SOIL MORPHOLOGY, GENESIS, CLASSIFICATION AND POTASSIUM RELEASE CHARACTERISTICS OF INTEGRATED WATERSHED DEVELOPMENT PROJECT AREA (ORM - 3 - 8 - 5 - 1) IN KANDHAMAL DISTRICT.

A THESIS SUBMITTED TO
THE ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY, BHUBANESWAR
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

MASTER OF SCIENCE IN AGRICULTURE
(AGRICULTURAL CHEMISTRY, SOIL SCIENCE AND BIOCHEMISTRY)

BY
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THESIS ADVISOR *Dr. G. C. Sahu*

DEDICATION

I affectionately dedicate this thesis to my beloved parents, wife and children, who have been patient and helpful as I isolated myself for long days preparing my study and research work for enabling me to get this degree.

APPROVAL SHEET

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1994

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CERTIFICATE

This is to certify that the thesis entitled *"SOIL MORPHOLOGY, GENESIS, CLASSIFICATION AND POTASSIUM RELEASE CHARACTERISTICS OF INTEGRATED WATERSHED DEVELOPMENT PROJECT AREA (ORM-3-8-5-1) IN KANDHAMAL DISTRICT"* Submitted in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** (Agricultural Chemistry, Soil Science and Biochemistry) to the Orissa University of Agriculture and Technology, Bhubaneswar is a faithful record of bona fide research work carried out by **Sri Narayan Das**, under my guidance and supervision during the academic session 1993-94. No part of this thesis has been presented in any form for any other degree or diploma.

All possible helps and sources of information availed during the course of this investigation have been duly acknowledged.

22.4.95
(G. C. Sahu)

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I bow down my head and pay my obeisance at the lotus feet of Lord Shiva, the supreme mater to bless me so that I lead a dedicated, devoted and balanced life surrendered at His feet.

Narayan Das.
(Narayan Das)

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Dated the th April 1995.

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TITLE OF THE THESIS	:	Soil Morphology, Genesis, Classification and Potassium Release characteristics of Integrated Watershed Development Project Area (ORM -3-8-5-1) in Khandamal District
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ABSTRACT

A study was undertaken in the Nedisahi Nalla mini-watershed (ORM 3-8-5-1) in Kandhamal district (20°28' N. latitude - 84°21' E. longitude). It was a sloping terrain land with a general slope of 8-15% and 3-5% within different physiographic units. Four physiographic unit from Sidingi village comprising, foot-hills, upper ridges, mid-upland and mid-medium land and another physiographic unit in the medium-valley land of Nedisahi village were demarcated and one profile each from these units were studied in detail. Besides, twenty composite surface samples from different physiographic units were analysed to know the general nutrient status and other characteristics of the study area.

The soil colour on the surface varied from reddish brown through reddish yellow to light reddish brown from upper ridges down the slope which gradually changed to yellowish red

in the sub-surface horizons along the sloping terrain. The profiles were heavier at the bottom regions than the surface regions. The surface soil texture of foot-hill was sandy which gradually changed to sandy clay loam and loam down the slope. Within the profiles of Sidingi area the clay content increased down the depth with presence of thin patchy clay cutans in the sub-surface horizons qualifying for argillic horizons. But a weakly developed cambic horizon was observed in Nedisahi series.

Soil pH value usually increased down the depth with some variation resulting in soil reaction almost medium to slightly acidic in different horizons of the profiles. The surface soil are usually medium acid. The organic carbon content was low (0.17 to 0.40%) on the surface which gradually decreased down the depth of the pedons. The CEC values were comparatively low on the surface horizons and increased gradually with depth and had a linear correlation with clay content (r = 0.945**). The exchange complex in all the profiles were dominated by Ca^{++} followed by Mg^{++}, K^{+} and Na^{+}. The percentage base saturation value, in general, increased from the surface downwards. The rating for available nutrient was low for nitrogen and medium for phosphorus and potash. Available nutrient values of composite surface samples ranged from 53 to 279, 2.61 to 33.38 and 110 to 370 kg/ha for N, P_2O_5 and K_2O respectively. For profile samples, they were 23 to 222, 17.72 to 34.32 and 110 to 240 kg/ha for N, P_2O_5 and K_2O respectively. The lime requirement for composite surface samples varied from 1.6 to 4.5 and for profile samples from 1.6 to 3.4 tonnes of $CaCO_3$ per acre. Free Fe_2O_3 content varied from 0.4 to 2.87 per cent in different horizons and showed a significant positive correlation with clay content (r=0.991**).

Percentage of free Fe_2O_3 increased along with the clay content. From the Potassium release characteristics it was clearly understood that different forms of K were in dynamic equilibrium with each other as they were significantly correlated with each other. The water soluble K had positive correlation with sand but negative correlation with clay, total K, exchangeable K, lattice K and non-exchangeable K. Exchangeable K had positive correlations with clay, non-exchangeable K and lattice K but negative correlation with sand. Positive correlation existed between non-exchangeable K and clay; lattice K and total K but negative correlation with sand. Lattice K had positive correlation with clay, silt and total K but negative correlation with sand. Total K was correlated positively with clay and silt.

This soils of foot-hills, upper ridges, mid-up land and mid-medium land (Sidingi series) under study were classified under *Haplustalfs*. The medium valley land of the study area (Nedisahi series) was classified under *Ustochrepts* as per Soil Taxonomy.

Necessary cropping system and suggestive treatments were given for the integrated management of the watershed area.

INTRODUCTION

Soil is our greatest natural resource. It is the heritage and basis of our economic stability and national strength. It differs in its productivity capacity, in value and in the uses to which it can be put with. For the fast growing population and rapidly expanding economy, increasing demand shall be made upon the land. Per capita land availability in India has reduced from 0.48 ha (1951) to 0.20 ha (1981) and expected to reach 0.15 ha by 2000 AD (Kanwar 1994). It is therefore, very necessary for us, as a first step towards agricultural production, to understand the soil, its characters which affect the productivity and evolve measures which would conserve the soil and maintain its fertility, in order to achieve a sustained higher production and ensure proper utilisation of the land.

To ensure sustainable use, we need a good inventory of our soil resources their distribution, quality and use-potentials. Since vast stretches of our soil resources are under going degradation fast enough with attendant risk of jeopardizing food security for the future generations, there is need to promote the most efficient systems of soil management which arrest this decline in soil quality.

Being an important component of our geosphere-biosphere system, soils provide food, fibre, fodder, fuel and forest for a variety of basic human needs via their direct contribution to the regulation and control of water and nutrient cycles. History records the rise and fall of civilizations in accordance with their wise use or abuse of the soil resources.

Considering the limited prospects of irrigated regions in meeting the future food requirement, there is a need for a shift in the development priorities in favour of dryland agriculture. Reversing the process of degradation and conserving water *in situ* with a purpose to sustain agricultural production from these rainfed lands is the need of the hour. It is in this context, that, the govt. of India is giving top priorities for the developmental work on WATERSHED basis. National watershed Development Project (NWDP) which is a central govt. funded programme and Integrated watershed Development Project (IWDP) which is funded by world Bank are in operation in various states including the state of Orissa. The broad objective of these programmes is to conserve the land and water resources *in situ* for intensive use and management through a holistic perspective of agricultural systems (Rajgopalan, 1991).

The Watershed is a manageable hydrological unit that makes a harmonious use of the prevailing climate, soils, water, locally available material and human resources towards stepping up crop yields.

Watershed management has been defined in India as a "rational utilization of land and water resources for optimum and sustained production with minimum hazard to natural resources. It is essentially related to soil and water conservation which means proper land use, protecting land against all forms of deterioration, building and maintaining soil fertility, conserving water for farm use, proper management of water for drainage, flood protection, sediment reduction and increasing productivity from all land uses".

In Orissa, the watershed programme actually operated through the soil conservation department, during the year, 1982 in a sporadic manner. Now under National Watershed Development Project for Dryland Agriculture (NWDPRA) the programme are in operation in 258 watersheds in the state. The I.W.D.P. was introduced in the districts of Ganjam and Phulbani in the year 1990-91. The Orissa University of Agriculture & Technology has taken the responsibility of providing research support to various activities undertaken by the state soil conservation department under the I.W.D.P. To provide basic information to a resource inventory with regards to soil characterisation, classification and nutrient status of the soil of a particular watershed area soil survey is a pre-requisite.

The final result of soil survey is a comprehensive inventory of the soil resources. The most important and widely recognised practical utility of soil surveys, soil classification and soil mapping is to provide a scientific and systemic basis for the study of soil-water-crop relationship with a view to properly utilise the land and water resources to increase crop production, develop irrigation efficiency, adopt water and soil conservation measures and to reclaim salty and water logged areas.

To feed the overwhelming population of our country, there is a need to produce about 250 million tonnes of food grains by 2000 A.D. This could be achieved by taking two area development approaches in the field of Agriculture and rural development. (1) Command area development which is adopted for comprehensive development of irrigated area, and (2) watershed area development.

Annual soil loss estimates in different regions of India are as follows (Dhruva Narayana & Ram Babu, 1983).

Sl. No.	Land resource region	Area (000'Km²)	Soil less (tonnes/km²)	Major land use
1.	North Himalayan forest region	131.70	287	Forest
2.	Punjab-Haryana alluvial plains	101.25	330	Agriculture
3.	Upper gangetic alluvial plains including ravines	200.00	1410-3320	Agriculture or Wasteland
4.	Lower Gangetic alluvial Plains	145.50	287-940	Agriculture
5.	North-Eastern forest region.	161.002	2780-4095	Agriculture, Shifting-Cultivation
6.	Gujurat alluvial plain region including ravines	62.75	240-3320	Agriculture
7.	Red soil region	68.80	240-360	-do-
8.	Black soil region	67.34	2370-11250	-do-
9.	Lateritic soil	61.0	3930	Agriculture

Hence much emphasis has been given in the VIII five year plan for integrated watershed area development for "ending the neglect of vast rainfed and dryland areas". The main objectives of the VIII five year plan are as follows;

I) Conservation, upgradation & utilisation of natural resources like land, water, plant, animal and human beings in a harmoneous and integrated manner;

II) generation of massive employment during the project period and regular employment after the completion of the project;

III) improvement of production environment and restoration of ecological balance through scientific management of land and rain water;

IV) reduction of inequalities between irrigated and rainfed areas; and

V) in addition, production of fuel, fooder, vegetables, spices etc. in suitable areas.

Keeping an eye to the above mentioned facts and bottlenecks, the mini-watershed, Nedisahi Nallah (ORM-3-8-5-1) in Khajuripada Block of Kandhamal (Phulbani) district has been selected as pilot watershed for the present study/investigation. The criteria for selection of this particular mini-watershed as pilot project were;

1. The mini-watershed area is approachable by all weather road from the district headquarters as well as state capital.
2. Within the mini-watershed necessary infrastructure facilities are available.
3. O.U.A.T. research project on I.W.D.P. is located at a close proximity to the mini-watershed area.
4. The mini-watershed area have a good range of on-farm and off-farm land management problems that need to be tackled.
5. The mini-watershed forms the catchment of pilasalki M.I.P.

The mini-watershed is located in Mahanadi catchment of Salki sub-catchment, Pilasalki watershed, Budharkedi sub-watershed. The Nedisahi Nallah mini-watershed is a pentad streamlet of the watershed system. The mini-watershed comprises of eight number of villages, the total area of which is 1045.999 ha.

In the present investigation an attempt has been made to study the soil morphology, genesis, classification as well as the potassium release characteristics of that area.

I.1. Objectives :

The objectives in the present investigations are :

i) to traverse the area and survey the sidingi and Nedishahi village in detail,

ii) to select the profile sites from different physiographic regions and have a morphological study of different profiles that represent the soils of the project area,

iii) to characterise the soils of the region,

iv) to classify the soils as per Soil Taxonomy,

v) to study the fertility status of the region with special emphasis on potasium release characteristics inside the profiles, and

vi) to suggest suitable land use management for sustainable production.

REVIEW OF LITERATURE

In this chapter a review of the literature pertaining to the present investigation has been made under the following important sections.

- Morphological and physical characteristics.
- Chemical characteristics.
- Physiography and Land form.
- Genesis of soil.
- Classification of soils.
- Different forms of potassium in soil and their releasing characteristics.

II.1. Morphological and physical characteristics :

The nature and morphology of the laterite soil profile is determined by the nature of the parent material (Pendelton 1942).

Sinha *et al.* (1962) studied the morphology of some red laterite soils of Ranchi in relation to topography of the land. They observed that, down the slope, the depth of profile increased, texture varies from lighter to heavier, structure changes from single grained or granular to blocky/prismatic, pH change from acidic to natural, status of organic carbon and nitrogen increases, variation in colour of surface soil is also in harmony with the topography in which these soils are found to occur. The profiles are encountered by iron stone gravels of irregular shape which appear to be undergoing dissolution. In these gravels, resistant material such as quartz standout sharply from the surface. The vesicular and indurated character of the surface crust is due to its exposure by which certain horizons had been washed by erosion.

The water stable aggregates of different sized fractions at different depths in profiles in a sal forest of Dehradun (Yadav and Banerjee, 1968) indicated a positive correlation between organic matter content and soil aggregation. Other properties show relatively feeble or no correlation.

Govindarajan and Datta Biswas (1968), studied the red soils occuring in the Eastern Ghat region particularly the soils falling in the Machkund basin. The soils in general are deep with light textured surface layer, grading to moderately fine to fine textured sub-surface horizon mixed with coarse fragments.

Murthy *et al.* (1968) studied the watershed features in Kundah project in Madras. They observed the soils are quite susceptible to erosion due to the prevailing undulating to very steep topography and high rainfall. They suggested that, management of land in the water shed reflects largely upon the run-off and the quantity of stream flow. Indiscriminate deforestation and cultivation on steep slopes without adoption of proper soil conservation practices lead to severe soil erosion and consequent siltation.

Martain *et al.* (1974) Studied on the red soils of south spain have shown a moderate to good porosity in the upper horizon with a decrease in the porosity in the B horizon. The increase in clay in the B horizon determines the physical properties studied in connection with the porosity.

The effect of soil texture and grass cover on water erosion in the foot-hill soils of Punjab was studied by Singh and Verma (1978). Soils with grass cover showed more run-off than the cultivated but bare soils. Run off and soil loss increase with increase in the fineness of soil texture. Major textural group of the area constituting sands and loamy sands are less erodible.

Rajamannar and Krishnamoorthy (1978). Studied the physico-chemical characters of forest soils of Western Ghat in south India. It was observed that, the soils of 200 m. altitude were colluvial in nature while the soils of 1010 m and 2237 m. altitude were laterite in origin. The clay content of the soil increases with increase in depth. Bulk density is reduced at higher altitude due to increase in organic matter content. The maximum water holding capacity, total pore space and moisture equivalent increases with increasing elevation.

There was no definite relation of humus fractions with Sand and Silt but clay was significantly related with organic carbon and humic acid carbon (Joshi and Ghonisikar 1979).

In toposequence of oxisols developed from basalt in the central plateau of Brazil, moist soil colour changed from dark reddish brown (2.5 YR 3/4) in upper slope position to dark yellowish brown (10 YR 4/4) in lower slope position (Curi and Franzneir 1984) soil colour is a reliable indicator of iron oxide mineralogy which reflect the genesis of soil and influence properties that affect plant growth. This colour should be used at a relatively high categorical level in soil classification system to define classes of latosols and oxisols.

A toposequence of soils in the mid-upland laterite region of Kerala showed a change from a reddish colour at the crest to gray in the valley (Venugopal and Koshy 1985).

Singh and Prakash (1985) studied on the soils of Kaphra- Bhaura sub-watershed in Almora dist (U.P.) and observed that the soils associated with well maintained terraces were stable and less erodible than those under poor terraces, grazing, degraded civil forests. Most of the soil characteristics except coarse soil fragments showed a negative correlation with elevation and terrain slope. Erodibility indices showed positive correlation with elevation and slope.

Sambyal and Sharma (1986) studied fifteen eroded forest soil profiles in lower Himalayas. The slope was 10-30% and degree of erosion was slightly to severe. An erodibility rating curve based on raindrop impact showed Alfisols are relatively stable, Inceptisols and Mollisols are moderately erodible and Entisols are most erodible. The more erodible nature of Entisols could be ascribed to their low organic matter and C.E.C. levels and high sand content, the parameters showing significant relationship with erodibility.

Studies on seven soil pedons of the catenary sequence indicated that the soil of the piedmont plain have relatively higher clay and CEC, lesser coarse fragments and well developed pedon with intersecting slicken sides as compared with the soils of flat topped hills, hill slopes and flood plains. The soils could be classified into Entisols, Inceptisols and vertisols in the sequence (Challa and Gaikward, 1986).

Four typical pedons, representing different land types in the Kandi areas of siwalik foot hills indicated that the soils are of calcareous type,stratified and variable in texture and have an ochric epidon underlain by a C-horizon (in chos-piedmont plain and foot-hill) and a structural/cambic B-horizon in the terraces. The soils in piedmont plain and foot-hills have been classified as Typic Ustifluvents, those in chos as Typic Ustipsamments and those in terraces qualify for Typic Ustochrepts (Sharma *et al.*, 1986).

In general, as elevation and slope decreases the soil texture become finner, the water retention capacity, hydraulic conductivity and infiltration rates improved in Kafra Bhaura sub- watershed (Kumar and Tripathy, 1987).

Zende (1987) conducted reconnaissance soil survey of a part of Mokokhung (Nagaland) using areal photograph (1:40000 scale) and observed that the dominant soils were; (i) Fine loamy, Typic Hapludults on very steep side slopes of high hills, low hills, broad valleys and Upper river terraces; (ii) Loamy skeletal Typic Udorthents on narrow ridges of high hills, (iii) Loamy skeletal, Typic Hapludalts on broad ridges of high hills, broad ridges of medium hills and very steep slopes of medium hills and (iv) Fine loamy, Typic Paleudults on steep side slopes of high hills, straight slopes of medium hills, steep slopes of medium hills and very low hills, steep side-slopes of medium hills and very low hills. (v) Sandy, Typic, Udifluvents in narrow valley to some extent in broad valleys.

The morphology, mineralogy and genesis of a hydrosequence of oxisols in Brazil was studied by Macedo and Bryant (1987). Well drained soils with water table more than 3m, had reddish hues (2.5YR to 5YR) indicating the oxidising environment and a codominant haematite and geothite iron mineralogy. The upper organic rich solum at sites with seasonally high water table (less than 2m) had yellowish hues (10YR or 7.5YR) and a dominantly geothitic Fe-mineralogy. In the deeper perennially saturated Zones of all profiles, the matrix colour has reddish hues (2.5YR to 10YR) and a dominantly haematitic Fe-mineralogy. The soils except those on steep slopes in East hill district of Meghalaya were very deep (Nair and Chamuah, 1988). High organic matter at the surface decreased with depth. The soils are strongly acidic throughout the solum. The cation exchange capacity of the soils range from 1.1 to 14.9 cmol (p^+)/kg and the values decreased with depth. The percentage base saturation is also higher in surface soils as compared to the subsurface layers possibly because of plant recycling.

Lahari and Chakravarti (1989) studied the soil samples of Sikkim having varying altitudes for soil texture, NPK and nature of organic matter. Soils contain high nitrogen, low available potassium and medium phosphorous. The clay content decreases and organic matter increases with increase in altitude. There was an appreciable movement of clay from upland to lowland situations in soils collected from South districts of Tripura (Dutta et al.1990). Besides there was a marked enrichment in silt content in low land soils as compared to upland ones in both north and west districts.

Characteristics and nutritional status of soils under Middle Hill Forest(MHF) and upper Hill Forest(UHF) of Eastern Himalayan region (Mandal et al.1990), indicated that, darkness in soil colour and coarseness in texture, increase with altitude. Soils at higher altitude had better soil structure, higher organic matter status, higher C.E.C. and high exchange acidity. Soils at lower altitude on the other hand had greater accumulation of exchgeabel Ca^{2+}, Mg^{2+} and contains higher amount of Fe_2O_3, Al_2O_3 and MgO.

Four typical pedons of soil series occuring on different land forms; Hill slopes (pl), piedmont(p2), lower flood plain (p3) and active flood plain (p4) in Kamrup district of Assam studied by Singh and Chamuh (1991), indicated that; soils are acidic at the surface and neutral at lower horizon except pl where pH values gradually decreases with depth. The soils contained higher amounts of oganic matter. The C.E.C. is low and does not show any relationship with the clay content. In spite of acidic nature of soils, exchange complex of all the soils is dominated by Ca and Mg.

Shyampura et al.(1994) characterising five pedons of different physiographic regions of Rajstan, observed that, the soils on very steeply slopping side slopes are shallow, excessively drained and coarser in nature where as, the soils of gently slopping pediment and undulating plains are deep, finer in texture and have better structural development. Clay cutans and fine clay to total clay ratio provided evidence of argillic horizons in the soils on very gently slopping and nearly levelled plains. Sand/silt ratio(more than 0.2mm) suggests lithological discontinuity between overlying Ap and underlying Bt horizon. The depth distribution of Al_2O_3, Fe_2O_3 and clay provided confirmative evidence of clay illuviation.

Five pedons representing distinct dominant physiographic units of the southern Rajstan (elevation 480-542m m.s.l.) indicated pedon 1 and 2 (steep slopping hills and gentle sloping undulating plateau) were shallow to moderate deep while those associated with pedon 3, 4 and 5 (gentle sloping plain, nearly levelled alluvial plain and dissected alluvial plain) were moderately deep to very deep (Sharma *et al.*, 1994) soils on the hills and plateau are lighter in colour (7.5YR) which may be ascribed to high carbon content and excessive drainage, where as rest of the pedons exhibited dark colour (10YR). In pedon 3 and 4 cracks and slicken sides were observed.

II.2. Chemical characteristics

Gowalkar and Barde (1964) reported that heavy clays are observed on plane areas and loams on hills and steep hills. Lime Kankars are also found on plain areas but absent on hill slopes. In plain areas therefore dominant exchangeable cation is Ca^{++} followed by Mg^{++} and the molar ratio indicated that montmorillonite type of clay. Similar results were obtained by Biswas *et al.* (1966) from a study of catenary soils of Andhra pradesh, in which the morphological feature and mechanical composition were related to the toposequence.

Govinda Rajan and Datta Biswas (1968) studied the soils of Machkund basin. From the chemical analysis it was revealed that, the clays have exchange capacity ranging between 25 and 55 m.e/100g. and consequently of mixed 1:1 and 2:1 type of minerals. The base saturation falls within the narrow range of 50 to 60%.

Zouzou and Furley (1975) reported from a 2000m transact study in Euphratas valley that with the distance and gradient of the slopes there is an increase in clay content, moisture status and soluble salts with depth.

Rajamannar and Krishnamoorthy (1978) studied the physico-chemical characters of forest soils of western ghat in South India and reported that, organic carbon was 0.24% for 200m. and 1.17% for 2237m, elevation. There is an increase in organic matter content due to altitude. Their work corroborated the findings of Biddapa and Venkat Rao (1973) and Sharma *et al.* (1956). The CEC and total nitrogen bears positive relationship with elevation. Surface soil of higher elevation contains higher amount of P than those of lower elevation. The K and Ca content were more in lower altitude than in higher altitude soils. The Fe content of lower altitude were very low than higher altitude.

From a geomorphic study of the soils of Similiguda Research station, Koraput (Orissa), Ray and Nanda (1979) have stated that with the increase in elevation, the organic carbon content, clay content, percentage base saturation decline and soil acidity have increased down the slope and clay mineralogy has changed from kaolinitic to mixed.

Rajamannar *et al.* (1979) studies some profile soil samples collected from Pudakottai (350m above m.s.l.) and Kodaikanal (2237m) representing a low and high level lateritic soils and observed that soils of Kodaikanal (Low temperature and high rainfall zone) contained much higher amount of organic carbon (0.44 to 9.74 %) than those from Pudukottai

(0.10 to 1.14%). The organic carbon content decreased with depth.

Chakravorty and Chakravarti (1980) studied on physico-chemical characteristics of soils of Eastern Himalayan Region and reported that the organic component varies with altitude (foot hills to 3400m) and climatological condition shows that (i) with increase in altitude, a decrease in clay content (ii) increase in organic matter and (iii) increase in the proportion of extractable fraction of humus are observed.

Singh and Dutta (1983) reported the hill soils of Mezoram in relation to altitude. High level of organic matter is associated with low pH values in the surface layer of hill range soil. With the increase of Al acidity down the profile, the pH instead of lowering down has shown a slight upward trend. Organic matter content decreases with fall in altitude.

Palomar Garcia-Villamil *et al.* (1984) studied morphological, analytical and chemical properties of five profiles in a toposequence near Terriente (Teruel, spain) developed on colluvial deposites of clay, sand, marl and lime stone. Horizons of all profiles at low altitude have fine textures, while the soils at higher altitude are coarser in texture. The $(CaO + MgO)/Al_2O_3$ ratios are lowest in profiles with less $CaCO_3$ and more clay, indicating a greater degree of weathering in the surface horizons of those profiles situated on the plain and the lower slopes.

Simple correlation studies of sixty four soil samples from different regions in Assam showed that the Lime requirement (LR) values are in general correlated negatively with pH and positively with exchange acidity, extractable acidity and exchange Al (Haldar and Mandal, 1985). Multiple regression studies showed that the LR values are very strongly influenced by the combined effect of the above mentioned four soil parameters.

Dadhwal and Tripathy (1986) studied the Lime requirement of twenty acid soils(Alfisols) from Kangra (H.P) and observed significant correlation with pH_w, pH_s, organic carbon, CEC. Exchange H^+ and CEC contributed by organic matter but not with clay. They recommended Woodruff's PNP buffer method for adoption in routine soil testing work.

Three pedons within an altitudinal range of 1970m and 2425m in Sikkim were acidic (Gangopadhyay *et al.*, 1986). Translocation of clay in the profile was very much pronounced. The organic matter content of these soils was high at the surface and gradually decreased down the profile. Ca^{++} is the dominant cation among the bases. The mobile form of Fe and Al-increases down the profile.

Singh and Dutta (1988) studied the organic carbon and nitrogen status of some soils of Mizoram occurring at different altitudes and observed that, organic carbon and readily oxidisable organic matter content rise with increasing elevation, with the former being significantly correlated to the altitude (r = 0.973). The C/N ratio of the surface soils at higher altitudes have narrower values than of the surface soils at lower altitudes. The ratio also shows a narrowing trend with increase in soil depth. The total and other forms of Nitrogen (available,ammoniacal and nitrate) increase with increase in altitude and decrease with depth. These bear significant positive correlation with altitude, and with organic carbon, besides positive and significant correlation among themselves. Multiple correlation study shows 89% of the variation in the total nitrogen content due to associative influence of altitude, organic carbon and pH and 99% of the variation in available nitrogen is due to the combined effect of organic carbon, total N, NH_4-N and NO_3-N. On the whole organic matter shows a greater contribution in the productivity of total and available nitrogen.

Nair and Chamuah (1988) found that, the soils except those on steep slopes in East Hill district of Meghalaya were very deep. High organic matter at the surface decreased with depth. The soils are strongly acidic throughout the solum. The CEC of the soils range from 1.1 to 14.9 cmol (p^+)/kg and the values decreased with depth. The percentage base saturation was also higher in surface soils as compared to the sub-surface layers possibly because of plant recycling. The soils belonged to order Entisols and Oxisols.

Sharma and Tripathy (1989) studied the lime requirement of acid soils of India and evaluated Seven lime requirements (LR) methods regarding their suitability for acid soils using LR values (pH 6.50) determined by laboratory incubation for three months. The buffer methods of shoemaker *et al.* (1961) and Pratt and Bair (1962) were found to be equally good and hence recommended for the present group of soils. Among soil properties, pH, CEC and organic matter were found to be significantly related to LR and a function of (pH 6.5 - soil pH) x % organic matter also correlated well.

Bhoumik and Totey (1990) studied the soils of Boriforest of Madhya pradesh and observed that, the soils are mildly acidic to neutral in reaction. The organic matter content of these soils was high at the surface and gradually decreased down the profile. Ca^{++} as compared to Mg^{++} was more recycled from lower to A-horizon. High Ca : Mg ratios in the upper layer relative to lower ones elucidated the active role of teak in the pedogenesis.

Sahu and Pattnaik (1990) studied the effect of lime and organic matter on pH, CEC and exchange phenomenon of seven Alfisols (surface and sub surface) of Orissa, after 10, 20 and 30 days of incubation. The effect was less after 20 days and least after 30 days. In such soils liming before 20 days of planting was recommended. But even after 30 days, these values were higher than the initial values.

Das *et al.* (1992) studied the nature of acidity and exchange chemistry of some laterite soils of Orissa. They observed that, laterite soils of Orissa belonging to Alfisols, Ultisols and Inceptisols have pH dependant acidity varying from 3.1 to 11.8 cmol (P^+)/kg and were mainly associated with the inorganic fractions of soil such as oxides of Fe, Al and clay. pH dependant acidity at pH 8.0 was 3 to 4 times greater than that, at pH 7.0 exchangeable Al^{+++} was detected below pH 5.2 and Al saturation (%) in the exchange complex varied from 2.4 to 61.3 and possessed a highly significant negative correlation with soil pH. Potential acidity in soil varied from 3.4 to 13.5 cmol (p^+)/kg of which the exchange acidity was 1 to 29.7% and the rest being pH dependant acidity. The permanent negative charge component in soil dominated over the pH - dependant ones at pH 7.0 where as, the reverse occurred at pH 8.0. More than half of the permanent charge was satisfied by H^+ and Al^{3+} below pH 4.7 and the value decreased to less than 2.3 per cent above pH 5.8.

