	0.093	36.30	12.25	2.07	0.34	118	20.96	0.24
Bg2	41-75	1.53	0.365	0.011	35.58	8.49	0.26	0.24	207	48.36	0.27
Bg3	75-103	1.44	0.379	0.009	29.94	7.88	0.19	0.26	223	48.06	0.22
Bg4	103-139	1.19	0.246	0.009	30.51	6.31	0.23	0.21	145	37.86	0.24
2B2	139-164	1.28	0.256	0.011	35.36	7.07	0.30	0.20	211	50.12	0.28

Contd...

Annexure IIg. Contd...

Horizon	Depth (cm)	Fe_d (%)	Fe_o (%)	Fe_p (%)	Per cent to Total Fe			Fe_o/Fe_d	Mn_d (ppm)	Mn_d/Mn_t	$\frac{Fe_d-Fe_o}{Fe_t}$
					Fe_d	Fe_o	Fe_p				
Pedon 10. Sellur											
Ap	0-14	1.56	0.106	0.021	38.05	2.59	0.51	0.07	128	34.50	0.35
Bg	14-29	1.23	0.051	0.007	23.61	0.98	0.13	0.04	218	46.88	0.23
Bw	29-63	1.30	0.207	0.038	27.48	4.38	0.80	0.16	257	50.10	0.23
2Bg1	63-82	0.44	0.062	0.002	14.24	2.01	0.06	0.14	53	23.46	0.12
2Bg2	82-117	0.33	0.043	0.004	15.94	2.07	0.19	0.13	21	22.58	0.14
2Bg3	117-152	0.65	0.058	0.008	39.88	3.56	0.49	0.09	33	29.20	0.36
3Bg1	152-174	1.08	0.193	0.027	44.81	8.01	1.12	0.18	47	25.41	0.37
3Bg2	174-190	0.69	0.172	0.031	33.99	8.47	1.53	0.25	13	12.62	0.26
Pedon 11. Vridhachalam											
Ap	0-21	0.83	0.320	0.013	54.60	21.05	0.86	0.39	153	55.24	0.34
Bsmt	21-53	2.61	0.960	0.011	72.30	26.59	0.30	0.37	138	58.97	0.46
Bt1	53-105	3.71	0.480	0.012	76.58	11.24	0.28	0.13	162	67.22	0.76
Bt2	105-156	2.45	0.950	0.027	61.56	23.87	0.68	0.39	142	53.38	0.38
Bsm	156-177	2.46	1.160	0.023	64.23	30.29	0.60	0.47	151	54.32	0.34
Pedon 12. Vamban											
Ap	0-12	4.01	0.897	0.027	77.12	17.25	0.52	0.22	226	60.75	0.60
Bsmt1	12-40	4.04	1.251	0.071	72.01	22.30	1.27	0.31	187	53.28	0.50
Bsmt2	40-77	3.75	1.053	0.043	69.44	19.50	0.80	0.28	278	60.43	0.49
Bsmt3	77-110	3.60	1.160	0.033	69.63	22.44	0.64	0.32	372	63.81	0.47
Bcs1	110-169	5.00	0.980	0.058	79.61	15.61	0.92	0.20	193	53.17	0.64

Contd...

Annexure IIg. Contd...

