CATION EXCHANGE STUDIES IN KERALA SOILS

BY

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CERTIFICATE

This is to certify that the thesis herewith submitted contains the results of bonafide research work carried out by Sri V.K. Venugopal under my supervision. No part of the work embodied in this thesis has been submitted earlier for the award of any degree.

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CONTENTS

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INTRODUCTION

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Knowledge regarding cation exchange phenomenon in soils dates back to the remote past. Since the discovery of cation exchange in soils by Way (1849) efforts by various workers have thrown much light on this phenomenon. The importance of cation exchange reaction was widely recognised by early workers in this field. Marshall (1935) has aptly described cation exchange as the most important reaction in nature surpassed in fundamental importance only by the photosynthetic process in green plants. Donahue (1958) considers the cation exchange capacity of the soil to be a single index of fertility.

It is a well established fact that the content and nature of the exchangeable bases has a profound bearing on the properties of the soil and in turn on crop growth. But for this reaction all nutrients in the soil would have been leached out and washed away into the ocean by the percolating water. A considerable portion of the plant nutrients present in the soil are held adsorbed in the exchange complex of the soil preventing leaching loss. Fully recognising the implications of this reaction on soil properties Hall (1924) has stated that a good soil is one with larger amounts of exchangeable bases. Emphasising on the same point Geisking (1949) stated that the fertility and productivity status of the soil depends on the nature and order of the exchangeable bases in the soil. In view of the dominant role played by cation exchange reaction and exchangeable bases in soil productivity and plant nutrition, it is very desirable that detailed investigation of soils in relation to their cation exchange properties be carried out which will be of considerable help in formulating suitable management practices.

It is well known that soils of Kerala are very low in their content of exchangeable bases and other plant nutrients. Very little work has been done in the past on the cation exchange properties of Kerala soils. The only work is probably that of Nambiar (1947) who studied the exchangeable cation in a number of surface soils of rice growing areas. As a large number of soil groups were left out in this study, it was considered desirable to undertake a more detailed investigation of the cation exchange properties of soil profiles representing the major soil groups of the state. Hence the present investigation was undertaken with the following objectives:

(1) To study the cation exchange capacity and nature of exchangeable bases in typical soils of Kerala and to trace their downward variation.

(2) To find out how cation exchange properties are correlated to other chemical and physical properties of soils.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The general literature on cation exchange and related properties of soils is voluminous. An extensive review of all the literature on the subject seems unnecessary in the present context and so only a brief review of the more recent work which appears pertinent to the present problem is attempted here.

(a) Cation exchange capacity and the exchangeable cation content

Mitchell and Muir (1937) have shown that the cation exchange capacity of a soil depends mainly on its clay content and its composition viz., the SiO_2/R_2O_3 ratio.

Mukherjee (1944), working on Indian soils, observed that of the different fractions obtained in the mechanical analysis of soils clay has the highest cation exchange capacity. The C.E.C. of the silt and sand fractions is considerably less while that of gravel is practically negligible. Organic matter has a greater cation exchange capacity than clay. The percentage of organic matter in Indian soils is low, but for soils with very small values for cation exchange capacity the contribution of organic matter becomes appreciable.

Turner (1932), as cited by Mukherjee (1944), obtained statistically significant correlations between the cation exchange capacity of soils and their contents of clay and organic matter. It was observed that the organic matter associated with clay had a higher base exchange capacity than that associated with silt or the entire soil.

Das et al. (1946) observed a higher cation exchange capacity for calcareous soils than for acid soils. In some of the profiles studied by them the C.E.C. increased with depth, while in some others it decreased with depth. There were also some profiles in which the intermediate layer had the highest cation exchange capacity. With a few exceptions the variations in the cation exchange capacity and clay content of the soils down the profile were similar. Calcium was the predominant cation and its variation in the profile depended on the total cation exchange capacity. Exchangeable calcium content was high in soils with higher pH and low in soils having a low pH. Magnesium generally showed an increase downwards. The higher cation exchange capacity of the top layer was attributed to the high organic matter content.

Hosking (1948) reported that clay minerals present in the coarser fractions also contribute to the cation exchange phenomena.

Toth and Bear (1948) suggested that for an ideal soil about 65% of the exchange complex should contain calcium, 10% magnesium, 5% potassium, and 20% hydrogen.

Pathak et al. (1949) studied the variation in C.E.C. of the different mechanical fractions in a number of soil profiles. They noted that the cation exchange capacity due to the clay fraction declined rapidly down the profile.

In the case of red and lateritic soils of Bihar Lall (1953) obtained only relatively low values for cation exchange capacity. The cation exchange capacity varied according to the clay content. Exchangeable calcium was the predominant cation. Exchangeable magnesium was proportionally low and potassium practically absent. The low C.E.C. suggested that the principal clay mineral was kaolinite.

Menon and Mariakulandai (1957) observed that the low cation exchange capacity of the red soils of Tamil Nadu was due to the predominance of the kaolinite type of clay mineral. So the cation exchange capacity depended mainly on the clay and organic matter contents. The cation exchange capacity and other related properties were higher in the surface soils, thereby clearly indicating the role played by the organic colloids. These organic colloids were found to have a higher cation exchange capacity which was 8 to 10 times more than that of the clay of red soils. Calcium formed the predominant cation followed by magnesium and potassium. Most of the red soils contained little or no exchangeable sodium.

In the laterite soils clay was made up mainly of the hydrous oxides of iron and aluminium, with only small quantities of silicate minerals. The mineral complex had a cation exchange capacity of only 2-4 me./100 g. The higher values recorded in the field were due to the organic matter content. In these soils also more than 50% of the exchangeable cations consisted of calcium. Magnesium was the cation next in importance followed by potassium and sodium.

In a study of the black soils of Tinnes tract, Menon et al. (1957) observed that cation exchange capacity increased with the depth of the soil. Of the different exchangeable cations, 80% was calcium. The contents of calcium and magnesium increased and that of potassium decreased, with depth in different profiles.

Donahue (1958) considered cation exchange capacity to be a single index of fertility. Therefore the more clayey a soil, the more is its cation exchange capacity and hence the greater are the chances of its being fertile.

Gopala Swami (1958) as cited by Pillai (1964) has reported a high cation exchange capacity (C.E.C.) for the kari soils of Kerala which was attributed to the high content of organic matter and a illitic and montmorillonitic types of clay present in them.

In a study of the red and laterite soils of Mand water shed, Roy and Landey (1962) observed, that the clay content and the cation exchange capacity were a maximum in the intermediate layers of the soil profiles studied by them.

Satyanarayana and Thomas (1962) have compared the chemical characteristics of Angadipuram and Kasargod laterites. In both types of laterities, the exchange capacities were low and this was attributed to the kaolinite type of clay minerals present in them. The exchangeable calcium, magnesium and potassium were found in these soils in traces only.

Fridland et al. (1966) observed that in soils rich in kaolinite, extraction with hydrochloric acid or H_2O_2 removed iron oxides and thus decreased the cation exchange capacity. This decrease in the cation exchange capacity was not due to destruction of the crystal lattices of silicates, but due to the removal of films of iron oxide involved in cation exchange reactions.

According to Yuan et al. (1967) the cation exchange capacity of the organic fraction in sandy soils may be appreciable because of the low C.E.C. of such soils. In other soils which have a higher C.E.C. the contribution of organic matter is often overlooked.

Alexander and Durairaj (1968) noted that the C.E.C. of black soils tended to increase with increase in pH. In acid soils, however, C.E.C. was negatively correlated to pH.

(b) Effect of exchangeable cations on soil properties

Different workers have pointed out that many of the physical and chemical properties of soils are influenced by the cations present.

According to Aarnio (1967) the pH of a soil is influenced by the different cations to different extents. With increase in the atomic weights of the cations present the pH is found to be low. A lower pH is recorded in the case of divalent cations as compared to monovalent bases.

Williams (1932) obtained data for total exchangeable bases clay content and total and easily oxidisable carbon in soils. He observed that there was a close relationship between the C.E.C. and clay content, as well as the total and easily oxidisable carbon.

Fraps (1935) studied the total exchange capacity of some Texas soils in relation to their chemical composition. It was observed that the contents of N, P_2O_5, K_2O and CaO increased regularly with increase in total C.E.C. until it exceeded the value of 20 me./100 g. There after the correlation between the C.E.C. and the chemical constituents was found to be very little.

Puffeles (1938) studied the influence of different exchangeable cations such as Ca, Mg, Na and K on the pH of light and heavy soils. He found that, of the soils saturated with these cations the pH was higher in heavy soils than in light soils.

Kelley and Dore (1938) studied the relationship between the nature of the parent rock, type of clay, cation exchange capacity and silica sesquioxide ratio in certain Californian soils and concluded that the type of clay was determined by the minerals present in the rock, and the C.E.C. by particle size and the nature of the surface.

Ravikovitch (1939) found that the liberation of adsorbed phosphate was dependent, not only on anion exchange, but also to a great extent on cation exchange. The amounts of cations present in the soil when phosphate was adsorbed, as well as the changes in the composition of the exchangeable bases after phosphate adsorption occurred, were found to influence the degree of phosphate availability.

Yatsevitch (1943) observed that within the pH range of 4.5 - 8.0 cation exchange capacity was a linear function of pH. At higher pH values a deviation from the linear relation in the direction of an increase in the exchange capacity was seen. The deviation was more marked in the case of soils having a higher content of inorganic substances and sesquioxides.

Milton and Wadleigh (1951) obtained a positive correlation between exchangeable sodium and pH. They concluded that exchangeable Na could be predicted, from the pH value.

Musierowicz _et al_. (1956) found that exchangeable calcium content increased with increase in the contents of clay and humus.

Heinonen (1960) estimated the C.E.C. of over 100 Finnish soils and determined its relationship to texture, humus level etc and analysed the results statistically. In the glacial soils cation exchange capacity was about 40 me./100 g. for the clay fraction and very low for the bigger fractions. The C.E.C. of the soil as a whole was variably affected by the clay content. The exchange capacity of the organic matter decreased with increasing clay content possibly due to the slower development of acid forms of humus in presence of high levels of clay of under environmental conditions conducive to high humus levels.

Durairaj (1961) found that the greater part of the total exchangeable cation content of black, red, brown and laterite soils of Tamil Nadu consisted of exchangeable calcium.

Ray Chaudhuri <u>et</u> <u>al</u>. (1962) working with Coimbatore profiles found that 60% of the exchangeable cation was made up of bivalent forms and that Na constituted the predominant monovalent cation.

Mahalingam <u>et</u> <u>al</u>. (1968) obtained a positive correlation between cation exchange capacity and exchangeable calcium for the high level Nilgiri soils.

(c) Effect of exchangeable bases on loss on ignition

Charlton (1932) studied the effect of replaceable bases on loss on ignition of Burma soils. He noted, that the effect of different cations on this property was in the order

$$Ca^{++} = H^{+} > Na$$

(d) Effect of exchangeable bases on the physical properties of soils

Several investigators have shown that the physical properties of a soil are influenced, not only by the clay content, but also by the nature of the ions present in the exchange complex.

Briggs and Shantz (1912) found that the clay content of a soil influenced its moisture equivalent and water holding capacity.

Gedroiz (1914) as cited by Baver (1928), Scofield and Headly (1921) Hissink (1923) and Cummins and Kelley (1923) studied the effect of exchangeable bases on the dispersion coefficient of soils and reported a higher degree of dispersion in soils saturated with sodium and the reverse in the case soils saturated with calcium. The same authors observed a low rate of percolation in soils saturated with sodium.

Hager (1923) as cited by Baver (1928) observed that sodium and potassium salts hardened argillaceous soils and spoiled their workability aeration, percolation and water capacity.

Hissink (1924) has stated that there is undeniable relationship between the structure of the soil and the relative proportion in which the adsorbed cations are present. As sodium comes into evidence the structure tends to deteriorate.

Gedroiz (1914, 1926) as cited by Baver (1928) noted that the degree of colloidability of any soil, depends on its state of saturation and the nature of the exchangeable bases. He (1924) also showed that the amount of the finest sized particles as shown by mechanical analysis, was greatly increased by saturating the exchange material with Na ions. He found that a substantive part of the silt and the fine sand portions was broken down by sodium saturation into ultrafine particles. This was not the condition when the soil was saturated with calcium. Calcium ions seemed to bind the fine sized particles into aggregates whereas sodium ions caused dispersion.

Kelley and Brown (1925) observed that soils saturated with sodium were sticky when wet and harsh when dry. Calcium on the other hand, produced a porous soil. Thus it appeared that physical properties of soils were in part dependent on the nature of the cations of the adsorbing complex.

Bouyoucos (1925) noted that practically all physical properties of soils were influenced by their colloidal contents.

Keen and Coutts (1928) examined a number of English soils for their clay content, moisture adsorption, sticky point moisture and other related properties. It was noted that heavy clay soils had a higher level of moisture adsorption and sticky point moisture.

Anderson (1929) has shown that the influence of the different cations on water adsorption by colloids varies in the order $Ca \leq Mg \leq Na \leq H \leq K \leq$ methylene blue.

Metzer (1929) working on Clarksville silt loam soils found that the nature and amount of replaceable bases have a very important bearing on the physical condition and productiveness of soils.

Gedroiz (1931) observed that Ca, when fully saturating the exchange complex, created a condition most favourable for plant life.

Coutts (1932) has established a correlation between the moisture equivalent, sticky point moisture, loss on ignition and the clay content of soils.

Charlton (1932) studied the effect of replaceable bases on sticky point moisture of Burma soils and the effect was found to vary as $H > Ca > Na$. Removal of organic matter reduced the sticky point value by about 3.2%.