Ramanamurthy and Sharma (1992) reported that high altitude profiles had larger organic matter accumulation as compared with the low altitude profiles. Higher contents of organic carbon in northern and high altitude profiles is facilitated by lower temperatures which are conducive to organic matter accumulation.

Soils at higher elevations in Raisen district of Madhya pradesh were less developed and had low pH, $CaCO_3$, clay content, CEC and exchangeable cations than the soils in lower elevations (Shrikanta *et al.* 1993). Differences in soil development were due to differences in parent material, vegetarian and elevation.

Bala and Sahu (1993) studied five pedons of the hill slope soils of middle Andaman Island which were strongly to extreamly acidic and fairly high in organic matter. The values of CEC varied from 10.6 to 23.2 cmol (p^+)/kg and calcium dominates the exchange coplex along with exchangeable Al^{+++}.

Satyavathi *et al.* (1994) studied the soils of Kathawara peninsula and observed that simple correlation co-efficient among different soil characteristics show significant correlation of CEC with clay, silt and organic matter content. However clay had a higher co-efficient of correlation (r=0.84) than silt (r=0.36). Clay content appeared to be the main contributing factor to the origin of CEC. CEC had also been found significantly correlated with organic matter based on organic carbon determination.

Ananthanarayan and Hanumantharaju (1994) studied the nature of soil acidity and lime requirement in the Agro-climatic zones of Shimonga district (Karnatak) and observed that total potential acidity contributed to major portion of cation exchange capacity. Aluminium saturation increased with increasing total potential acidity where as calcium saturation decreased it. pH-dependant acidity contributed more than 90% of the potential acidity.

Sharma *et al.* (1994) studied the soils developed across a toposequence over Basaltic parent rock at the southern Rajstan and observed the chemical characteristics like pH, E.C., $CaCO_3$, available P and K, in general, increased along the transact. This may be due to the migration of salts and bases from the region of higher topography to lower one. Apart from this organic carbon and available Nitrogen at elevated topography were higher and decreased along the transact.

II.3. Physiography and Land form :

The term toposequence was introduced by Jenny (1941). The topography and land form affect the air and water movement in soil by their effect on drainage, runoff and erosion to a great extent.

Biswas and Gawande (1962) from the study of drainage condition of chhatisgarh basin postulated that differential transport of eroded material, leaching, translocation and redeposition of mobile soil constituents influenced the genesis of the soil. From well drainage to impeded drainage condition down the slope the solum depth increased and the profile character reflected the same. There were some traditional and gradational changes also appear; like, colour from red to dark grey brown; reaction from acidic to alkaline; structure from structureless to blocky; texture from sandy loam to clay; consistency from non-plastic to very plastic and finally presence or absence of $CaCO_3$.

Report published by Klant and Beatty (1972) on the soil sequence in Brazil reported that the soils developed on slopes or steep hills are less affected by weathering process than plateau soils.

Kabachiev *et al.* (1972) reported from Bulgeria that from the granite parent material various types of soils have been formed depending upon the degree of slope. Towards the toe slope the soils contained $CaCO_3$ and on the foot hill position shallow acidic soils were formed.

Dan *et al.* (1972) from Israel reported that the development of catena on northern slope consisted of grumusolic dark brown soils on flat hill tops; thick, non-calcareous brown soils on the moderate slope; typical brown rendzina on steep slope and brown rendzinic colluvial-alluvial soils on gullies.

Zouzou and Furley (1975) reported from a 2000m transact study in Euphratas valley that having same parent material and different geo-morphological unites, Aridisols were formed at the top of the slope and Entisols at the bottom. With the distance and gradient of the slope there was an increase in clay content, moisture status and soluble salts with depth.

Dutta (1980) reported that, the largest streches of acid soils are seen in the north-eastern parts of India and the pH of Nagaland soils varying between 4.0 to 6.5. He observed that, the factors particularly dominant in the development of acid soils are rainfall, temperature,acid igneous rock, hydrological condition and vegetation.

Saxena and Singh (1982) studied eight soil groups occurring in semi-arid to humid agro-climatic regions of Rajsthan and observed that, though parent material seemed to exert a major influence, a gradient in degree of profile development was observed. Soils of sub-humid region generally showed a higher degree of weathering and formation of secondary products. Different soils can be arranged in order of increasing intensity of pedogenic development as, (i) in semi-arid region-: Alluvial soils of recent origin < non-calcic brown < grey brown < brown soils, (ii) in sub humid to humid region: Hill soils < Yellowish brown < red loam < deep medium black soils.

Gavaud *et al.* (1987) described the soil landscapes of the venezuelan territories of Amazonia. The soils from a sequence included lithosols, podzols, and peat at the highest altitude (2000m), a number of ferrolitic soils (Petroferric Gibbsiorthox, Petroplinthic Haplorthox, Acric Umbriorthox) from a 2000 to 100m and sandy soils (Quartzipsamments) at lowest altitudes.

Morphology and other characteristics of the Nimkheda soils in Jabalpur, Madhya Pradesh were studied in relation to topography (Prasad *et al.*, 1989). Taxonomically these soils were classified into Alfisol, Entisol, Inceptisol, Mollisol and Vertisol. Entisols were the dominant soils of hillocks and convex erosional slopes; Alfisols were next dominant and Mollisols and vertisols gradually down the slope gradient.

II.4. Genesis of Soil:

From a study of the origin, structure and minerals in the laterites, Campbell (1917) stated that laterites were formed by two types of reactions, such as alteration and weathering. The former takes place within the zone of permanent saturation and consists in the elimination of iron, much of silica and some alumina and conversion of alkaline and silicates of alumina to hydrous aluminium silicates. True weathering took place above the water table in the zone of intermittent saturation.

High precipitation, temperature and internal drainage are considered essential for the genesis of laterite and lateritic soils (Vander Merwe 1950). These factors result in rapid decomposition and disintegration of the parent rock and also the soil material, release of silica and fixation of sesquioxides on the surface horizon. Alternate wet and dry conditions with high temperature during rains was pointed out (Prescott and Pendeleton 1952) as the pre-requisite for the formation of laterite.

The process of laterization and the occurrence of morrum in the red earths, valley bottoms and plain surfaces is not a matter of leaching silica alone, but also the remobilization of Fe, Mn and Al either up or down the soil profile depending on the prevalent drainage condition (Spurr 1959).

Laterite formation involves seven phases (Kubiena 1952). These were: formation of a concretionary layer, mottling and encasing of iron coating, scoria formation, penetration of earthworm tubes, concretion formation, formation of vesicular structure and hardening of the materials, dehydration of gels, production of Fe and Al minerals by contraction, stagnation of ground water and release of bases.

Maignion (1958) had shown that ferruginous laterites may develop in a variety of materials provided there is a source of iron either in the parent rock or in the adjacent higher lying areas from which water may introduce ferruginous materials.

Tamhane and Namjoshi (1959) held the view that red soils are derived from granitic and gneissic rocks rich in orthoclase feldspar and micas rather than in plagioclase, red shales and sand stones.

The laterite from basic rock is highly aluminous and in the case of medium acid rocks it is predominantly kaolinitic. The presence of high amounts of quartz in acid rocks possibly permited the development of red loams and red earths of greater depth in place of laterite structure (Satyanarayan and Thomas 1962). Anjaneyulu and Raychoudhuri

(1964) showed that the Alfisols and Ultisols of Mysore and Gujrat state were formed from fresh or slighty pre-weathered granites or gneisses and crystalline schists and subordinate rocks rich in ferromagnesian minerals which gave rise to the red soils.

Gowalkar (1972) from a study of the clay mineralogy of laterite soils of south India indicated that high rainfall and a dry period of 4-5 months are essential for the process of laterization on the acid igneous rocks. The soils were under kaolinization as against laterization which is achieved on basic rocks abundant in alkaline earths, which promote alkaline hydrolysis. He also stated that, the climatic environment will not necessarily reflect in the genesis of laterite soil lying at lower altitudes.

Bhargava *et al.* (1973) observed that granite gneiss type of rocks rich in quartz and orthoclase feldspars have given rise to red soils (Alfisols) in Tungavadra Catchment area.

Physical, chemical and mineralogical properties of a mediterranean red soil characterised by Tarzi and paeth (1975) have shown that the soil was almost decalcified. As a consequence, it had a fairly well developed soil profile. Illuviation of clay and the formation of an argillic horizon, accumulation of organic matter, enrichment of sesquioxides and kalonization were the major processes in the development of these soils.

Wu and Ding (1992) studied the soil in Hunan province china. The soil formation in this region was characterised by strong eluviation, distinct disilicification and allitization as well as marked biologicals activity. The soil sequence from mountain foot comprises mountain yellow and red soil(400-650m a.s.l). mountain yellow soil (650-1100m) and mountain para- yellow soil (above 1100m).

Gupta and Verma (1992) studied some soils of the Kandibelt in Jammu Shiwalik and observed that, Quartz was the dominant mineral in light sand fraction followed by muscovite/sericite and feldspar while ferruginous minerals (Hematite and Mgnetite) with fair amount of garnet, epidote, hornblend, biotite, kyanite, tourmaline and zircon from the heavy fraction. Mica/illite, chlorite smectite, vermiculite and kaolinite were in the main clay minerals. Similarly of clay minerals in all the pedons showed dominant influence of parent material on their genesis.

II.5. Classification of Soil :

Luzio (1972) studied the soils developed on toposequence from granites and granodiorites and classified as; Ultic Haploxeralfs and Typic Xerofluvents respectively, from higher altitude to lower altitude.

Bakr *et al.* (1978) reported that Inceptisols and Entisols were common on hill slopes due to younger age and slopes, which did not allow profile differentiation. Cooler sites were congenial for formation of Mollisols.

Dutta (1980) stated that, the large variation in altitude is from 300-3300m in Nagaland had given rise to diversity in climate and Vegetation which are the pre-dominant factors for the classification of Nagaland soils into four orders-Entisols, Oxisols, Mollisols and Spodosols.

Chakravarthy and Barua (1983) studied five pedons from citrus growing belts of Assam developed on tertiary sedimentary deposites over Archean gneiss, under sub-tropical hyperthermic and thermic climate representing varying topographic position. The soils were very deep, well structured and exhibit varying stages of development with weakly developed argillic horizon. The texture varied from sandy clay loam to silty clay in surface horizon to clayloam to clay in the sub-surface and classified as Paleustalf, Hapludult, Paleudult and Haplohumult.

Sehgal *et al.* (1985) studied two dominant soils of the warm temperate and humid region of the central Himalayas. He observed that, the mountain soils on slopes formed on chlorite- schist under deciduous forest have a mollic epipedon under-lain by a cambic harizon. The soils in the valley developed on colluvium (derived mainly from gneiss) show a clay-enriched Bt horizon and an ochric or mollic like ochric epidedon. The soils of mountain and valley were classified as Typic Hapludolls and Mollic Hapludalfs respectively. The classification finds support from their geographic distribution with umbrepts in their north-east (cool per-humid) and Humults in the south-west (warm per-humid) zones.

Tiwary *et al.* (1989) studied the red, yellow and black coloured soils in a topographical sequence in Rajmahal Trap of Bihar. Red soils were Alfisols, while black soils are Inceptisols, vertisols, Entisols and Alfisols. The yellow soils were Inceptisols.

Prasad *et al.* (1989) studied the profile development in relation to topography. He observed that, Entisols are the dominant soils of hillocks and convex erosional slopes. Alfisols are the next dominant soils and then the Mollisols and vertisols gradually down the slope. Undulating land scape, poor ground cover, moderate to severe erosion and high shrinkage and swelling properties were some of the problems of the soils.

Walia and Chamuah (1990) studied four typical pedons representing foot-hill slopes, piedmont plains and flood plains in Tirap (Arunachal Pradesh). They observed that the soils of foot-hill slopes (P_1) are characterised by argillic horizon and low base saturation (< 35%) and therefore, keyed out as Hapludults. Soils of piedmont plain and flood plain (P_2, P_3, and P_4) showed the development of cambic horizon (B_2) and qualified for the order Inceptisols.

Singh *et al.* (1990) studied soils of mid-shiwalik region representing upland with steep slopes, strongly sloping land valley land and land in the vicinity of streams. Upland soils had only ochric epipedon and no sub-surface diagnostic horizon and classified as Typic Udorthents. Strongly sloping soils had ochric epipedon underlain by an argillic horizon and were classified as Hapludalfs. Valley land soils were quite deep, attributed to free infiltration and percolation and were classified as Typic Hapludalfs. Soils of vicinity of stream had an ochric epipedon underlain by stratified layers with preponderance of coarse fragments, qualified for Typic Udifluvents.

Singh *et al.* (1991) conducted a detailed soil survey to characterise and classify the mid altitude soils of outer Himalays in order to generate and transfer agro-technology to other areas having comparable soil site characteristics. The soils have been developed on Simla group of rocks under monsoon climate as conditioned by undulating topography and peculiar natural drainage system. Soils of high and low altitudes were Dystrochrepts and the mid-hill soils were Hapludults.

The pedo-chemical characterisation and genesis of soils in relation to altitude in Mizoram was studied by Singh *et al.* (1991), where they found that silica, the dominant constituent of all the soils decreased with depth with simultaneous increased in sesquioxides where as, CaO and MgO contents increase with decreasing, altitude. Soils of high and low altitude were Umbric Dystrochrepts while mid-hill soils were Typic-Hapludults.

Four pedons from a lateritic zone and three pedons from a mixed red and black soil zone under subtropical monsoonic climate of Khurda district in a toposequence (Panigrahi 1991) indicated shallow sandy profiles in the upper ridges and deep clay loam at the bottom region. There was an increase in the clay content and CEC and gradual decrease of organic matter down the profile. The upper ridge soils and mid upland soils were classified under Alfisols and the soils of mid-low land were classified under Inceptisols.

Studies on the high level and low level laterites of Orissa (Sahu & Pattnaik, 1991) in the Eastern ghat region indicated the high level laterites to be more clayey, higher CEC but were dominated by kaolinite. The low level laterites are comparatively light textured, lower CEC and were of mixed mineralogy. The high level laterites were classified as Rhodic Paleustalfs and that of low level laterites as Plinthic Haplustults.

Bhatacharyya *et al.* (1992) studied the soils in part of western Maharastra and configurated into four major physiographic units viz. hills, plateau, pediment and piedmont plains. (i) In hills the entire land form was severely eroded, rugged with frequent rock out crops, steep to very steeply sloping, very shallow to shallow, gravelly fine loamy, reddish to reddish brown, non calcareous and were grouped under Lithic Ustorthents (ii) In plateau these were gently sloping, shallow to moderately deep, siltclay to clay, brown to very dark greyish brown, non- calcareous soils with more than 0.5 cm cracks vertically extending to a depth of 30-80 cm, peds had pressure-faces, and/or slicken sides and were grouped into Typic Haplustalf, Typic chromustert, Typic Ustropept. (iii) In pediment the soils having moderately sloping, eroded, very shallow to shallow to the lithic contact, gravelly and calcareous were grouped into Lithic Udorthents, and soils having moderately deep, gentle sloping, gravelly clay loam, dark brown, calcareous with 1-2 cm wide cracks extending to a depth of 32-60 cm, peds exhibiting pressure faces were classified as Typic Ustropepts and vertic Ustropepts. (iv) In piedmont plains, the area having very gently sloping, moderately deep, clay loam, dark brown, calcareous, very slightly to moderately eroded having peds with pressure faces and cracks of 1 cm wide and 30-50 cm deep were classified as Vertic Ustropepts where as, the area having very, gently sloping deep to very deep, slightly clay to clay very dark greyish brown calcareous and very slightly eroded with well developed slickensides and 2-4 cm wide cracks vertically extending to a depth of 70-80 cm. have been classified as Typic Chromusterts.

Gupta and Verma (1992) studied five typical pedons representing Kandi belt of Siwalik region of Jammu and observed that; pedons 2nd to 5th situated on flat topography and well levelled lands were less developed as they have no other horizon except ochric epipedon and therefore keyout as Entisols but 1st pedon had more or less well developed characterised with altered or cambic sub-surface horizon beside ochric epipedon therefore put under Inceptisols.

Kaistha and Gupta (1993) studied the soils of the sub-humid temperate highlands of the central Himalayas. The soils formed on steep slopes over granite/ gneiss parent material having mixed vegetation had ochric intergrading to mollic epipedon. Contrary to this, the soils on mild slopes over similar parent materials and under potato cultivation had mollic epipedon underlain by cambic subsurface horizon. The soils have been classified as Mollic Udorthents and Fluventic Hapludolls.

Five pedons of the hill slope soils of middle Andaman Island were characterised and classified taxonomically (Bala and Sahu, 1993). The soils were situated on a slightly sloping land terrain with undulating surfaces. Soils were strongly to extreamly acidic and fairly high in organic matter. The value of CEC varied from 10.6 to 23.2 cmol (P+) kg^{-1} and calcium dominated the exchange complex along with exchangeable Al^{3+}. Soils of mid-hill and terrace and terrace-hill slope were classified as Ustifluvents, mid-hill terraced undulating up land as Typic Ustifluvents, and undulating sloppy medium land as Dystrochrepts.

Sharma *et al.* (1993) studied six soil series (Bathu, Koharchan, Garget, Tooli, Mairi and Pandogha) in the hilly parts of soan river catchment in Himachal Pradesh. The soil series namely Tooli, Bathu, Koharchan, Mairi and gagret were characterised by the absence of B horizon and showed very poor profile development and were put under Entisols. Soils of pandogha series showed the presence of an ochric epipedon underlained by the sub-surface horizon showing absence of rock structure for at least half of the volume and qualified only for cambic horizon and order Inceptisols.

Walia and Chamuah (1994) studied six soil profiles of Arunachal Pradesh occurring in different land forms viz. alluvial plain, piedmont, recent flood plain, channelbar, flood channel and terrace. The soils were stratified, coarse textured, slightly acidic to neutral with high organic carbon content, low CEC and high per cent base saturation. The terrace and piedmont soil exhibited A-B-C horizons and were classified as Inceptisols. While soils of other land form lack in B horizon and hence keyout as Entisols.

Sharma *et al.* (1994) studied Eight soil series in lower Siwaliks of Himachal Pradesh. The soil series of piedmont plain and of flood plain were characterised by the absence of B horizon and shown very meagre profile development and were grouped under Ustipsamments and ustifluvents. The soils of other series in piedmont plain showed the presence of an ochric epipedon underlained by cambic sub-surface horizon showing the absence of rock structure in atleast half of the volume were classified as Typic Ustochrepts.

Orissa. Four series viz. saplahara (ridgetop), Badsahir (upper valley), Bhandarimal (lower valley), and Kusamura (valley bottom) were identified. All the three pedons except Kusamura have a moderate, medium, subangular blocky structure. There was presence of patchy clay cutans on the ped faces in the sub-surface layer indicating the presence of argillic horizon. The soils of Kusamura had coarse fragments and distinct reddish brown to yellowish red mottles on the surface. Badsahir and Bhandarimal soil series were classified under Udic Haplustalfs, Saplahara series under Udic Paleustalfs and Kusumura series under Aeric Hapluquents.

II.6. Different forms and status of potassium in soil and their releasing characteristics :

II.6.1. Forms and status of soil potassium :

Potassium exists in soil in different forms i.e., water soluble, exchangeable, fixed (non-exchangeable) and lattice K. All these forms of potassium are in a dynamic equilibrium with each other. Water soluble K increases with dilution because of the increase in hydrolysis of exchangeable K and further replacement of K by divalent cations or dissociation from potash bearing mineral (Reitemeier 1951).

Following schemes have been proposed by different workers to explain the equilibrium between various forms of potassium in soil.

a) Primary mineral ⟶ Fixed K (acid insoluble ⇌ Acid soluble) ⇌ Replaceable K ⇌ water soluble K

..... Exchangeable K (Wood and Deturk, 1940).

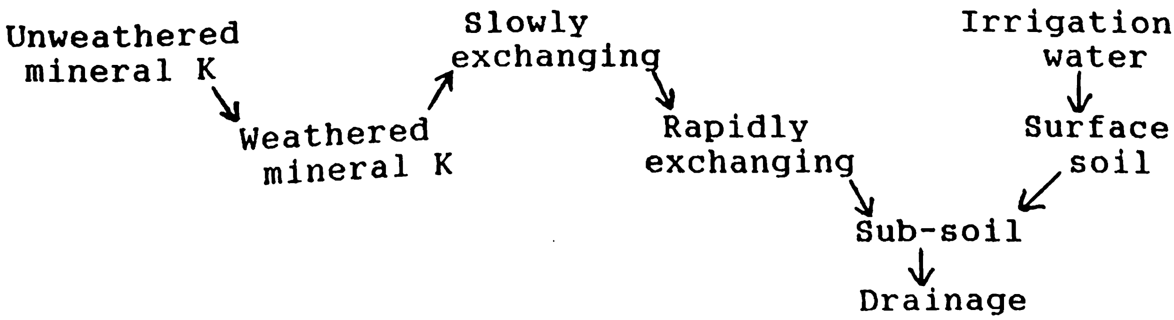
b) Structural K ⇌ adsorbed K ⇒ water soluble K

..... Non-exchangeable K (German, 1957).

c) K in solution ⇌ Exchangeable K ⇌ Fixed or reverted K on external surfaces (Rapid and Continuous exchange) slow and contigent exchange ⇌ ⟶ K definitely fixed.

..... (Barbier, 1962).

d)



..... (Talibudeen, 1972).

Arnold (1960) reported that exchangeable K is easily available and non-exchangeable K is difficulty available to the plant.

Variation in the potassium content in soil is due to the variation in primary and secondary potash bearing minerals (Prasad *et al.*, 1967).

Verma and Verma (1968) observed significant positive correlation between available K and pH in red and yellow soils, and also between available K and organic carbon in alluvial and mixed red and black soils.

Pareek *et al.* (1972) found considerable amount of non-exchangeable K (106 meq/100 g) in red soils of Rajsthan which they attributed to the presence of muscovite. High content of non-exchangeable K in red soils of Ranchi and Tamil Nadu was however attributed to the presence of illite (Ekambaram 1975).

Choudury and Pareek (1976) observed that, reserve K correlated significantly with sand, silt, exchangeable K, fixed K, inter layer K, and total K content of the soils. K fixing capacity ranged from 0.15 to 1.41 meq/100 g correlating significantly with organic carbon and clay content. Resistance of the soil to K-depletion was closely correlated with silt and clay content.

Tiwari and Ram (1976) observed significant positive correlation between watersoluble K and available K, HCl soluble K and clay, available K and organic carbon content of the soils.

Ranganathan and Satyanarayan (1980) studied the potassium status of soils of Karnatak and observed that, the variation in the distribution of potassium depended upon the mineral present, particle size and degree of weathering.

Singh *et al.* (1983) reported that both lattice and fixed K were positively correlated with silt and clay; exchangeable and non-exchangeable K with C.E.C., organic carbon and clay; but all the forms were negatively correlated with sand. The different forms of K were positively correlated to each other except watersoluble K which had positive correlation with exchangeable K only. The changes in soil K supply and contribution of K to crops from the non-exchgeable source in 2 soils (Typic Ustochrepts) were studied by Geneswarmurthy *et al.* (1985).

Bandopadhyay *et al.* (1985) studied the different fraction of K and Q/I relationship in relation to K supply capacity to plants and observed that, there was a good correlation between clay content and non-exchangeable K of soil.

Singh *et al.* (1985) studied the distribution of different forms of potassium in the soils of western part of Hariyana and observed that, the total K, conc. HCl soluble- K, 1<u>N</u> HNO_3-K and NH_4OAc-K were positively correlated with per cent

Yadav and Swami (1988) studied the effect of potassium fertilizer on dry matter yeild and observed the decrease in exchangeable K content with cropping. The contribution of soil reserve K towards K-nutrition of plant was considerable.

Potassium availability as related to climate, soil texture, clay mineral composition, soil moisture were studied by Kemmler and Hobt (1991) they reported that, (i) under humid tropics and subtropics the soils were poor in plant available K than temperate region in concequence of intensive leaching of nutrients. (ii) At the same level of exchangeable K, clay soils showed low concentrations of K in the soil solution, sandy soils high concentration. Clay minerals like illite and vermiculite in particular adsorb K selectively resulting in a lower K- concentration in soil solution. This was reverse in case of kaolinitic type of clay minerals. Organic matter had no specific binding sites for K, (iii) The effective availability of potassium was higher at optimum soil moisture as it was largely controlled by mass flow.

Deshmukh *et al.* (1991) studied different forms of potassium in soils of Vidarbha region and obtained significant positive correlations among various forms of K. The clay content was correlated significantly and positively with water soluble-K, NH_4OAc extractable-K, HNO_3 soluble-K and HR-8-K. The clay contained higher amount of potassium as compared to non-clay fraction.

Sharma and Sekhar (1992) studied the soil-plant K interrelationship in six soil series differing in K status through short-term adsorption with sorghum and observed that, K supply considerably influenced dry matter yield and K uptake and its distribution in shoot-root portion of the crop. The lowest and highest estimates of these parameters in soils were low and high in both NH_4OAc-K and HNO_3-K respectively. A major part of potassium is absorbed by plant from non-exchangeable source. Both NH_4OAc-K and HNO_3-K correlated significantly and positively with the K content in the plant.

Basumatary and Bordoloi (1992) reported that the significant positive relationship of different forms of K and K- fixation capacity with clay, silt, organic carbon, CEC, percentage base saturation and negative relationship with sand, water soluble, exchangeable, non-exchangeable-K and K-fixation capacity showed positive correlation with pH where as, total and Lattice-K showed negative relationship.

Talete *et al.* (1992) stated that, all the forms of K were related with each other and showed highly significant positive correlations with per cent K-saturation, soil pH, $CaCO_3$ equivalent, exchangeable Ca, CEC where as, these were negatively correlated with organic carbon, sand and silt content of the soil.

Venkatesh and Satyanarayan (1994) studied potash reserve in particle size fractions of vertisols of north Karnatak. They stated that, the percentage contribution of coarse sand, fine sand, silt and clay towards total soil-K was 4.2, 9.8, 18.7 and 67.3% respectively in different soil profiles. All the forms of potassium in soil were positively and significantly correlated with K-content in silt and clay.

Srirajual *et al.* (1994) studied on different methods of potassium determination in some selected soil of Bangaladesh. They observed that, all the forms of K were directly related with one another. In a rice pot culture they tried to find out a suitable K determination method by correlating the soil K values with the drymatter yield and K uptake. They stated that, NH_4OAc and bioling HNO_3 extractable K had the highest correlation coefficient with the dry matter yield (r=0.802 and 0.729) and the K uptake (r = 0.859 and 0.87) by the rice husk.

Venkatesh and Satyanarayan (1994) studied the status and distribution of potassium in vertisols of north Karnatak and stated that the variation in distribution of K depends on the types of the mineral present, particle size and degree of weathering. Water soluble, exchangeable, non-exchangeable and lattice K constituted on an average 0.02%, 2.6%, 8.4% and 86.5% of the total soil potassium respectively. Major fraction of K was constituted by the mineral fraction. All the forms of soil K were inter-correlated indicating the existence of dynamic equilibrium among them.

II.6.2. Release of soil potassium :

Ramanathan (1977) defined potash releasing power of the soils as the sum of non-exchangeable potassium converted to exchangeable from thus becoming available to crops besides the exchangeable and water soluble potassium already present in soil. In an attempt to distinguish between the potassium releasing and potassium supplying power of soils, Nash (1971) defined potassium supplying power of a soil as the amount of K supplied to the growing plant from soil solution, exchangeable and non-exchangeable sources. The potassium releasing power denotes the total availability but not total uptake of K, because of the entire amount that is released is not used by the plant.

MaClean (1968) stated that, the release of potassium from non-exchangeable source serves as an index of the ability of the soil to supply potassium to the crop without any addition of potashic fertilizers. Therefore, efficient soil fertility management warrants a thorough knowledge of this phenomenon.

Mohapatra and Rajendra prasad (1970) stated that lack of response to potassic fertilizers in many soils may be partly attributed to the greater ability of these soils to release non-exchangeable - K.

Tabatabai and Hanway (1969) reported that unless a minimum level of exchangeable K is leached there is practically no release of K from the non-exchangeable source.

The potassium released from the minerals due to weathering and delivered to the roots must first pass through the exchangeable state and soil solution. Therefore, a reliance on potassium release from the non-exchangeable state results in a declining fertility status (Grimme, 1975).

Ramanthan (1977) found that red soils in general release much lower amounts of K than other soil groups. He showed that non-exchangeable K utilised by the plants grown in the glass house pots ranged from 40.8 to 95.2% under exhaustive cropping. When potassium fertilizer was applied, the extent of non-exchangeable K used by rice was reduced. When the extent of non-exchangeable K used was higher, the K uptake from supplied source was lower.