Horizon	Depth (cm)	Fe_d (%)	Fe_o (%)	Fe_p (%)	Per cent to Total Fe			Fe_o/Fe_d	Mn_d (ppm)	Mn_o/Mn_t	Fe_d-Fe_o / Fe_t
					Fe_d	Fe_o	Fe_p				
Pedon 13. Madural											
Ap	0-26	1.51	0.105	0.032	41.60	2.89	0.88	0.07	226	39.72	0.39
Bt1	26-44	2.56	0.308	0.053	54.70	6.58	1.13	0.12	211	40.04	0.46
Bt2	44-86	2.58	0.326	0.048	63.86	8.07	1.19	0.13	322	58.65	0.56
Bcs1	86-121	1.71	0.208	0.014	41.01	4.99	0.34	0.12	427	73.24	0.36
Bcs2	121-150	2.29	0.195	0.022	52.89	4.50	0.51	0.09	517	70.24	0.48
Pedon 14. Pechiparai											
Ap	0-18	5.31	0.510	0.032	87.48	8.40	0.53	0.10	133	50.19	0.70
Bw1	18-45	4.70	0.301	0.047	91.09	5.83	0.91	0.06	135	89.40	0.74
Bw2	45-68	4.95	0.621	0.053	79.20	9.94	0.85	0.13	116	57.25	0.69
Bcs1	68-100	6.79	0.618	0.073	86.06	7.83	0.93	0.09	85	47.75	0.78
Bcs2	100-155	5.83	0.600	0.068	84.37	8.68	0.98	0.10	73	47.40	0.76
Bcs3	155-203	7.02	0.711	0.081	86.88	8.80	1.00	0.10	88	45.50	0.78
Pedon 15. Ooty											
Ap	0-14	3.55	0.320	0.042	84.52	7.62	1.00	0.09	71	33.65	0.77
Bw1	14-37	3.65	0.410	0.063	83.52	9.38	1.44	0.11	53	34.64	0.74
Bw2	37-62	3.52	0.510	0.078	75.70	10.97	1.68	0.14	77	35.32	0.65
Bt1	62-95	3.73	0.680	0.083	78.20	14.26	1.74	0.18	112	42.75	0.65
Bt2	95-120	4.46	0.530	0.097	79.71	9.60	1.76	0.12	101	52.33	0.71
Bt3	120-150	5.72	0.380	0.108	87.86	5.84	2.76	0.07	92	50.55	0.82
2Bt1	150-183	6.83	0.280	0.118	92.05	3.77	1.59	0.04	114	49.35	0.88

Annexure IIh. Exchange properties of soils

Horizon	Depth (cm)	CEC cmol(p$^+$) kg^{-1}	ECEC cmol(p$^+$) kg^{-1}	Exch. cations cmol(p$^+$) kg^{-1}				BSP	Per cent saturation				Ca/ Mg	Na/ K	Exch acidity cmol(p$^+$) kg^{-1}	Potential acidity cmol(p$^+$) kg^{-1}
				Ca^{++}	Mg^{++}	Na^+	K^+		Ca	Mg	Na	K				
Pedon 1. Paiyur																
Ap	0-20	7.50	4.01	1.61	1.31	0.08	0.91	52.13	21.47	17.47	1.07	12.13	1.22	11.38	0.10	3.10
Bw1	20-52	11.30	8.24	4.27	2.32	0.14	1.18	70.00	37.79	20.53	1.24	10.44	1.85	8.43	0.33	4.72