Russell (1933) has statistically analysed the physical properties of some Natal soils and concluded that the cation exchange capacity was of prime importance for predicting the hygroscopic moisture and water holding capacity.

Singh and Nijawan (1936) studied the effect of various cations saturating the soil exchange complex on the physical properties of soils and reported that dispersion coefficient, water holding capacity and water of percolation were greatly influenced by the nature and amount of cations present. They have also shown that the different cations influenced water holding capacity in the order $Ca > Mn > Mg > K > NH_4 > Na$.

Freustal and Byers (1939) noted that the moisture absorbing and retaining capacities of peat were nearly twice that of a mineral soil when compared on an equal volume basis.

Joachim and Kandiah (1947) working on Ceylon soils obtained a positive correlation between the clay content, water holding capacity, sticky point and many other similar properties. Cation exchange capacity was determined primarily by the nature of the clay and the organic matter content.

Robinson (1949) in Great Britain studied the effect of exchangeable bases on soil properties and showed that the nature and amount of exchangeable bases profoundly influenced the general characteristics of the soil. He concluded that calcium soils possessed many desirable qualities such as a granular structure, which helped in the infiltration of water and better aeration. He also observed greater dispersion in the case of sodium soils as compared to calcium soils.

Brooks et al. (1956) showed that exchangeable potassium and magnesium were very similar in their effect on the permeability of soils. Potassium affected the permeability individually or in combination with sodium. There was a slight increase in permeability with increase in the amounts of magnesium.

Gill and Reaves (1957) observed that the shrinkage of natural clods was closely related to the cation exchange capacity which was in turn closely related to most other properties of the soil.

Kandaswamy (1961) observed that in the case of black, red, alluvial and laterite soils cation exchange capacity did not have any influence on sticky point. Moisture equivalent and water holding capacity were found to be mainly controlled by the clay content, organic matter, and the cation exchange capacity.

✓ Delmer *et al*. (1966) explained that the properties of soil such as structure, dispersiveness, permeability, cohesion, plasticity, water holding capacity and friability are affected by the replaceable bases, sodium and calcium. Calcium had a favourable effect on soils, whereas Na was found to be associated with cloddy and poorly drained soils.

(e) Percentage base saturation and soil properties

Joffe and Maclean (1926) studied the relationship between the H ion concentration and percentage base saturation of a large number of soils and concluded that the H ion concentration of water extracts was not a suitable index of the percentage base saturation of soils. However, Green (1929) obtained a high correlation between H ion concentration and percentage base saturation.

According to Harda (1929) soils of the same pH can have different degrees of base saturation.

Pierre and Scarseth (1931) concluded that in soils of similar origin, differences in weathering can bring about different degrees of base saturation. They observed that the presence of soluble acids, the nature of bases in the exchange complex, the organic matter content, the silica: sesquioxide ratio and the strength of acids are factors which determine the percentage base saturation of soils at similar pH values.

Morgan (1939) obtained a definite correlation between pH and percentage base saturation.

Martilla <u>et</u> <u>al</u>. (1965) working on Finnish soils observed the base saturation percentage to be greater in the deeper layers of soils than in the surface layers.

Alexander and Durairaj (1968) observed and increase in percentage base saturation with increase in the pH.

(f) Cation exchange capacity and chemical composition of clay

The total cation exchange capacity of soils and soil colloids has been used extensively for characterising clay minerals.

Grim (1953) enumerated the importance of various clay minerals in base exchange and reported the following approximate values for each type of clay mineral viz., 40-50 me./100 g. for halloysite, 80-150 me./100 g. montmorillonite and 100-150 me./100 g. for vermiculite.

Many workers have reported the cation exchange capacity of clays isolated from Indian black soils. Nagelschmidt et al. (1940), Ray Chaudhuri et al. (1943), Menon and Sankaranarayanan (1957) and Parthasarathy (1959) reported 60-120 me./100g. for the clays from these soils.

Manickam (1961) observed a cation exchange capacity of more than 60 me./100 g. for black soil clay and < 50 me./100 g for laterite soil clays.

Cation exchange studies in the rice soils of Kerala

Nambiar (1947) in a study of some typical rice soils of Kerala observed that calcium formed the principal replaceable base followed by magnesium, sodium and potassium. The low level of exchangeable calcium on the surface soils was attributed to the continuous leaching by heavy rains, as shown by the increase in the exchangeable calcium in the sub-surface soils. He also studied the percentage of total bases in the exchangeable form. The percentage of calcium and potassium was much higher in wet-land soils than in dry cultivated soils. The percentage of total magnesium that was exchangeable tended to increase as the soil became heavier. Base exchange capacity showed wide variations ranging from 3.04 - 73.4 me./100 g , but there was a general relationship between cation exchange capacity and the soil texture. The degree of unsaturation and pH of the soils did not show any consistent relationship.

Investigations by the same author on the effect of cropping on exchangeable bases revealed that continuous cropping brought about a significant decrease in exchangeable potassium but showed no measurable change in the other exchangeable bases. Laboratory investigations on the effect of soil flooded with sea water showed that the flooded soils were considerably poor in exchangeable calcium and richer in exchangeable magnesium and sodium as compared to unflooded soils. Exchangeable potassium was not materially influenced by flooding with sea water. The relative increase in the exchangeable base content as a result of flooding was in the order $\mathrm{Mg} > \mathrm{Na} > \mathrm{K}$. The results revealed that magnesium, and not sodium, was the chief exchangeable base found in soils flooded with sea water.

Experiments conducted by Nambiar (1947) on the effect of fresh water on the replaceable bases of saline water flooded soils showed that fresh water restored to the soils the exchangeable calcium that was lost as a result of inundation with sea water. The fresh water also reduced considerably the damage caused to the soil by saline water.

Results of experiments conducted by the above author on the effect of soil moisture conditions on the replaceable bases of the soil indicated that soils flooded with distilled water underwent a decrease in exchangeable calcium and a significant increase in magnesium and potassium. Exchangeable sodium was not significantly affected by flooding.

MATERIALS AND METHODS

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Fourteen soil profiles representing the major soil groups of Kerala were collected from different parts of the State. As the horizon differentiations were not very well defined in most of these soils, samples were collected in each case from fixed depths of 0 - 30, 30 - 60 and 60 - 90 cm. The details regarding the profiles collected are given in the table below:-

TABLE I

Details of soil profiles

Profile No.	Location	Soil group
I	Kayamkulam	Sandy
II	Kayamkulam	Sandy
III	Trichur	Kole land
IV	Alwaye	Alluvial
V	Chirayinkil	Alluvial
VI	Perinthalmanna	Laterite ✓
VII	Angadipuram	Laterite ✓
VIII	Vellayani	Laterite ✓
IX	Vechoor	Kari (Peaty)
X	Vechoor	Kari (Peaty)
XI	Kozhinjampara	Black
XII	Kozhinjampara	Black
✓ XIII	Palode	Virgin Forest
XIV	Patchalloor	Red ✓

Laboratory studies

1. Preparation of sample

The samples were air dried for a week, gently ground with a wooden mallet and passed through a 2 mm sieve. The material passing through the sieve was stored in labelled bottles and used for the analysis.

2. Chemical and mechanical composition

The chemical and mechanical analysis of the soil samples were carried out by adopting standard analytical procedures as outlined by Jackson (1958). The following estimations were carried out.

a. Moisture
b. Loss on ignition
c. Total phosphorus
d. Total potassium
e. Total calcium
f. Total magnesium
g. Total nitrogen
h. Organic carbon
i. Soil reaction
j. Mechanical analysis

3. Physical properties

Apparent specific gravity, absolute specific gravity, water holding capacity, pore space and volume expansion were determined using a keen Raczkowiski box as described by Wright (1939). Moisture equivalent was determined by the indirect method using the formula,

Moisture equivalent = (Waterholding capacity - 21) 0.635

Sticky point was determined by the method described by Piper (1950).

4. Cation exchange capacity and exchangeable cations

Cation exchange capacity and exchangeable cations in the samples were determined by adopting standard methods as outlined in Piper (1950). The methods are briefly given below:

(a) Cation exchange capacity

A sample of soil weighing 50 g was taken in a 500 ml conical flask and to this was added 250 ml of neutral N ammonium acetate solution. The flask and contents were set aside for 2 hours with occasional shaking. The solution was then filtered through a Buchner funnel under gentle suction. The soil was also transferred on to the filter paper in the Buchner funnel. It was then leached with neutral N ammonium acetate solution

(20 - 25 ml at a time) until about 500 ml of the leachate was collected. The residue on the filter paper was washed with 60% ethanol to remove the excess ammonium acetate. The fixed ammonium in the soil was determined by distillation using magnesium oxide. The distillate was absorbed in a known volume of standard acid, and the excess acid titrated with standard alkali. The cation exchange capacity was calculated and expressed as me./100 g of soil.

In the case of black soils the samples were first treated with 40% ethanol (100 ml) to remove soluble salts. The washing was repeated twice, each time using 100 ml of ethanol to ensure complete removal of salts. The washed soil was treated with neutral ammonium acetate solution and the C.E.C. determined as detailed above.

(b) Exchangeable cations

The leachate obtained from the above estimation was used for determining the exchangeable cations. As the black soils (samples 29 - 34) contained free calcium carbonate the estimation of exchangeable Ca and Mg was made by leaching the soils with ammonium acetate solution buffered to pH 8.5. This prevented the calcium from the free calcium carbonate from going into solution and distorting the results.

(i) Exchangeable calcium

An aliquot of the leachate (100 ml.) was evaporated to dryness on a water bath. The residue was ignited over a flame until white to convert the acetates to carbonates. To the ignited residue was added 12 ml of 2:1 ammonia solution and 7 ml of 10% ammonium per sulphate to precipitate the sesqui oxides and heavy metal ions. The precipitate formed was filtered washed with hot water and the washings collected in a volumetric flask and made up. An aliquot from this was used for estimating exchangeable Ca by the versenate method using murexide as indicator.

(ii) Exchangeable magnesium

An aliquot (100 ml) of the above washings was used for estimating magnesium by the vesenate method using erichrome - Black - T as indicator.

(iii) Exchangeable potassium

100 ml of the ammonium acetate leachate was evaporated to dryness, ignited and the residue extracted with hot water. It was filtered through Whatman No.42 filter paper and the washings collected in a beaker. In this solution potassium was precipitated as sodium potassium cobaltinitrite and estimated volumetrically.

(iv) Exchangeable sodium

100 ml of the leachate was evaporated to dryness and the residue ignited. It was then extracted with hot water and the filtered hot water extract, used for the estimation. Sodium was precipitated as the triple salt uranyl sodium zinc acetate. The precipitate was washed with alcohol saturated with crystals of the triple salt. The washed residue was dried at 105°C for half and hour and weighed to constant weight after thorough cooling in a desiccator.

(v) Exchangeable hydrogen

This was determined as the difference between the total cation exchange capacity and the sum total of exchangeable Ca, Mg, K and Na.

Separation of clay fraction

The clay fraction of the surface samples of seven soils profiles was separated by the sodium chloride method as outlined by Piper (1950).

Analysis of clay fraction

Cation exchange capacity of the clay was estimated by the neutral ammonium acetate method as in the case of the whole soil.

The estimation of silica, sesquioxides, iron oxide and alumina of the clay fraction was carried out using standard methods as outlined by Sankaram (1966).

From the results obtained correlation coefficients were calculated between various soil characteristics.

RESULTS

RESULTS

A. Mechanical composition

The results of the mechanical analysis of the soil samples are given in Table II.

The data show that the texture of the soils examined varied from loamy sand to clay. The coarse sand fraction varied from 1.0 to 60.6 %, the maximum value being for a sandy soil (No.4) and the minimum for a kari soil (No.28). The fine sand fraction ranged from 4.5% in a black soil (No.28) to as high a value as 43.3% in an alluvial soil. A laterite soil (No.20) gave the maximum value for clay content (62.5%) while a sandy soil (No.1) contained the least amount (7.4%) of this fraction. The range of variation for silt was from 2.0 to 26.5%, the maximum being recorded for a kari soil (No.25) and the minimum for a red soil (No.40). The coarser fraction showed no definite pattern in its distribution in the profiles. It was observed that clay fraction increased with depth in profiles I, II, IV, VIII, X, XI, XIII, and XIV. A decrease in clay content with depth was noted in profiles III and IX while the maximum accumulation of clay in the intermediate layers was observed in profiles V, VI and VII.