Feigenbaum *et al.* (1971) reported that soil samples with a distribution ratio above unity (i.e. with K mainly in silt fraction) and a high total K content released K at a higher rate than those with a distribution ratio below unity and a high total K content.

Aggriadis *et al.* (1978) calculated a value for the activation energy of the release reaction, which must be considered to lend support to the view that potassium release in the soil is diffusion dependant.

According to MaClean (1978), as exchangeable K is exhausted, non-exchangeable K is released though release may be an insufficient suppliment of crop needs due to limitations both in quantity and in rate. Still more intensive removal of K by prior cropping or other means of extraction removes native non-exchangeable K, opening additional wedges in the clay lattice causing potential fixation of subsequently added K. Conversely addition of soluble K cause first adsorption to cation exchange complex and then fixation of a portion in non-exchangeable from which appears to be a more closing of the wedges in the partially opened illitic structure.

Ramanathan and Krishnamoorthy (1982) defined K supplying power of soil as the amount of K supplied to growing plants from soil solution exchangeable and non-exchangeable form, whereas K releasing power is the sum of non-exchangeable K converted into exchangeable form and the exchangeable in to water soluble.

Ram and Prasad (1983) assessed the K release from 30 soil samples of East Khasi hills of Meghalaya and reported that, the levels of exchangeable K decreased by 13.2 to 80% after five cropping of maize and finger millet. The percent of uptake of non-exchangeable K decreased with increase in exchangable K; total K removed by the crop gave negative relationship with the per cent of non-exchangeable K. Both exchangeable and released non-exchangeable K were significantly correlated with K uptake and dry matter yield.

Joshi (1986) studied the potassium release behaviour in some acid soils. He observed that the amount of K extratable by 1N NH_4OAc and that after first heating was relatively higher in grey brown loam than in the light loam and light brown soils on further heating except in a few cases there was not much difference in K - release. K-release in first heat treatment was significantly associated with organic matter in all the three types of soil; with subsequent heating in grey brown loam and brown light loam soils, weathered K bearing minerals in silt fraction and illite nature of clay mineral appeared to contribute for the release. Multiple regression of K release on some soil properties indicated better predictability in grey brown loam and brown light loam than in light brown sandy soils.

Sawili and Chahal (1986) studied about the potassium release in alluvial soil. They observed the rate of release of non-exchangeable K by Na-TPB (sodium tetraphenyl boron) increased with time and can be defined by first order reaction. The cumulative K release and calculated rate constant was related to soil texture. The rate of release was more in case of illite followed by chlorite, then smectite within the same textural class.

Sahu and Gupta (1987) studied the fixation and release of potassium in some alluvial soils. K release was studied by executive extractions with 1N HNO_3, 0.01 $CaCl_2$ and by subjecting the soil to alternate submergence and drying followed by extraction with 1N NH_4OAc (pH 7.0). 1N HNO_3 released much more K than other two extractants. Only a small fraction of the non-exchangeable K was released by 0.01 M $CaCl_2$ and 1N NH_4OAc.

Swarup and singh (1987) studied on the movement of potassium in a sodic soil profile and observed that a major portion of the applied K remained in the top 30cm soil and moved in successively decreasing amount down the profile to a depth of 75cm.

Sharma and Dubey (1988) studied the potassium status of vertisols and associated soils in a toposequence and observed that the surface soils had high water soluble K which in most cases decreased along the depth of the profile. The higher lattice K content in the pediment soil could be attributed to the presence of higher amounts of less weathered micaceous clay mineral.

Krishna kumari and Khera (1989) stated that, 1N boiling HNO_3 which extracted the non-exchangeable K release in the form of available K by K-bearing minerals, during crop growth can be recommended for use of micaceous soils where there was substantial release and utilization of K from non-exchangeable form under intensive cropping.

Bhangu and Sidhu (1991) studied on release of potassium from soil differing in ammonium acetate extractable potassium in soils of five bench mark soil series from Amarabati and Akola district of western vidharbha and reported that, all soils exceeds suggested response levels for available K and Step K. Among the Entisols and vertisols, entisols from both the districts had high amount of available K and potentially available K (rating based on the amount of K extractable by 1N boiling HNO_3). Cumulative K released from non-exchangeable source ranged from 2.81 to 6.05 mg/100g.

Mishra and Singh (1992) studied on the potassium release characteristics of some bench mark soil of India and obsereved that, the release rates of external K (P1) were computed from the linear portion and for lattice or matrix K (P2) from the curvilinear portion of the k release curve. In all the soil classes the value of P1 was higher than P2. The rate of K-release (P1) for the illitc soils were found faster followed by smectite soils than the kaolinitic soils. Although illitic soils have lower value of NH_4OAc - K than smectictic soil, the rate of K-release was in reverse order.

Pal and Mukhopadhayay (1992) studied on potassium releasing power of soils in a green house and observed that, significant positive correlation were between cumulative K released and the initial level of exchangeable as well as non-exchangeable K, thus justifying that, K status governed the K-release characteristic of the soils. Highest significant correlations were observed between cumulative K release after 5, 10 and 15 times stepwise extraction by 0.01 N HCl and cumulative K uptake as well as dry matter production. The highest correlation coefficient was observed between cumulative K release in the 5th step of extraction with both cumulative K uptake.

Pal and Durge (1993) studied on potassium release from clay mica in alluvial soils of India enriched with fine grained micas from semi-arid, moist sub-humid and per-humid climatic zones. They observed that, the K release is governed by only nature of clay mica. Rapid K release in semi-arid and moist sub-humid clays was due to higher biotite content while the much reduced rate in per humid clays was due to mica with more muscovite character.

Dey *et al.* (1993) studied on the release pattern of non-Labile potassium in some Entisols, Inceptisols, Mollisols, Alfisols of West Bengal. The reserve of step K and constant rate K were evaluated in these soils by repeated extraction with bioling nitric acid. The threshold level of K in soil solution below which the release from initially non-exchangeable K reserve starts was also measured for the given soils. The trend of the threshold K values follow the same sequence as the amounts of specifically held K and total non-exchangeable K reserves in the soils, which in turn was found to be related to the illitic mineral content of the clay fraction of the given soils. The step K and constant rate K were further correlated with the reserve of the intermediate K as well as the amount of exchangeable K which was specifically held in wedge zones.

II.6.3. Mechanism of K - Release :

Mechanism of potassium is associated with the expansion of clay mineral lattices. Exploitation of lattice upon drying especially in presence of $CaCO_3$ is important for supplying K (Ruymbeke, 1963). Potassium may be released due to replacement by other cations such as Ca^{++} from the interlattice position of micaceous clay minerals (Addiscott and Talibudeen, 1969).

Kunishi (1963); Raman and Jackson (1965) and Beckett (1970) reported that during drying surface tension forces acting on the weathered edges of micaceous minerals of regions of those minerals which are interstratified with expansible and non-expansible layers, expose potassium atoms which are replaced by aluminium from the lattice. Scott and Smith (1968) reported the development of visible cracks in the interlattice position due to drying which exposed K.

II.6.4 Extent of Potassium Release :

The extent of potassium released by different soils varies considerably depending on genetic character of the soils and the numerous factors influencing them. Different crops have got different abilities to use non-exchangeable potassium reserves (Salmon, 1965) In temperate climates many soils often contain few weatherable mineral reserves and are believed to release potassium (Nye, 1963) Salmon (1965) reported release of non-exchangeable K by love grass to vary from 3-293 lbs K_2O per acre. Varying amount of K released under cropping has also been reported by Tabatabhai and Hanway (1969) and Ataya (1973). According to Biswas (1974) soils which are already exhausted with respect to potassium, released very low amount of K from non-exchangeable forms.

MATERIALS AND METHODS

The Integrated Watershed Development Programme in the state is being implemented in four watersheds at G. Udayagiri and Khajuripada in Kandhamal (Phulbani) district and Jagannath Prasad and Sorada in Ganjam district. The project area encompases both aerable and non-aerable lands under slopy terrain, prone to moderate to severe erosion hazards. The present case study is limited to Khajuripada block of Kandhamal district only.

III.1. Location and extent :

The district of Kandhamal is one of the centrally located district of Orissa. It is drained by three primary rivers namely : the Mahanadi ; the Vansadhara and the Rusikulya. The catchment area of these rivers have been delineated and codified upto mini-watershed level. Each mini-watershed forms the unit of any integrated developmental programme.

The hierarchy of the Nedisahi Nallah Mini-watershed is as follows :

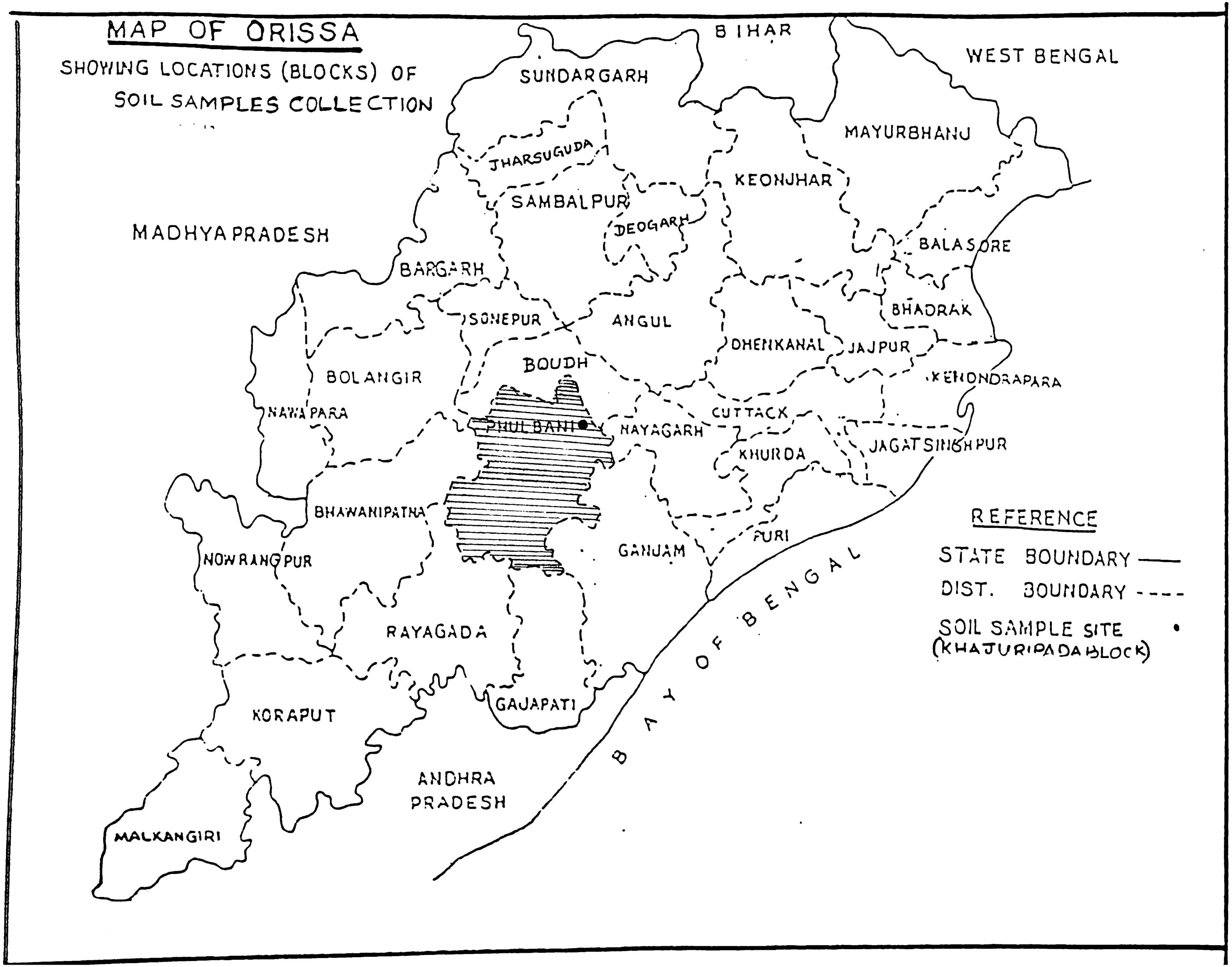


Fig.1 Map of Orissa showing soil sample collection site

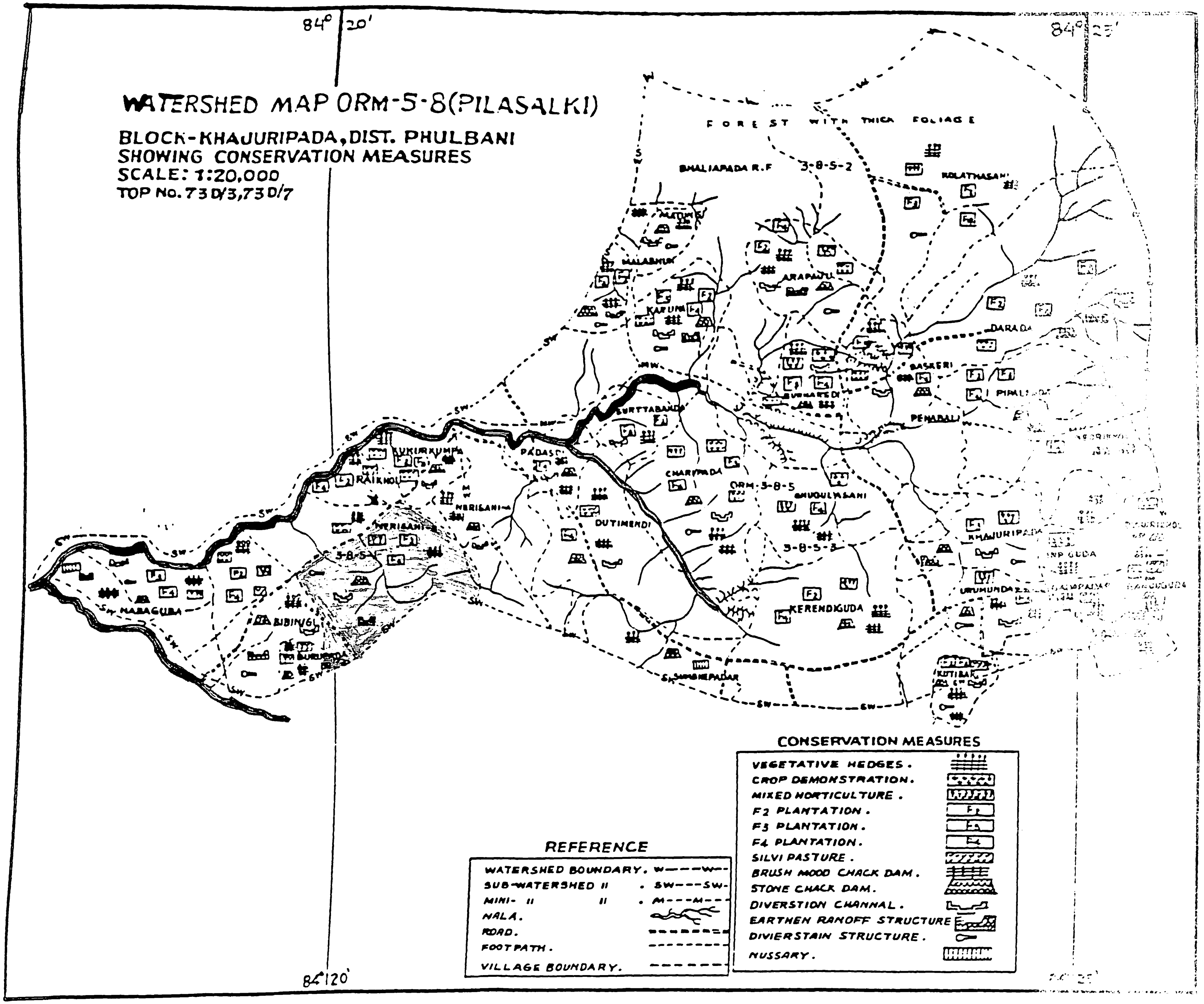


Fig.2 Watershed map of ORM-5-8 showing Nedisahinalla miniwate

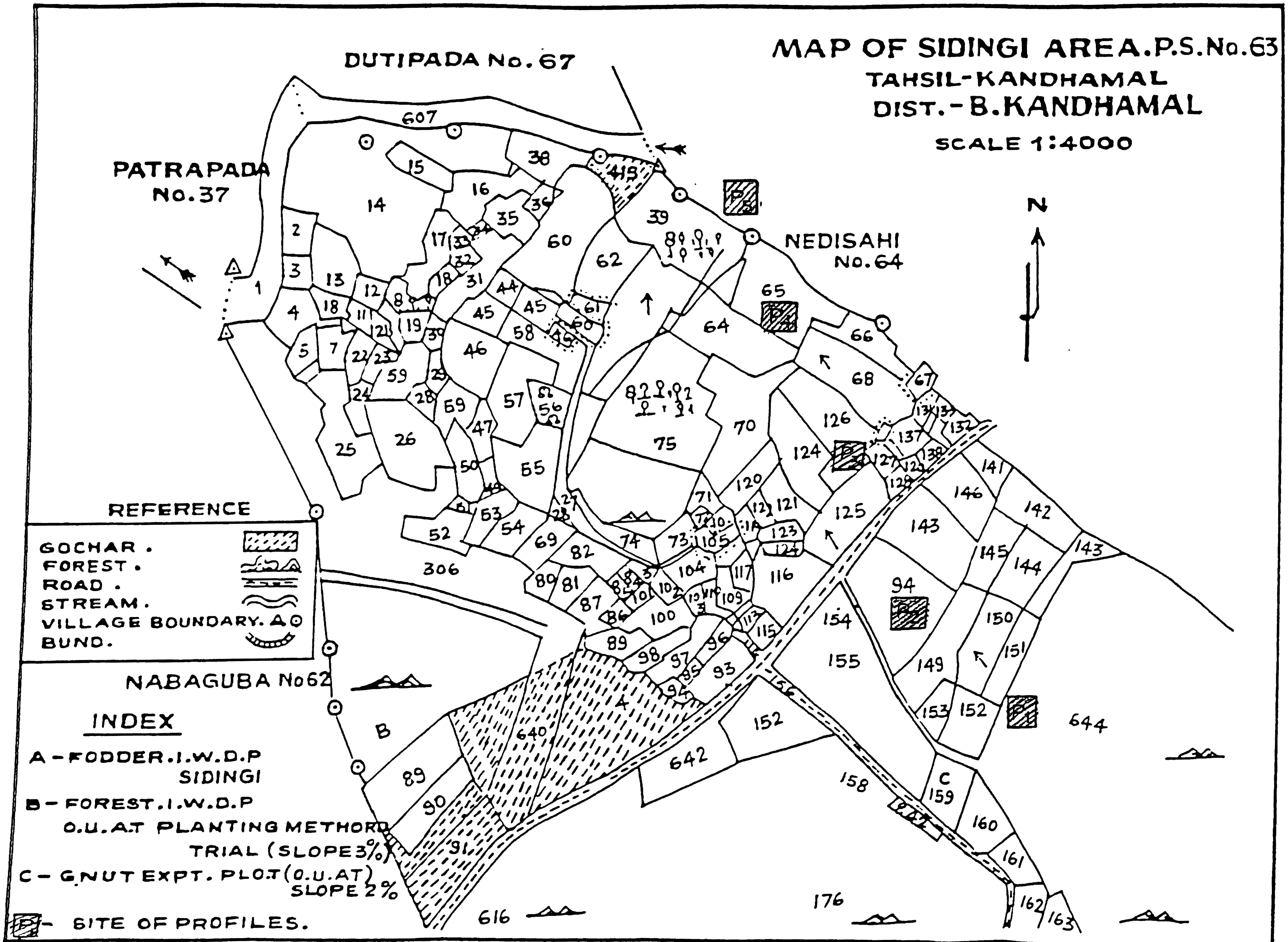


Fig.3 Map of Sidingi and Nedisahinalla

ORM (Mahanadi catchment)	(Primary river)
ORM-3 (Salki sub-catchment)	(Secondary river)
ORM-3-8 (Pilasalki watershed)	(Tertiary stream)
ORM-3-8-5 (Budharkedi sub-watershed)	(Quarternary stream)
ORM-3-8-5-1 (Nedisahi nallah mini-watershed)	(Pentad streamlet)

The Nedisahi Nallah mini-watershed (ORM-3-8-5-1) located in watershed ORM-3-8 (Pilasalki) and sub-watershed ORM-3- 8-5 (Budharkedi Nallah) in Khajuripada Block of Kandhamal district lies in between 20°26' to 20°29' N latitude and 84°17' to 84°26' E longitude (Fig. 2). It includes eight villages out of which the village sidingi and Nedisahi with the total geographical area of 265.705ha. has been taken for the present study (Fig. 3).

The present land use pattern of the above two villages are given below along with some socio-economic informations (Anonymous, Soil Survey Staff (1989), Project Report on IWDP).

III.2. Socio economic information :

Name of the village	Total population	Male	Female	S.C.	S.T.	Others
1) Nedisahi	47	23	24	-	47	-
2) Sidingi	219	105	114	81	138	-

III.3. Drinking water facility :

Village	Well	Tube well	Tank	Total
1) Nedisahi	1	1	-	2
2) Sidingi	2	2	-	4

The mini-watershed comes under Eastern ghat hill tract having folded topography of anticlinal ridges and synclinal valleys. The entire land scape is sedentary origin with two broad categories.

(1) Sedentary land scape in eroded phase with hill, hill slopes (Pediment) and ridges (up land) and ;

(2) Sedentary land scape in depositional phase (valley).

For the present investigation surface as well as the profile soil samples were collected from foot hills (pl), upper ridge (P_2), mid-upland (P_3), mid-medium land (P_4) and medium valley land (P_5) P_1 was under high land (forest), P_2, P_3, and P_4 were under up land and P_5 was under medium land situations.

III.4. Land holding pattern (Area in ha) :

Name of the village	Agricultural land			Non-agricultural land			Cultivable wasteland	Unculti-vable wasteland
	Upland	Medium land	Low land	Hill	Forest	Gochar		
Nedisahi	10.848	3.076	6.134	1.810	-	-	-	0.280
Sidingi	83.691	11.886	4.846	10.223	9.669	6.760	0.685	0.600
Total	94.539	14.962	10.980	12.033	9.669	6.760	0.685	0.880

III.5. Non-Agricultural land :

Non-Agricultural land								Total area	Reserve forest	G. total
Community land	Village site	Orchard	Road & Path	River, Tank & Nallah	Burial ground	village welfare dev.	Rakhit Land			
0.485	0.325	-	0.230	1.653	-	2.185	-	25.026	-	25.026
1.719	1.416	-	2.891	4.910	0.383	-	-	240.679	-	240.679
2.204	1.741	-	3.121	6.563	0.383	2.185	-	265.705		265.705

The climate of the project area is hot and moist subhumid and falls in the North eastern ghat agroclimatic zone of Orissa with an average rainfall of 1280.16 mm. The mean maximum temperature is 37°c (May) and the mean minimum temperature is 10.4°c (December). The relative humidity ranges from 64-80%.

III.6. Natural Vegetation of the mini-watershed areas :

Some of the dominant species found in the localities are as follows :

Sal (*Shorea robusta*), Piasal (*Pterocarpus marsupium*), Mango (*Mangifera indica*), Mahula (*Madhuca latifolia*) Tamarind (*Tamarindus indica*), Banyan (*Ficus bengalensic*), Sisal (*Agave Sisalana*), Jack fruit (*Artocarpus integrifolia*), Bamboo (*Dendrocalamus strictus*), Khajuri (*Phoenix sylvestris*), Kendu (*Diosyrous melanoxylon*), Chakunda (*Cassia accidentles*) Sisoo (*Dalbergia sisoo*), Pokasunga (*Ageratum conyzoides*), Salapa (*Caryoto Urens*).

III.7. METHODS OF ANALYSIS :

III.7.1. Collection of soil sample :

Field traversing was done in the mini-watershed areas under study. Profile sites were choosen taking into consideration ground cover,micro relief, degree of erosion, surface drainage, proximity to trees and all other factors likely to affect the soil in comparision with the normal type

Colour chart and was designated by the given notation i.e. hue, value and chroma.

III.7.3.2. Mechanical analysis :

The particle size analysis to determine the percentage of sand, silt and clay was carried out by Bouyoucos hydrometer method as described by Piper (1950). Sodium oxalate was used as the dispersing agent and the proportion of different sand, silt and clay fractions were determined. Textural class were determined using International Triangular chart.

III.7.3.3. Bulkdensity, particle density and water holding capacity :

Water holding capacity, bulk density, particle density and total pore space were determined by adopting the procedures outlined by Chopra & Kanwar (1976).

III.7.4 Chemical characteristics :

III.7.4.1 Organic Carbon :

The organic carbon was determined by modified Walkley and Black's rapid titration method using ortho-phenanthroline ferrous complex (Ferroin) as indicator following the procedures described by Chopra & Kanwar (1976).

they intended to represent. Profile pits were dug in such a way that there was maximum sunshine on one end at the time of sampling. After clearing one face of the pit carefully with a spade the succession and depth of each horizon was noted and morphological studies were made. Then soil samples were collected from each layer vertically down and kept in separate bags with an informations sheet attached to each sample.

Composite surface samples (0-15 cm) were collected from each physiogrphic regions for determining the fertility status and other properties of soil.

III.7.2 Processing of soil sample :

The soil samples were air dried, ground with a mortar with wooden pestle and passed through a 2mm seive to remove undecomposed roots etc. and then mixed throughly. The samples so obtained were preserved (approximately 1.0kg) in a stoppered bottles, lebelled and stored in a dry place for further study.The materials remaining on the seive were volumetrically measured as coarse fragments and then discarded.

III.7.3. Physical methods :

III.7.3.1. Soil colour :

The colour of the air dried and moist soil samples were determined by matching the colour with Munsell's Soil

Colour chart and was designated by the given notation i.e. hue, value and chroma.

III.7.3.2. Mechanical analysis :

The particle size analysis to determine the percentage of sand, silt and clay was carried out by Bouyoucos hydrometer method as described by Piper (1950). Sodium oxalate was used as the dispersing agent and the proportion of different sand, silt and clay fractions were determined. Textural class were determined using International Triangular chart.

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The organic carbon was determined by modified Walkley and Black's rapid titration method using ortho-phenanthroline ferrous complex (Ferroin) as indicator following the procedures described by Chopra & Kanwar (1976).

III.7.4.2 Soil reaction :

The pH of the soil samples were determined in 1:2 soil:water suspension after equilibriating for half an hour with intermittent stirring by the ELICO pH meter, model-LI-10T.

III.7.4.3 Electrical conductivity :

The electrical conductivity of soil samples were determined in 1 : 2.5 soil water suspension after equilibriating for half an hour by using ELICO conductivity bridge type CM 82 T.

III.7.4.3 Exchange acidity :

The KCl extractable acidity were determined by Lin and Coleman method (1980); 10g of soil and 25ml of 1N KCl solution was equilibrated for 30 minutes. It was filtered and then washed with additional volume of 125ml. of 1N KCl in 25ml increments. The filtrate was titrated against standard NaOH using phenolphthalein indicator to know the exchange acidity. Exchangeable Al^{+++} was determined by adding NaF and back titrating with standard HCl. Exchangeable H^{+} was calculated from differences of total exchange acidity and exchangeable Al^{+++}.

III.7.4.5. Cation exchange capacity :

The cation exchange capacity of soil was determined as per Chapman (1965) by leaching with neutral normal NH_4OAc

and distilling off the absorbed NH_4^+ into boric acid solution after washing out excess saturating solution by ethanol. Then it was estimated by titrating with standard acid using Bromocresol greenethyl-red mixed indicator.

III.7.4.6. Exchangeable metalic cation :

Exchangeanble sodium and potassium were determined from the NH_4OAc leachate collected from CEC determination by 'ELICO' model; CL 22 D digital flame photometer. Exchangeable calcium and magnesium from the same leachate were determined by the versenate titration method as out lined by Heald (1965) after the leachate was evaporated to dryness, digested with aquaregia (one part HNO_3 & three parts HCl), washed in diluted hydrochloric acid and finally made to the original aliquot volume (Diehl *et al.* 1950).

III.7.4.7. Lime requirement :

It was determined by woodruff's buffer method as described by Chopra & Kanwar (1986). In this method 10g of soil and 20ml of buffer solution (PH 7.5) was shaken for 10 minutes and the PH was determind. The lime requirement is proportional to the depression in pH of the buffer. The lime requirement can be determined from the lime requirment scale for buffer method.

III.7.4.8. Detrmination of iron oxides :

It was determined by the procedure developed by A.F.O. In this method 0.5g soil was taken and 30ml. distilled water was added to it, kept in hot water bath (40-45°) for 15 min, 1g sodium dithionite was added and stirred for 15 min. It was centrifused at 2500 rpm for 10 min, and the supernatant was collected to a 250 ml. volumetric flask. Then to the residual soil, 25 ml. 0.02 N HCl was added and kept in hot water bath for 5-10 min at 40-50°C. Then it was centrifused as before and the supernatant was collected into the same 250 ml volumetric flask. The above procedure was repeated till 100-110 ml of supernatant was collected & the volume madeup. Fifty ml solution was taken and charcoal filtered if turbidity/ colour development was there. If no turbidity or colour was there, 2ml filtrate was taken in a 50ml. volume flask 10 ml, acetic acid and NH_4OAc buffer, 2 ml. of 0.25% orthophenanthroline indicator was added & volume made up and colorimeter reading was taken in 508 nm.