Bw2	52-74	10.91	7.74	3.14	3.47	0.14	0.42	65.72	28.78	31.81	1.28	3.84	0.90	3.00	0.57	5.83
Bc	74-100	9.11	6.86	3.00	2.17	0.14	0.88	67.95	32.93	23.82	1.54	9.66	1.38	6.29	0.67	4.13
Pedon 2. Bhavanisagar																
Ap	0-18	17.32	11.15	5.31	4.22	0.12	0.23	57.04	30.66	24.36	0.69	1.33	1.26	1.92	1.27	10.23
Bw	18-50	18.40	13.28	6.62	4.81	0.12	0.58	68.67	35.98	26.12	0.64	3.15	1.45	4.83	1.15	6.43
B3	50-59	10.34	7.84	2.83	2.10	0.08	1.30	61.03	27.37	20.31	0.77	12.57	1.35	16.25	1.53	5.41
Pedon 3. Thenkasi																
Ap	0-16	23.80	20.96	9.41	8.10	0.23	1.10	79.16	39.54	34.03	0.96	4.62	1.16	4.78	1.12	5.27
Bwc1	16-38	31.72	24.52	12.14	9.61	0.27	0.92	72.32	38.27	30.30	0.85	2.90	1.26	3.41	1.58	5.81
Bwc2	38-54	18.33	17.20	7.41	6.65	0.12	1.10	83.36	35.30	31.15	0.65	6.00	1.13	9.17	1.92	4.23
Bc1	54-89	11.41	11.34	4.60	4.53	0.06	0.92	88.60	35.15	34.53	0.53	8.06	1.02	15.33	1.23	3.81
Bc2	89-155	14.83	13.08	6.42	4.79	0.10	0.75	81.32	41.07	30.14	0.67	6.20	1.34	7.50	1.02	3.30
Pedon 4. Periyakulam																
Ap	0-23	10.05	7.98	5.54	1.34	0.09	0.68	76.12	51.84	10.15	0.90	6.77	4.13	7.56	0.33	1.07
A1	23-52	11.25	8.57	5.78	2.18	0.11	0.22	73.69	49.16	17.16	0.97	1.96	2.65	2.00	0.33	1.21
E	52-88	9.70	8.45	5.75	2.22	0.06	0.21	84.95	56.70	20.31	0.62	2.79	2.59	3.50	0.21	2.11
2Bt1	88-125	21.21	17.08	12.42	3.92	0.18	0.29	79.25	56.20	16.12	0.85	1.37	3.17	1.61	0.27	3.14
2Bt2	125-163	19.73	16.72	11.48	4.59	0.15	0.29	83.68	55.75	18.40	0.76	1.47	2.50	1.93	0.21	2.53
Pedon 5. Sathankulam																
Ap	0-20	9.81	3.35	1.22	0.95	0.02	0.04	22.73	12.44	9.68	0.20	0.41	1.28	2.00	1.12	5.26
Bw1	20-48	8.72	3.17	1.01	0.82	0.04	0.08	22.36	11.58	9.41	0.46	0.92	1.23	2.00	1.22	7.21
Bt1	48-72	10.70	5.22	2.20	1.31	0.06	0.08	34.11	20.56	12.24	0.56	0.75	1.68	1.33	1.57	6.83
Bt2	72-123	11.42	4.47	1.22	1.52	0.02	0.28	26.62	10.68	13.31	0.18	2.45	0.80	14.00	1.43	8.16
Bt3	123-175	10.22	4.34	1.22	1.82	0.06	0.36	33.86	11.94	17.81	0.59	3.52	0.67	6.00	0.88	6.29