TABLE II

Mechanical composition of soils

Sample No.	Profile No.	Depth (cm.)	Organic matter %	Clay %	Silt %	Coarse sand %	Fine sand %
1	Profile I	0-30	0.3	7.4	4.0	58.2	30.1
2		30-60	0.2	7.7	4.8	58.5	28.8
3		60-90	0.2	8.6	5.0	58.5	27.7
4	Profile II	0-30	0.3	7.4	4.4	60.6	27.3
5		30-60	0.3	7.9	4.9	60.5	26.4
6		60-90	0.2	8.4	4.9	60.3	26.2
7	Profile III	0-30	4.9	28.6	4.0	31.3	31.2
8		30-60	0.6	28.5	5.2	32.2	33.5
9		60-90	0.3	27.6	4.5	34.8	32.8
10	Profile IV	0-30	7.2	25.7	21.0	5.8	40.3
11		30-60	4.4	30.7	19.5	3.5	41.9
12		60-90	3.9	31.3	19.5	2.8	42.5
13	Profile V	0-30	0.3	11.3	5.8	39.4	43.2
14		30-60	0.1	15.3	4.0	40.3	40.3
15		60-90	0.3	15.0	5.4	38.8	40.5
16	Profile VI	0-30	0.6	35.0	6.5	37.6	20.3
17		30-60	0.9	61.5	6.2	22.3	9.1
18		60-90	0.3	48.2	8.1	24.8	18.6

1	2	3	4	5	6	7	8
19	Profile VII	0-30	1.6	41.1	2.5	35.1	19.7
20		30-60	0.7	62.5	4.2	22.1	10.5
21		60-90	0.3	60.0	4.0	20.9	14.8
22	Profile VIII	0-30	0.6	39.5	3.1	34.6	22.2
23		30-60	0.3	40.4	3.3	34.3	21.7
24		60-90	0.4	49.4	3.3	34.8	12.1
25	Profile IX	0-30	13.9	52.4	26.5	1.4	5.8
26		30-60	18.3	50.9	24.5	1.6	4.7
27	Profile X	0-30	17.3	50.0	24.1	1.8	6.8
28		30-60	16.6	53.4	24.5	1.0	4.5
29	Profile XI	0-30	0.9	53.5	21.8	5.6	18.2
30		30-60	0.5	57.0	19.6	5.1	17.8
31		60-90	0.6	57.5	20.1	4.7	17.1
32	Profile XII	0-30	0.4	57.0	19.2	5.6	17.8
33		30-60	0.7	59.5	17.1	5.1	17.6
34		60-90	0.6	60.7	16.9	4.6	17.2
35	Profile XIII	0-30	1.8	32.5	5.1	38.9	21.7
36		30-60	1.1	35.5	8.2	38.7	16.5
37		60-90	0.3	37.0	8.7	39.7	14.3
38	Profile XIV	0-30	0.7	27.1	2.5	40.2	29.5
39		30-60	0.5	28.0	2.2	40.8	28.5
40		60-90	0.3	28.5	1.9	40.8	28.5

The organic matter status of the samples studied varied from 0.1 to 18.3%. An alluvial soil (No.14) showed the minimum value while the maximum value was observed for a kari soil (No.26). The distribution of organic matter down the profile showed much variation. A steady decrease in this constituent with depth was noted in profiles I, II, III, IV, VII, X, XIII and XIV.

B. Single value constants

The single value constants of the soils studied are given in Table III.

(a) Apparent density

The apparent density of the soils ranged from 0.79 - 1.96, the minimum recorded being for a kari soil (No.26) and the maximum for a forest soil (No.37). There was no regularity with regard to its distribution down the profile. However, the sandy soil profiles I and II showed a steady fall in apparent density with depth.

(b) Absolute specific gravity

A black soil (No.32) had the minimum value (2.0) for absolute specific gravity whereas the maximum value (2.7) was given by a sandy soil, a kole land soil and a laterite soil.

TABLE III

Physical properties of soils

Sample No.	Profile No.	Depth (cm.)	Apparent density	Absolute specific gravity	Maximum water holding capacity %	Moisture equivalent %	Pore Space %	Volume expansion %	Sticky point moisture %
1	2	3	4	5	6	7	8	9	10
1	Profile I	0-30	1.67	2.49	22.1	0.71	33.9	0.27	14.5
2		30-60	1.58	2.33	21.9	1.21	32.1	0.10	14.1
3		60-90	1.48	2.37	24.9	2.45	37.6	0.00	13.6
4	Profile II	0-30	1.71	2.73	22.6	1.04	38.4	0.00	17.3
5		30-60	1.53	2.38	24.9	2.50	38.2	0.08	9.3
6		60-90	1.47	2.44	25.8	3.02	39.7	0.59	9.0
7	Profile III	0-30	1.49	2.06	28.5	4.73	38.5	4.34	26.7
8		30-60	1.54	2.59	29.7	5.49	40.7	3.86	11.4
9		60-90	1.46	2.73	32.4	7.24	43.9	2.98	12.9
10	Profile IV	0-30	0.87	2.03	63.9	27.26	46.4	7.26	54.3
11		30-60	0.97	2.36	59.0	24.16	58.9	6.34	45.7
12		60-90	0.96	2.47	62.1	26.11	61.2	6.25	40.3
13	Profile V	0-30	1.52	2.32	23.4	1.52	33.8	0.18	16.2
14		30-60	1.49	2.28	22.9	1.24	34.6	0.57	19.1
15		60-90	1.53	2.46	25.2	2.69	38.2	0.41	19.5
16	Profile VI	0-30	1.42	2.42	26.3	3.38	41.1	1.51	17.1
17		30-60	1.27	2.00	36.9	23.58	50.7	2.21	22.4
18		60-90	1.34	2.73	34.5	21.19	50.9	2.02	22.1
19	Profile VII	0-30	1.35	2.34	29.7	5.49	43.9	0.46	14.5
20		30-60	1.33	2.37	50.1	18.50	43.6	1.84	24.8
21		60-90	1.27	2.69	39.1	11.52	52.9	1.53	24.0

1	2	3	4	5	6	7	8	9	10
22	Profile VIII	0-30	1.36	2.29	28.8	4.93	40.6	0.41	23.2
23		30-60	1.41	2.46	29.2	5.21	42.9	0.46	24.1
24		60-90	1.03	2.35	32.8	7.52	44.1	0.53	19.2
25	Profile IX	0-30	1.04	2.22	36.3	9.73	48.2	6.20	29.6
26		30-60	0.79	2.39	47.1	16.59	55.9	6.67	28.2
27	Profile X	0-30	1.18	2.36	40.9	12.64	49.8	6.51	30.7
28		30-60	1.36	2.58	45.9	15.83	49.4	5.97	31.2
29	Profile XI	0-30	1.39	2.17	42.8	13.87	51.9	27.26	17.8
30		30-60	1.37	2.33	46.8	16.39	58.3	27.76	17.8
31		60-90	1.41	2.19	45.6	15.63	54.3	28.55	17.3
32	Profile XII	0-30	1.44	1.90	45.8	15.72	50.9	26.85	17.5
33		30-60	1.35	2.36	46.8	16.39	56.2	28.01	16.9
34		60-90	1.32	2.59	48.8	17.63	51.6	29.67	17.5
35	Profile XIII	0-30	1.19	2.36	26.7	3.59	40.9	0.97	18.5
36		30-60	1.45	2.52	27.5	4.15	42.7	1.11	19.2
37		60-90	1.96	2.17	28.8	4.93	43.9	1.35	20.0
38	Profile XIV	0-30	1.41	2.28	27.0	3.82	38.2	0.19	13.6
39		30-60	1.59	2.18	32.2	7.01	37.6	0.00	10.5
40		60-90	1.42	2.32	45.8	15.74	38.5	1.15	14.6

(c) Maximum water holding capacity

The highest value for water holding capacity (63.9%) was observed for an alluvial soil (No.10) and the lowest value for a sandy soil (No.1). In profiles I, II, III, VIII, IX, X, XII, XIII and XIV the 3rd layer (60-90 cm.) showed the maximum value, the general trend being that of an increase of this constant down the profile. The intermediate layer (30 - 60 cm.) gave the maximum value for water holding capacity in the case of profiles VI, VII and XI.

(d) Moisture equivalent

The values for moisture equivalent showed considerable variation ranging from 1.04 - 27.26%. The minimum was observed for a sandy soil (No.4) and the maximum for an alluvial soil (No.10). Profiles I, II, III, VIII, IX, X, XII, XIII and XIV showed a steady increase in moisture equivalent with depth.

(e) Pore space

The pore space for the different samples lies within the limits of 32.1 and 61.2%. A sandy soil (No.2) showed the minimum pore space and an alluvial soil (No.12) the maximum. With regard to the variation of this property down the profile it is observed that profiles I, II, VII and XIV showed the lowest value in the intermediate layers (30 - 60 cm.) while profiles III, IV, V, VI, VIII, IX and XIII showed an increase in pore space with depth. The maximum value for the intermediate layer has been observed for profiles XI and XII.

(f) Volume expansion

Volume expansion of soils showed a wide variation from 0 - 29.67%. Sandy soils (No.3 and 4) and a red soil (No.39) gave the minimum value, whereas the maximum expansion was noted for a black soil (No.34). A definite decrease in volume expansion with depth was noted, in profiles I, III, IV and X. Increase in the value with depth was observed in profiles II, VIII, IX, XI, XII and XIII.

(g) Sticky point

Sticky point ranged from 8.98 - 54.31%, the lowest value observed being for a sandy soil (No.6) and the highest value for an alluvial soil (No.10). As regards the changes in the sticky point moisture down the profile, a decrease was observed with increase in depth, in the case of profiles IV and IX. A steady increase in sticky point with depth was noted in profiles V, X and XIII.

C. Chemical composition

The chemical composition of the soils is given in Table IV.

TABLE IV

Chemical composition of soils

Sample No.	Profile No.	Depth (cm.)	Moisture %	Percentage oven dry basis							pH
				Loss on ignition	N	P_2O_5	K_2O	CaO	MgO	Organic carbon	
1	2	3	4	5	6	7	8	9	10	11	12
1	Profile I	0-30	0.91	2.27	0.03	0.05	0.06	0.13	0.06	0.17	5.1
2		30-60	1.33	2.59	0.06	0.05	0.15	0.15	0.10	0.16	5.4
3		60-90	1.04	3.01	0.04	0.13	0.07	0.06	0.12	0.14	5.2
4	Profile II	0-30	1.55	2.43	0.04	0.10	0.06	0.02	0.06	0.19	5.0
5		30-60	1.30	4.71	0.03	0.02	0.10	0.03	0.08	0.15	5.3
6		60-90	1.39	3.19	0.02	0.01	0.05	0.02	0.06	0.12	5.2
7	Profile III	0-30	6.78	11.42	0.40	0.18	0.30	0.20	0.70	2.84	5.0
8		30-60	2.74	5.41	0.04	0.18	0.17	0.13	0.03	0.34	4.5
9		60-90	2.75	5.10	0.05	0.11	0.17	0.13	0.07	0.15	4.8
10	Profile IV	0-30	0.24	22.06	0.41	0.18	0.49	0.35	1.16	4.16	4.1
11		30-60	3.20	16.00	0.27	0.07	0.54	0.30	1.34	2.54	4.3
12		60-90	6.71	16.76	0.29	0.23	0.35	0.22	1.30	2.26	4.2
13	Profile V	0-30	0.72	5.34	0.01	0.11	0.09	0.04	0.12	0.17	6.0
14		30-60	0.30	2.51	0.01	0.07	0.08	0.06	0.11	0.08	5.0
15		60-90	0.40	2.81	0.01	0.06	0.08	0.06	0.09	0.15	5.1
16	Profile VI	0-30	3.82	10.64	0.11	0.22	0.15	0.12	0.11	0.33	4.6
17		30-60	6.22	14.51	0.21	0.20	0.24	0.20	0.30	0.52	4.7
18		60-90	6.81	15.91	0.07	0.23	0.11	0.29	0.09	0.16	4.7

1	2	3	4	5	6	7	8	9	10	11	12
19	Profile VII	0-30	4.56	11.22	0.10	0.12	0.16	0.14	Trace	0.92	4.4
20		30-60	3.81	15.90	0.08	0.12	0.20	0.12	0.06	0.39	4.8
21		60-90	5.54	15.29	0.08	0.22	0.21	0.14	0.02	0.15	4.6
22	Profile VIII	0-30	1.02	6.67	0.04	0.04	0.08	0.05	0.07	0.35	4.3
23		30-60	0.94	6.67	0.03	0.02	0.06	0.07	Trace	0.30	4.3
24		60-90	2.20	9.32	0.02	0.03	0.04	0.06	0.09	0.23	4.4
25	Profile IX	0-30	3.88	26.22	0.45	0.12	0.30	0.34	0.30	8.06	3.0
26		30-60	3.81	25.69	0.41	0.01	0.35	0.27	0.35	10.60	3.9
27	Profile X	0-30	4.19	27.33	0.45	0.04	0.31	0.35	0.67	10.06	3.7
28		30-60	3.99	27.55	0.54	0.03	0.42	0.30	0.59	9.66	3.0
29	Profile XI	0-30	2.47	14.00	0.08	0.10	0.35	1.74	1.48	0.57	7.8
30		30-60	7.46	14.20	0.07	0.09	0.36	1.88	1.11	0.29	7.5
31		60-90	10.32	9.69	0.04	0.08	0.41	1.89	2.69	0.37	7.8
32	Profile XII	0-30	9.08	10.12	0.05	0.08	0.40	1.67	2.00	0.23	8.0
33		30-60	10.21	8.92	0.03	0.07	0.41	1.75	1.70	0.40	7.6
34		60-90	10.51	14.22	0.04	0.08	0.42	2.04	2.54	0.37	7.9
35	Profile XIII	0-30	1.60	10.22	0.12	0.08	0.12	0.05	0.04	1.04	4.6
36		30-60	1.30	7. 71	0.05	0.07	0.10	0.05	0.04	0.65	4.8
37		60-90	1.20	6. 27	0.01	0.05	0.12	0.05	0.10	0.17	4.9
38	Profile XIV	0-30	0.08	5. 15	0.04	0.02	0.04	0.06	0.07	0.43	4.7
39		30-60	0.29	5. 19	0.03	0.02	0.04	0.06	0.07	0.33	4.9
40		60-90	0.37	4. 41	0.02	0.02	0.05	0.04	0.04	0.20	4.9

1. Total nitrogen

The nitrogen content of the soils varied from .01 - 0.54%. The minimum value noted was for an alluvial soil (No.15) and the maximum value for a <u>kari</u> soil (No.28). The general trend in the distribution of N was for a decrease in its content with depth. Profiles II, VII, VIII, IX, XI, XIII and XIV showed a steady decrease in nitrogen with depth, whereas the intermediate layers (30-60 cm.) showed maximum accumulation in the case of profiles I and VI.