III.7.5. Determination of available nutrient status :

III.7.5.1. Available nitrogen :

Available nitrogen was determined by the method described by Jackson (1973). Nitrogen released as ammonia during distillation of 20 g soil with 100 ml of 0.32% $KMnO_4$ and 100 ml of 2.5% NaOH was received in 2% boric acid containing mixed indicator and 30 ml of the distillate was collected. The ammonia was titrated against standard H_2SO_4.

III.7.5.2. Available phosphorus :

III.7.5.2.1. Bray's method :

It was determined by shaking 2 g soil in 20 ml of extracting solution (0.03N NH_4F in 0.025 N HCl) for 5 minutes. The filtrate was estimated by colorimeter for P after development of colour by $SnCl_2$ (Jackson 1973).

III.7.5.2.2. Olsen's method :

Available phosphorous was determined by olsen's method taking 1g soil in 20 ml 0.5 M $NaHCO_3$ and shaking for 30 minutes in a mechanical shaker then it was filtered. A filtrate of 10 ml was mixed with 10 ml of chloromolybdic acid and volume madeup to 25 ml and reading was taken colorimetrically (Jackson 1973) using 1 ml $SnCl_2$ as indicator in Bausch and Lamb (340) colorimeter.

III.7.5.2.3. Available potassium :

It was determined by equilibriating 5g soil in 25ml neutral normal ammonium acetate (Jackson 1973) and the reading of extract after dilution was taken in an ELICO digital Flame photometer model No CL22D.

III.7.6. Potassium extraction by different methods :

III.7.6.1. Water soluble K :

Five grams of soil was taken in a 100 ml conical flask and equilibriated with 25 ml distilled water and shaken for one hour in a mechanical shaker. Then it was filtered and potassium concentration in the filtrate was determined by a Flame photometer.

III.6.2. Exchangeable K :

It is the difference of NH_4OAc K and water soluble K.

III.7.6.3. Non-exchangeable K :

It was determined from the difference of 1N HNO_3 - extractable K and NH_4OAc - K. To determine the 1N HNO_3 extractable K 2.5 g of air dried soil was taken in a 100 ml conical flask and 25 ml of 1N HNO_3 was added and the content was allowed to boil for 10 minutes. Then it was filtered to a 100 ml volumetric flask and made up to volume by six time washing with 10 ml portion of 0.1 HNO_3. The potassium concentration in the extract was determined after necessary dilution in a Flame photometer (Wood & Deturk 1940).

III.7.6.4. Lattice - K :

It is the difference of total - K and 1N HNO_3 extractable - K.

III.7.6.5. **Total - K :**

One gram soil was taken into a 100 ml conical flask and 10 ml concentrate HNO_3 was added to it. After keeping it over night digestion was done on a hot plate till complete evaportion of HNO_3. Then 5 ml of diacid mixture was added (HNO_3: $HClO_4$ in 3:2) and placed over the hot plate till 0.5 ml of the residue remained. Then the conical flask was washed from neck to bottom by distilled water and filtered to a 100 ml volumetric flask. The volume was made up by repeated washing with distilled water. Then after required dilution the concentration of potassium was determined by a Flame photometer.

III.7.6.6. **Step-K (K-Releasing power of soil) :**

K-release characteristics of the soils from the non-exchangeable source were studied following the method of Haylock (1956). Potassium was extracted repeatedly for ten times by boiling with 1N HNO_3 in 1:10, Soil : solution ratio at 10 minutes interval. To compute the non-exchangeable K in the 1st extract the NH_4OAc - K was substracted from the 1st HNO_3 extractable K.

The amount of K extracted by HNO_3 decreased gradually with successive extractions to attain a constant value which was termed as constant rate K(CR-K). The amount extracted in excess of constant rate-K is termed as the step-K (Stanton & Orchard 1963).

III.7.7. NUTRIENT INDEX :

III.7.7.1. Nutrient index was calculated by using the formula given below :

$$\text{Nutrient index} = \frac{\text{No. of samples in low} \times 1 + \text{No of samples in medium} \times 2 + \text{No of samples in high} \times 3}{\text{Total no. of sample analysed.}}$$

Rating of Nutrient index :

< 1.5 ... Deficient.

1.5 to 2.5 ... Average.

> 2.5 ... Adequate.

This rating was done as per the procedure described by Muhr *et al.* (1963).

III.7.7.2. The grouping under low, medium and high for the organic carbon, available phosphorus and available potash was done based on the values, described by Mitra *et al.* 1980 as follows :

III.7.7.2.1

Organic Carbon (%)	Rating
< 0.5	Low
0.5 to 0.75	Medium
> 0.75	High

III.7.7.2.2 Available N content (Alkaline K M_nO_4 method) (kg/ha)

Available N content (Alkaline K M_nO_4 method) (kg/ha)	Rating
< 250	Low
250-500	Medium
> 500	High

III.7.7.2.3 Bray's available P_2O_5 (kg/ha)

Bray's available P_2O_5 (kg/ha)	Rating
< 14	Low
14 to 40	Medium
> 40	High

III.7.7.2.4 Olsen's available-P (kg ha^{-1})

Olsen's available-P (kg ha^{-1})	Rating
< 9	Low
9 to 22	Medium
> 22	High

III.7.7.2.5 NH_4OAc-K (kg/ha)

NH_4OAc-K (kg/ha)	Rating
< 118	Low
118 to 280	Medium
> 280	High

CHAPTER IV

RESULTS AND DISCUSSION

Results of the investigation together with suitable and proper discussion are presented through the following aspects for convenience in this chapter.

- Morphological characteristics of the soil profiles.
- Physical characteristics including densities, water holding capacity, total pore-space and mechanical composition of the soil samples collected
- Chemical properties including pH (soil reaction), electrical conductivity, organic carbon, cation exchange capacity and exchange compositions, exchange acidity.
- Lime requirement of the soils.
- Available nutrient status of the soil
- Forms of potassium in soil and their release characteristics in the profiles.
- Soil Genesis.
- Classification of soils as per Soil Taxonomy.

IV.1. Morphological characteristics of the soil profiles:

After traversing the Sidingi and Nedisahi area of Khajuripada P.S. in Khandhamal district, four pedons from sidingi and one pedon from Nedisahi were exposed one day prior

Table : 1 Morphology of the pedons of I.W.D.P. areas of Khajuripada

Pedon	Horizon	Depth(Cm)	Soil Colour Dry	Soil Colour Moist	boundary	Texture	Structure	Consistence	Special features
P_1	A2	0-14	5YR 5/4	7.5YR 4/4	Cs	s	sg	dl,ml,ws.wp	
	B21	14-40	5YR 5/6	2.5YR 4/6	Dw	sl	sg	dl,mrfr,wss	
	B22t	40-72	5YR 5/8	10YR 4/4	Dw	l	f,l,sbk	dsh,mfi,ws	few fine Fe and Mn & thin patchy Clay cutan
	B23t	72-150	5YR 4/6	10YR 4/4		cl	m,2,sbk	dh,mvfi,wvsup	-do-
P_2	Ap	0-11	5YR 6/8	5YR 4/8	Cs	scl	fl sg	dsh,mfr,wsswps	
	B21t	11-52	5YR 5/8	5YR 4/8	Dw	c	fl sbk	dsh,mfr,wvswp	Thin patch Clay cutons
	B22t	52-88	5YR 5/8	5YR 5/6	Dw	c	fl sbk	dsh,mfr,wvswp	Thin patchy clay cutans
	B23	88-115	5YR 5/8	5YR 5/6	Dw	c	m2 sbk	dsh,mfr,wvswp	few medium Fe and Mn
	C	115-150	5YR 5/8	5YR 5/6		Gc	m2 sbk	dsh,mfr,wvswp	-do-
P_3	Ap	0-14	5YR 6/4	7.5YR 5/6	Cs	l	m2 sbk	dsh,mfi,wss	
	B21t	14-42	5YR 5/4	10YR 4/6	Cs	cl	m2 sbk	dh,mfi,wswp	
	B22t	42-90	5YR 5/6	2.5YR 4/6	Cs	c	m3 sbk	dh,mvfi,wvswvp	Few fine Fe and Mn
	B23t	90-172	5YR 5/6	2.5YR 4/6		c	c3 sbk	dvh,mvfi,wvs wvp	many fine Fe and Mn
P_4	Ap	0-14	5YR 6/4	5YR 5/4	Cs	l	m2 sbk	dsh,mfr,wswps	
	B21	14-27	5YR 6/6	5YR 6/4	Cs	sl	m2 sbk	dsh,mfr,wsswps	
	B22t	27-60	5YR 5/4	5YR 4/4	Cs	cl	m2 sbk	dsh,mfi,ws wp	Thin patchy clay cutan
	B23t	60-150	5YR 6/4	5YR 5/4		c	c3 sbk	dh,mvfi,wvs wvp	-do-
P_5	AP	0-14	5YR 6/4	5YR 5/4	dw	sl	m2 sbk	dsh,mfr.wss wps	
	B21	14-32	5YR 6/4	5YR 5/4	cw	Gsl	m2 sbk	dsh,mfr,wss wps	Quartz grain of 2-20mm size & Thin patch,clay cutan
	B22w	32-84	5YR 6/6	5YR 5/6	cs	Gcl	c2 sbk	dh,mfr,wswp	Few fine Fe and Mn & Qurtz & thin patch clay cutan
	C	84-155	5YR 5/6	5YR 5/8		Ge	m2 sbk	dh,mfr,wvs wvp	Quartz grains of 2-20mm size.

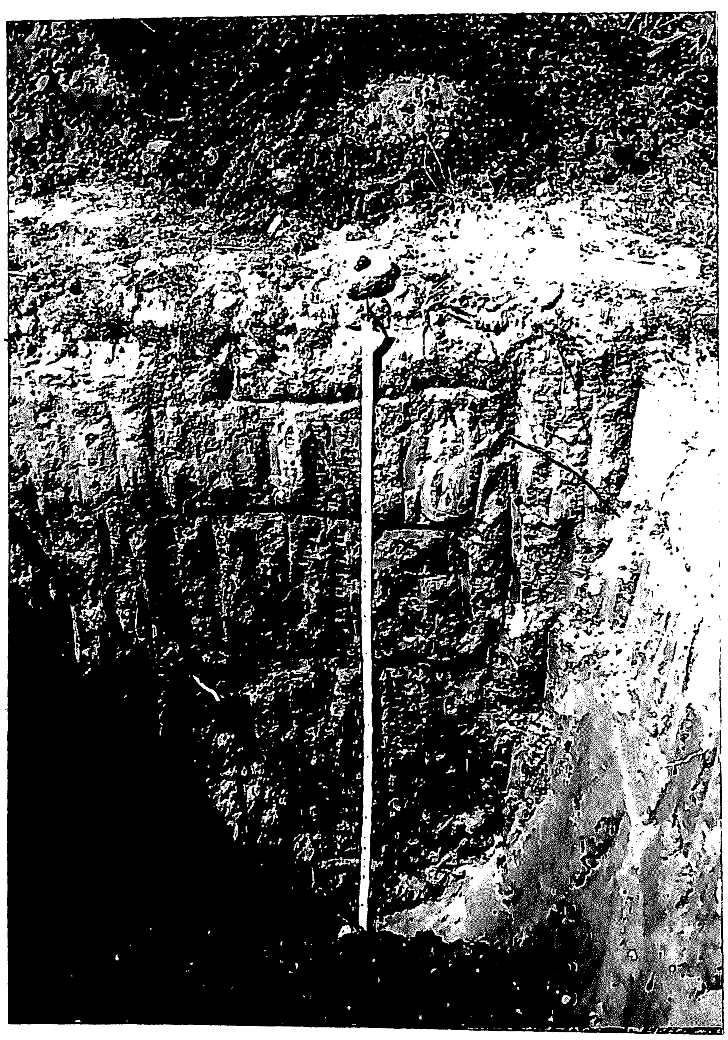
to study and morphological characteristic were described in the following manner and presented in table 1 ('m' denotes moist condition).

Pedon - I (Sidingi)

Setting - Village- Siding, Tahsil - Kandhamal, Dist- Kandhamal

Site characteristics	:	(Photo Plate - 1)
Location	:	250 m right of the Bisipada - Khajuripada road
Land form	:	Slopy, slope 5-8% (E-W)
Surface condition	:	Bushy forest
Parent material	:	Laterite
Ground Water table	:	10.5 m in summer
Natural Vegetation	:	Pokasunga, Small bushes.
Erosion	:	e_1
Surface drainage	:	Well drained
Land use	:	Fallow

Genetic horizon	Depth (cm)	Description
A2	0-14	Reddish brown (5YR 5/4), dark brown (7.5YR 4/4 m); sandy; single grained; loose, friable, nonsticky, non-plastic; many, very fine roots inside peds, rapid permeability; medium acid; clear smooth boundary;



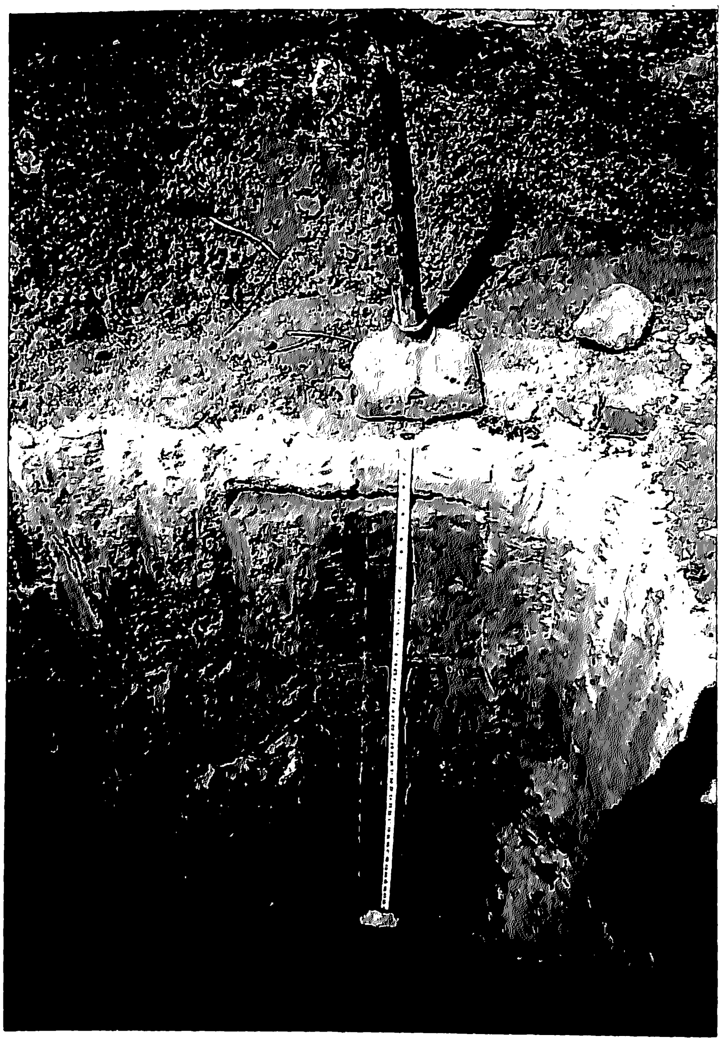
PHOTOPLATE -1 Soils of foot hill (P_1)

B21	14-40	Yellowish red (5YR 5/6); red (2.5YR 4/4 m); sandy loam; single grained; lose, very friable, slightly sticky; fine fibrous medium roots; medium acid; rapid permeability; clear smooth boundry;
B22t	40-72	Yellowish red (5YR 5/8); dark yellowish brown (2.5YR 4/6m); loam; weak fine subangular blocky; slightly hard, friable, sticky; thin patchy clay cutans; Fe, Mn concretions, common fine imped roots; moderate permeability; medium acid; diffuse smooth boundary;
B23t	72-150	Yellowish red (5YR 4/6); dark yellowish brown (10R 4/4m); clay loam; moderate, medium, sub-angular blocky; hard, very firm, very sticky, plastic; Fe, Mn concretions aboundant; thick patchy clay cutans; very few, thick palm roots; medium acid; moderate permeability.

Pendon - II

Setting: Village - Sidingi, Thahsil-Kandhamal, Dist-Kandhamal

Site characteristic	:	(Photo plate - 2)
Location	:	200m right of Bisipada-Khajuripada road
Land form	:	Slopy, slope 3-5% (E-W)
Surface condition	:	Cultivated fallow
Parent material	:	Laterite
Ground water table	:	8.5m in summer.
Natural vegetation	:	*Shorea robusta, Mangifera indica, Madhuka Latifolia, Tamarindus indica*, etc.
Erosin	:	e_1
Surface drainage	:	Well drained
Land use	:	Upland crop i.e. Niger, Horse gram.



PHOTOPLATE -2 Soils of upper ridges (P_2)

Genetic horizon	Depth (cm)	Description
AP	0-11	Reddish yellow (5YR 6/8), Yellowish red (5YR 4/8m); sandy clay loam; weak, fine, single grain to massive; slightly hard, friable, slighty sticky, slightly plastic; many, fibrous, very fine roots, rapid permeability; medium acid; common fine continuous vertical imped pores; clear smooth boundary;
B21t	11-52	Yellowish red (5YR 5/8), yellowish red (5YR 4/8m); clay; weak, fine, subangular blocky; slightly hard, friable, very sticky, plastic; moderate permeability; medium acid; thin patchy clay cutans; common very fine roots impeds; common fine continuous vertical imped pores; diffuse smooth boundary;
B22t	52-88	Yellowish red (5YR 5/8); yellowish red (5YR 5/6m); clay; weak, fine, subangular blocky, slightly hard friable, very sticky, plastic; fine incipient Fe-Mn concretion; common fine, vertical imped pores; few medium roots; thin, patchy clay cutans; slow permeability; medium acid; diffuse smooth boundary;
B23	88-115	Yellowish red(5YR 5/8); yellowish red(5YR 5/6m); clay; moderate,medium,subangular blocky; slightly hard,friable, very sticky, plastic; semi rounded 2-5mm Fe-Mn concretions 5-10%; slightly acid; diffuse smooth boundary.

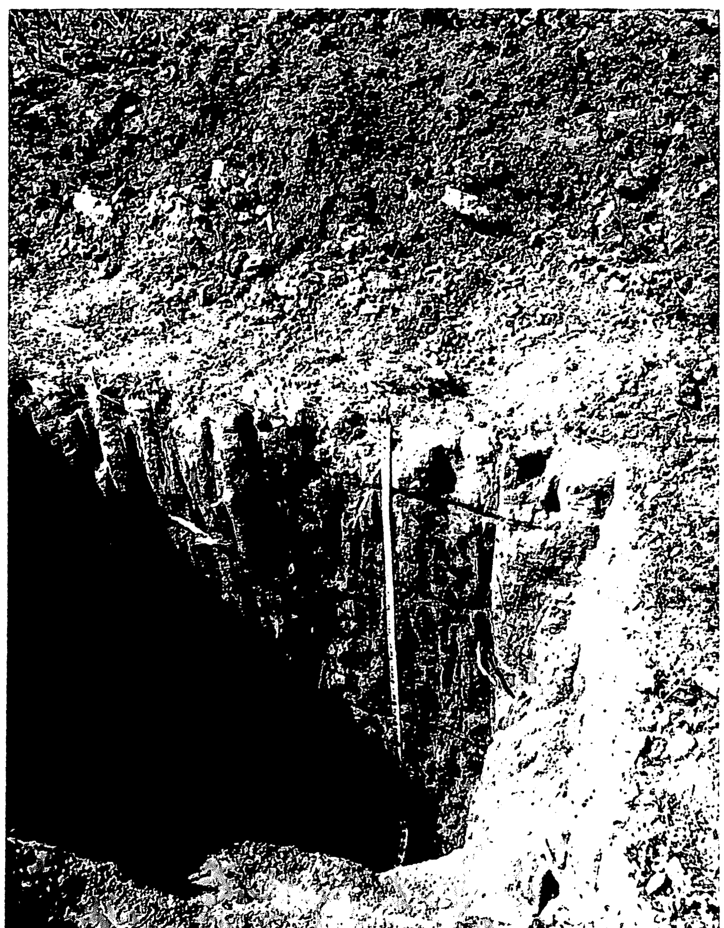
C	115-150	Yellowish red(5YR 5/8); yellowish red(5YR 5/6m); gravelly clay; moderate, medium, subangular blocky; slightly hard, friable very sticky, plastic; semirounded 5-10mm, Fe-Mn concretion 10-25%; Slightly acid.

Pedon - III

Setting - Village- Siding, Tahsil - Kandhamal, Dist- Kandhamal

Site characteristics	:	(Photo Plate - 3)
Location	:	100m left of the Bisipada - Khajuripada road
Land form	:	Almost levelled, slope-1-3% (SE-NW)
Surface condition	:	grasses and bushes
Parent material	:	Laterite
Ground Water table	:	7.00m in summer
Natural Vegetation	:	*Mangifera indica, Tamarindus indica*
Erosion	:	e_1
Surface drainage	:	Well drained
Land use	:	Fallow

Genetic horizon	Depth (cm)	Description
AP	0-14	Light reddish brown (5YR 6/4); strong brown (7.5YR 5/6m); loam; moderate, medium, subangular blocky; slightly hard, firm, slightly sticky; many fibrous fine roots; moderate permeability; medium acid; clear smooth boundary;
B21t	14-42	Reddish brown (5YR 5/4); dark yellowish brown (10YR 4/6m); clay loam; moderate, medium, subangular blocky; slightly hard firm, sticky & plastic; thin patchy, clay cutans; few fine roots; low permeability; medium acid; clear smooth boundary;



PHOTOPLATE -3 Soils of mid-upland (P_3)

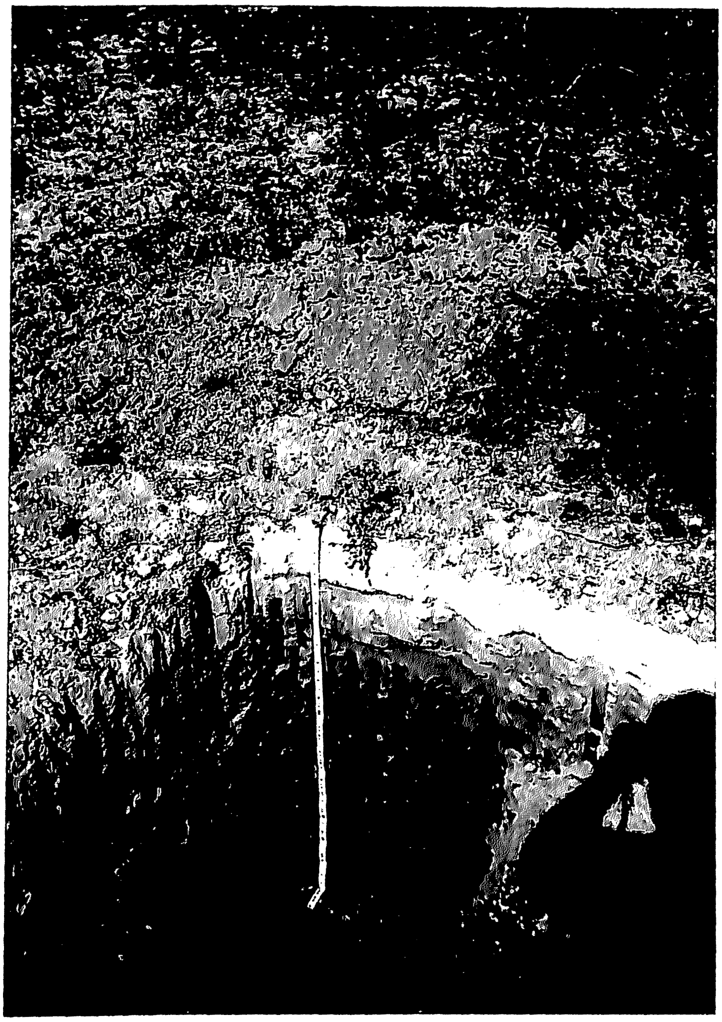
B22t	42-90	Yellowish red (5YR 5/6), red (2.5YR 4/6m); clay; strong, medium, subangular blocky; hard very firm, very sticky, very plastic; few medium (1-2mm and 5 to 10%) Fe-Mn concretions; common fine and few medium roots; thin patchy clay cutan; slow permeability; medium acid; clear smooth boundary;
B23t	90-172	Yellowish red (5YR 5/6); red (2.5YR 4/6m); clay; strong,coarse, subangular blocky; very hard,very firm,very sticky and very plastic; many medium (5-10% & 2-5mm) Fe-Mn concretions; common, fine and few medium roots; thick patchy clay cutan; slow permeability; medium acid.

Pedon - IV

Setting - Village- Siding, Tahsil - Kandhamal, Dist- Kandhamal

Site characteristics	:	(Photo Plate - 4)
Location	:	About 200m left of the Bisipada - Khajuripada road
Land form	:	Slopy, slope 3-5% (S-N)
Surface condition	:	Unbunded land-cultivated fallow
Parent material	:	Laterite
Ground Water table	:	6.50m in summer
Natural Vegetation	:	*Mangifera indica, Madhuka latifolia, caryota urens*
Erosion	:	e_2
Surface drainage	:	Well drained
Land use	:	Niger, sweet potato, termeric are grown nearby.

Genetic horizon	Depth (cm)	Description



PHOTOPLATE -4 Soils of mid-medium land (P_4)

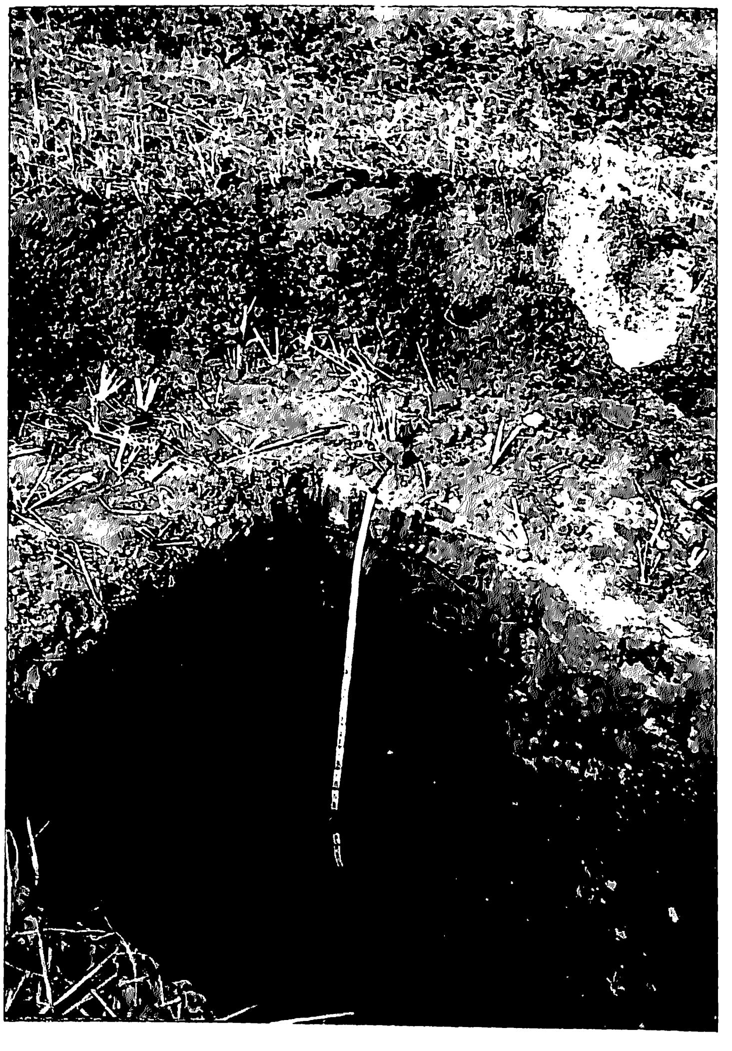
AP	0-14	Light reddish brown (5YR 6/4); reddish brown (5YR 5/4m); loam; moderate, medium, subangular blocky; slightly hard, friable, sticky and slightly plastic; many, fibrous, fine roots; common, fine, tubular imped pores; moderate permeability; medium acid; clear smooth boundary;
B21	14-27	Reddish yellow (5YR 6/6); light reddish brown (5YR 6/4m); sandy loam; moderate, medium, subangular blocky; slightly hard, friable, slightly sticky, slightly plastic; many, medium roots between peds; common fine tubular imped pores, moderate permeability; medium acid; clear smooth boundary;
B22t	27-60	Reddish brown (5YR 5/4); reddish brown (5YR 4/4 m); clay loam; moderate, medium, subangular blocky; slightly hard, friable, sticky and plastic; many medium roots; thin patchy clay cutans; 5-20 % coarse fractions (< 5mm); few, fine vertical imped pores; slow permeability; medium acid; clear smooth boundary;
B23t	60-150	Light reddish brown (5YR 6/4); reddish brown (5YR 5/4m); clay; strong coarse, subangular blocky; hard, very firm, very sticky and very plastic; few fine roots; thin patchy clay cutans; 5-20% coarse fractions (< 5mm), very slow permeability; medium acid.