Contd

Annexure IIh. Contd...

Horizon	Depth (cm)	CEC cmol(p$^+$) kg^{-1}	ECEC cmol(p$^+$) kg^{-1}	Exch. cations cmol(p$^+$) kg^{-1}				BSP	Per cent saturation				Ca/ Mg	Na/ K	Exch acidity cmol(p$^+$) kg^{-1}	Potential acidity cmol(p$^+$) kg^{-1}
				Ca^{++}	Mg^{++}	Na^+	K^+		Ca	Mg	Na	K				
Pedon 6. Aruppukkottai																
Ap	0-19	43.81	40.66	28.18	10.11	1.09	0.61	91.28	64.32	23.08	2.49	1.39	2.79	0.56	0.67	11.40
Ack	19-52	51.82	48.61	27.83	18.01	1.56	0.71	92.83	53.71	34.76	3.01	1.37	2.75	0.46	0.50	9.55
Assck1	52-80	56.90	52.01	32.73	16.15	1.72	0.83	90.38	57.52	28.38	3.02	1.46	2.03	0.48	0.58	14.70
Assck2	80-112	56.42	51.30	33.43	14.82	1.60	0.79	89.73	59.25	26.27	2.84	1.40	2.26	0.49	0.67	13.71
Crck	112-159	45.33	40.55	23.89	14.09	1.18	0.65	87.83	52.70	31.08	2.60	1.43	1.70	0.55	0.74	7.75
Pedon 7. Coimbatore																
Ap	0-22	38.98	34.25	18.42	14.21	0.53	0.41	86.12	47.26	36.45	1.36	1.05	1.30	0.77	0.68	4.29
Bwck	22-48	35.27	31.84	16.55	13.56	0.73	0.32	88.35	46.92	38.45	2.07	0.90	1.22	0.44	0.68	5.38
Bckss	48-77	36.51	35.84	18.42	14.74	1.12	0.72	94.30	50.45	40.37	3.07	1.97	1.25	0.46	0.84	1.03
Bck1	77-97	26.35	24.87	11.82	10.32	1.14	0.51	90.28	44.86	39.17	4.33	1.94	1.15	0.45	1.08	2.10
Bck2	97-120	27.57	23.20	10.71	9.72	0.90	0.79	80.23	38.85	35.26	3.26	2.18	1.10	0.87	1.08	4.20
2Bck	120-157	21.31	18.52	9.22	6.83	0.83	0.71	82.54	43.27	32.05	3.89	3.33	1.35	0.86	0.93	1.01
Pedon 8. Palladam																
Ap	0-17	18.08	15.49	8.13	5.01	0.62	1.09	82.13	44.97	27.71	3.43	6.03	1.62	1.76	0.64	3.10
Ak1	17-42	18.92	17.22	8.78	6.21	0.72	0.72	86.84	46.41	32.82	3.81	3.81	1.41	1.00	0.79	2.72
Ak2	42-76	15.41	13.67	7.63	3.60	0.62	1.18	84.56	49.51	23.36	4.02	7.66	2.12	1.90	0.64	1.47
Pedon 9. Aduthurai																
Ap	0-21	46.30	41.22	27.28	12.71	0.72	0.30	88.57	58.92	27.45	1.56	0.65	2.15	0.42	0.21	5.20
Bg1	21-41	40.82	39.55	22.11	14.72	1.12	0.52	94.24	54.16	36.06	2.74	1.27	1.50	0.46	0.88	4.72
Bg2	41-75	44.11	42.73	24.12	16.03	1.18	0.52	94.88	54.68	36.34	2.68	1.18	1.50	0.44	0.88	5.71
Bg3	75-103	27.14	25.11	14.73	7.85	0.88	0.73	89.13	54.27	28.92	3.24	2.69	1.88	0.83	0.92	3.41
Bg4	103-139	29.82	27.17	16.12	9.32	0.95	0.48	90.11	54.06	31.25	3.19	1.61	1.73	0.51	0.30	3.80
2B2	139-164	26.41	22.08	13.94	6.40	0.72	0.39	81.22	52.78	24.23	2.73	1.48	2.18	0.54	0.63	4.91
Pedon 10. Sellur																
Ap	0-14	39.60	36.35	14.72	14.10	4.95	1.05	87.93	37.17	35.61	12.50	2.65	1.04	0.21	1.53	5.27
Bg	14-29	38.51	36.87	13.80	12.62	7.52	1.15	91.12	35.83	32.77	19.53	2.99	1.09	0.15	1.78	4.28
Bw	29-63	36.17	34.46	12.21	11.93	6.46	2.18	90.63	33.76	32.98	17.86	6.03	1.02	0.34	1.68	2.19
2Bg1	63-82	22.28	18.02	7.00	7.40	1.72	0.77	75.81	31.42	33.21	7.72	3.46	0.95	0.45	1.13	4.63
2Bg2	82-117	26.76	21.08	7.91	7.40	2.82	1.97	76.83	30.24	28.29	10.78	7.53	1.07	0.70	0.98	5.56
2Bg3	117-152	20.55	15.80	5.72	7.20	1.04	0.71	71.39	27.83	35.04	5.06	3.46	0.79	0.68	1.13	5.81
3Bg1	152-174	22.61	15.73	5.60	7.10	1.04	0.97	65.06	24.78	31.40	4.60	4.29	0.79	0.93	1.02	7.08
3Bg2	174-190	20.43	13.71	5.51	5.82	0.78	0.71	62.75	26.97	28.49	3.82	3.48	0.95	0.91	0.35	8.27