2. Total phosphorus

The range of P_2O_5 in the soils studied was between 0.01 and 0.23%. A <u>kari</u> soil (No.26) had the lowest P_2O_5 content while a laterite soil (No.18) had the highest. The phosphorus content was found to decrease steadily with depth in profiles II, V, IX, X, XI and XIII. Maximum accumulation of this element in the 3rd layer (60-90 cm.) was noted in profiles IV, VI and VII.

3. Total Potassium

The K_2O content of the soils under study ranged from 0.04 - 0.54%. The minimum potassium content was in a red soil (No.39) and the maximum value was obtained for an alluvial soil (No.11).

In profiles I, II, IV and VI there was maximum accumulation of potassium in the intermediate layer (30-60 cm.). A steady decrease in potassium content with depth was noted in profile VIII while profiles IX, X, XI and XII showed an increase in potassium status with increase in depth.

4. Total calcium

The percentage of total CaO varied from 0.02 - 2.04%. The lowest value recorded was for a sandy soil (No.4) and the highest value was for a black soil (No.34). Profiles I, II and VIII showed an accumulation of CaO in the intermediate layer (30-60 cm.). An increase in CaO content with depth was observed, in the case of profiles VI and XI. Profiles IV, IX and X showed a steady decrease in this element with depth.

5. Total magnesium

Total MgO content of the soils under study ranged from a trace to 2.69%. The minimum value was observed in the case of a laterite soil (No.21) and the maximum value in a black soil (No.31). A perusal of the data revealed no regularity in distribution of this element down the profile.

6. Organic carbon

The organic carbon content of samples varied from 0.08 - 10.6%. An alluvial soil(No.14) showed the minimum value whereas the maximum organic carbon content was observed in a kari soil (No.26). Much variation was observed in the distribution of organic carbon down the profile. A steady decrease with depth was noted in profiles I, II, III, IV, VII, X, XIII and XIV.

7. Loss on ignition

Loss on ignition varied from 2.27 - 27.6% in the soils studied. The minimum and maximum value observed were for a sandy soil (No.1) and a kari soil (No.28) respectively.

8. Hydrogen ion concentration (pH)

The pH of the soils studied, varied widely from 3.0 for a kari soil (No.25) to 8.0 for a black soil (No.32).

D. Cation exchange properties

The cation exchange properties of the soils are given in Table V.

(i) Cation exchange capacity

The values for cation exchange capacity of the various soils examined are given in Table VIII.

Cation exchange capacity of the soils varied from 1.5 me./100 g for a sandy soil (No.4) to as high as 49.6 me./

TABLE V

Exchangeable base content of soils

Sample No.	Profile No.	Depth (cm.)	me./100 g of oven dry soil					Relative proportion of exchangeable bases (Percentage on total)			
			Ca	Mg	K	Na	Total	Ca	Mg	K	Na
1	2	3	4	5	6	7	8	9	10	11	12
1	Profile I	0-30	0.77	0.66	0.22	0.16	1.81	42.5	36.5	12.1	8.9
2		30-60	1.43	0.50	0.08	0.17	2.18	65.6	22.9	0.0	11.5
3		60-90	0.77	0.33	0.20	0.09	1.39	55.4	23.7	14.4	6.5
4	Profile II	0-30	Trace	Trace	Trace	0.19	0.19	0.0	0.0	0.0	0.0
5		30-60	"	"	"	0.28	0.28	0.0	0.0	0.0	0.0
6		60-90	"	"	"	0.33	0.33	0.0	0.0	0.0	0.0
7	Profile III	0-30	2.09	1.76	1.24	0.27	5.36	39.0	32.8	23.1	5.1
8		30-60	1.10	1.65	1.27	0.25	4.27	25.8	38.6	29.7	5.9
9		60-90	1.21	2.86	1.38	0.16	5.61	21.6	51.0	24.6	2.8
10	Profile IV	0-30	1.32	3.74	0.67	0.21	5.94	22.2	63.0	11.3	3.5
11		30-60	0.59	2.05	1.40	Trace	4.04	14.6	50.7	34.7	0.01
12		60-90	0.88	1.44	1.29	"	3.61	24.4	39.9	35.7	0.0
13	Profile V	0-30	0.44	Trace	0.57	"	1.01	43.6	0.0	56.4	0.0
14		30-60	1.21	0.22	Trace	"	1.43	84.6	15.4	0.0	0.0
15		60-90	0.99	0.55	0.03	"	1.57	63.1	35.0	1.9	0.0
16	Profile VI	0-30	1.91	1.60	0.69	0.16	4.36	43.8	36.7	5.8	3.7
17		30-60	1.24	1.61	0.78	Trace	3.63	34.2	44.3	21.5	0.0
18		60-90	1.65	0.50	0.18	0.12	2.45	67.3	20.4	7.4	4.9

1	2	3	4	5	6	7	8	9	10	11	12
19	Profile VII	0-30	1.98	Trace	0.31	0.12	2.41	62.2	0.0	9.8	28.0
20		30-60	1.76	0.50	0.31	0.13	2.70	65.2	18.5	11.5	4.8
21		60-90	2.64	0.88	0.18	0.25	3.95	66.9	22.3	4.5	6.3
22	Profile VIII	0-30	1.49	0.44	0.22	0.25	2.40	62.8	18.3	9.2	9.7
23		30-60	0.66	Trace	0.12	Trace	0.78	84.6	0.0	15.4	0.0
24		60-90	0.99	0.33	0.12	"	1.48	66.8	22.4	10.8	0.0
25	Profile IX	0-30	4.50	2.90	0.75	2.22	10.37	43.5	27.9	5.5	21.1
26		30-60	5.18	4.18	0.61	3.22	13.19	39.3	31.7	4.6	24.4
27	Profile X	0-30	4.50	2.50	Trace	2.94	9.94	45.3	25.1	0.0	29.6
28		30-60	3.60	2.20	0.74	1.79	8.33	43.2	26.4	8.8	21.6
29	Profile XI	0-30	28.05	17.60	0.45	1.04	47.14	59.5	37.3	0.9	2.3
30		30-60	23.65	19.80	0.99	2.79	47.23	50.1	41.9	2.1	5.9
31		60-90	17.05	20.90	0.74	6.04	44.73	38.1	46.7	1.7	13.5
32	Profile XII	0-30	26.95	17.05	0.47	1.12	45.59	59.0	37.4	1.3	2. 3
33		30-60	25.30	18.70	0.47	3.52	47.99	52.7	39.0	1.0	7.3
34		60-90	20.55	19.80	0.51	4.49	45.35	45.3	43.7	1.1	9.9
35	Profile XIII	0-30	0.83	0.28	0.28	0.33	1.72	48.2	16.3	16.3	19.2
36		30-60	1.05	Trace	0.16	0.13	1.34	78.4	0.0	11.9	9.7
37		60-90	1.27	0.39	0.41	0.46	2.53	50.2	15.4	16.2	18.2
38	Profile XIV	0-30	1.32	Trace	0.16	0.16	1.64	80.5	0.0	9.8	9.7
39		30-60	0.94	0.39	0.83	Trace	2.16	43.5	18.1	38.4	0.0
40		60-90	0.63	0.79	0.75	"	2.17	29.0	36.4	34.6	0.0

100 g. of soil for a black soil (No.33). In profiles X, XI and XIII the cation exchange capacity tended to decrease with depth whereas it increased with depth in profiles II and IX.

(ii) Exchangeable calcium

The content of exchangeable calcium in the soils examined ranged from a trace to 28.1 me./100 g of soil. Of the total exchangeable bases present in the exchange complex of the soil the proportion of exchangeable calcium ranged from a trace to 84.6 per cent with an average of 46.5%. With regard to the distribution of exchangeable calcium down the profile it was observed that there was a steady decline of this exchangeable cation with depth in profiles X, XI, XII and XIV. The laterite profiles VI, VII and VIII showed a decrease in exchangeable calcium in the intermediate layers and an increase thereafter.

(iii) Exchangeable magnesium

The amounts of exchangeable Mg were quite variable, ranging from a trace to 20.9 me./100 g of soil. The minimum value observed was for three sandy soils (Nos. 4, 5 and 6) and two laterite soils (Nos. 19 and 23). The maximum value was for a black soil (No.31). The proportion of exchangeable Mg to the total exchangeable bases varied from a trace to 62.9% with an average of 27.69. Profiles I and IV showed

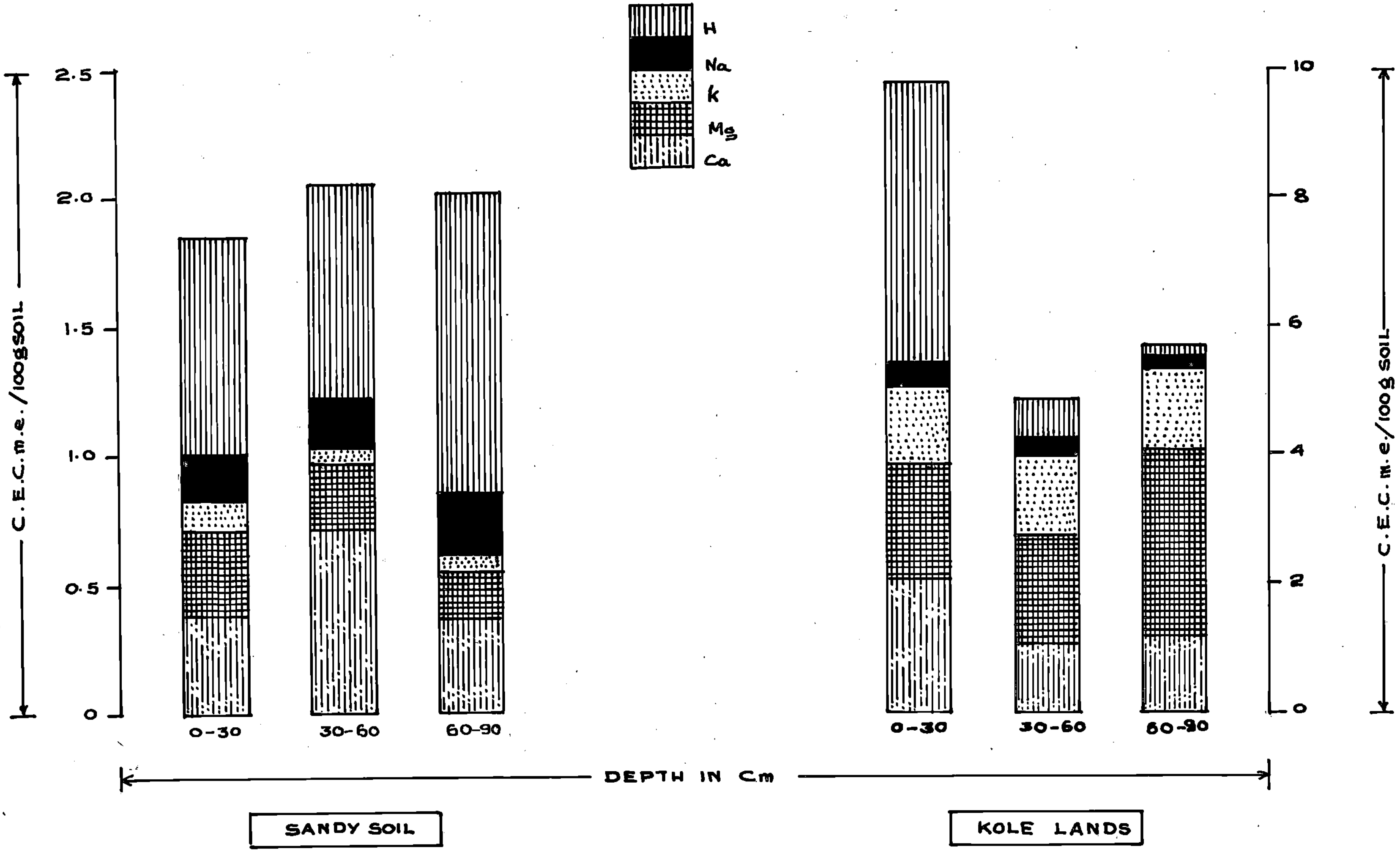
TABLE VIII

Cation exchange capacity & exchangeable cations

Sample No.	Profile No.	Depth (Cm.)	Exchangeable cations me./100g oven dry soil					Cation exchange capacity
			Ca.	Mg.	K.	Na.	H (By difference)	
1	2	3	4	5	6	7	8	9
1	Profile I kay	0-30	0.77	0.66	0.22	0.16	0.31	2.12
2		30-60	1.43	0.50	0.08	0.17	0.06	2.24
3		60-90	0.77	0.33	0.20	0.09	0.58	1.97
4	Profile II	0-30	Trace	Trace	Trace	0.19	1.33	1.52
5		30-60	"	"	"	0.28	1.60	1.88
6		60-90	"	"	"	0.33	1.75	2.08
7	Profile III	0-30	2.09	1.76	1.24	0.27	4.48	9.84
8		30-60	1.10	1.65	1.27	0.25	0.61	4.88
9	Profile III	60-90	1.21	2.86	1.38	0.16	0.07	5.68
10	Profile IV	0-30	1.32	3.74	0.67	0.21	12.90	18.84
11		30-60	0.59	2.05	1.40	Trace	19.36	13.40
12		60-90	0.88	1.44	1.29	"	10.23	13.84
13	Profile V	0-30	0.44	Trace	0.51	"	3.39	4.40
14		30-60	1.21	0.22	Trace	"	0.97	2.40
15		60-90	0.99	0.55	0.03	"	0.43	2.00
16	Profile VI	0-30	1.91	1.60	0.69	0.16	1.04	5.40
17		30-60	1.24	1.61	0.78	Trace	3.21	6.84
18		60-90	1.65	0.50	0.18	0.12	1.37	3.82