Pedon - V (Nedisahi)

Setting - Village- Nedisahi, Tahsil-Kandhamal, Dist-Kandhamal

Site characteristics	:	(Photo Plate - 5)
Location	:	300m left of the Bisipada - Khajuripada road
Land form	:	Terraced. Slope 3-5% (S-N)
Surface condition	:	Bounded agricultural land
Parent material	:	Laterite and rounded sandstone boulders below 80cm depth.
Ground Water table	:	5m in summer
Natural Vegetation	:	*Madhuka latifolia, Mangifera indica*
Erosion	:	e_1
Surface drainage	:	Well drained
Land use	:	Early Paddy.

Genetic horizon	Depth (cm)	Description
AP	0-14	Light reddish brown (5YR 6/4); Reddish brown (5YR 5/4m); sandy loam; moderate, medium, subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; many, fine, imped roots; many, macro pores; moderate permeability; slightly acid, diffuse smooth boundary;
B21	14-32	Light reddish brown (5YR 6/4); reddish brown (5YR 5/4m); sandy loam; moderate, medium, subangular blocky; slightly hard, friable slightly sticky, slightly plastic, 5-10 cm rounded stones, many, medium, roots; many macro pores; moderate permeability; slightly acid; diffuse smooth boundary;



PHOTOPLATE -5 Soils of medium valley land (P_5)

B22w	32-84	Reddish yellow (5YR 6/6); yellowish red (5YR 5/6m); clay loam; moderate, course, subangular blocky; hard, friable, sticky and plastic; medium Fe-Mn concretions; 10-20 cm rounded boulders; common, fine, roots; slightly acid; clear smooth boundary;
C	84-155	Yellowish red (5YR 5/6); yellowish red (5YR 5/8m); clay; moderate, medium, subangular blocky; hard, friable, very sticky, very plastic; morrum layer with many coarse fragments and boulders; common, fine roots; slow permeability; slightly acid.

IV.2. Physical Characteristics :

Data on physical properties and mechanical composition of profile and composite surface soil samples are presented in table 2 and 3 and clay distribution along with the depth of profiles are displayed in Fig. 4. In profile 1 the content of sand is the highest on the surface (88.64%) which gradually decreased downwards. The content of silt and clay were comparatively much less on the surface, which almost gradually increased downwards reaching a value of 12.0% and 31.36% respectively. The textural class ranged from sand in the A2 horizon to clayloam in B23t horizon. Although there was decrease of bulk density values from surface downwards with concurrent increase in the porespace volumes, the values of particle density remained almost constant. The available

Table : 2 Physical Properties and mechanical Composition of profile Soils.

Pedons	Horizons	Depth(Cm.)	MECHANICAL COMPOSITION Sand(%)	Silt(%)	Clay(%)	Textural Class	Bulk density (Mgm^{-3})	Particle density (Mgm^{-3})	Pore space (%)	Water holding Capacity(%)	Sand/Silt	Silt/Clay
P_1	A2	0-14	88.64	4.0	7.36	Sand	1.46	2.58	43.4	48.8	22.16	0.54
	B21	14-40	80.64	8.0	11.36	Sandy loam	1.37	2.55	46.3	45.4	10.08	0.70
	B22t	40-72	62.64	14.0	23.36	Loam	1.33	2.54	47.6	41.4	4.47	0.60
	B23t	72-150	56.64	12.0	31.36	Clay loam	1.25	2.53	50.6	42.1	4.72	0.38
			(72.14)	(9.5)	(18.36)		(1.35)	(2.55)	(46.9)	(44.4)	(10.35)	(0.55)
P_2	Ap	0-11	72.64	6.0	21.36	Sandy Clay loam	1.44	2.61	44.8	48.0	12.11	0.28
	B21t	11-52	54.64	10.0	35.36	Clay	1.37	2.60	47.3	41.7	5.46	0.28
	B22t	52-88	52.64	11.0	36.36	Clay	1.33	2.55	47.8	46.7	4.78	0.30
	B23	88-115	54.64	8.0	37.36	Clay	1.30	2.57	49.4	49.4	6.83	0.21
	C	115-150	54.64	10.0	35.36	Gravelly Clay	1.34	2.65	49.4	43.8	5.46	0.28
			(57.84)	(9.0)	(33.16)		(1.36)	(2.60)	(47.7)	(45.9)	(6.92)	(0.27)
P_3	Ap	0-14	72.64	12.0	15.36	Loam	1.42	2.60	45.4	42.8	6.05	0.78
	B21t	14-42	54.64	16.0	29.36	Clay loam	1.38	2.56	53.9	46.0	3.41	0.54
	B22t	42-90	48.64	6.0	45.36	Clay	1.30	2.60	50.0	48.2	8.10	0.13
	B23t	90-172	38.64	16.0	45.36	Clay	1.30	2.53	48.6	46.3	2.42	0.35
			(53.64)	(12.5)	(33.86)		(1.35)	(2.57)	(49.5)	(45.8)	(4.99)	(0.45)
P_4	Ap	0-14	66.64	18.0	15.36	Loam	1.43	2.63	45.6	43.7	3.70	1.17
	B21	14-27	78.64	4.0	17.36	Sandy loam	1.45	2.63	44.9	40.7	19.66	0.23
	B22t	27-60	64.64	8.0	27.36	Clay loam	1.29	2.60	50.4	41.9	0.08	0.29
	B23t	60-150	32.64	20.0	47.36	Clay	1.27	2.65	52.0	47.5	1.63	0.42
			(60.64)	(12.5)	(26.86)		(1.36)	(2.63)	(48.2)	(43.4)	(8.26)	(0.52)
P_5	Ap	0-14	80.64	6.0	13.36	Sandy loam	1.43	2.57	44.3	45.9	13.44	0.45
	B21	14-32	80.64	4.0	15.36	Gravelly Sandy loam	1.41	2.60	45.8	40.9	20.16	0.26
	B22w	32-84	54.64	14.0	31.36	Gravelly Clay loam	1.34	2.61	47.8	48.9	3.90	0.45
	C	84-155	50.64	12.0	37.36	Gravelly Clay	1.32	2.59	49.0	41.6	4.22	0.32
			(66.64)	(9.0)	(24.36)		(1.37)	(2.59)	(46.7)	(44.3)	(10.43)	(0.37)
			62.18*	10.5*	27.32*	Sandy Clay loam*	1.36*	2.59*	47.8*	44.76*	8.19*	0.43*

Figures in parenthesis indicated mean values per profile.
Figures having * indicating total means values of all the profiles.

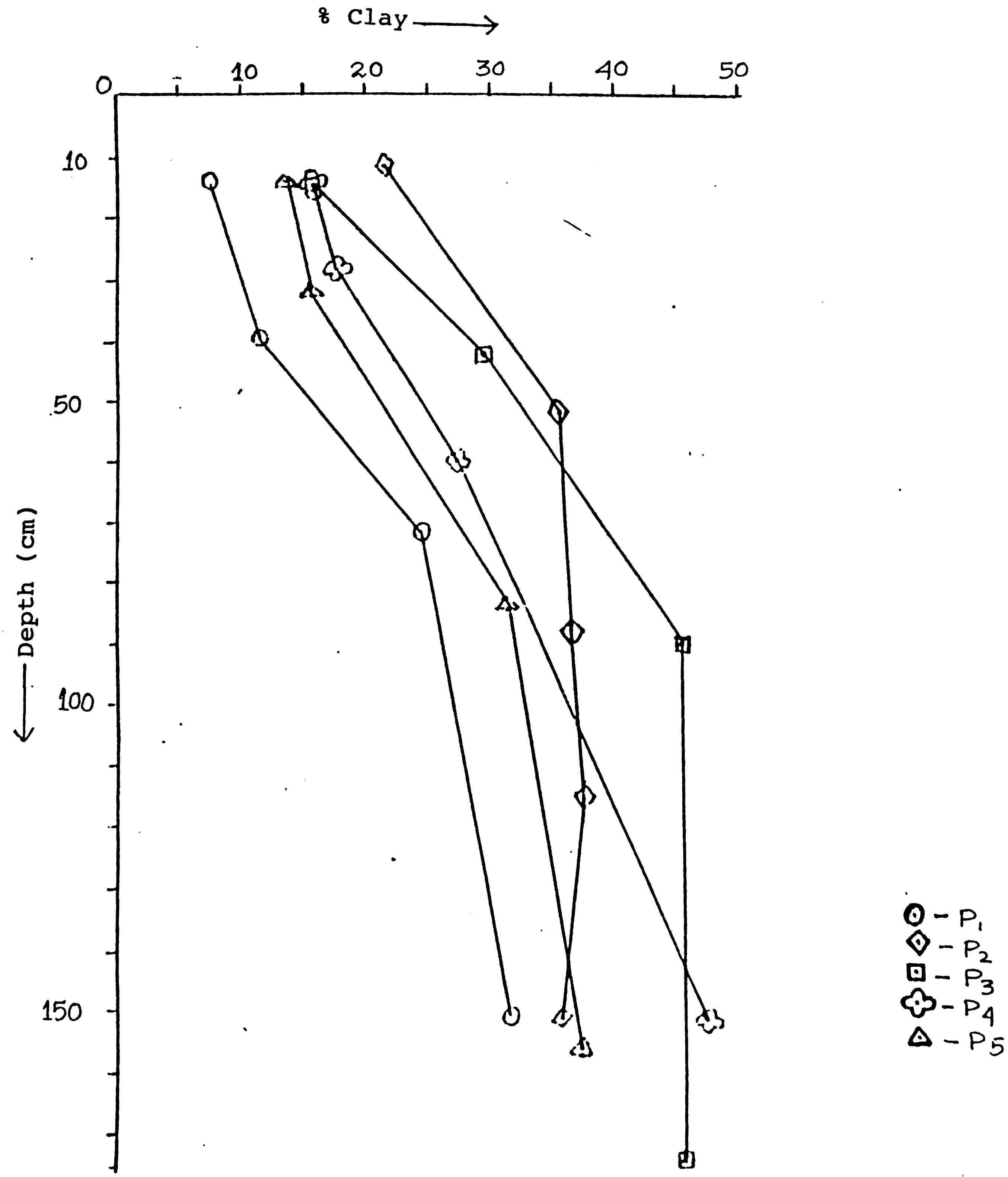


Fig.4 % Clay vs depth of profile

water holding capacity varied from 41.4% to 48%. The sand/silt ratio decreased from surface (22.16) downwards and silt clay ratio also almost decreased downwards. The gradual accumulation of clay downwards and presence of thin patchy clay cutans below 40cm depth indicated the presence of an argillic horizon. Presence of heavy minerals was ruled out as the particle density ranged from 2.53 to 2.58 Mg m^{-3}.

Although the sand content was the highest in the surface layer of profile-2, it was almost constant in other layers. On the other hand the clay content was comparatively less on the surface and higher almost constant values were obtained in sub-surface horizons. The textural class was sandy clay loam on the surface and clay in other three horizons. The bulk density values decreased from surface downwards indicating higher compactness in the lower layers. The particle density values remained almost constant. Gradual increase of clay content in the subsurface horizons and presence of clay cutans through morphlogical observations confirmed the presence of argillic horizon. Higher values of sand/silt ratio was observed on the surface which decreased downwards and silt/clay ratio was almost constant with a slightly lower value in B23 horizon.

Table : 3 Physical Properties and Mechanical Composition of Composite Surface Soil Samples.

Sl.No.	Depth (Cm.)	MECHANICAL COMPOSITION			Textural Class	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Pore Space (%)	Water holding Capacity (%)
		Sand(%)	Silt(%)	Clay(%)					
1.	0-15	75.44	9.0	15.56	Sandy loam	1.41	2.60	45.8	32.3
2.	0-15	77.44	8.0	14.56	Sandy loam	1.57	2.56	38.7	36.8
3.	0-15	81.44	6.0	12.56	Sandy loam	1.65	2.62	37.0	36.0
4.	0-15	83.44	6.0	10.56	Sandy loam	1.51	2.62	42.4	37.5
5.	0-15	72.64	8.0	19.36	Sandy loam	1.48	2.54	41.8	35.6
		(78.08)	(7.4)	(14.52)	Sandy loam	(1.52)	(2.59)	(41.1)	(35.6)
6.	0-15	76.04	9.0	14.96	Sandy loam	1.43	2.56	44.1	30.1
7.	0-15	81.44	6.0	12.56	Sandy loam	1.44	2.61	44.8	35.8
8.	0-15	76.04	8.0	15.96	Sandy loam	1.45	2.62	44.7	38.4
9.	0-15	63.04	9.0	27.96	Clay loam	1.38	2.64	47.7	36.1
10.	0-15	61.04	12.0	26.96	Clay loam	1.33	2.53	47.4	32.1
		(71.52)	(8.8)	(19.68)	(Sandy loam)	(1.34)	(2.59)	(45.7)	(34.5)
11.	0-15	73.44	14.0	12.56	Sandy loam	1.45	2.57	43.6	39.5
12.	0-15	78.04	10.0	11.96	Sandy loam	1.42	2.63	46.0	43.7
13.	0-15	70.04	16.0	13.96	Loam	1.48	2.43	39.1	39.4
14.	0-15	81.04	9.0	9.96	Sandy loam	1.46	2.58	43.4	40.4
		(75.64)	(12.3)	(12.11)	(Loam)	(1.45)	(2.55)	(43.0)	(4.07)
15.	0-15	57.04	17.0	25.96	Clay loam	1.41	2.59	54.4	43.6
16.	0-15	66.04	20.0	13.96	Loam	1.41	2.55	44.7	42.5
17.	0-15	54.04	30.0	15.96	Silt loam	1.37	2.58	46.9	42.3
18.	0-15	84.44	7.0	8.56	Loamy sand	1.38	2.65	47.9	41.3
		(65.39)	(18.5)	(16.11)	Loam	(1.39)	(2.59)	(48.5)	(42.4)
19.	0-15	74.44	11.0	14.56	Sandy loam	1.53	2.54	39.8	38.8
20.	0-15	74.04	10.0	15.96	Sandy loam	1.48	2.56	42.1	43.9
		(74.24)	(10.5)	(15.26)	(Sandy loam)	(1.50)	(2.55)	(40.9)	(41.4)
		(72.95)	(11.5)	(15.54)	(Loam)	(1.44)	(2.57)	(43.8)	(38.92)

In profile-3, the sand content was the highest on the surface (72.64%) which gradually decreased to almost half in B23t horizon. The silt content was erratic in different horizon. The clay content was the lowest on the surface (15.36%) which increased even 3 times reaching a value of 45.36% below 42 cm depth. Gradual decrease of bulk density values from the surface downwards was noticeable indicating the compactness of sub-surface horizon. Almost gradual decrease in the sand/silt ratio and silt/clay ratio was observed from the surface downwards.

The sand content was the highest in B21 horizon of profile-4,and value gradually decreased downwards. The surface soil showed slightly lower values. The clay content increased from surface downwards and there was presence of clay cutans indicating the presence of argillic horizon. The texture was loam on the surface to clay in B23t horizon with 47.36% clay. The value of particle density remained almost constant but the bulk density valuses gradually decreased and porespace value gradually increased with depth. No consistent values on silt/clay ratio or sand/silt ratio could be obtained.

Much higher content of sand was obtained in the upper two horizons of profile-5, the values of which decreased downwards. Concurrently the clay content was almost constant in upper two horizons and much higher value was obtained in the lower horizons. The porticle density values and per cent porespace were almost constant. Erratic trend was observed with sand/silt ratio and silt/clay ratio.

Considering all the profiles from Sidingi it may be seen that there was gradual decrease of sand content from the surface downwards with concurrent increase of clay content. Oriented clay accumulation in sub-surface horizons and presence of clay cutans confirmed the presence of argillic horizon. Although clay content in the bottom horizons ranged from 41.36 to 47.36%, the permeability of soil was not hampered which might be due to kaolinite type of clay minerals and presence of coarse fragments.

Although increase of clay content below 32cm in Nedisahi series was seen, no clay cutans could be observed inferring there by, the absence of argillic horizon. But some textural changes and presence of Fe-Mn concretions in the Bzzw horizon indicated the presence of a cambic horizon.

The soils of the entire area were very deep and the parent materials could be observed only in P_2 and P_5 (Table 1). The soils were usually well drained, porous and having rapid permeability. Common to many, semi-rounded to rounded Fe-Mn concretions and quartz grains are observed in sub-surface horizons of all the profiles indicating the parent material to be rich in Fe bearing minerals. The weathering environment being slightly acid the Fe moved from the Fe bearing minerals and entered into the colloidal hydrous oxides of Fe which might have later developed to concretionary stages under alternate wetting and drying processes. Presence of semirounded to rounded boulders of more than 10 cm size in profile-5 might be due to the transportaion of these boulders from the higher altitudes and their deposition in the valley medium land before the construction of Bisipada - Khajuripada road and the sub-canal.

Considering the mechanical composition of the composite surface samples adjoining profile-1, it was seen that, the sand content was much higher with mean value of 78.08% and the textural class was sandy loam. Comparatively higher clay content in the surface samples of profile-2 was obtained (mean value was 19.68%) indicating accumulation of clay in the lower topographic situation. Further removal of clay from Profile-2 situation to profile-3 situation by run-off is not observed because of the Bisipada - Khajuriapada road in between the two profile situation which might have restricted the clay transportation by run-off water. Similar frend was observed in physiographic position of profile-3 and 4 which were in a slopy terrain and were subjected to transportation of clay by run-off water. The sub-branch canal of Pilasalki M.I.P. existed between profile-4 and profile-5 area which might have restricted the transportation of clay and the value of clay content in profile-5 area was less in comparision to profile-4 area. The mean values for bulk density varies from 1.34 to 1.52 Mg m-3 in different physiographic positions with a total mean of 1.44 Mg m-3. The particle density mean values in different physiographic positions did not vary much and the total mean remained at 2.57 Mg m^{-3}, but the mean value of percent pore-space adjoining profile-4 was much higher and profile-5 area was much lower with a total mean of 43.8%. Considering the surface taxture of the entire study area it was acertain to be loam with total mean values of 72.95% sand, 11.5% silt and 15.55% clay.

IV.3. Chemical characteristics :

The chemical properties of the soils of the study area; both profile samples and composite surface samples are presented in table: 4 and 5 respectively.

The soil reaction of all the profiles was almost medium to slightly acidic (Table 4) As the soils were highly weathered, leached and devoid of basic cations, the trend in pH down the profile did not occur in profile-1 and profile-5 and pH in different horizons were almost similar varying from 5.45 to 6.25. In profile 2,3 and 4 the pH slightly increased down the depth (Fig. 5) which might be attributed to the leaching of basic cations from the surface downwards in the

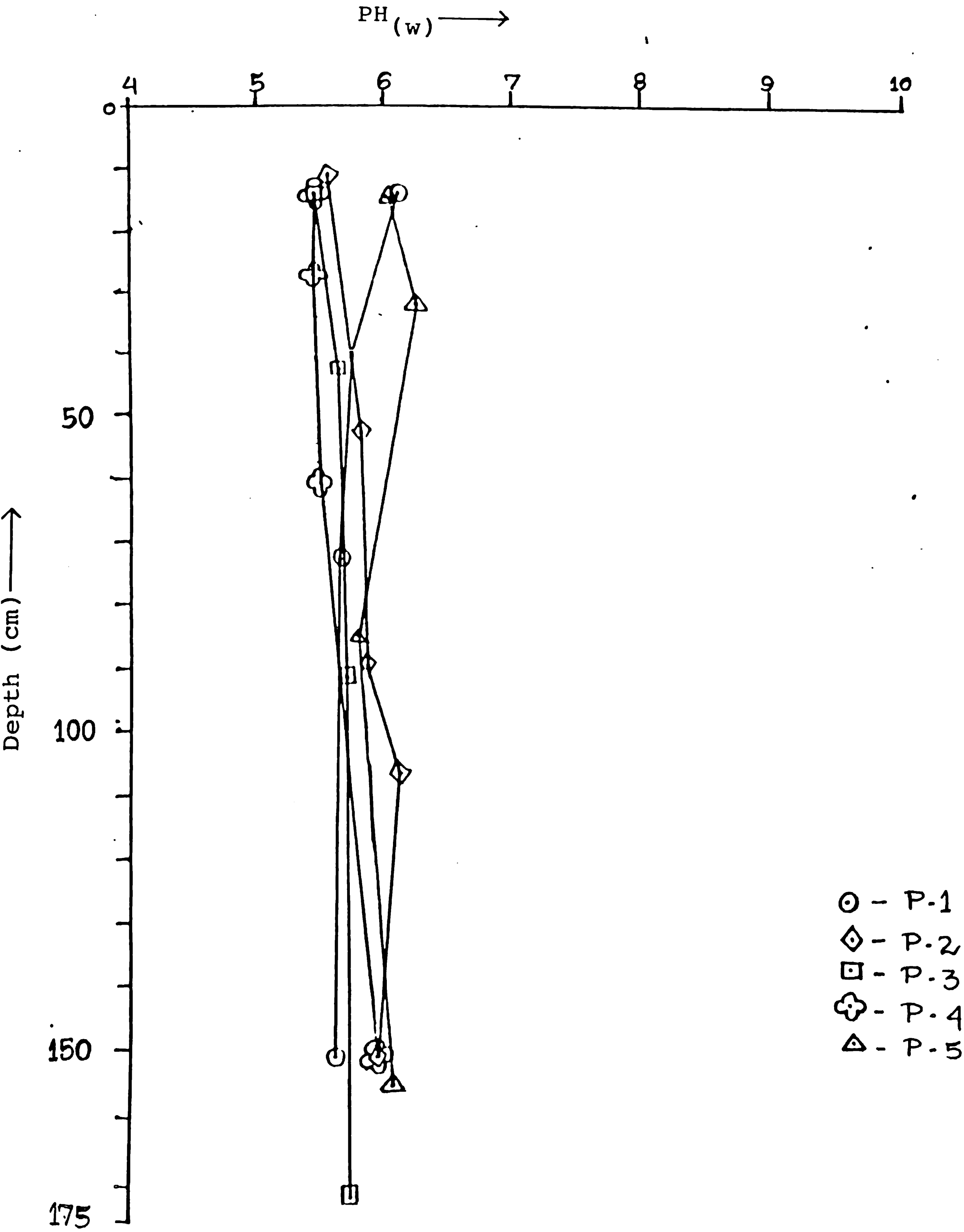


Fig.5 $PH_{(w)}$ vs Depth of profiles

Table : 4 Chemical Properties of Profile Soils.

Pedons	Depth(Cm.)	pH(1:2)(w)	E.C. dsm^{-1}	Organic carbon(%)	Kcl Acidity $Cmol(P^+)Kg^{-1}$	Exch.Al^{3+} $Cmol(P^+)Kg^{-1}$	Exch.H^+ $Cmol(P^+)Kg^{-1}$	Free Fe_2O_3 (%)
P_1	0-14	6.10	0.12	0.17	0.27	-	0.27	0.40
	14-40	5.75	0.15	0.17	0.27	-	0.27	0.66
	40-72	5.65	0.13	0.14	0.99	-	0.99	1.35
	72-150	5.60	0.16	0.14	0.45	-	0.45	1.92
		(5.73)	(0.14)	(0.16)	(0.50)			(1.08)
P_2	0-11	5.55	0.09	0.20	0.81	-	0.81	1.07
	11-52	5.80	0.15	0.16	0.45	-	0.45	2.02
	52-88	5.85	0.10	0.15	0.09	-	0.09	2.12
	88-115	6.10	0.06	0.08	0.09	-	0.09	2.12
	115-150	5.90	0.12	0.10	0.27	-	0.27	2.02
		(5.84)	(0.10)	(0.14)	(0.34)			(1.87)
P_3	0-14	5.45	0.15	0.39	0.99	-	0.99	0.82
	14-42	5.65	0.18	0.30	0.27	-	0.27	1.34
	42-90	5.70	0.10	0.24	0.09	-	0.09	2.65
	90-172	5.70	0.18	0.13	0.09	-	0.09	2.76
		(5.63)	(0.15)	(0.27)	(0.36)			(1.90)
P_4	0-14	5.45	0.09	0.33	1.53	-	1.53	0.82
	14-27	5.45	0.11	0.28	1.53	-	1.53	0.98
	27-60	5.50	0.07	0.24	0.81	-	0.81	1.63
	60-150	5.90	0.06	0.23	0.27	-	0.27	2.87
		(5.58)	(0.05)	(0.27)	(1.04)			(1.57)
P_5	0-14	6.05	0.06	0.40	0.09	-	0.09	0.73
	14-32	6.25	0.04	0.20	0.09	-	0.09	0.81
	32-84	5.80	0.09	0.14	0.27	-	0.27	1.82
	84-155	6.00	0.11	0.15	0.45	-	0.45	2.12
		(6.03)	(0.08)	(0.22)	(0.23)			(1.37)
		(5.76)	(0.104)	(0.21)	(0.5)			(1.51)

Sl.No.	Depth (Cm.)	pH(1 : 2)	E.C. dsm^{-1}	Org.carbon(%)	$Cmol(P^+)Kg^{-1}$ Kcl.Acidity	Exch.Al^{3+}	Exch. H^+
1.	0-15	5.30	0.31	0.49	1.15	0.02	1.13
2.	0-15	5.70	0.06	0.23	1.13	-	1.13
3.	0-15	5.80	0.15	0.76	0.63	-	0.63
4.	0-15	5.70	0.18	0.28	0.99	-	0.99
5.	0-15	5.60	0.19	0.32	0.27	-	0.27
		(5.62)	(.18)	(0.42)	(0.83)		(0.83)
6.	0-15	5.60	0.24	0.30	0.81	-	0.81
7.	0-15	5.45	0.13	0.28	0.63	-	0.63
8.	0-15	5.30	0.76	0.17	0.27	0.02	0.25
9.	0-15	5.70	0.45	0.24	0.09	-	0.09
10.	0-15	5.90	0.18	0.22	0.09	-	0.09
		(5.59)	(0.35)	(0.24)	(0.38)		(0.37)
11.	0-15	5.45	0.25	0.36	0.63	-	0.63
12.	0-15	5.55	0.33	0.36	0.27	-	0.27
13.	0-15	5.55	0.24	0.29	0.27	-	0.27
14.	0-15	5.65	0.32	0.32	0.27	-	0.27
		(5.55)	(0.28)	(0.33)	(0.36)		(0.36)
15.	0-15	6.35	0.16	0.49	0.09	-	0.09
16.	0-15	5.65	0.24	0.54	0.45	-	0.45
17.	0-15	5.70	0.44	0.66	0.27	-	0.27
18.	0-15	6.25	0.44	0.42	0.09	-	0.09
		(5.99)	(0.32)	(0.53)	90.22)		(0.22)
19.	0-15	5.90	0.18	0.26	0.45	-	0.45
20.	0-15	5.65	0.23	0.19	0.81	-	0.81
		(5.78)	(0.20)	(0.22)	(0.63)		(0.63)
		(5.69)	(0.27)	(0.36)	(0.45)	(0.02)	(0.44)

well drained condition of the soils. Considering all the horizons of different profiles the mean soil pH was calculated to be 5.76 which was under medium acid condition. The electrical conductivity values were very low ranging from 0.04 to 0.18 dSm^{-1} indicating the soils to be almost free of soluble salts. The total mean of the E.C. value in all the profiles was 0.104 dSm^{-1}.

There was gradual decrease of organic carbon content from surface down the profile (Fig. 6) ranging from 0.4 to 0.08% which indicated the low organic carbon content of the soils in all the horizons. This may be attributed to mineralisation of organic matter in the tropical and sub-tropical belt for which the organic carbon content was low. The total acidity in different horizons of all the profiles varied from 1.53 to 0.09 cmol (P^{+}) kg^{-1} with a mean value of 0.5 throughout the profile. The total acidity in soil was mostly due to exchangeable H^{+} ions as the exchangeable Al^{3+} ions content was nil and the pH values of all the horizons were above 5.3 (Das *et al.*, 1992). The free iron oxide content values were low on the surface horizons and increased downwards in all the profiles with a range of 0.4 to 2.87% and with a mean value of 1.51% all throughout the profiles. The gradual increase of Fe_2O_3 along with clay (Fig. 7) might be due to the translocation of free Fe_2O_3 through leaching in the mild acid condition and gradual accumulation in the lower horizons.