Contd..

Annexure IIh. Contd...

Horizon	Depth (cm)	CEC cmol(p$^+$) kg^{-1}	ECEC cmol(p$^+$) kg^{-1}	Exch. cations cmol(p$^+$) kg^{-1}				BSP	Per cent saturation				Ca/ Mg	Na/ K	Exch acidity cmol(p$^+$) kg^{-1}	Potential acidity cmol(p$^+$) kg^{-1}
				Ca^{++}	Mg^{++}	Na^+	K^+		Ca	Mg	Na	K				
Pedon 11. Vridhachalam																
Ap	0-21	9.18	7.45	3.21	2.54	0.08	0.41	67.97	34.97	27.67	0.87	4.47	1.26	5.13	1.21	4.13
Bsmt	21-53	14.91	11.58	5.30	4.33	0.16	0.92	71.83	35.54	29.04	1.07	6.17	1.22	5.75	0.87	3.47
Bt1	53-105	11.80	9.05	4.13	2.62	0.11	1.21	68.39	35.00	22.20	0.93	10.25	1.58	11.00	0.98	5.28
Bt2	105-156	17.52	13.50	6.02	5.10	0.16	1.11	70.72	38.93	31.96	0.91	6.34	1.18	6.94	1.11	4.81
Bsm	156-177	16.42	12.98	6.22	4.31	0.16	1.24	72.66	37.88	26.25	0.97	7.55	1.44	7.75	1.05	6.21
Pedon 12. Vamban																
Ap	0-12	31.94	27.73	15.41	10.26	0.42	0.81	84.22	48.25	32.12	1.31	2.54	1.50	1.93	0.83	3.71
Bsmt1	12-40	29.46	19.80	10.26	6.41	0.30	0.98	60.93	34.83	21.76	1.02	3.33	1.60	3.27	1.85	6.27
Bsmt2	40-77	32.14	24.43	14.86	7.21	0.53	0.47	71.78	46.24	22.43	1.65	1.40	2.06	0.89	1.36	5.82
Bsmt3	77-110	33.26	24.46	12.74	8.41	0.53	0.81	67.62	38.30	25.29	1.59	2.44	1.52	1.53	1.97	6.45
Bcs1	110-169	30.61	26.49	14.06	9.26	0.34	0.98	80.50	45.93	30.25	1.11	3.20	1.52	2.88	1.85	3.91
Pedon 13. Madurai																
Ap	0-26	22.10	21.79	11.72	6.12	1.11	1.92	94.43	53.03	27.69	5.03	8.68	1.92	1.73	0.92	1.06
Bt1	26-44	24.40	21.10	9.03	8.00	1.82	1.43	83.11	37.01	32.79	7.46	5.86	1.13	0.79	0.82	1.34
Bt2	44-86	20.81	17.85	10.72	4.21	1.42	0.63	81.60	51.51	20.23	6.82	3.03	2.55	0.44	0.87	1.21
BcS1	86-121	15.21	13.10	7.21	3.00	1.22	0.90	81.07	47.40	9.72	8.02	5.92	2.40	0.74	0.77	1.72
BcS2	121-150	13.82	12.17	3.23	4.82	1.73	1.62	82.49	23.37	34.88	12.52	11.72	0.67	0.94	0.77	0.98
Pedon 14. Pechiparai																
Ap	0-18	17.40	5.52	2.11	1.92	0.13	0.80	28.51	12.13	11.03	0.75	4.60	1.10	6.13	0.56	17.20
Bw1	18-45	19.82	5.80	1.87	1.92	0.17	1.21	26.08	9.43	9.69	0.86	6.11	0.97	7.11	0.63	15.31
Bw2	45-68	16.53	4.94	1.63	1.38	0.11	0.92	24.44	9.86	8.35	0.67	5.57	1.18	8.36	0.90	12.73
Bcs1	68-100	11.32	3.81	1.02	1.38	0.09	0.42	25.71	9.01	12.19	0.80	3.71	0.74	4.67	0.90	14.61
Bcs2	100-155	15.72	4.18	1.02	1.92	0.11	0.57	23.03	6.49	12.21	0.70	3.63	0.53	5.18	0.56	16.03
Bcs3	155-203	16.83	5.69	1.83	1.97	0.09	1.12	29.76	10.87	11.71	0.53	6.65	0.93	12.64	0.68	16.26
Pedon 15. Ooty																
Ap	0-14	10.31	3.08	1.42	0.93	0.09	0.11	24.73	13.78	9.02	0.87	1.07	1.53	1.22	0.53	18.28
Bw1	14-37	14.71	4.25	1.89	1.61	0.11	0.23	26.10	12.85	10.95	0.75	1.56	1.18	2.09	0.41	19.23
Bw2	37-62	15.28	4.10	2.02	1.58	0.12	0.23	25.85	13.22	10.34	0.79	1.51	1.28	1.92	0.15	19.83
Bt1	62-95	16.21	4.23	2.02	1.58	0.15	0.11	23.81	12.46	9.75	0.93	0.68	1.28	0.73	0.37	18.94
Bt2	95-120	15.81	3.52	1.47	1.38	0.11	0.15	19.67	9.30	8.73	0.70	0.95	1.07	1.36	0.41	18.26
Bt3	120-150	17.24	3.97	1.73	1.53	0.09	0.21	20.65	10.03	8.87	0.52	1.22	1.13	2.33	0.41	20.23
2Bt1	150-183	16.78	4.26	2.13	1.68	0.09	0.21	24.49	12.69	10.01	0.54	1.25	1.27	2.33	0.15	21.26