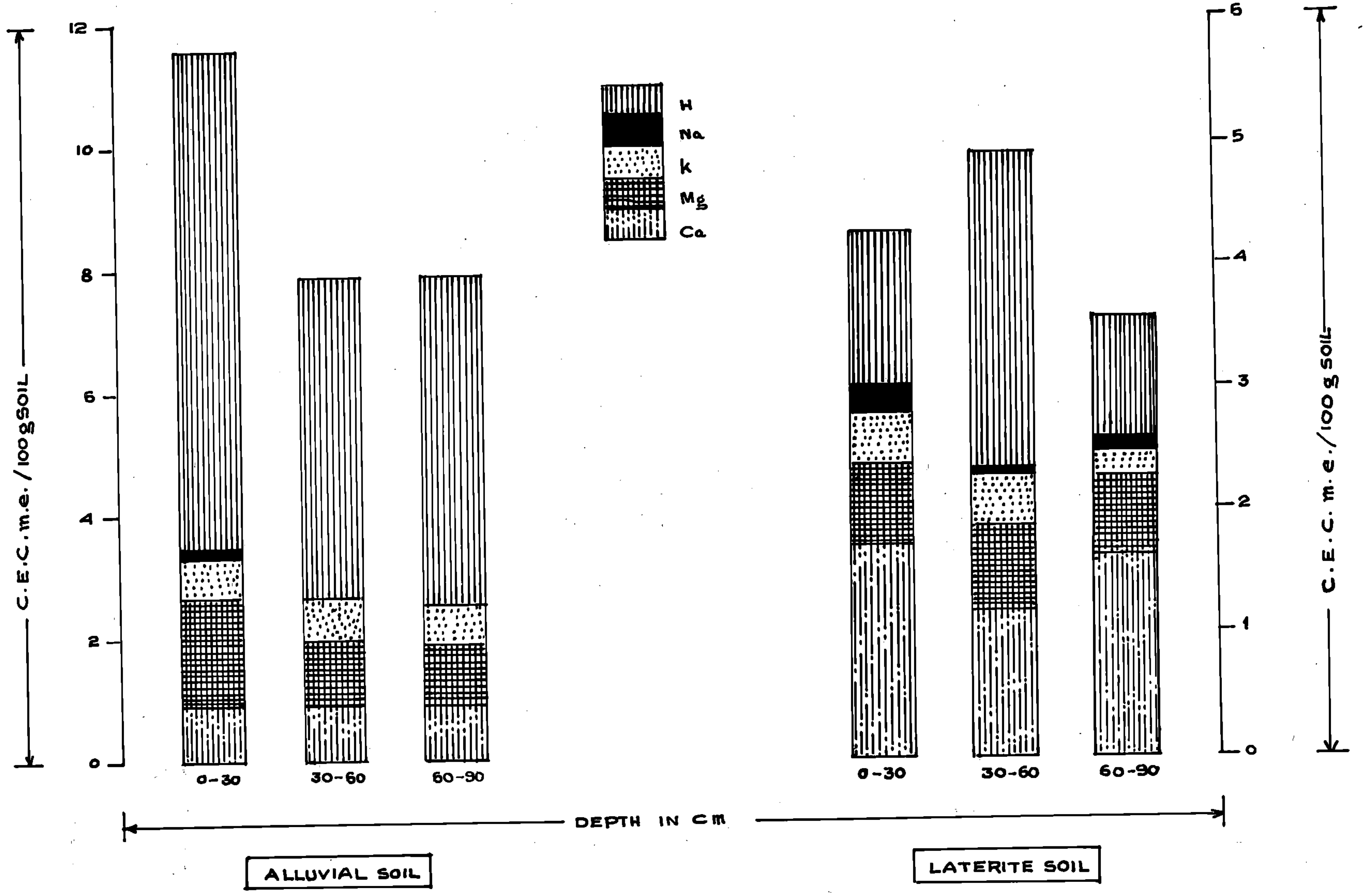
(Contd..

1	2	3	4	5	6	7	8	9
19	Profile VII	0-30	1.98	Trace	0.31	0.12	2.69	5.10
20	Profile VII	30-60	1.76	0.50	0.31	0.13	3.54	6.24
21		60-90	2.64	0.88	0.18	0.25	1.47	5.42
22	Profile VIII	0-30	1.49	0.44	0.22	0.25	0.10	2.50
23		30-60	0.66	Trace	0.12	Trace	1.06	1.84
24		60-90	0.99	0.33	0.12	"	0.14	1.62
25	Profile IX	0-30	4.50	2.90	0.75	2.22	13.85	24.32
26		30-60	5.18	4.18	0.61	3.22	12.91	26.12
27	Profile X	0-30	4.50	2.50	Trace	2.94	13.90	23.84
28		30-60	3.60	2.20	0.74	1.79	15.03	23.36
29	Profile XI	0-30	28.05	17.60	0.45	1.04	0.86	48.00
30		30-60	23.65	19.80	0.99	2.79	0.07	47.30
31		60-90	17.05	20.90	0.74	6.04	2.19	46.92
32	Profile XII	0-30	26.95	17.05	0.47	0.12	1.57	47.16
33		30-60	25.30	18.70	0.47	3.52	1.57	49.56
34		60-90	20.55	19.80	0.51	4.49	1.61	46.96
35	Profile XIII	0-30	0.83	0.28	0.28	0.33	4.18	5.90
36		30-60	1.05	Trace	0.16	0.13	2.26	3.60
37		60-90	1.27	0.39	0.41	0.46	0.47	3.00
38	Profile XIV	0-30	1.32	Trace	0.16	0.16	0.48	2.12
39		30-60	0.94	0.39	0.83	Trace	0.38	2.54
40		60-90	0.63	0.79	0.75	"	0.23	2.40



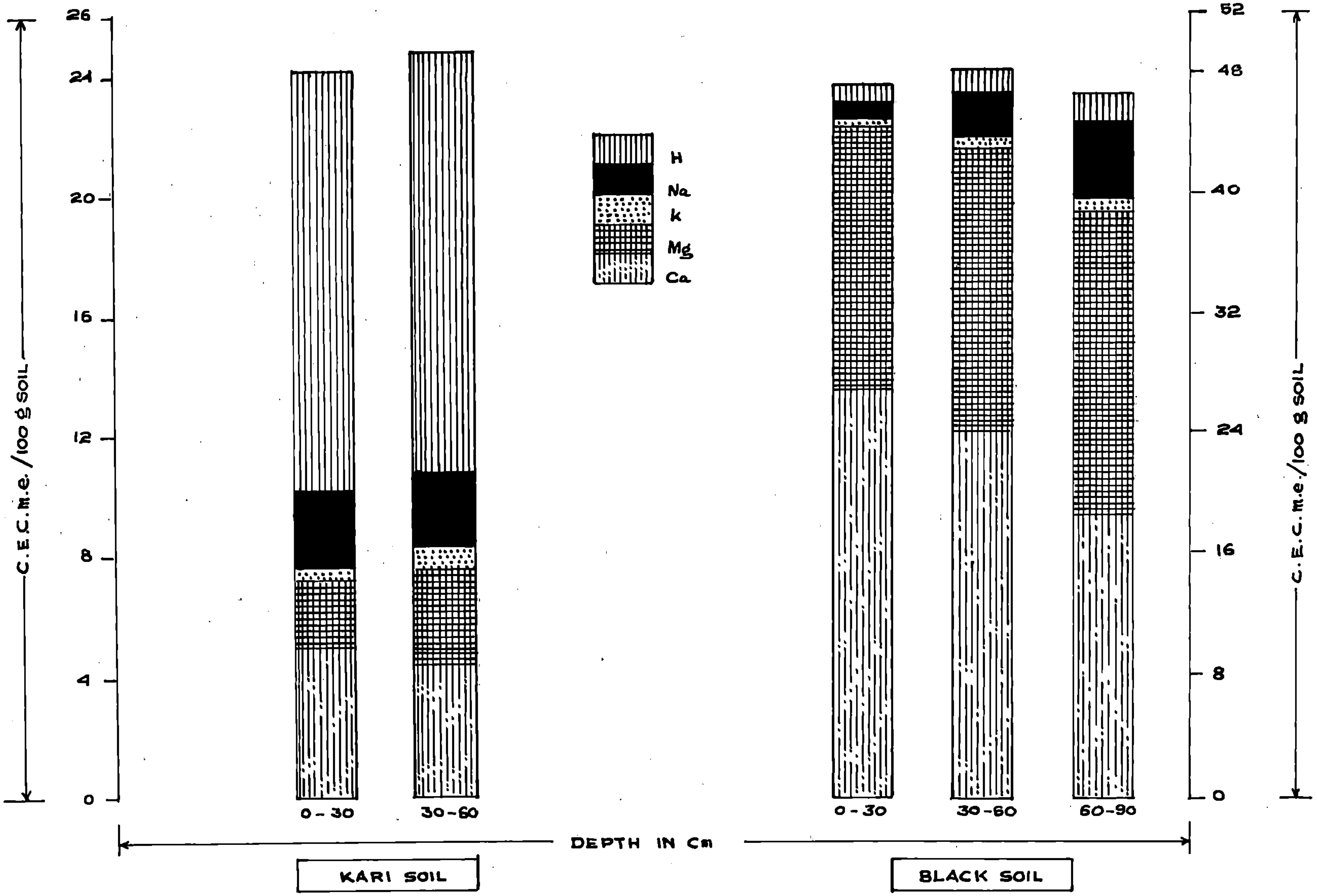
CATION EXCHANGE CAPACITY AND EXCHANGEABLE CATIONS IN SANDY AND KOLE LAND SOILS

FIG: 1



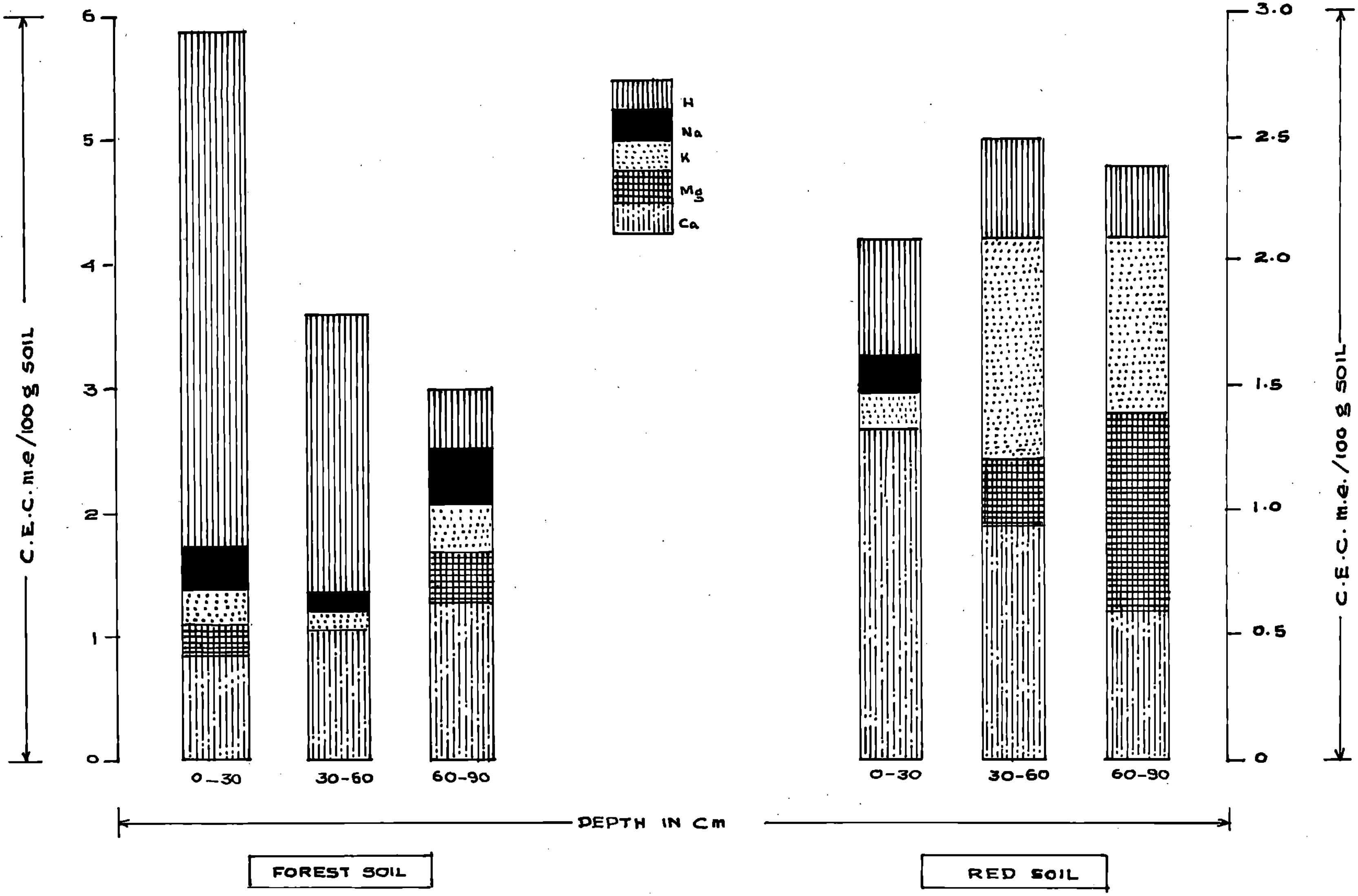
CATION EXCHANGE CAPACITY AND EXCHANGEABLE CATIONS IN ALLUVIAL AND LATERITE SOILS

FIG 2



CATION EXCHANGE CAPACITY AND EXCHANGEABLE CATIONS IN KARI AND BLACK SOILS

FIG 3



CATION EXCHANGE CAPACITY AND EXCHANGEABLE CATIONS IN FOREST AND RED SOILS

FIG. 4

a decrease in exchangeable Mg content with depth, while an increase in this constituent was observed in profiles V, VII, IX, XI, XII and XIV. Profile II showed only traces of this element in the exchangeable form.