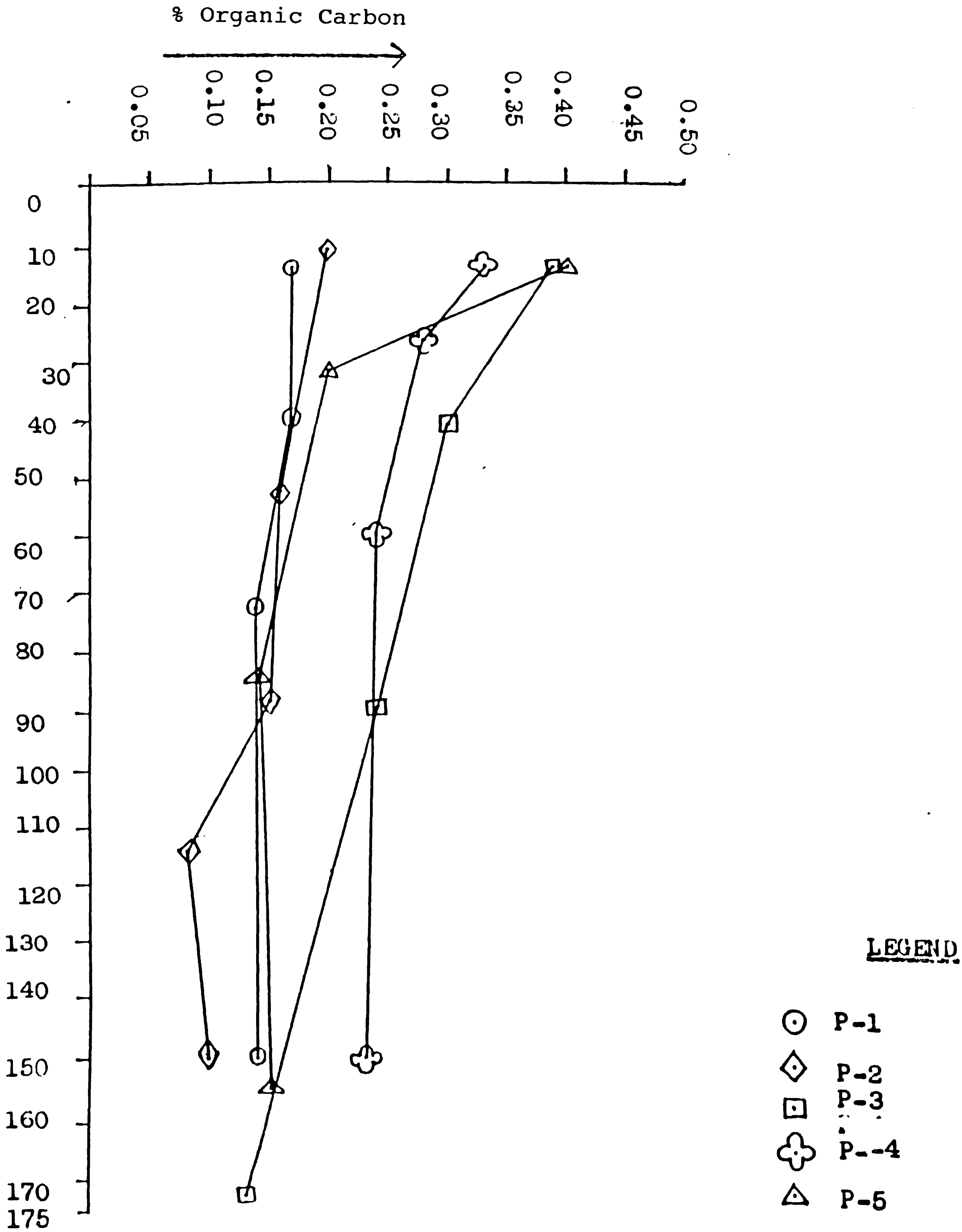


Fig.6 Organic Carbon vs depth of profile

Table : 6 Cation Exchange Capacity and Composition of exchange complex of profile soils.

Pedons.	Depth(Cm.)	CEC $(Cmol(P^+)Kg^{-1})$	Exchangeable Cations $(Cmol(P^+)Kg^{-1})$				Total basic Cations $(Cmol(P^+)Kg^{-1})$	Base Saturation (%)	$\frac{CEC}{Clay}$ %
			Ca^{++}	Mg^{++}	Na^+	K^+			
P_1	0-14	1.68	0.76	0.32	0.026	0.086	1.192	70.42	23
	14-40	2.72	1.34	0.70	0.038	0.056	2.134	78.45	24
	40-72	4.80	2.43	1.20	0.030	0.056	3.716	77.41	21
	72-150	4.96	2.55	1.26	0.030	0.060	3.896	78.54	16
		(3.54)	(1.77)	(4.35)	(0.031)	(0.064)	(2.73)	(76.2)	(21)
P_2	0-11	2.80	1.12	0.76	0.041	0.065	1.986	70.92	13
	11-52	5.36	2.28	1.50	0.043	0.060	3.883	72.44	15
	52-88	5.84	2.54	1.81	0.035	0.056	4.441	76.04	16
	88-115	6.16	2.68	2.08	0.038	0.056	4.774	77.50	16
	115-150	6.00	2.52	1.61	0.043	0.056	4.229	70.48	17
		(5.23)	(2.23)	(1.55)	(0.004)	(0.058)	(3.86)	(73.48)	(15.4)
P_3	0-14	2.64	1.04	0.52	0.025	0.056	1.641	62.15	17
	14-42	4.80	2.25	1.05	0.028	0.065	3.393	70.68	16
	42-90	6.80	3.55	1.35	0.038	0.065	4.963	72.98	15
	90-172	7.36	4.06	1.41	0.035	0.056	5.561	75.55	16
		(5.4)	(2.73)	(1.08)	(0.032)	(0.06)	(3.89)	(70.34)	(16)
P_4	0-14	2.32	0.93	0.26	0.035	0.60	1.285	55.38	15
	14-27	3.36	1.04	0.70	0.023	0.060	1.823	54.25	19
	27-60	4.72	1.60	1.20	0.025	0.060	2.885	61.12	17
	60-150	6.88	3.00	2.02	0.017	0.056	5.093	74.02	15
		(4.32)	(1.64)	(1.05)	(0.025)	(0.059)	(2.77)	(61.19)	(16.5)
P_5	0-14	2.24	1.03	0.34	0.012	0.060	1.442	64.37	17
	14-32	2.40	1.15	0.38	0.023	0.056	1.609	67.04	16
	32-84	3.20	1.32	0.61	0.033	0.060	2.023	63.21	10
	84-155	5.12	2.78	0.87	0.038	0.065	3.753	73.30	14
		(3.24)	(1.57)	(0.55)	(0.026)	(0.06)	(2.20)	(66.98)	(14.25)
		(4.39)	(2.0)	(1.05)	(0.031)	(0.06)	(3.13)	(69.82)	(16.57)

Table : 7 Cation Exchange Capacity & Composition of the Exchange Complex of Surface Soi

Sl. No.	Depth(Cm.)	CEC (Cmol(P$^+$)Kg^{-1}	Exchangeable Cations(Cmol(P$^+$)Kg^{-1})				Total basic Cations (Cmol(P$^+$)Kg^{-1}	Base Saturation (%)	$\frac{CEC}{Clay}$ %
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}			
1.	0-15	2.72	0.96	0.45	0.056	0.065	1.531	56.28	17
2.	0-15	2.48	0.71	0.46	0.060	0.080	1.310	52.82	17
3.	0-15	2.56	1.04	0.75	0.054	0.068	1.912	74.68	20
4.	0-15	2.48	0.93	0.40	0.050	0.075	1.455	58.70	23
5.	0-15	2.56	0.96	0.42	0.060	0.085	1.525	59.57	13
		(2.56)	(0.92)	(0.5)	(0.056)	(0.067)	(1.546)	(60.41)	(18)
6.	0-15	3.20	1.32	0.72	0.065	0.083	2.118	68.37	21
7.	0-15	2.88	0.92	0.78	0.060	0.083	1.843	64.00	23
8.	0-15	2.56	0.86	0.79	0.060	0.080	1.790	69.90	16
9.	0-15	2.56	0.92	0.81	0.065	0.075	1.870	73.00	09
10.	0-15	2.72	1.02	0.88	0.043	0.056	1.999	73.49	10
		(2.78)	(1.0)	(0.80)	(0.058)	(0.075)	(1.924)	(69.75)	(15.8)
11.	0-15	2.48	0.88	0.68	0.035	0.050	1.615	65.10	19
12.	0-15	2.56	0.86	0.82	0.038	0.056	1.774	69.29	21
13.	0-15	2.56	0.84	0.86	0.025	0.056	1.781	69.57	18
14.	0-15	2.40	0.82	0.72	0.023	0.060	1.623	67.62	24
		(2.5)	(0.85)	(0.77)	(0.030)	(0.055)	(1.698)	(67.9)	(20.5)
15.	0-15	2.24	0.94	0.51	0.035	0.060	1.545	68.97	09
16.	0-15	2.48	0.94	0.48	0.033	0.065	1.518	61.20	17
17.	0-15	2.40	0.92	0.40	0.038	0.056	1.414	58.90	15
18.	0-15	2.48	1.04	0.54	0.035	0.065	1.678	67.66	29
		(2.4)	(0.96)	(0.48)	(0.035)	(0.061)	(1.538)	(64.18)	(17.5)
19.	0-15	2.48	0.92	0.52	0.012	0.060	1.512	60.96	17
20.	0-15	2.40	0.93	0.55	0.023	0.065	1.568	65.33	15
		(2.44)	(0.925)	(0.53)	(0.017)	(0.062)	(1.54)	(63.14)	(16)
		(2.56)	(0.94)	(0.63)	(0.044)	(0.065)	(1.669)	(65.27)	(17.65)

Chemical properties of the composite surface soil samples are presented in table 5. In most of the composite samples, the soil reaction varied from slight acidic to medium acidic. The pH values ranging from 5.3 to 6.25. The total mean surface pH value was 5.69. Electrical conductivity values were low and ragnges between 0.6 to 0.76 with a total mean of 0.27 dSm^{-1}. The organic carbon content of the 20 surface samples were less than 0.75 per cent, which ranged from 0.17 to 0.76% with a total mean value of 0.36% Total acidity of the surface samples varied from o.9 to 1.15 cmol (p+) kg^{-1}. Here also the total acidity was mostly due to exch. H^+ excepting sample-1 and 8 in which the exch. Al^{3+} contributed only 0.02 cmol(p+) kg^{-1}.

Cation Exchange Capcity and compositon of the exchange complex in different horizons of the profiles are presented in table: 6. The CEC values varied from 1.68 to 7.36 cmol (P+) kg^{-1}. The values were comparatively less on the surface horizons and increased gradually with depth and having a linear correlation with clay content (Fig. 8). As the organic carbon content was not appreciable in these soils, the CEC values could be attributed to the nature and the quantity of clay minerals. The CEC/clay value for all the profiles was almost similar and varying from 10 to 24 per cent indicating the nature of clay minerals to be mixture of kaolinite with traces of illite (Sahu *et al.* 1983). The total mean CEC of all the profiles was 4.39 cmol (P+) kg^{-1}, where as the the total mean value of the CEC/clay was of 16.57%. The percentage base saturation values, in general, increased from the surface downwards indicating removal of bases from the surface and gradual accumulation in the sub-surface horizons. Calcium dominated the exchange complex followed by Mg^{++}, K^{+}, and Na^{+} with a total mean value of 2.0, 1.6, 0.06 and 0.03 c mol (P+) kg^{-1} respectively. The increase in individual exchangeable cation down the depth almost coincided with the CEC values and base saturation value.

CEC values of surface samples were very low with a total mean of only 2.56 cmol (P+) kg^{-1} Ca^{++} dominated the exchange complex followed by Mg^{++}, K^{+} & Na^{+} as in case of profile samples. CEC/clay ratio varied from 9 to 24 per cent indicating the dominance of kaolinite with traces of illite (Table 7).

IV.4. Correlation among soil properties :

From the analytical data of soil profiles taken together, three correlations among the soil proporties have been statistically worked out and the results are discussed as follows:

Fig.7 Relation between clay & Fe_2O_3 content

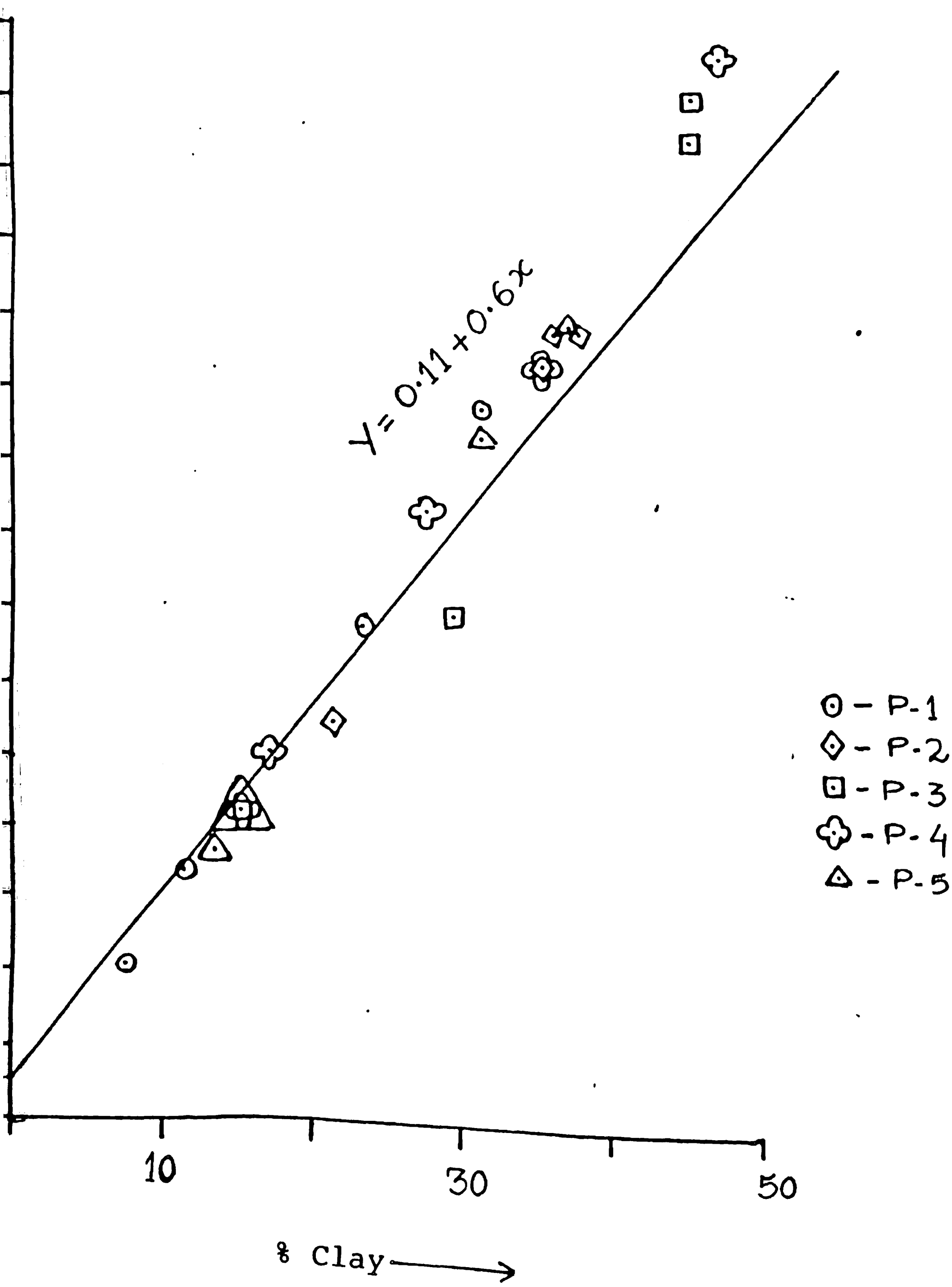


Fig.8 CEC vs per cent clay

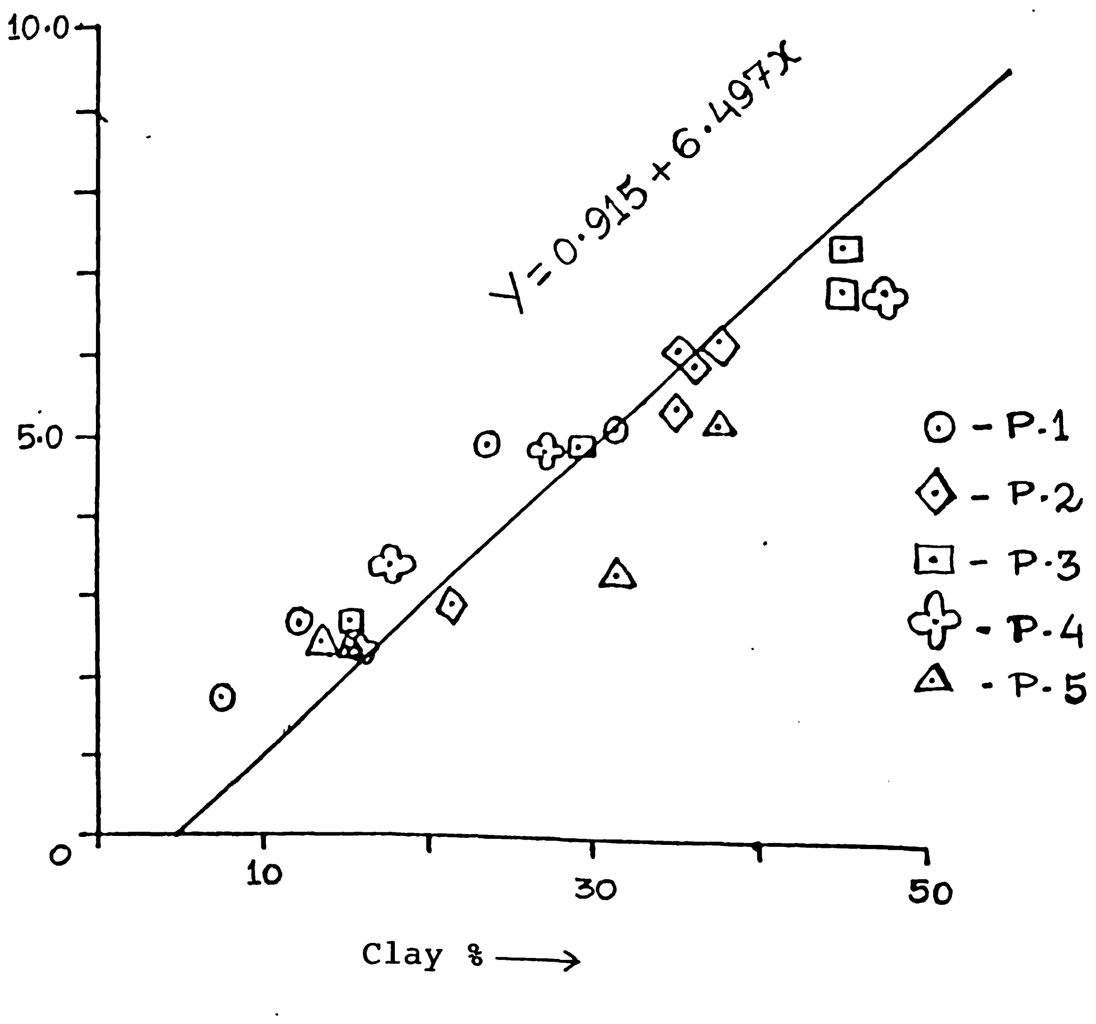
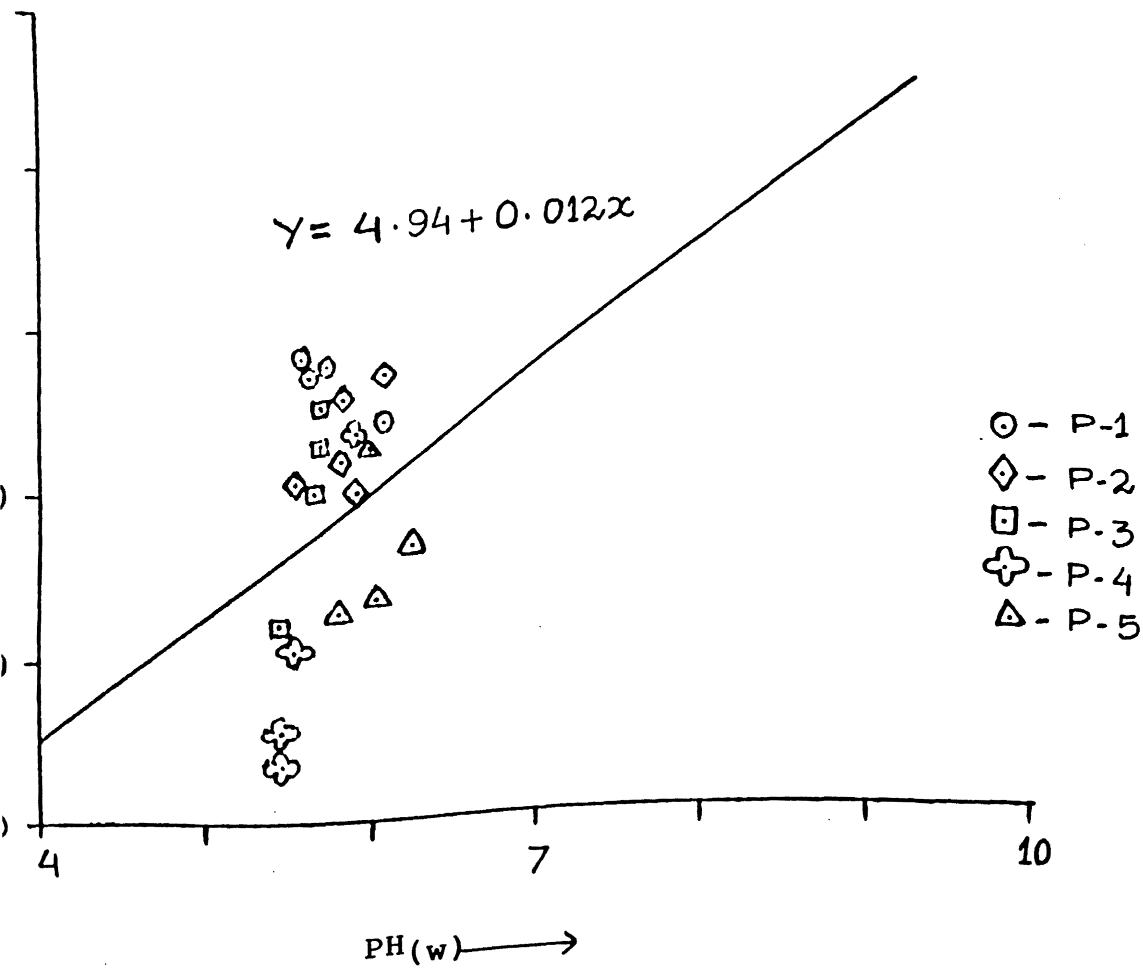


Fig.9 Relation between percent base saturation with PH



4.1. CEC vs per cent clay :

The relationship between percentage of clay and CEC cmol (P+) Kg^{-1} soil have been presented in Fig. 8. It was erved that these properties were positively correlated ing 'r' value + 0.945**, significant at 1% level (Kasawal *al.* 1983). The regression equation fitted was;

$$Y=-0.915 + 6.497x$$

Y=CEC in cmol (P+) kg^{-1} soil

X= Percentage of clay in soil.

This direct relationship was explained by the fact that clays, being negatively charged, are the seats of exchange nomena taking place in soil. Thus the amount of cations orbed depends on quantity of clays present.

4.2. Per cent base saturation Vs pH.

A significant positive correlation as shown in Fig.9 was found to exist between percentage base saturation and The 'r' value was worked out to be + 0.366 which was nificant at 1% level. The regression equation fitted as :

$$Y = 4.94 + 0.012X$$

re, Y = Per cent base saturation.

X = pH.

The explanation to such relationship is that the pH governed by electrostatically bound H^{+} and Al^{+++} of the exchange complex which is in equilibrium with soil solution. With increase in pH there is decrease in H^+ and Al^{+++} in the exchange complex with consequent increase in the basic cations such as Ca^{++}, Mg^{++}, K^+ & Na^+ which resulted in higher base saturation.

IV.4.3 Fe_2O_3 percentage Vs clay percentage :

A positive significant correlation as shown in Fig.7 was found to exist between percentage free Fe_2O_3 and percentage clay. The 'r' value was worked out to +0.991** which was highly significant at 1% level. The regression equation worked out to be as follows :

$$Y = 0.11 + 0.6X$$

where, Y = Free Fe_2O_3 percentage

X = Percentage clay content.

which indicated that the silicate clays and hydrous oxide clays are intimately associated with such soils.

IV.5. Lime requirements :

It has been stated that soil pH may indicate the need for lime, but the value alone gives no indication relative to amount of lime required unless other soil factors are known. The lime requirement of soil is considred to be that amount of lime ($CaCO_3$ or equivalent amount of other liming material) required to raise the soil pH to some pre-determined value. It is believed that the major components

Table : 8 Lime requirement of Profile Soil Samples.

Pedon	Depth (CM.)	pH(1:2) Soil : Water	pH(1:2) Soil : Buffor	Lime requirement (Tons of $CaCo_3$/acre)
P_1	0-14	6.10	6.7	1.6
	14-40	5.75	6.6	2.2
	40-72	5.65	6.6	2.2
	72-150	5.60	6.6	2.2
				(2.05)
P_2	0-11	5.55	6.5	2.8
	11-52	5.80	6.6	2.2
	52-88	5.85	6.7	1.6
	88-115	6.10	6.7	1.6
	115-150	5.90	6.7	1.6
				(1.96)
P_3	0-14	5.45	6.4	2.3
	14-42	5.65	6.4	2.3
	42-90	5.70	6.5	2.8
	90-172	5.70	6.6	2.2
				(2.4)
P_4	0-14	5.45	6.4	3.4
	14-27	5.45	6.5	2.8
	27-60	5.50	6.5	2.8
	60-150	5.90	6.6	2.2
				(2.8)
P_5	0-14	6.05	6.7	1.6
	14-32	6.25	6.7	1.6
	32-84	5.80	6.6	2.2
	84-155	6.00	6.7	1.6
				(1.75)
				(2.19)

Table : 9 Lime requirement of Composite Surface Soil Samples.

Sl.No.	Depth(Cm.)	pH(1:2) Soil : Water	pH(1:2) Soil : Buffer	Lime requirement (Ton of $CaCo_3$/acre)
1.	0-15	5.30	6.2	4.5
2.	0-15	5.70	6.5	2.8
3.	0-15	5.80	6.5	2.8
4.	0-15	5.70	6.5	2.8
5.	0-15	5.60	6.3	4.0
				(3.38)
6.	0-15	5.60	6.3	4.0
7.	0-15	5.45	6.3	4.0
8.	0-15	5.30	6.3	4.0
9.	0-15	5.70	6.4	3.4
10.	0-15	5.90	6.4	3.4
				(3.76)
11.	0-15	5.45	6.4	3.4
12.	0-15	5.55	6.5	2.8
13.	0-15	5.55	6.4	3.4
14.	0-15	5.65	6.6	2.2
				(2.95)
15.	0-15	6.35	6.7	1.6
16.	0-15	5.65	6.3	4.0
17.	0-15	5.70	6.3	4.0
18.	0-15	6.25	6.5	2.8
				(3.1)
19.	0-15	5.90	6.6	2.2
20.	0-15	5.65	6.6	2.2
				(2.2)
				(3.08)

of acidity in soil that must be nutralised by liming are exchangeable Al^{+++} and H^{+} and possibly Mn^{++}. Extensively used woodruff's PNP buffer method involes measuring the change in pH which occurs when a given quantity of a calibrated buffer solution was allowed to react with a given quantity of soil. From the change in pH value one can measure directly the quantity of lime required to neutralise the pH value.

Considering table 8 it may be seen that the lime requirement in different horizons of the profifles ranged from 1.6 to 3.4 with a total mean value of 2.19 tonnes of $CaCO_3$ per acre at a desired pH of 6.5. Much variation in different horizons of the profiles could be observed. The lime requirement in Profile-5 was comparatively low. This might be due to comparatively higher pH values in different horizon of the profile.

Considering the lime requirement of composite surface samples presented in table 9, it was observed that the value was comparatively higher than the profile samples. The value ranged from 1.6 to 4.5 with a total mean value of 3.08 tonnes of $CaCO_3$ per acre.

IV.6. Available nutrient Status :

Rarely a soil is competely devoid of available nutrient. The quantity of available nutrient present in a soil

Table :10 Available nutrient Status of the Profile Soil Samples(Kg ha^{-1})

Pedon	Depth(Cm.)	Available 'N'	Olsen's Available 'P_2O_5'	Bray's Available 'P_2O_5'	Available 'K_2O'
P_1	0-14	60	1.25	28.72	120
	14-40	58	3.16	34.32	180
	40-72	55	2.51	23.19	190
	72-150	55	5.91	30.58	210
		(44.5)	(3.2)	(29.3)	(175)
P_2	0-11	88	4.46	26.87	230
	11-52	62	2.51	19.54	240
	52-88	60	3.16	23.19	200
	88-115	35	2.51	25.02	220
	115-150	23	3.16	25.94	230
		(37.6)	(3.16)	(24.1)	(224)
P_3	0-14	188	5.13	18.63	160
	14-42	175	1.25	24.10	190
	42-90	88	1.87	26.87	200
	90-172	53	1.87	34.32	220
		(126)	(2.53)	(26.98)	(192.5)
P_4	0-14	165	5.13	26.87	170
	14-27	95	7.86	34.32	150
	27-60	88	7.86	22.27	180
	60-150	85	16.08	17.72	150
		(108.25)	(9.23)	(25.29)	(162.5)
P_5	0-14	222	23.73	25.02	110
	14-32	95	13.73	29.65	140
	32-84	60	7.86	27.79	210
	84-155	72	5.13	25.02	230
		(112.25)	(10.09)	(26.87)	(172.5)
		(85.72)*	(5.64)*	(26.49)*	(185.3)*

Figures in the parenthesis indicate the average value.
Figures indicated * mark shows the total mean average value.

may or may not be adequate to meet the crop requirement. Soil test results for available nutrient only indicate the relative quantities present. To know whether the quantity is sufficient or not, one has to depend upon the information obtained from the soil test crop responce correlation studies and the soil fertility trials. Fertilizer reccomendation is a complex process. This should be taken into account the crop requirement and probable yield response to added nutrient which is controlled by a variety of soil, climate and human factors. To reduce the cost-benefit ratio and to recommend proper dose of balance fertilization, available nutrient status of soils are essentially required.