Annexure III. Water soluble ions

Horizon	Depth (cm)	Cations (mmol (+) kg^{-1})				Anions (mmol (-) kg^{-1})		
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^-	Cl^-	$SO_4^{=}$
Pedon 1. Palyur								
Ap	0-20	7.40	2.21	0.31	0.28	4.21	3.38	0.23
Bw1	20-52	6.10	1.07	0.96	0.15	3.77	3.08	0.32
Bw2	52-74	5.90	2.71	1.09	0.13	4.81	3.21	0.48
Bc	74-100	9.35	2.21	1.17	0.15	5.91	4.02	0.32
Pedon 2. Bhavanisagar								
Ap	0-18	3.61	3.11	0.63	0.27	2.98	3.82	0.53
Bw	18-50	4.32	2.95	0.77	0.32	4.82	2.62	0.68
B3	50-59	5.61	2.05	0.60	0.32	5.47	2.79	0.48
Pedon 3. Thenkasi								
Ap	0-16	4.55	3.11	1.22	0.25	5.72	2.81	0.52
Bwc1	16-38	3.25	3.11	0.96	0.13	3.52	3.22	0.43
Bwc2	38-54	5.70	3.28	2.22	0.28	6.67	3.87	0.52
Bc1	54-89	4.15	2.87	0.32	0.15	3.39	2.98	0.68
Bc2	89-155	5.80	2.21	0.72	0.13	4.80	3.78	0.43
Pedon 4. Periyakulam								
Ap	0-23	7.25	1.56	0.61	0.33	4.70	3.03	0.67
A1	23-52	6.20	1.72	0.81	0.28	5.62	2.28	0.81
E	52-88	4.90	2.21	0.36	0.23	6.21	1.83	0.93
2Bt1	88-125	2.10	2.38	1.11	0.23	3.93	2.27	0.78
2Bt2	125-163	2.07	1.56	1.05	0.20	2.21	2.70	0.18
Pedon 5. Sathankulam								
Ap	0-20	4.85	1.48	0.10	0.21	2.28	4.11	0.72
Bw1	20-48	2.15	1.07	0.27	0.23	1.41	2.72	0.38
Bt1	48-72	4.05	1.56	0.32	0.18	2.43	2.16	0.80
Bt2	72-123	3.15	1.56	0.10	0.28	1.03	2.89	0.97
Bt3	123-175	2.15	4.02	0.27	0.43	2.77	2.53	0.72

Contd..

Annexure III. Contd...

Horizon	Depth (cm)	Cations (mmol (+) kg^{-1})				Anions (mmol (-) kg^{-1})		
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{--}
Pedon 6. Aruppukkottai								
Ap	0-19	7.10	3.28	0.65	0.33	6.88	2.02	1.42
Ack	19-52	8.60	1.56	1.39	0.18	7.22	1.71	1.37
Assck1	52-80	8.60	2.21	1.48	0.18	5.87	4.25	1.17
Assck2	80-112	6.75	3.77	2.04	0.18	7.17	3.67	1.08
Crck	112-159	5.90	2.54	1.39	0.15	4.02	1.83	2.63
Pedon 7. Coimbatore								
Ap	0-22	5.20	3.52	2.48	0.26	7.23	3.14	1.89
Bwck	22-48	4.60	3.11	1.65	0.23	5.27	2.49	1.03
Bckss	48-77	6.65	2.21	3.87	0.28	5.04	7.28	0.47
Bck1	77-97	5.20	2.95	6.22	0.41	6.81	7.09	1.21
Bck2	97-120	6.35	2.54	5.83	0.56	9.87	3.07	3.71
2Bck	120-157	5.40	0.98	6.13	0.33	10.78	2.28	3.43
Pedon 8. Palladam								
Ap	0-17	5.40	2.62	0.78	0.18	2.17	2.31	3.11
Ak1	17-42	4.85	1.48	0.83	0.13	1.83	1.79	2.29
Ak2	42-76	6.66	3.61	0.87	0.13	2.99	3.09	3.22
Pedon 9. Aduthurai								
Ap	0-21	9.71	2.54	6.01	0.36	9.28	8.38	1.67
Bg1	21-41	5.42	3.20	8.91	0.23	8.63	7.29	0.93
Bg2	41-75	4.35	1.48	8.52	0.23	7.59	4.34	1.22
Bg3	75-103	3.66	2.62	6.43	0.26	7.93	3.88	0.88
Bg4	103-139	3.12	2.13	5.35	0.23	6.96	2.26	1.03
2B2	139-184	3.20	2.70	5.52	0.28	8.24	2.82	0.98

Contd..

Annexure III. Contd...