(iv) Exchangeable potassium

The content of exchangeable potassium in the soils under study was comparatively low, the range of variation being from a trace to 1.4 me./100 g soil. A sandy soil (No.5) gave the lowest value whereas the highest value was observed in the case of an alluvial soil (No.11). The relative proportion of exchangeable K to the total exchangeable bases varied from a trace to 56.4% with a mean value of 12.4%. With regard to the distribution of this exchangeable cation in the profile a steady increase with depth was observed in the case of profiles III and X. Profiles IV, VI, XI and XIV however showed an accumulation of exchangeable K in the intermediate layer (30 - 60 cm.).

(v) Exchangeable sodium

In most of the soils examined exchangeable sodium was found only in traces except in <u>kari</u> and black soil profiles. The range of variation was from a trace to 6.04 me./100 g of soil. The maximum value obtained was for a black soil (No.31). The relative proportion of exchangeable Na to the total

TABLE IX

Total bases and exchangeable bases in soils

Sl. No.	Profile No.	Depth (Cm.)	Total bases me./100g. oven dry soil			Exchangeable bases me./100g. oven dry soil			Percentage of exchangeable on total		
			Ca.	Mg.	K.	Ca.	Mg.	K.	Ca.	Mg.	K.
1	2	3	4	5	6	7	8	9	10	11	12
1	Profile I	0-30	4.45	2.75	1.33	0.77	0.66	0.22	17.3	24.1	16.5
2		30-60	5.30	4.83	3.09	1.43	0.50	0.08	26.9	10.4	2.6
3		60-90	1.95	6.17	1.55	0.77	0.33	0.20	39.5	5.3	12.9
4	Profile II	0-30	0.85	3.08	1.19	Trace	Trace	Trace	0.0	0.0	0.0
5		30-60	1.10	4.17	2.87	"	"	"	0.0	0.0	0.0
6		60-90	0.85	3.08	1.02	"	"	"	0.0	0.0	0.0
7	Profile III	0-30	7.20	34.67	6.44	2.09	1.76	1.24	29.3	5.1	19.3
8		30-60	4.60	2.67	3.59	1.10	1.65	1.27	23.9	6.2	35.4
9		60-90	4.60	3.67	3.51	1.21	2.86	1.38	26.3	77.9	39.3
10	Profile IV	0-30	12.35	58.83	10.33	1.32	3.74	0.67	10.7	6.4	6.5
11		30-60	10.85	67.83	11.46	0.59	2.05	1.40	5.4	3.0	12.2
12		60-90	8.00	64.67	7.38	0.88	1.44	1.29	11.0	2.2	17.5
13	Profile V	0-30	1.45	6.00	1.82	0.44	Trace	0.57	30.4	0.0	31.3
14		30-60	2.25	5.75	1.72	1.21	0.22	Trace	53.8	3.8	0.0
15		60-90	1.60	3.42	1.64	0.99	0.55	0.03	47.1	12.2	1.7
16	Profile VI	0-30	4.20	5.42	3.15	1.91	1.60	0.69	45.5	28.5	21.9
17		30-60	7.30	14.83	5.00	1.24	1.61	0.73	17.0	10.9	15.60
18		60-90	10.45	4.33	2.26	1.65	0.50	0.18	15.8	11.6	0.8

(contd..

1	2	3	4	5	6	7	8	9	10	11	12
19	Profile VII	0-30	5.40	Trace	3.31	1.98	Trace	0.31	3.7	0.0	0.7
20		30-60	4.20	3.00	4.05	1.76	0.50	0.31	42.0	16.7	7.7
21		60-90	4.85	1.85	4.41	2.64	0.88	0.18	54.4	47.56	4.1
22	Profile VIII	0-30	1.60	3.42	1.64	1.49	0.44	0.22	93.1	12.9	13.4
23		30-60	2.45	Trace	1.33	0.66	Trace	0.12	26.9	0.0	9.0
24		60-90	2.00	4.58	0.89	0.99	0.33	0.12	49.5	7.2	18.0
25	Profile IX	0-30	11.95	14.75	6.38	4.50	2.90	0.75	37.7	19.7	11.8
26		30-60	9.80	17.42	7.51	5.18	4.18	0.61	52.9	24.0	8.1
27	Profile X	0-30	12.35	33.33	6.56	4.50	2.50	Trace	36.4	7.5	0.0
28		30-60	110.60	29.50	8.93	3.60	2.20	0.74	33.9	7.4	2.5
29	Profile XI	0-30	62.00	73.75	7.41	28.05	17.60	0.45	45.2	23.9	6.1
30		30-60	67.00	55.33	7.71	23.65	19.80	0.99	35.3	35.8	12.8
31		60-90	67.50	134.17	8.69	17.05	20.90	0.74	25.3	15.6	8.5
32	Profile XII	0-30	59.50	100.00	8.46	26.95	17.05	0.47	45.5	17.1	5.6
33		30-60	62.50	85.00	8.74	25.30	18.70	0.47	40.5	22.0	5.4
34		60-90	73.00	126.67	9.26	20.55	19.80	0.51	28.2	15.6	5.5
35	Profile XIII	0-30	1.85	1.92	2.46	0.83	0.28	0.28	44.9	14.6	11.4
36		30-60	1.60	2.17	2.08	1.05	Trace	0.16	65.7	0.0	7.7
37		60-90	1.85	5.08	2.51	1.27	0.39	0.41	68.7	7.7	16.3
38	Profile XIV	0-30	2.20	3.42	0.87	1.32	Trace	0.16	60.0	0.0	18.39
39		30-60	1.95	3.42	0.85	0.94	0.39	0.83	48.2	11.4	97.6
40		60-90	1.35	1.83	1.00	0.63	0.79	0.75	46.7	43.2	75.00

exchangeable bases varied from a trace to 29.6% with a mean value of 6.9%. In most of the profiles examined there was not much variation in exchangeable sodium content down the profile. However profiles II, IX, XI and XII showed an increase in this exchangeable cation with depth. In profiles III, X and XIV a decline in exchangeable Na with increase in depth of the profile was observed.

(vi) Total bases and exchangeable bases

Exchangeable Ca, Mg and K expressed as percentage of total, Ca, Mg and K, is given in Table IX. It is seen that total calcium in soil range from 0.85 - 73.0 me./100 g of soil with a mean of 13.9. The percentage of exchangeable Ca expressed as percentage of total calcium ranged from 0 - 93.13% with an average value of 27.1%.

The content of total Mg varied from a trace to 126.7 me./100 g of soil with an average of 25.1 me./100 g. The exchangeable portion ranged from a trace to 84.75 per cent with a mean value of 12.8%.

The total potassium content of soil lies between 0.85 - 11.46 me./100 g. of soil the average being 4.3 me./100 g. Exchangeable K expressed as per cent of total K, lies within the limits 0 - 97.64% with a mean value of 14.5%.

TABLE VII

Cation exchange capacity, degree of unsaturation and percentage base saturation of soils

Sample No.	Profile No.	Depth (Cm.)	Total bases (s) me./100 g. Soil.	Exchange capacity (T) me./100 g. Soil	Degree of unsaturation $\frac{(T-S) \times 100}{T}$	Percentage base saturation $\frac{S}{T} \times 100$	pH
1	2	3	4	5	6	7	8
1	Profile I	0-30	1.81	2.12	19.8	80.2	5.1
2		30-60	2.18	2.24	2.7	97.3	5.4
3		60-90	1.39	1.97	29.4	70.6	5.2
4	Profile II	0-30	0.19	1.52	87.5	12.5	5.0
5		30-60	0.28	1.88	85.1	14.9	5.3
6		60-90	0.33	2.08	84.1	15.9	5.2
7	Profile III	0-30	5.36	9.84	45.5	54.5	5.0
8		30-60	4.27	4.88	12.5	87.5	4.5
9		60-90	5.61	5.68	0.5	99.5	4.8
10	Profile IV	0-30	5.94	18.84	68.5	31.5	4.1
11		30-60	4.04	13.40	66.4	33.6	4.3
12		60-90	3.61	13.84	73.9	26.1	4.2

(Contd.

1	2	3	4	5	6	7	8
13	Profile V	0-30	1.01	4.40	77.4	22.6	6.0
14		30-60	1.43	2.40	40.4	59.6	5.0
15		60-90	1.57	2.00	21.5	78.5	5.1
16	Profile VI	0-30	4.36	5.40	23.6	76.4	4.6
17		30-60	3.63	6.80	46.9	53.1	4.7
18		60-90	2.45	3.82	35.9	64.1	4.7
19	Profile VII	0-30	2.41	5.10	39.6	60.4	4.4
20		30-60	2.70	6.24	56.7	43.3	4.8
21		60-90	3.95	5.42	27.1	72.9	4.6
22	Profile VIII	0-30	2.40	2.50	2.3	97.7	4.3
23		30-60	0.78	1.84	55.2	44.8	4.3
24		60-90	1.48	1.62	8.6	91.4	4.4
25	Profile IX	0-30	10.37	24.32	57.9	42.1	3.0
26		30-60	13.19	26.12	46.4	53.6	3.9
27	Profile X	0-30	9.94	23.84	58.4	41.6	3.7
28		30-60	8.33	23.36	64.3	35.7	3.0
29	Profile XI	0-30	47.14	48.00	1.8	98.2	7.8
30		30-60	47.23	47.30	0.1	99.9	7.5
31		60-90	44.73	46.92	4.7	95.3	7.8
32	Profile XII	0-30	45.59	47.16	3.3	96.7	8.0

(Contd.

1	2	3	4	5	6	7	8
33	Profile XII	30-60	47.99	49,56	3.2	96.8	7.6
34		60-90	45.35	46.96	2.5	97.5	7.9
35	Profile XIII	0-30	1.72	5.90	71.5	28.5	4.6
36		30-60	1.34	3.60	62.6	37.4	4.8
37		60-90	2.53	3.00	15.6	84.4	4.9
38	Profile XIV	0-30	1.64	2.12	22.6	77.4	4.7
39		30-60	2.16	2.54	15.0	85.0	4.9
40		60-90	2.17	2.40	9.6	90.4	4.9

(vii) Exchangeable hydrogen

The variation of exchangeable H in the soils is given in Table VIII.

The exchangeable H varied from 0.06 - 14.9 me./100 g. of soil. The lowest value was obtained for a sandy soil (No.2) and a laterite soil (No.28). Exchangeable H was found to increase with depth in profiles II and X, whereas in profiles III, V, XIII and XIV it tended to decline down the profile.

(viii) Base saturation and unsaturation

The percentage base saturation of the various soils studied is given in Table VII. It is found to vary from 12.5% for a sandy soil (No.4) to 99.9% for a black soil (No.30).

E. Cation exchange capacity of the clay fraction and its composition

Data relating to the cation exchange capacity of the clay from surface soils and their chemical characteristics are given in Table X.

It is seen that the cation exchange capacity of the clay fraction varied from 10 me./100 g for the laterite soil to 57 me./100 g for the black soil.

TABLE X

Chemical composition of clay

Sl. No.	Soil type	Cation exchange capacity me./100 g.	Sesqui-oxides (R_2O_3) %	Fe_2O_3 %	Al_2O_3 %	SiO_2 %	Fe_2O_3/Al_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_2
1	Sandy Soil	28	24.75	11.67	13.08	55.50	0.57	7.23	4.60
2	Alluvial Soil	34	38.75	15.58	23.17	51.95	0.43	3.81	2.67
3	Laterite Soil	10	46.00	17.62	28.38	30.89	0.39	1.81	1.32
4	Black Soil	57	28.68	13.26	15.42	50.80	0.54	5.59	3.63
5	Forest Soil	19	34.67	13.67	21.00	42.88	0.41	3.47	2.50
6	Red Soil	11	38.55	12.22	26.33	37.96	0.24	2.45	1.97
7	Kari Soil	33	38.66	16.00	22.66	50.43	0.45	3.73	2.62

The total sesquioxides in the clay fraction ranged from 24.75 to 46.0%, the lowest value being for the clay separated from a sandy soil and the highest for the clay obtained from a laterite soil.

The Fe_2O_3 content of the clay fraction varied between the limits of 11.67% in the clay from the sandy soil to 17.62% for the clay from a laterite soil.

The minimum content of Al_2O_3, 13.08% was obtained for the clay separated from the sandy soil, while the maximum value (28.38%) was obtained in the case of the laterite soil.

The SiO_2 content was found to vary from 30.89% for the laterite soil to 55.5% for the sandy soil.

Iron/alumina ratio was found to vary from 0.24% for the red soil to 0.57% for the sandy soil.