The available nutrient satus of the profile samples and composite surface soil samples are presented in table 10 and 11, respectively. Considering table No.10 it may be seen that, the available N content of profile samples are very low excepting three surface horizon samples; the value is less than 100 in all the horizons. In general, the gradual decrease of available N from the surface downwords (Fig. 10) might be due to accumulation and decomposition of organic matter (Sharma *et al.* 1994) on the surface. The total mean value of available N in all the horizons is 85.72 kg ha^{-1}. Available phosphorous (Bray's) content are medium and value ranges from 17.72 to 34.32 with a total mean of 26.49 kg ha^{-1}. No definite trend in the available P_2O_5 content could be observed (Fig.

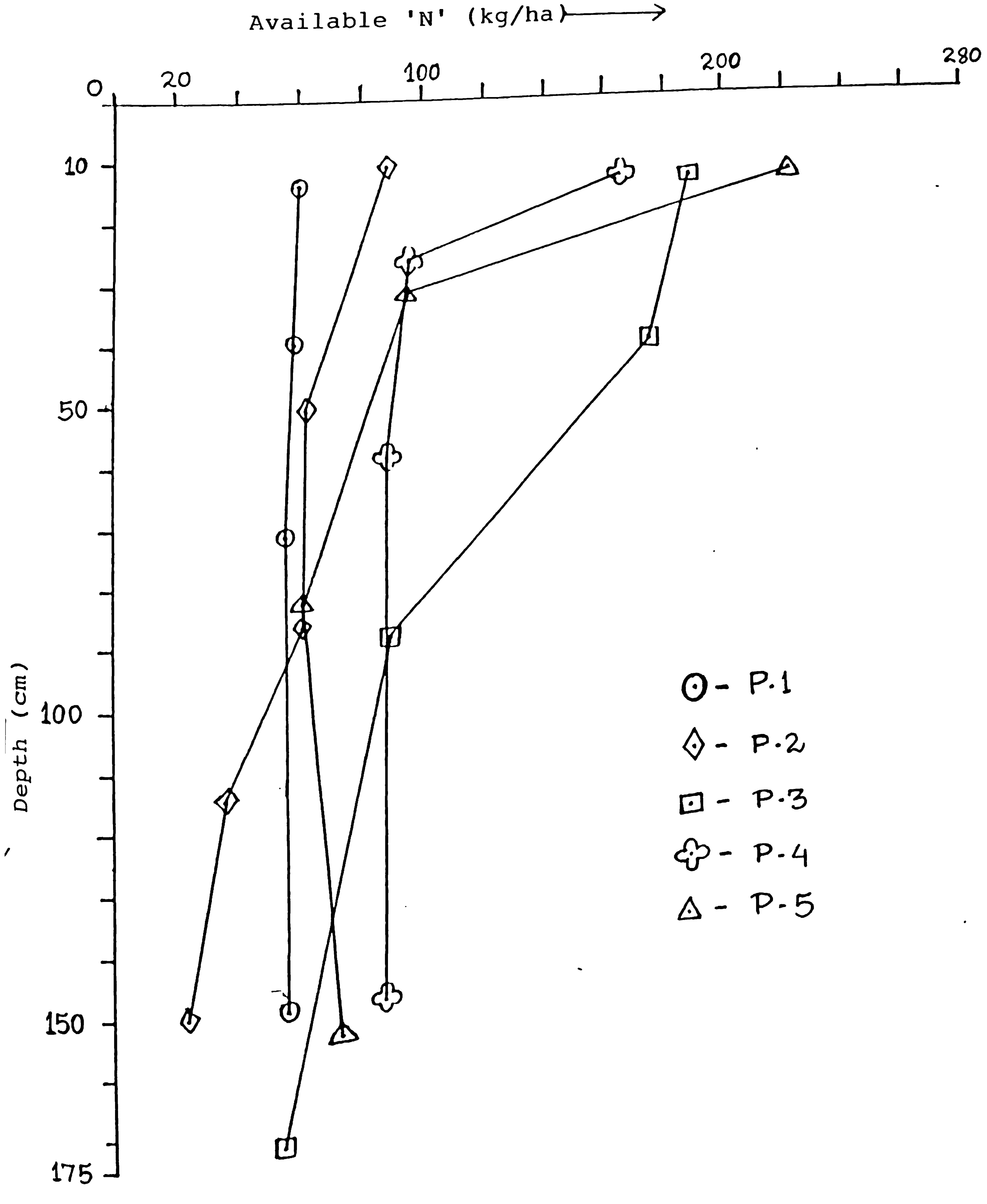


Fig.10 Available 'N' content with depth of profiles

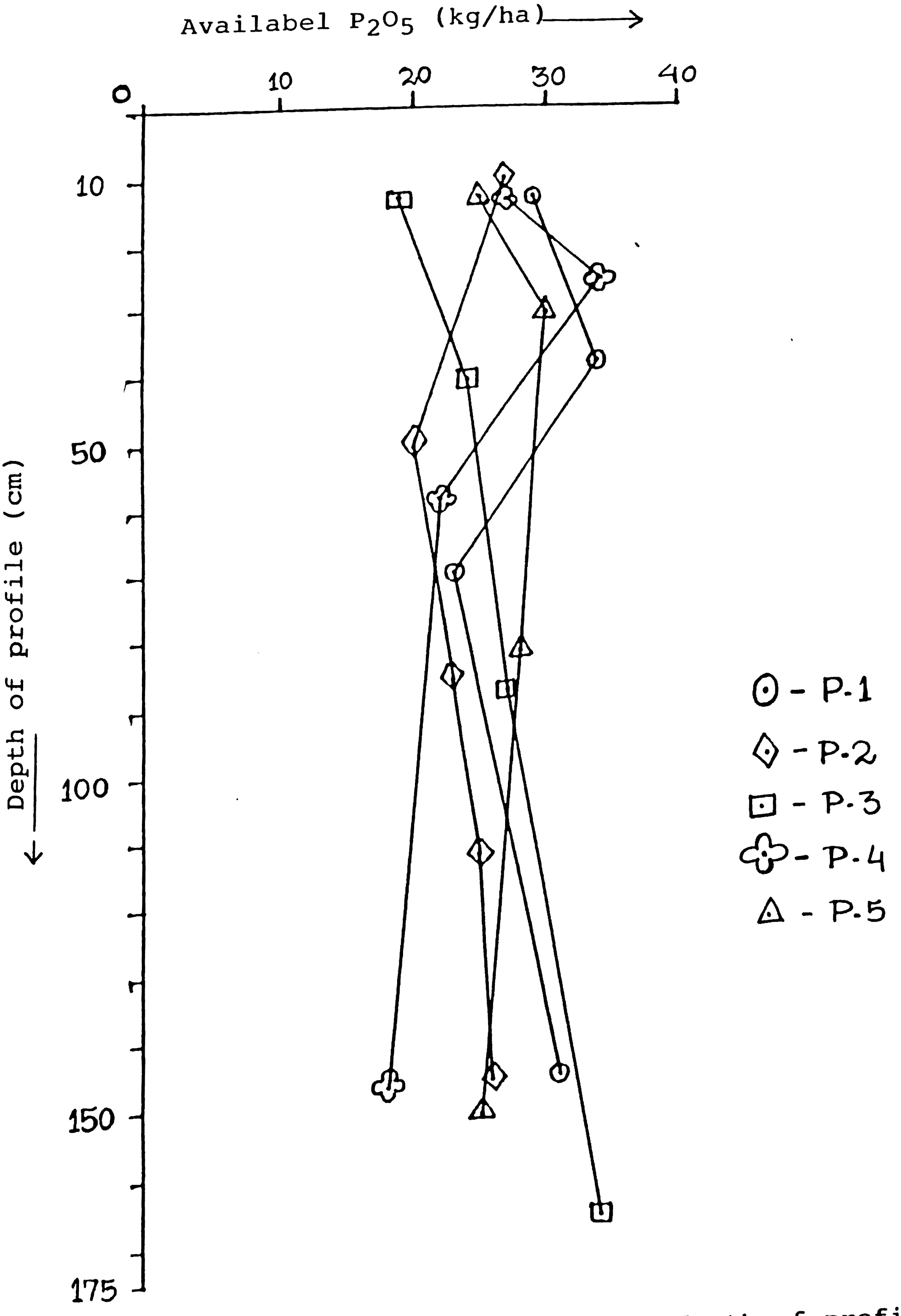


Fig.11 Available P_2O_5 content with depth of profile

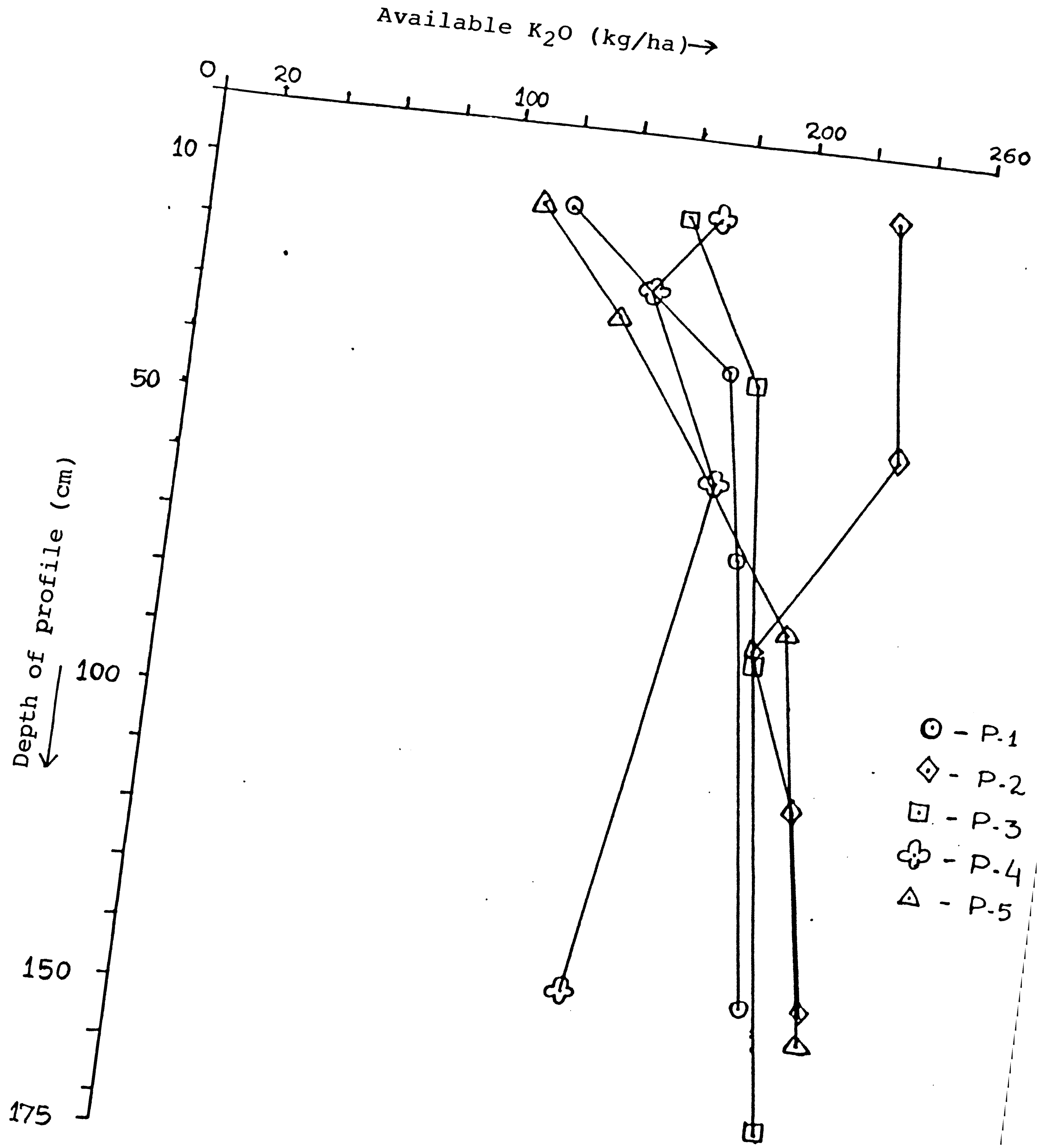


Fig.12 Available K_2O content with depth of profile.

Table : 11 Available nutrient Status of the Composite Surface Soil Samples

Sl. No.	Depth(Cm.)	Available-N ($Kg\ ha^{-1}$)	Olsen's P_2O_5	Bray's P_2O_5	Available, K_2O
1.	0-15	251	8.57	6.12	230
2.	0-15	88	9.28	5.24	150
3.	0-15	279	3.81	10.55	150
4.	0-15	135	4.46	15.02	160
5.	0-15	201	10.73	2.61	150
		(190.8)	(7.37)	(7.9)	(148)
6.	0-15	173	4.46	9.66	220
7.	0-15	142	9.28	4.36	170
8.	0-15	57	7.86	17.72	370
9.	0-15	126	6.49	8.77	360
10.	0-15	73	10.00	22.27	210
		(114.2)	(7.61)	(12.55)	(266)
11.	0-15	220	37.91	26.87	200
12.	0-15	245	21.07	16.82	260
13.	0-15	157	19.37	13.22	130
14.	0-15	157	13.73	14.12	150
		(194.75)	(23.02)	(17.75)	(185)
15.	0-15	251	12.96	8.77	130
16.	0-15	267	20.22	8.77	150
17.	0-15	273	17.70	22.27	170
18.	0-15	236	9.28	23.19	370
		(256.75)	(15.04)	(15.75)	(205)
19.	0-15	110	0.62	33.38	110
20.	0-15	53	6.49	24.10	180
		(81.5)	(3.55)	(28.74)	(145)
		(167.6)	(11.32)	(16.48)	(190)

Table : 12 Nutrient index and rating of Soils of Nedisahi Nalla (ORM-3-8-5-1) mini-watershed.

District : Kandhamal.

Sl. No.	Particulars of the samples.	No. of Sample	Nutrient index			Rating of nutrient index		
			N	P_2O_5	K_2O	N	P_2O_5	K_2O
1.	Composite surface samples	20	1.35	1.5	2.1	deficient	average	average
2.	Profile Soil samples;							
	a) Profile - 1	4	1.00	2.00	2.00	deficient	average	average
	b) Profile - 2	5	1.00	2.00	2.00	deficient	average	average
	c) Profile - 3	4	1.00	2.00	2.00	deficient	average	average
	d) Profile - 4	4	1.00	2.00	2.00	deficient	average	average
	e) Profile - 5	4	1.00	2.00	1.75	deficient	average	average
	Average of all the profiles	21	1.00	2.00	1.95	deficient	average	average

11). Available K_2O content was also medium, the value ranging from 110 to 230 with a total mean of 185.3 kg ha^{-1}. In general, there was a gradual increase of available K_2O content from surface downwards (Fig. 12).

Considering the available nutrient status of composite surface samples presented in table 11 it may be seen that the available nitrogen (N) content was low to medium. The value ranging from 53 to 273 with a total mean of 167.6 kg/ha. Available phosphorous (Bray's) was low to medium excepting three samples which were very low. Physiographically there was gradual increase of available P_2O_5 content from higher elevation to the lower topographic situations. Available K_2O content was also medium. The value ranged from 110 to 260 with a total mean average value of 190 kg/ha. Considering the nutrient index and rating of soil presented in table 12 it might be seen that all the soils were deficient in N, average in P_2O_5 and K_2O.

IV.7. Genesis of soils:

Soil genesis proceeds with the breakdown and alternation of primary minerals constituting the rock. The sand faraction contains mainly the accessory minerals derived from the parent rocks on account of weathering. In subsequent stages of soil development, the weatherable minerals of this fraction undergo physical comminution and chemical decomposition and supply the reactant component for the weathering reaction leading to the genesis of secondary minerals including the clay minerals in the soil.

High temperature accompanied by alternate wet and dry season in the humid tropical and sub-tropical climate is congenial for the formation of laterite and lateritic soils. The above climatic condition alongwith the physiography and the parent material appeared to have been favourable for the formation of Alfisols in Sidingi area. The soils were exposed in Althgarh Sand stone of the Upper Gandwana period and the parent material constituted coarse sand stones, conglomerates and laterites. The presence of a very high content of light minerals (guartz and feldspars) in the fine sand fractions might be attributed to the moderate weathering condition of the soils (Sahu *et al.* 1983). Much higher proportions of potash bearing minerals (orthoclase feldspar) explain the prevalence of moderate weathering conditions and is condusive for the development of illites due to decomposition and partial hydrolysis of feldspars. The occurance of kaolinite and free oxides in these soils were expected as the soils were highly weathered and leached and parent material was borne of khondalitic rocks. Under good drainage conditions and high rainfall, a high degree of weathering takes place and the soil colloids consist mostly of kaolinite (Vander Merwe and Heystek 1952) as was found in the area. But the climatic environments will not necessarily reflect the genesis of laterite soils lying at lower altitude (Gowalkar 1972) and under a poor drainage condition Inceptisols may be formed with different mineralogy as was observed in profile-5 (Nedisahi series).

The area is under hot and humid climate with average annual rainfall of 1280.16mm, maximum average annual temperature of 37°C (May) and minimum average annual temperature of 10.4°C (December). The soils studied in this area were in a sloping terrain, so the factors of soil formation i.e. climate, parent material, topography and drainage condition were responsible for development of these soils. Because of hot and humid climate there was intense weathering and the weatherable materials leach down. Alternate wet and dry condition alongwith rise and fall of water table persisted in the area, which resulted in the rise and fall of free Fe_2O_3, Al_2O_3 and release of basic cations and finner materials. This has resulted in the gradual increase of Fe_2O_3 down the profile. Soils of the upper ridge (Profile-1 to 4) are moderately well drained resulting in accumulation of eluvial layer lattice clay in the sub-surface horizons and formation of an argillic horizon. Accordingly soils of these four profiles are classified under Alfisols. Moderately well drained condition prevailed in profile-5 with high water stable resulting in formation of Fe, Mn concretions and development of a cambic horizon and hence these soils were placed under the order Inceptisols.

IV.8. Soil classification (soil Taxonomy) :

An attempt has been made in the present investigation to classify the soils as per the Soil Taxonomy (1978) and Keys to Soil Taxonomy (1987) and are presented in Table 13.

PEDON :1

These are the mineral soils placed under order *Alfisols* because they have :

i) an argillic horizon

ii) a hue in the argillic horizon of 5 YR and a value, moist of 4

iii) percentage base saturation is more than 35% in the argillic horizon

iv) an epipedon that is massive and hard when dry

v) an Ustic moisture regime

vi) no cracks are seen on the surface and the soil below 18 cm has less than 30% clay.

These soils are placed under sub-order *Ustalfs* and great group *Haplustalfs* because they :

i) have an ustic moisture regime

ii) have an epipedon that is both massive, hard and very hard when dry, and

iii) do not qualify to be placed under other great groups.

These soils are placed under *Arenic Kanhaplic Haplustalfs* sub-groups because they satisfy all the requirements of Typic Haptustalfs expecting the following :

i) do not have texture finner than loamy fine sand within 50 cm of soil surface

ii) have CEC of less than 24 c mol (P+) Kg^{-1} clay (by 1M NH_4OAc pH 7.0).

In the family level they are placed under fine loamy, mixed, hyperthermic (Weighted average clay per cent is 23.94 in the control section).

PEDONS : 2, 3 & 4

These soils are placed under the order *Alfisols* because they have :

i) an argillic horizon,

ii) a hue in the argillic horizon of 5 YR and a value, dry of 5,

iii) base saturation by sum of cations is more than 35% upto a depth of 73 cm of the argillic horizon,

iv) have an epipedon that is massive and hard when dry,

v) an ustic soil moisture regime, and

vi) no cracks are seen on the surface.

These soils are placed under the sub-order *Ustalf* and great group *Kanhaplustalfs* as they :

i) have an ustic moisture regime,

ii) have an epipedon that is both massive and hard and very hard when dry, and

iii) have a CEC less than 16 cmol (P+) Kg^{-1} clay (by 1M NH_4OAc pH 7) and ECEC less than 12 c mol (P+) Kg^{-1} clay in major part of the argillic horizon.

These soils are placed under *Aridic kanhaplustalfs* sub-group as they satisfy all the requirements of Typic sub-group excepting that, the soils are not moist in some or all parts of moisture control section for 180 or more days.

In the family level, Pedon 2 and 3 are, fine, mixed, hyperthermic with the weighted average clay per cent of 36.14 and 41.73 respectively. Pedon:4 is having, fine loamy, mixed, hyperthermic family because of the weighted average clay per cent of 21.9.

PEDON : 5

The soils of Pedon : 5 have been placed under, order *Inceptisols*, and sub-order *Ochrepts* because they ;

i) do not have spodic, argillic, natric, oxic, gypsic, petrogypsic or salic horizon in the pedon,

ii) do not have plinthite, that forms a continuous phase within 30 cm of soil surface, Table : 13 **Classification of Soils according to Soil Taxonomy.**

Pedon No.	Name of the Soil Series	Order	Sub-order	Great group	Sub-group	Family
1	Sidingi - 1	Alfisols	Ustalfs	Haplustalfs	Arenic Kanhaplic Haplustalfs	Fine loamy, mixed, hyperthermic.
2	Sidingi-2	Alfisols	Ustalfs	Kanhaplustalfs	Aridic Kanhaplustalfs	Fine, mixed, hyperthermic.
3	Sidingi-3	Alfisols	Ustalfs	Kanhaplustalfs	Aridic Kanhaplustalfs	Fine, mixed, hyperthermic.
4	Sidingi-4	Alfisols	Ustalfs	Kanhaplustalfs	Aridic Kanhaplustalfs	Fine loamy, mixed, hyperthermic.
5	Nedisahi	Inceptisols	Ochrepts	Ustochrepts	Aridic Ustochrepts	Fine loamy, mixed, hyperthermic.

iii) have an ochric epipedon with a cambic horizon with regadrds to texture, colour, structure and concretions,

iv) have bulk density of more than 0.85 Mg m^{-3} in all horizons, and

v) have a chroma too high for Aquepts.

These soils are placed under *Ustochrepts* great group because they have an ustic moisture regime.

In the sub-group level they satisfy all the requirements of Typic sub-group excepting that, the soils are not moist in some or all parts of the soil moisture control section for 90 consecutive days or more and for which they are placed under *Aridic Ustochrepts* sub-group.

In the family level they are placed under, fine loamy, mixed, hyperthermic with the weighted average clay per cent of 31.1. For better clarity, soil classification as per Soil Taxonomy have been presented in table 13.

IV.9. Potassium release characteristics :

Potassium exists in soil in various forms like; water soluble, exchangeable, non-exchangeable and in crystal lattice of rocks and minerals. As potassium in soil solution is exhausted by the crop the reaction proceeds from lattice K through other steps to water soluble K to maintain the equilibrium. As per the reportes of different workers 1N HNO_3 extractable K which includes water soluble, exchangeable and non-exchangeable K showed a better correlation with crop yield, uptake and responce (Nath and Purkaystha, 1988). This emphasized the study of the K-release behaviour of soils by extraction with boiling IN HNO_3. Although the roots of the field crops are usually confined to 0-20 cm of the soil surface, the roots of deep rooted crops penetrate deeper into soil in search of nutrients. This needs an investigation on various forms of K and K release behaviour of soil down the surface. The work on the content of various forms of K in different horizons and their release characteristics are very meagre. An attempt has been made to study the various forms of K and their relase behaviour within the profile and in the transact.

IV.9.1. Basic physical and chemical characteristics of the soil :

Some of the basic physical and chemical characteristics of different layers of the profiles selected for this investigation have been presented in Table 14. Sand content varied from 66.64 to 88.64% at the surface layers and decreased with depth in the profile. Concurrently the clay content varied from 7.36 to 21.36% on the surface increasing gradually with depth. Silt content on the surface layers

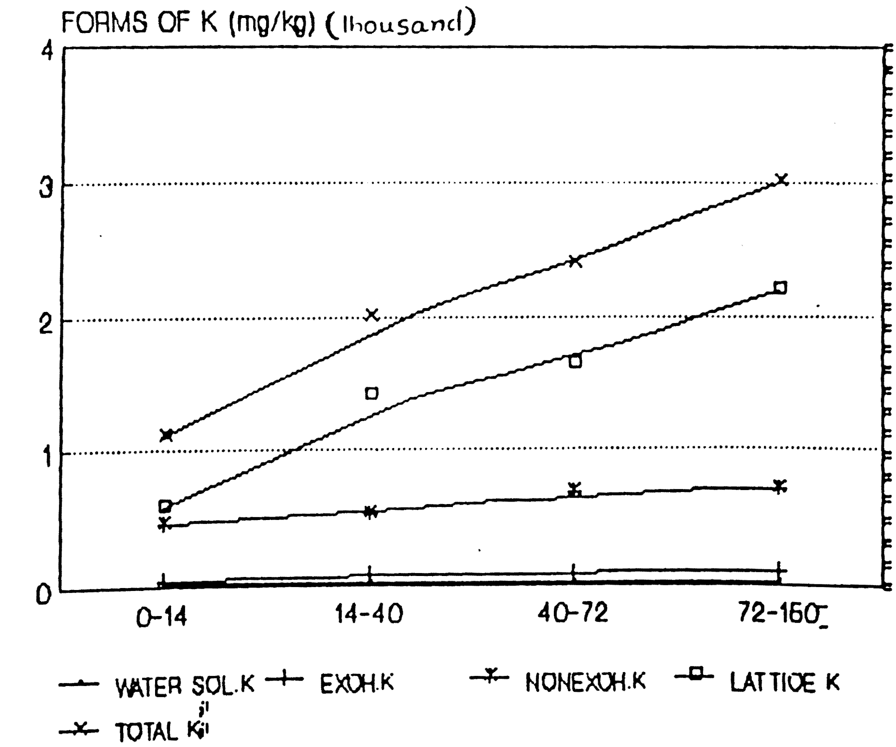
Table : 14 Physical and Chemical Properties of Soil Samples.

Profile	Genetic Layer	Depth (Cm.)	Mechanical Composition Sand(%)	Silt(%)	Clay(%)	Soil pH (1:2)	E.C. dsm^{-1}	Org. Carbon(%)	CEC $Cmol(P^+)Kg^{-1}$	K-Saturation(%)
I	A2	0-14	88.64	4.0	7.36	6.10	0.12	0.17	1.68	6.10
	B21	14-40	80.64	8.0	11.36	5.75	0.15	0.17	2.72	6.65
	B22t	40-72	62.64	14.0	23.36	5.65	0.13	0.14	4.80	4.46
	B23t	72-150	56.64	12.0	31.36	5.60	0.16	0.14	4.96	5.01
II	Ap	0-11	72.64	6.0	21.36	5.55	0.09	0.20	2.80	8.84
	B21t	11-52	54.64	10.0	35.36	5.80	0.15	0.16	5.36	5.26
	B22t	52-88	52.64	11.0	36.36	5.85	0.10	0.15	5.84	4.11
	B23t	88-115	54.64	8.0	37.36	6.10	0.06	0.08	6.16	4.31
	C	115-150	54.64	10.0	35.36	5.90	0.12	0.10	6.00	4.57
III	Ap	0-14	72.64	12.0	15.36	5.48	0.15	0.39	2.64	6.07
	B21t	14-42	54.64	16.0	29.36	5.65	0.18	0.30	4.80	4.43
	B22t	42-90	48.64	6.0	45.36	5.70	0.10	0.24	6.80	3.34
	B23t	90-172	38.64	16.0	45.36	5.70	0.18	0.13	7.36	3.48
IV	Ap	0-14	66.64	18.0	15.36	5.45	0.90	0.33	2.32	7.92
	B21	14-27	78.64	4.0	17.36	5.45	0.11	0.28	3.36	4.73
	B22t	27-60	64.64	8.0	27.36	5.50	0.07	0.24	4.72	4.24
	B23t	60-150	32.64	20.0	47.36	5.90	0.06	0.23	6.88	2.52
V	Ap	0-14	80.64	6.0	13.36	6.05	0.06	0.40	2.24	4.52
	B21	14-32	80.64	4.0	15.36	6.25	0.04	0.20	2.40	6.30
	B22w	32-84	54.64	14.0	31.36	5.80	0.09	0.14	3.20	7.57
	C	84-155	50.64	12.0	37.36	6.00	0.11	0.15	5.12	5.26

Table : 15 Change on various forms of K with depth on soil profiles.