Horizon	Depth (cm)	Cations (mmol (+) kg^{-1})				Anions (mmol (-) kg^{-1})		
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{--}
Pedon 10. Sellur								
Ap	0-14	2.91	2.95	12.35	1.06	6.33	3.13	6.82
Bg	14-29	5.73	2.62	12.65	1.24	5.28	4.81	6.98
Bw	29-63	3.66	2.21	13.30	0.86	7.83	5.78	4.72
2Bg1	63-82	4.55	3.20	11.78	1.24	10.31	7.73	3.13
2Bg2	82-117	4.58	3.61	13.39	1.08	11.42	5.28	7.28
2Bg3	117-152	6.65	4.18	14.91	1.32	9.28	10.83	7.81
3Bg1	152-174	7.65	2.71	13.96	1.76	10.34	8.67	8.21
3Bg2	174-190	35.08	19.34	4.30	0.14	18.88	14.92	25.16
Pedon 11. Vridhachalam								
Ap	0-21	5.25	2.71	0.41	0.46	3.33	4.91	0.51
Bsmt	21-53	6.80	3.11	0.89	0.15	3.07	5.73	0.68
Bt1	53-105	4.35	2.62	0.77	0.10	2.17	3.39	0.72
Bt2	105-156	3.85	3.03	1.03	0.13	3.08	3.01	0.87
Bsm	156-177	5.41	3.12	1.26	0.13	3.71	4.88	0.91
Pedon 12. Vamban								
Ap	0-12	5.71	2.62	2.00	0.13	6.63	8.89	0.72
Bsmt1	12-40	4.61	3.69	0.96	0.10	2.51	5.73	0.78
Bsmt2	40-77	3.92	2.62	0.61	0.10	1.83	3.93	0.52
Bsmt3	77-110	4.85	2.21	0.65	0.10	2.11	4.32	0.66
Bcs1	110-169	2.67	3.11	0.83	0.13	1.51	3.47	0.52
Pedon 13. Madurai								
Ap	0-26	5.11	2.71	8.18	0.59	5.37	7.21	0.48
Bt1	26-44	4.65	1.72	7.91	0.43	7.00	4.87	0.48
Bt2	44-86	3.35	1.48	8.52	0.46	8.27	3.21	0.52
Bcs1	86-121	4.85	2.21	3.43	0.23	5.32	2.18	0.72
Bcs2	121-150	3.60	2.38	5.00	0.23	3.22	3.73	0.72

Contd...

Annexure III. Contd...

Horizon	Depth (cm)	Cations (mmol (+) kg^{-1})				Anions (mmol (-) kg^{-1})		
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^-	Cl^-	$SO_4^{=}$
Pedon 14. Pechiparai								
Ap	0-18	3.21	2.21	1.06	0.20	3.91	1.93	0.68
Bw1	18-45	3.43	1.15	0.83	0.13	2.08	1.79	0.81
Bw2	45-68	6.92	2.38	0.61	0.13	4.61	3.77	0.72
Bcs1	68-100	3.40	2.21	0.70	0.10	3.37	1.93	0.52
Bcs2	100-155	4.12	2.05	0.78	0.13	3.62	2.20	0.48
Bcs3	155-203	5.27	2.54	0.78	0.10	4.49	2.93	0.52
Pedon 15. Ooty								
Ap	0-14	2.15	2.62	0.41	0.13	3.22	1.93	0.32
Bw1	14-37	5.50	2.21	0.74	0.10	3.72	2.99	0.91
Bw2	37-62	4.62	2.54	0.61	0.08	2.83	3.38	0.43
Bt1	62-95	3.41	1.56	0.74	0.10	1.37	3.14	0.53
Bt2	95-120	5.22	2.13	0.65	0.05	3.43	3.71	0.66
Bt3	120-150	4.75	2.13	0.53	0.08	2.91	3.96	0.51
2Bt1	150-183	5.73	1.15	0.41	0.08	2.49	3.38	0.51

Annexure IIj. Spectral reflectance

Horizon	Depth (cm)	Blue	Green	Red	Infra red
Pedon 1. Paiyur					
Ap	0-20	16.55	18.71	20.22	24.00
Bw1	20-52	14.50	15.67	19.20	18.64
Bw2	52-74	9.65	11.04	12.28	17.28
Bc	74-100	8.10	10.21	12.93	17.62
Pedon 2. Bhavanisagar					
Ap	0-18	13.72	15.85	25.91	27.93
Bw	18-50	19.90	23.95	27.81	31.83
B3	50-59	14.86	17.96	20.23	20.43
Pedon 3. Thenkasi					
Ap	0-16	13.60	18.18	19.50	21.34
Bwc1	16-38	10.07	12.04	12.68	17.04
Bwc2	38-54	7.11	12.89	19.65	27.20
Bc1	54-89	6.63	7.02	10.83	12.72
Bcs2	89-155	6.28	7.17	15.91	23.84
Pedon 4. Periyakulam					
Ap	0-23	23.81	31.38	43.10	49.21
A1	23-52	39.01	38.10	38.70	59.20
E	52-88	22.10	23.80	27.60	33.34
2Bt1	88-125	23.50	24.70	26.80	29.14
2Bt2	125-163	13.60	18.80	23.28	38.10
Pedon 5. Sathankulam					
Ap	0-20	11.35	18.62	20.21	24.75
Bw1	20-48	5.91	8.09	10.42	15.87
Bt1	48-72	12.64	17.22	23.04	26.86
Bt2	72-123	10.32	12.27	13.38	21.83
Bt3	123-175	10.22	16.29	17.10	18.61
Pedon 6. Aruppukkottai					
Ap	0-19	9.61	10.20	13.24	15.21
Ack	19-52	10.21	15.10	16.27	22.41
Assck1	52-80	7.02	9.30	12.92	16.41
Assck2	80-112	11.82	14.72	15.71	19.21
Crck	112-159	15.92	17.31	18.31	26.21