The clay separated from the laterite soil showed the minimum value for silica : alumina ratio (1.81) whereas the sandy soil gave the maximum value(7.23).

The lowest silica sesquioxide ratio of 1.32, was shown by a laterite soil, whereas sandy soil showed the maximum value of 4.6.

Correlations

Correlation coefficients were worked out for the individual soil groups between C.E.C., clay, single value constants, total N, P, K, Ca and Mg. Correlations between pH, exchangeable sodium, percentage base saturation and unsaturation and exchangeable calcium were also calculated. The values for correlation coefficients are given in Table VI B.

An examination of the data revealed that C.E.C. and clay are positively correlated in all soil groups. Organic matter and C.E.C. are positively correlated in all soil groups examined except in sandy soils where a negative correlation is observed.

With regard to correlation between C.E.C. and single value constants it is found that C.E.C. and pore space are positively correlated in the case of alluvial, laterite, kari, black and red soils. The above two properties show a negative correlation in sandy, kole land and forest soils. Volume expansion and cation exchange capacity are positively correlated in all the soil groups studied except in the kari and forest soils. Negative correlation is observed between C.E.C. and water holding capacity in all soil groups except

TABLE VI (a)

Simple Correlations

Sl. No.	Relationship between X	Relationship between Y	Correlation coefficient	Nos. of pairs of values
1	Cation exchange capacity	Organic matter	0.295	40
2	"	Clay	0.614*** ✓	40
3	"	Pore space	0.681*** ✓	40
4	"	Volume expansion	0.501***	40
5	"	Water holding capacity	0.517***	40
6	"	Sticky point	0.149	40
7	"	Moisture equivalent	0.494**	40
8	"	Total nitrogen	0.550***	40
9	"	Total P_2O_5	-0.312	40
10	"	Total K_2O	0.467**	40
11	"	Total CaO	0.931***	40
12	"	Total MgO	0.867***	40
13	pH	Exchangeable sodium	0.417**	40
14	"	Exchangeable calcium	0.398**	40
15	"	Percentage base saturation	0.483**	40

1	2	3	4	5
16	pH	Percentage base unsaturation	-0.489**	40
17	Clay	Loss on ignition	0.639***	40
18	Clay	Total potassium	0.329*	40
19	"	Exchangeable calcium	0.574***	40
20	"	Pore space	0.736***	40
21	"	Volume expansion	0.571***	40
22	"	Sticky point	0.236	40
23	"	Moisture equivalent	0.599***	40
24	"	Water holding capacity	0.604***	40
25	Total exchangeable bases	Exchangeable calcium	0.981***	40

*** 0.1% level of significance
** 1% "
* 5% "

TABLE VI (b)

Simple Correlations

Sl. No.	Relationship between X	Relationship between Y	Correlation coefficients Sandy soil	Kole land	alluvial soil	laterite soil	Kari soil	Black soil	Forest soil	Red Soil
1	Clay	Cation exchange capacity	+0.213	+0.346	+0.845	+0.521	+0.449	+0.163	+0.454	+0.967
2	Organic matter	"	-0.021	+0.876	+0.985	+0.417	+0.812	+0.326	+0.866	+0.550
3	Pore Space	"	-0.545	-0.888	+0.742	+0.384	+0.532	+0.431	-0.026	+0.968
4	Volume Expansion	"	+0.681	+0.668	+0.975	+0.737	-0.246	+0.972	-0.617	+0.264
5	Waterholding capacity	"	-0.001	-0.907	+0.968	+0.494	-0.729	-0.480	-0.734	+0.503
6	Sticky point	"	-0.650	+0.997	+0.975	-0.352	-0.100	-0.204	-0.634	-0.305
7	Moisture equivalent	"	+0.090	-0.638	+0.968	+0.608	-0.278	+0.056	-0.815	+0.457
8	Total nitrogen	"	+0.022	+0.288	+0.225	+0.069	-0.859	-0.056	-0.332	-0.045
9	Total phosphorous	"	-0.510	+0.414	+0.687	+0.057	-0.012	+0.051	+0.186	-0.386
10	Total potash	"	+0.266	+0.396	+0.960	+0.532	-0.038	-0.016	+0.204	+0.001
11	Total calcium	"	+0.648	-0.482	+0.562	+0.208	-0.500	-0.648	+0.762	Nil
12	Total magnesium	"	-0.003	+0.993	+0.931	+0.463	+0.847	-0.028	-0.701	-0.275
13	pH	Exchangeable sodium	+0.792	-0.289	-0.369	-0.574	+0.038	-0.121	+0.042	+0.867
14	pH	Exchangeable calcium	+0.551	+0.898	-0.762	+0.379	-0.062	-0.044	+0.987	+0.686
15	pH	Percentage base saturation	+0.906	-0.288	+0.210	-0.261	-0.238	-0.986	+0.965	+0.402
16	pH	Percentage base unsaturation	-0.886	+0.739	-0.131	+0.551	-0.222	+0.065	+0.349	-0.365

the alluvial, laterite and red soils. Sticky point has a negative correlation to C.E.C. in all cases except kole land soils and alluvial soils. Moisture equivalent and C.E.C. are positively correlated in sandy, alluvial, laterite black and red soils, whereas negative correlation is observed, in the other soil groups.

Sandy, kole land, alluvial and laterite soils have a positive correlation between C.E.C. and Total N, while the other soil groups give negative correlations. Total phosphorus is positively correlated with C.E.C. in all the soil groups except the sandy, kari and red soils in which the correlation observed is negative. Total Potash is positively correlated to C.E.C. in all soils except kari and black soils. Total Ca and C.E.C. gave positive correlations in the case of sandy, alluvial, laterite, and forest soils. The others show negative correlations. Negative correlation is also observed between C.E.C. and total Mg in the case of sandy, black, forest and red soils. These two properties are positively correlated in the case of kole land, alluvial, laterite and kari soils.

The pH and exchangeable sodium show positive correlations in the case of sandy, kari, forest and red soils. Sandy, kole land, laterite, forest and red soils show positive correlation between pH and exchangeable calcium. In the other soil groups, a negative correlation is observed. Percentage base saturation and pH, give positive correlation for sandy, kole land, laterite and black soils. pH and base unsaturation percentage are positively correlated in the case of kole land, laterite, black and forest soils. Negative correlation is observed for the other soil groups.

TABLE XI

Range and mean values of results obtained

Serial No.	Property or constituent	Maximum	Sample No.	Minimum	Sample No.	Mean for 40 samples
1	2	3	4	5	6	7
1	Moisture %	10.51	34	0.08	38	3.43
2	Loss on ignition %	27.55	28	2.27	1	10.69
3	Nitrogen (N) %	0.54	28	0.01	15	0.12
4	Phosphorus (P_2O_5) %	0.23	18	0.01	26	0.09
5	Potassium (K_2O) %	0.54	11	0.04	39	0.20
6	Calcium Oxide %	2.04	34	0.02	4	0.27
7	Magnesium oxide %	2.69	31	Trace	21	0.28
8	Organic Carbon %	10.60	26	0.08	14	1.54
9	pH	8.0	32	3.00	25	5.10
10	Coarse Sand %	60.6	4	1.00	28	28.27
11	Fine Sand %	43.3	13	4.50	28	23.12
12	Silt %	26.50	25	2.00	40	9.97
13	Clay %	62.50	20	7.4	1	35.98

(Contd ...)

1	2	3	4	5	6	7
14	Apparent density	1.96	37	0.79	26	1.37
15	Absolute Sp: gravity	2.7	30	2.00	17	2.49
16	Maximum water holding capacity %	63.9	10	22.1	1	34.57
17	Pore space %	61.2	12	32.1	2	44.87
18	Volume expansion %	29.67	34	0.0	3	6.06
19	Sticky point %	54.31	10	8.98	6	20.90
20	Moisture equivalent %	27.26	10	1.04	4	10.19
21	Total cation exchange capacity me./100g	49.6	33	1.5	4	13.77
22	Exchangeable calcium me./100 g.	28.05	29	Trace	5	4.82
23	Exchangeable Magnesium me./100 g.	20.90	31	"	5	3.26
24	Exchangeable Potassium me./100 g.	1.40	11	"	5	0.49
25	Exchangeable Sodium me./100 g.	6.04	31	"	5	0.85
26	Total Exchangeable bases me./100 g.	47.99	33	0.19	4	9.91
27	Base Saturation %	99.9	30	12.50	4	63.76
28	Exchangeable Hydrogen me./100 g.	14.97	28	0.06	2	13.32
29	Base unsaturation %	87.50	4	0.53	9	36.24
30	Organic matter %	18.27	26	0.14	14	2.59

DISCUSSION

DISCUSSION

Cation exchange capacity

Cation exchange is a universal property of soils. The extent to which soils are able to exchange cations varies widely from a few milliequivalents to as high a value as 200 me./100 g of soil. Generally speaking the C.E.C. of a soil depends on two variables, namely the amount and kind of exchange material present. Thus soils containing montmorillonitic clay have a relatively high C.E.C. while soils with hydrous micas come intermediate followed by those containing kaolinite which usually show a very low C.E.C. The cation exchange capacity shows extreme variations because of the variable influences of organic matter. The silt and fine sand fractions also possess C.E.C. though to a lesser extent than clay. The high cation exchange capacity of humus (200 me./100 g) would explain why soils rich in kaolinite but associated with humus sometimes give high values for C.E.C. Thus the exchange capacity of a soil varies with the content and nature of the exchange material.

With regard to the results of the present investigation, the C.E.C. shows wide variations between the soil groups studied, which may be explained as a reflection of the differences in the parent material and the nature of the exchange complex of the soils under study.

The sandy soils (Nos. 1 - 6) with a low content of clay (7.4 - 8.6%) possess a low value for C.E.C. (1.62 - 2.24 me./100 g). These soils have only a very low status of organic matter (0.21 - 0.32%) whose contribution to the C.E.C. is practically negligible. This fact is strengthened by the negative correlation in (r = - 0.021) obtained between C.E.C. and organic matter in sandy soils. Therefore it may be concluded that the main contributing factor to the C.E.C. of sandy soil is the clay fraction as brought out by the results of the present study. In this connection it would be worth mentioning the positive correlation obtained (r = + 0.231) between clay and C.E.C. of these soils. Another point to be noted with regard to the importance of clay in the C.E.C. of these soils is the changes in its values down the profile which follow the changes in the clay content. The clay content increases with depth in both profiles with corresponding increases in the values for C.E.C. This clearly indicates that eluviation of clay down the profile has occurred as a result of leaching. Nambiar (1947) working with rice soils of Kerala obtained low values for sandy soils which again is in accordance the results of the present study.

The kole land soils (No.7-9) have a C.E.C. ranging from 4.27 - 5.36 me./100 g). The surface horizon shows a high organic matter content (4.89%) compared to the lower layers. The clay content is also a maximum in the surface layer and hence the high C.E.C. of the surface soils (5.36 me./100 g) can be attributed to the combined effects of clay and organic matter. Turner (1932) as cited by Mukherjee (1944) observed that organic matter associated with clay had a comparatively higher C.E.C. The present observation substantiates the above assumption.

Of the two alluvial profiles studied profile IV had a comparatively high C.E.C. (13.4 - 18.84 me./100 g), the surface layer showing the maximum value. The high organic matter content of the surface layers (7.2%) is a major contributing factor to the C.E.C. of the whole soil. The decrease in organic matter content with depth was accompanied by a corresponding decline in C.E.C. also. Moreover the soils contained a high proportion of clay, silt and fine sand, all of which would have contributed to the C.E.C., though in a decreasing order. The role played by fractions other than clay characterising the C.E.C. of a soil has been brought out by Mukherjee (1944) in his studies on Indian soils. Because of the dominance of the finer fraction in the soils under study its contribution cannot be over looked. Moreover the positive correlation between clay and C.E.C. (+ 0.845) as well as between organic matter and C.E.C. (+0.985) bears ample testimony to the fact that clay and organic matter are the important factors affecting the C.E.C. of these soils. In contrast to this, profile V which is also an alluvial deposit, showed very low values ranging from 2 - 4.4 me./100 g. A perusal of the data on the mechanical composition of these soils show that they are dominated by the fine sand fraction which has a low C.E.C. The slightly higher C.E.C. for surface soils is mainly due to the organic matter content, since the amount of clay appears to be least in this layer. This observation agrees with the result of Yuan *et al*. (1967) who observed that in sandy soils it is the organic matter which decisively influences its cation exchange capacity. In this case since the value for C.E.C. is low the contribution of the organic fraction becomes appreciable.

The laterite soils (Nos. 16-24) have a low C.E.C. Of the three profiles studied the range in exchange capacity is from 1.62 - 6.84 me./100 g. In spite of the high content of clay (35-62.5%) present in these soils, the extremely low values for C.E.C. clearly indicates that not only the quantity but also the type of clay mineral present plays a major role in deciding the exchange capacity. This view has been stressed by Kelley (1948) who observed the importance of the content and kind of exchange material as factors affecting the cation exchange capacity of the soil. The laterite soils have been found to possess kaolinite as the dominant clay mineral in addition to oxides of Fe and Al . Grim (1953) enumerating the importance of clay minerals in cation exchange placed the C.E.C. of pure kaolinite between 3 and 15 me./100 g. The Fe and Al oxides also possess C.E.C. though to a much lesser extent. Hence the low C.E.C. of these soils can be attributed to the characteristically predominant kaolinite type minerals and free oxides in these soils. Satyanarayana and Thomas (1967) working with Malabar laterites, Menon and Mariakulandai (1957) working on red and laterite soils of Tamil Nadu and Koshy (1962) working on Kerala soils obtained results which are in agreement with the present observation. In all the three profiles studied the surface horizon had a higher C.E.C. than the lower layers indicating clearly the role played by organic colloids which possess a high C.E.C. The present observation is also in line with that of Menon and Mariakulandai (1957). The clay content in two profiles (Nos. VI and VII) shows maximum accumulation in the intermediate layers, with a corresponding high value for C.E.C. This observation is in harmony with the findings of Roy and Landey (1962) in the red and laterite soils of Mand water shed. The correlation coefficient worked out between clay and C.E.C.

has given a positive relationship (r = + 0.521). Because of the low C.E.C. of the clay, increase in clay content naturally results in a corresponding increase in C.E.C. values. The correlations between C.E.C. and organic matter is also positive (r = +0.417). The C.E.C. being generally low for these soils the contribution of the organic fraction becomes more apparent. So an increase in these two components will definitely increase the C.E.C. of the soil. This is quite clear from the results of the present investigation.

Kari soils (Nos 25-28) possess a comparatively high C.E.C. ranging from 23.4 - 26.7 me./100 g which agrees with the values obtained by Kurup (1967) working with similar soils (23.4 - 42.5). Kari soils have a characteristically high content of organic matter. In fact these soils possess the highest organic matter content (13.9 - 18.3%) among the soils studied. Apart from this, the clay fraction of these soils is reported to have a preponderance of a mixture of illitic and montmorillonitic types of clay minerals, (Gopalaswamy 1958; Pillai 1964). Illitic and montmorillonitic clay mineral have a high C.E.C. as reported by Grim (1953). Hence the high C.E.C. of these soils can be attributed to a high content of organic matter coupled with the presence of illitic and montmorillonitic clay minerals. This is in agreement with the findings of Kurup (1967). The increase in the C.E.C. of the subsurface horizon in profile IX is evidently due to the higher organic matter content of that layer.

The highest value for C.E.C. (46.92 - 49.56 me./ 100 g) observed in the present investigation is in the black soils Nos 29-34). High values for the C.E.C. of black soils have also been reported, by Alexander and Durairaj (1968). Ray Chaudhuri et al. (1943) observed beidellite type of clay minerals in the clay fraction, of these soils. Grim (1953) has reported very high values of C.E.C. for the 2:1 type of clay minerals. Hence the high C.E.C. of these soils can be due to a predominance of these clay minerals. The more or less uniform trend in the clay and C.E.C. of the profile shows that very little eluviation has taken place. These soils have a comparatively low level of organic matter and hence the contribution of organic colloids in the cation exchange reaction is only of minor importance. Decrease in C.E.C. with depth is noticed in profile XI while increase in intermediate layers is seen in profile XII. Das et al. (1946) working with Indian soils also made similar observations with regard to the variation of C.E.C. down the profile.

The forest soils Nos (35-37) show very low values for C.E.C. (3-5.9 me./100 g). The deeper layers tend to be lateritic with characteristically low values for C.E.C. The increased organic matter content of the surface and subsurface layers appears to be the contributing factor in the high C.E.C. values of these layers. The clay content shows an increasing trend downwards with no corresponding change in the C.E.C., clearly indicating that the clay fraction has only a low C.E.C.

Red soils in general have a low C.E.C. The profile studied in the present investigation also confirms this. The results obtained agree with the findings of Lall (1953) in the red soils of Bihar, and Menon and Mariakulandai (1957) in red soils of Tamil Nadu. The predominance of kaolinite type of clay minerals in these soils may be the main factor responsible for the observed low value of C.E.C.

Exchangeable bases

An examination of the exchangeable base status of the various soils (Table V) indicate characteristic differences among the soil groups studied.

In the sandy soils (Nos 1-6) it was found that calcium formed the predominant exchangeable base followed by Mg, K and Na. Profile II showed only traces of exchangeable Ca, Mg, and K. While exchangeable sodium was present in small quantities.

Because of the low clay content the nutrients added to the soils are immediately leached down, as evidenced by the increase in the total exchangeable bases with depth. Because of the low C.E.C., and exchangeable base, the fertility status of these soils is poor. The importance of cation exchange phenomenon has been emphasized by Hall (1924) according to whom "a good soil is one with larger amounts of exchangeable bases". Donahue (1958) considered C.E.C. as a single index of fertility, so that soils with low exchange capacities had a correspondingly low fertility status. The positive correlation between pH and exchangeable Na noted in these soils agrees with the findings of Milton and Wadleigh (1951) working with Western soils.

The kole land soils are characterised by submerged conditions during most part of the year. The Ca formed the predominant exchangeable base in the surface layer. Musierowicz et al. (1956) working with Warsaw soils, observed an increase in the content of exchangeable Ca with increase in humus and clay. So the higher Ca content in these soils can be attributed, to the presence of relatively higher amounts of humus and clay. The higher Mg content of the soils may be attributed to the presence of Magnesium bearing minerals, which release Mg on weathering. The increase in Mg down the profile is obviously due to leaching. In the case of Ca it is not washed down to the same extent as Mg especially in soils containing sufficient organic matter, where Ca forms Ca humate which is relatively insoluble. This was observed by Stephenson (1926) working with Oregon soils.

In alluvial soils (Nos. 10-15) exchangeable Ca and Mg showed an increase in the subsurface layers clearly indicating that eluviation has taken place. The greater Mg content can be due to the preponderance of Mg bearing minerals. Profile V which is also an alluvial deposit shows a low content of exchangeable bases. Lower down the profile it was pure sand and this is clearly the reason for the poor content of bases in these soils.

In the lateritic profile Ca formed the predominant exchangeable base (60%) followed by Mg. Na and K were found only in traces. These observations agree with the results of Menon _et_ _al_.(1953). In laterite soils they observed, more than 50% of the bases to be Ca followed by magnesium. Potassium and sodium were found only in traces. In the present study, of the 3 profiles examined, profile VII showed accumulation of the bases in the subsurface layer which may be due to the intense leaching to which these soils are subjected. The increased content of Mg in profile VI suggests the presence of ferromagnesium minerals which liberate Mg on weathering.

Kari soils are peculiar in that they are submerged soils and hence show variation in the content and behaviour of exchangeable bases. In the profiles studied (IX and X), Ca constituted, the predominant divalent cation. The range of exchangeable Ca observed in these soils (3.6 - 4.5 me./100 g) is comparable to the results (1.52 - 7.7 me./100 g) obtained by Kurup (1967). The low pH of these soils reflects the presence of a high content of hydrogen in the exchange complex. Mg formed the next predominant divalent cation, the range observed being 2.2 - 4.18 me./100 g which is in agreement with the figures (1.95 - 6.63 me./100 g) reported by Kurup (1967) for *kari* soils. Exchangeable K was found only in relatively small quantities ranging from a trace to 0.75 me./100 g. Martilla (1965) working with Finnish soils, observed only traces of K, and Na in organic soils. In the present investigation, the exchangeable sodium content of the kari soils was comparatively higher. The periodical inundation of these soils with sea water which contains Na and Mg salts will explain the presence these elements in the exchangeable form in these soils. This again is in agreement with the findings of Nambiar (1947) in the rice soils of Kerala.

The black soils showed a high C.E.C. which is to be attributed to the 2 : 1 type of clay minerals present in them. The dominant cation was Ca followed by Mg, Na and K. The dominance of Ca and Mg in calcareous soils has been observed by Das <u>et al</u>.(1947) working with Indian soils, and also by Menon <u>et al</u>.(1957) working with the black soils of the Tinnes tract. In both the profiles in the present study Ca was a maximum in the surface layers whereas Mg tended to increase downwards. This observation is in agreement with the findings of Das <u>et al</u>. (1947) in some Indian soils. The clay content of these soils increases with depth showing thereby that eluvation has occurred. The variations in the bases especially K with depth as seen from the present study indicate that the bases were also leached down the profile.

As in the case of most of the soils studied, the forest soils showed a predominance of Ca and Mg. The nature and distribution of the exchangeable bases in these soils as revealed by the present study reflects the intense leaching to which these soils are subjected. The low C.E.C. of these soils also suggest a low content of exchangeable bases.

The red soils are very poor in bases. The occurrence of bases decreased in the order Ca > Mg > K > Na.

This is of the same order as observed by Menon and Mariakulandai (1957) working with the red soils of Tamil Nadu. They observed only traces of exchangeable Na in these soils. The present study also gives a low value for exchangeable Na. The total bases increase with depth showing the effect of rainfall and the resultant leaching of bases.

pH and unsaturation

Correlations worked out between pH and base unsaturation for all the soils samples considered together are negative. Since pH is a measure of the H - ion concentration the above relation between the two factors is only to be expected. When correlations were worked out between these two factors for individual soil groups the general relationship did not always hold good. Rost and Zetterberg (1931) working with soils of Minnesota obtained this general relationship, but these workers observed that since pH is influenced by a number of factors other than H - ions a close relationship is not always obtained, when it is attempted to correlate pH with unsaturation alone. The results of the present investigation also conform to the findings of the above workers.

The pH and base saturation also did not show consistent relationship for individual soil groups, while they were positively correlated for all the samples taken together. Wilson (1930) working on New York soils observed that change in pH will not bring about corresponding changes in base saturation of soils or in other words, soils of the same pH may have different degrees of unsaturation. The present findings are in line with this observation.

Cation exchange capacity and chemical composition of clay

The C.E.C. of the clay separated from each soil group showed a wide variation (10-57 me./100 g), clearly indicating the differences in their electro-chemical nature. Several investigators have stressed the importance of the nature of the clay complex in deciding the C.E.C. of a soil. In the present study C.E.C. for the clay from the laterite soil (10 me./100 g) and red soil (11 me./100 g) clearly indicates the preponderance of kaolinitic type of clay minerals in them. This observation has been corroborated by other workers like Satyanarayana and Thomas (1967), Menon and Mariakulandai (1957) and Ray Chaudhuri *et al*. (1943). The C.E.C. of black soils (57 me./100 g) is the highest observed in the present study. Manickam (1961) observed a C.E.C. of 60 me./100 g for the clay from black soils. Ray Chaudhuri *et al*. (1943) Menon and Sankaranarayanan (1957) and Parthasarathy (1959) have also reported values ranging from 60-120 me./100 g. The results of the present investigation agree with the findings of the above workers. Ray Chaudhuri et al. (1943) working with black soils of Coimbatore observed in them beidellite type of clay minerals characterised by a high C.E.C. Hence the high values for C.E.C. obtained, for these soils can be reasonably attributed to the presence of 2 : 1 type of clay minerals. The clay from kari soil has a C.E.C. of 39 me./100 g. Pillai (1964) obtained a high C.E.C. (44 - 50 me./100 g) for the clay from kari soil, and has suggested that the high C.E.C., high SiO_2/R_2O_3 ratio ($>$ 2) and the silica/alumina ratio (3.5 - 6.0) indicated the predominance of the montmorillonitic type of clay mineral with possibly some illitic mineral also. Gopalaswamy (1958) also observed a mixture of montmorillonite and illite clay minerals in kari soils. Kanno et al. (1958) suggested that clay separated from peat consists mainly of halloysite, illite, and hydrated halloysite, with some amounts of chlorite. The results of the present study are also in agreement with the above observation and it can be concluded that these soils have a dominance of the 2:1 type clay mineral.

Generally speaking the chemical composition of the clay fraction does not throw much light on the clay mineral content of the soils. This is primarily because soil clay consists of mixtures of different clay minerals. The molecular ratios refer to pure clay minerals only. The usefulness of the SiO_2/R_2O_3 ratio for the identification of clay minerals was doubted by workers like Marshall (1935) for mixtures. It was suggested that these are useful for laterite soils only. The following molar ratios were used for characterising clays from Madras soils : a SiO_2/R_2O_3 ratio of 2.2 - 3.2 for black soils, 0.8 - 1.4 for laterite soils, 1.8 for clay from alluvial soils and 1.8 - 1.9 for red soils (unpublished data. A.C. &. R.I., Coimbatore), Manickam (1961) studied the clay separated from typical black, red, laterite and alluvial soil from Tamil Nadu and reported that SiO_2/R_2O_3 ratio was >3 for black soil, 2 for laterite soil and between 2 and 3 for other soils. The present findings are also in confirmity with the above results.

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

A study was made of the cation exchange properties of forty soil samples representing fourteen typical soil profiles of Kerala in relation to their various physico-chemical properties. The chief findings are summarised below:-

(1) The cation exchange capacity of the different soil groups exhibited wide variations, the sandy soils recording the lowest and the black soils the highest values. With the exception of the black, kari and some alluvial soils all other soil groups gave very low values for this property.

(2) Correlation between cation exchange capacity and clay for all the samples taken together was positive and highly significant. The same positive relationship was observed when the individual soil groups were considered.

(3) The relationship between organic matter and cation exchange capacity for all the samples together was positive but not significant.

(4) The exchangeable base content of the different soils was in the order Ca > Mg > K > Na. In the case of kari and black soils the exchangeable sodium showed a higher content over potassium. The maximum amounts of exchangeable Ca, Mg, and Na was observed in the black soils.

(5) The highest values for exchangeable H was observed in the case of kari soil which also recorded very low values for pH.

(6) Of all the soil groups studied, black soils had the highest base saturation percentage.

(7) The pH was correlated positively and significantly with base saturation, and negatively and significantly to base unsaturation.

(8) The clay fraction from laterite soils recorded the minimum value for the C.E.C., while the clay from the black soils gave the maximum value for this property.

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