Annexure IIj. Contd...

Horizon	Depth (cm)	Blue	Green	Red	Infra red
Pedon 7. Coimbatore					
Ap	0-22	11.33	11.84	17.26	19.41
Bwck	22-48	15.31	15.61	19.41	21.18
Bckss	48-77	11.94	12.60	21.14	28.14
Bck1	77-97	10.98	15.51	18.71	20.91
Bck2	97-120	17.21	21.50	26.71	37.60
2Bck	120-157	15.53	17.78	23.41	26.31
Pedon 8. Palladam					
Ap	0-17	10.38	10.85	18.84	21.71
Ak1	17-42	6.91	7.07	11.24	17.81
Ak2	42-76	5.69	8.28	9.80	11.87
Pedon 9. Aduthurai					
Ap	0-21	6.70	10.94	15.82	19.21
Bg1	21-41	13.38	14.51	16.12	21.52
Bg2	41-75	12.94	18.91	20.64	35.93
Bg3	75-103	9.43	11.11	17.62	17.89
Bg4	103-139	7.57	8.57	9.94	10.21
2B2	139-164	6.68	9.65	11.21	12.74
Pedon 10. Sellur					
Ap	0-14	11.31	13.72	23.40	38.14
Bg	14-29	10.81	14.61	15.07	27.53
Bw	29-63	8.40	10.08	12.70	13.20
2Bg1	63-82	7.20	14.61	16.21	19.68
2Bg2	82-117	9.83	13.00	13.20	13.39
2Bg3	117-152	8.70	8.91	14.72	14.91
3Bg1	152-174	13.31	17.81	21.92	27.91
3Bg2	174-190	11.10	13.10	17.20	22.14
Pedon 11. Vridhachalam					
Ap	0-21	13.37	14.79	21.85	25.61
Bsmt	21-53	12.30	12.87	28.99	37.50
Bt1	53-105	9.88	14.94	22.37	30.91
Bt2	105-156	6.47	7.11	10.84	18.21
Bsm	156-177	12.50	14.58	14.95	16.85

Contd...

Annexure IIj. Contd...

Horizon	Depth (cm)	Blue	Green	Red	Infra red
Pedon 12. Vamban					
Ap	0-12	6.71	7.29	12.32	21.00
Bsmt1	12-40	6.11	7.27	20.58	25.40
Bsmt2	40-77	6.80	12.76	18.66	24.06
Bsmt3	77-110	6.66	7.42	14.10	21.17
Bcs1	110-169	8.57	10.12	16.31	22.72
Pedon 13. Madurai					
Ap	0-26	10.31	13.18	15.17	47.21
Bt1	26-44	11.61	14.08	19.92	32.90
Bt2	44-86	12.08	15.91	18.72	33.08
Bcs1	86-121	21.30	23.91	28.62	29.99
Bcs2	121-150	16.70	22.41	26.71	33.08
Pedon 14. Pechiparai					
Ap	0-18	10.32	11.62	11.77	17.02
Bw1	18-45	8.21	8.97	9.21	14.44
Bw2	45-68	7.60	10.97	11.19	17.26
Bcs1	68-100	8.93	12.80	16.46	22.03
Bcs2	100-155	6.99	8.82	9.56	16.21
Bcs3	155-203	10.71	13.62	16.67	19.47
Pedon 15. Ooty					
Ap	0-14	12.75	13.45	14.37	18.18
Bw1	14-37	13.10	13.45	19.08	23.28
Bw2	37-62	7.44	8.14	9.50	11.70
Bt1	62-95	10.98	11.99	15.39	24.52
Bt2	95-120	14.29	16.32	20.63	25.21
Bt3	120-150	9.63	9.76	11.76	12.40
2Bt1	150-183	5.42	7.17	11.22	24.37