Profile	Depth(Cm.)	Water Soluble K	Exch.K	Non-exch.K	Lattice.K	Total.K	Per cent of total-K				Ratio among different forms of K			
		←	mg kg^{-1}			→	Water Soluble.K	Exch.K	Non-exch.K	Lattice K	Water Soluble / Exch.	Exch. / Non-exch.	Non-exch / Lattice	Lattice / Total
I	0-14	20	40.0	460	580	1100	1.8	3.6	41.8	52.8	0.50	0.09	0.79	0.52
	14-40	19.5	70.5	510	1400	2000	1.0	3.5	25.5	27.0	0.28	0.14	0.36	0.70
	40-72	11.5	83.5	665	1640	2400	0.5	3.5	27.7	68.3	0.14	0.13	0.40	0.68
	72-150	8.0	97.0	695	2200	3000	0.3	3.2	23.2	73.3	0.08	0.14	0.32	0.73
II	0-11	18.5	96.5	645	1840	2600	0.7	3.7	24.8	70.8	0.19	0.15	0.35	0.70
	11-52	10.0	110.0	820	1860	2800	0.4	3.9	32.9	62.8	0.09	0.12	0.52	0.63
	52-88	6.5	93.5	860	2040	3000	0.2	3.1	28.7	68.0	0.07	0.11	0.42	0.68
	88-115	6.5	103.5	850	1940	2900	0.2	3.6	29.3	66.9	0.06	0.12	0.44	0.67
	115-150	8.0	107.0	925	1660	2700	0.3	4.0	34.4	61.4	0.07	0.12	0.55	0.61
III	0-14	17.5	62.5	600	1520	2200	0.8	2.8	27.3	69.1	0.28	0.10	0.39	0.69
	14-42	12.0	83.0	945	1760	2800	0.4	3.0	33.7	62.9	0.14	0.09	0.53	0.63
	42-90	11.5	88.5	1100	1800	3000	0.4	2.9	36.7	60.0	0.13	0.08	0.61	0.60
	90-172	10.0	100.0	1130	2260	3500	0.3	2.9	32.2	64.6	0.10	0.09	0.50	0.65
IV	0-14	13.5	71.5	675	1040	1800	0.7	4.0	37.5	57.8	0.19	0.11	0.65	0.58
	14-27	13.0	62.0	765	1360	2200	0.6	2.8	34.8	61.8	0.21	0.08	0.50	0.62
	27-60	12.0	78.0	830	1580	2500	0.5	3.1	33.2	63.2	0.15	0.09	0.52	0.63
	60-150	7.5	67.5	1045	2080	3200	0.2	2.1	32.7	65.0	0.11	0.06	0.50	0.65
V	0-14	15.5	39.5	505	840	1400	1.2	2.8	36.0	60.0	0.39	0.08	0.60	0.60
	14-32	11.0	59.0	570	860	1500	0.7	3.9	38.0	57.4	0.19	0.10	0.66	0.57
	32-84	10.5	94.5	775	2020	2900	0.4	3.2	26.7	69.7	0.11	0.12	0.38	0.70
	84-155	10.0	105.0	885	2100	3100	0.3	3.4	28.5	67.8	0.01	0.12	0.42	0.68

Fig. 13 Change in various forms of K with soil depth. (PROFILE-1)



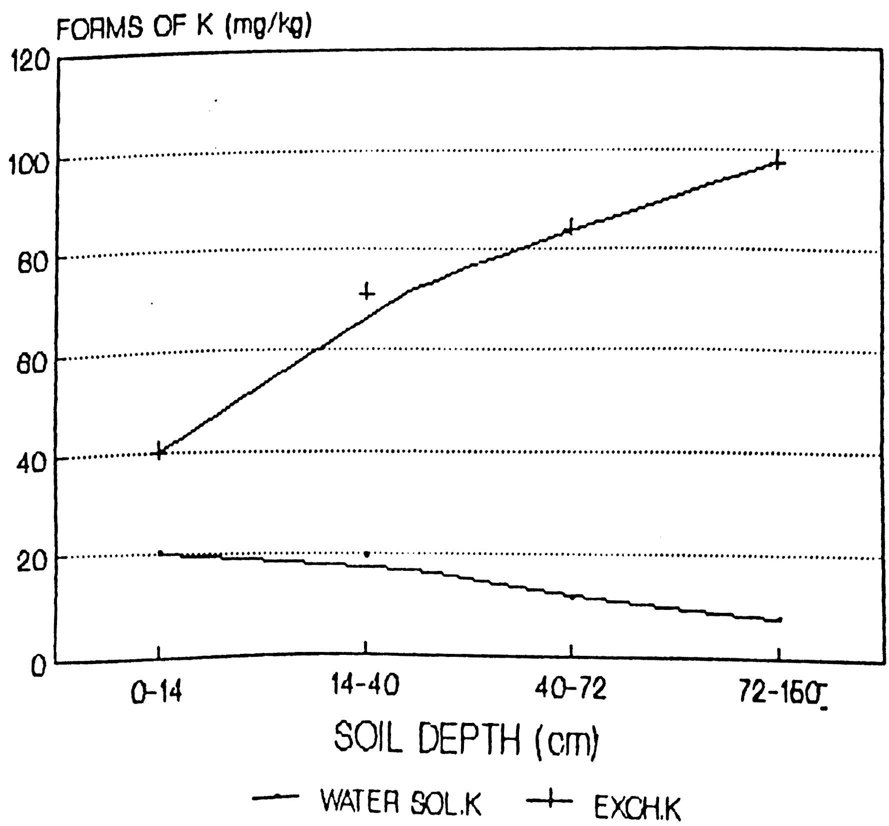


Fig.13 Change in various forms of K with soil depth.(Profile-2)

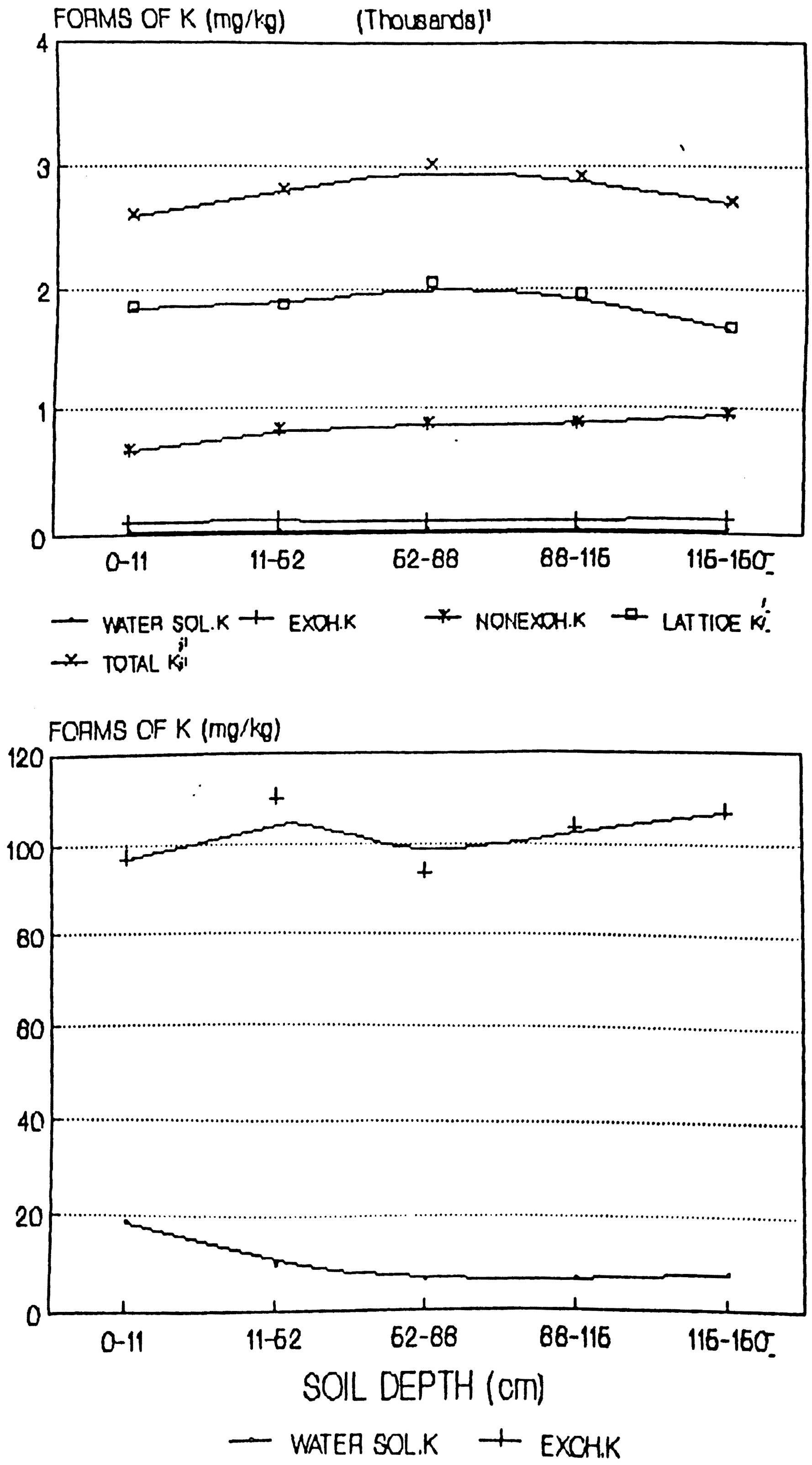


Fig.13 Change in various forms of K with soil depth.(Profile-3)

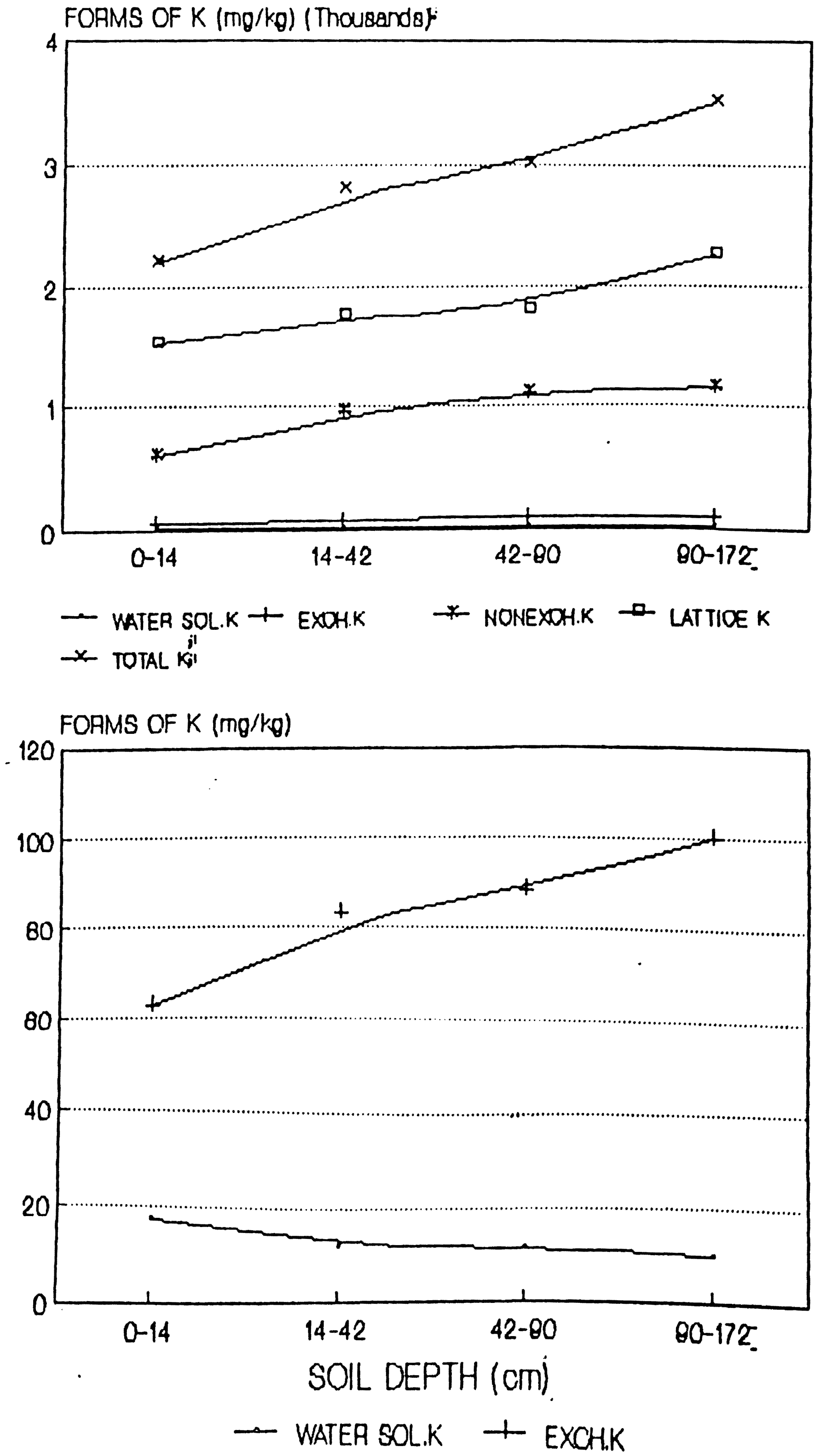


Fig.13 Change in various forms of K with soil depth.(Profile-4)

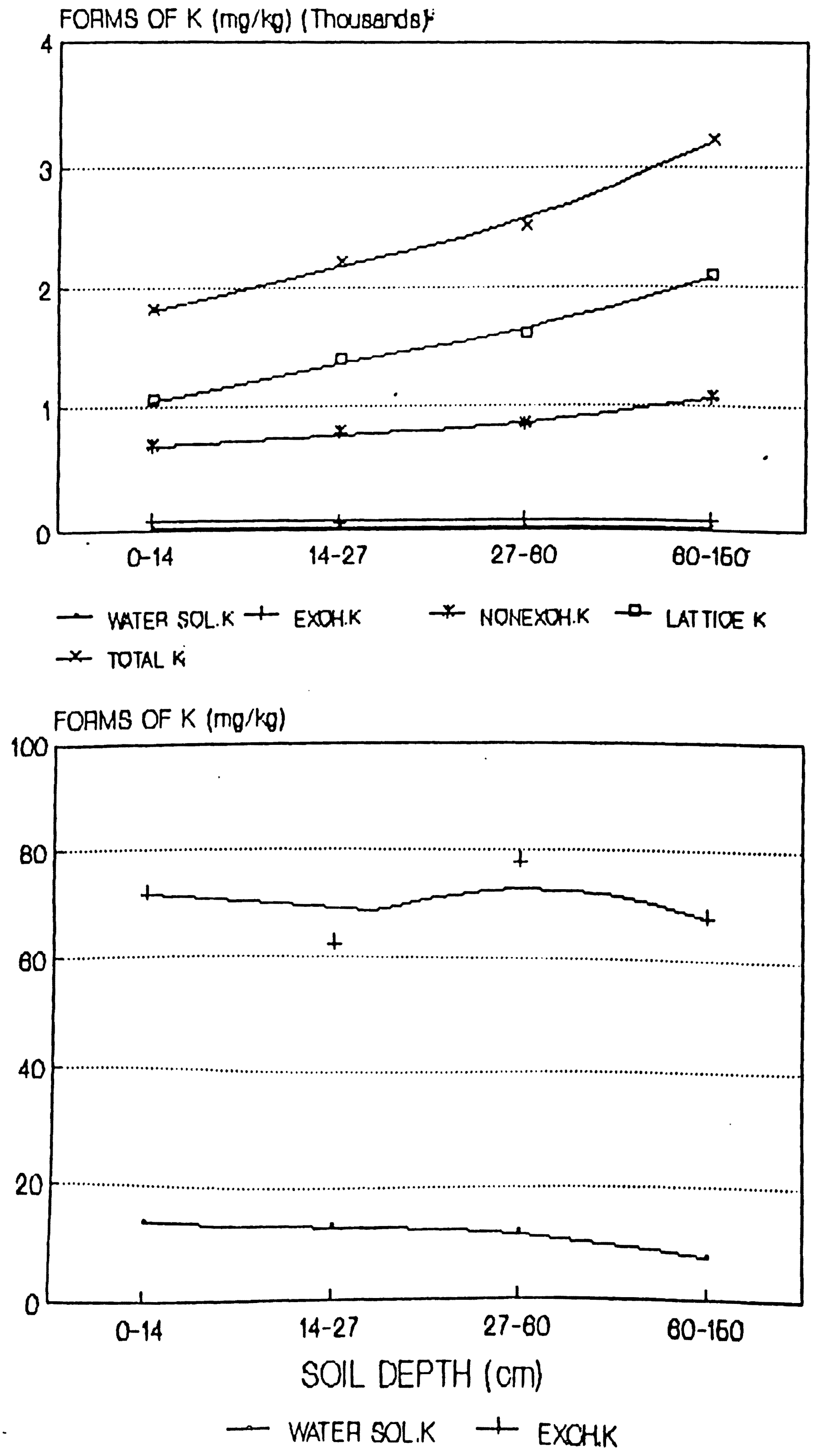
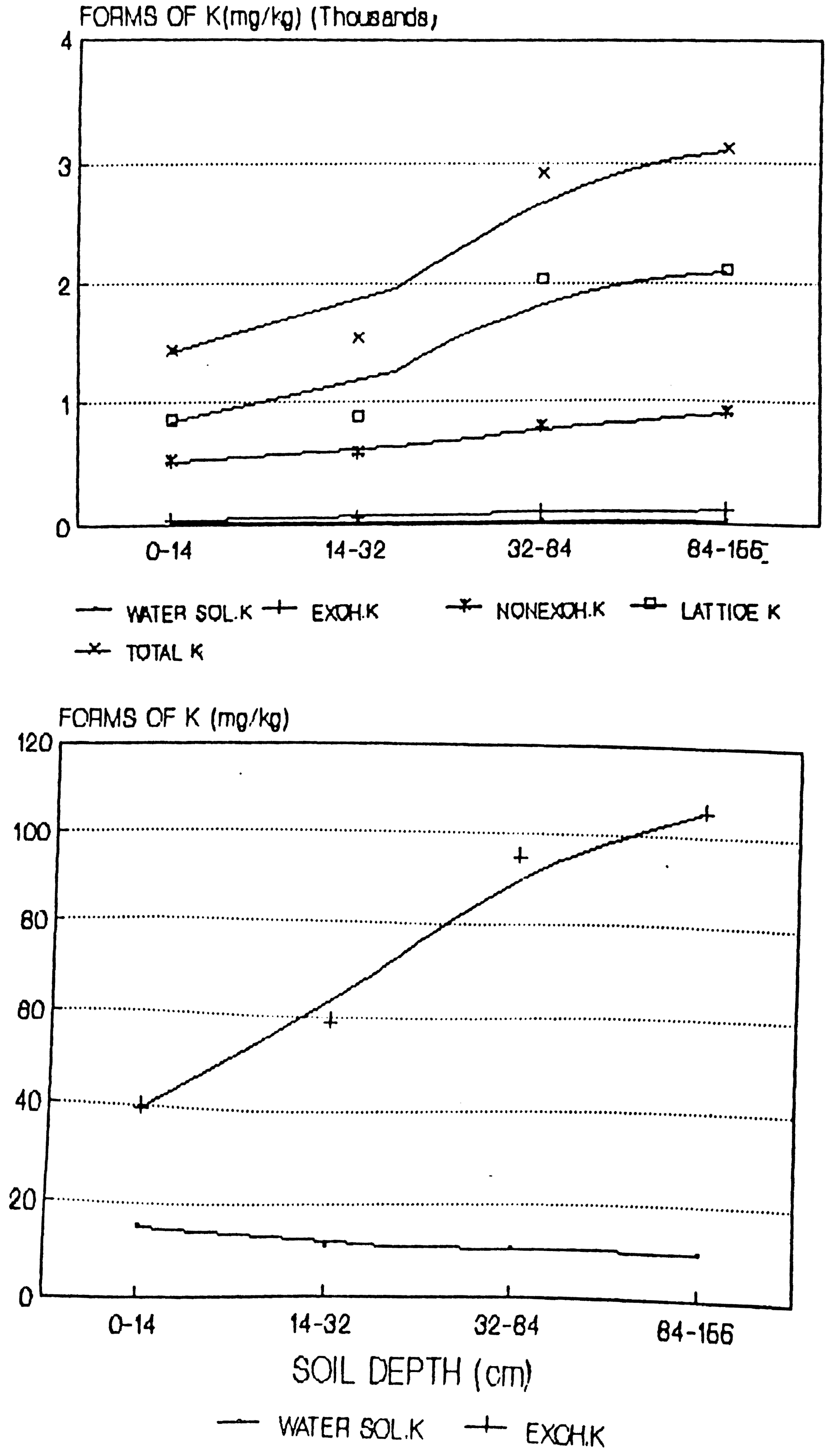


Fig.13 Change in various forms of K with soil depth.(Profile-5)



varied from 4.0 to 18.0% changing inconsistently with soil depth. Soil pH varied from 5.45 to 6.25 at different layers of the profiles. Organic carbon content on the surface layers varied from 0.17 to 0.40%, declining gradually with depth. CEC of the surface soils varied between 1.68 to 2.8 c mol (P^+) Kg^{-1} with a gradual increase with the depth in the profile. K-saturation per cent varied from 2.52 to 8.84% at different horizons of the profiles.

IV.9.2. Forms of K :

The change in various forms of K i.e. water soluble, exchangeable, non-exchangeable, lattice and total K in the profile have been presented in table 15.

IV.9.2.1. Water soluble K :

This is the fraction of K present in the soil solution and is immediately available to the crop. Water soluble-K in the surface layers varied from 13.5 mg/kg in profile 4 to 20 mg/kg in profile 1 with a gradual decrease with soil depth. It varied from a minimum value of 6.5 mg/kg in the 3rd and 4th layer of profile 2 to the maximum value of 20 mg/kg in the 1st layer of profile 1 and constituted 0.2 to 1.8% of the total K in different layers. Water soluble K decreased with concurrent increase in clay content in the profile and a significant negative correlation was obtained (r= -0.78**) (Table 20 and Fig. 13). The slope value of -0.266

of the corresponding regression equation indicated that with one unit increase in clay content there was decrease of 0.266 unit of water soluble K. Water soluble K was positively correlated with sand (r = 0.76**). Water soluble K decreased along with the increase in clay content in the profile. This might be due to an increase in specific adsoption sites with increase in clay content and retaining a greater part of potassium with high adsorption energy.Accordingly a significant positive correlation between water soluble K and K saturation in soil (r= 0.57**) existed.

IV.9.2.2. Exchangeable-K :

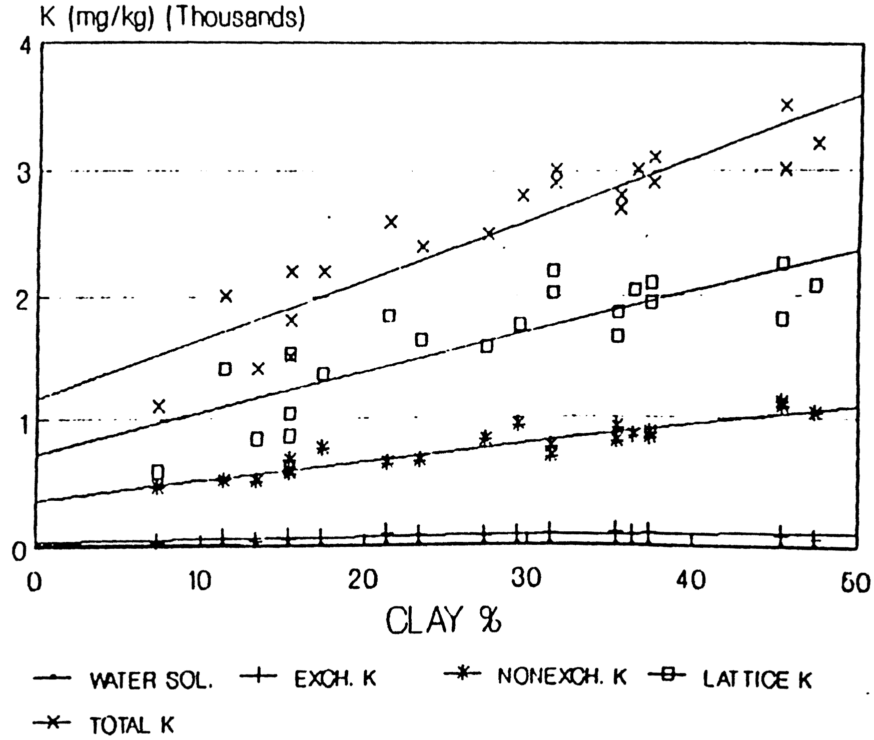
This part of potassium is held electrostatically on the surface of the exchange complex and is available to crop after exhaustion of the water soluble K. Exchangeable K in surface layers varied from 39.5mg/kg (P-5) to 96.5 mg/kg (P-2) and showed overall increase in different horizons down the profile. It varied from a minimum value of 39.5 mg/kg in the surface layers of P-1 to the maximum value of 110 mg/kg in the second layer of P-2 constituing 2.1 to 4.0 % of the total K.

Exchangeable K showed a significant positive correlation with clay (r=0.71**) indicating a general increase in exchangeable K with increase in clay content (Fig. 14). The slope value of 1.23 of the corresponding regression equation indicated that for one unit increase in clay, three was 1.23 units increase in exchangable K. Exchangeable K was negatively correlated with sand (r = -0.67**) and showed a nonsignificant correlation with silt. The increase in exchangeable K in the profiles might be due to its greater retention at the lower layers because of higher clay contents.

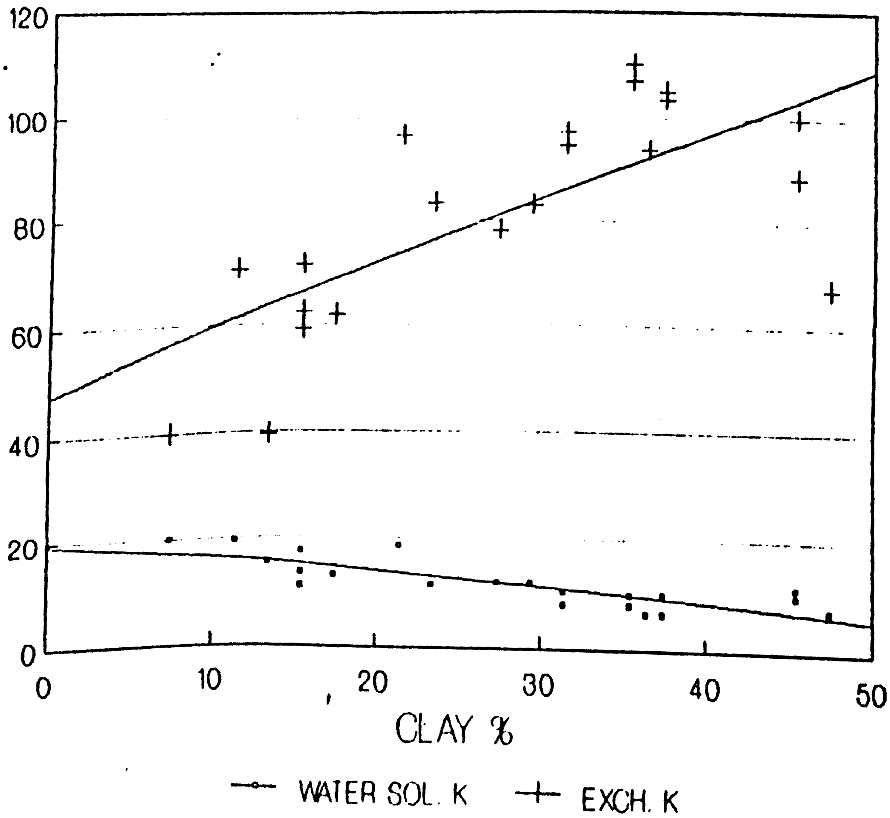
IV.9.2.3. Non-exchangeable K :

This form of K mainly exists in the hexagonal oxygen cavities between two crystal units of the 2:1 type of silicate clay minerals. Non-exchangeable K is changed to exchangeable form with exhaustion of exchangeable K and gradually becomes available to the plants. The values of non exchangeable K in the surface layer varied from 460 mg/kg in the P-1 to 675 mg/kg in P-4 and gragually increased with depth attaining the highest value of 1130 mg/kg in the last layer of P-3.It contributed 23.2 to 41.8 % of the total K in different horizons. Considering different horizons in the profiles it may be seen that non-exchangeable K increased along with the increase in clay contant and a highly significant positive correlation (r=0.92**) was obtained (Fig. 14). This observation indicated that, non-exch-K is mainly associated with the clay fraction of soil. The slope value of 14.8 of the corresponding regression equation indicated that with one unit increase in clay there was 14.8 unit increase in non-exchangeable K. Non-exchangeable K was also significantly correlated with silt fraction of soil with a decreased 'r'

Fig.14 Relationship of different forms of K with clay (A)



(B)



value of 0.44* indicating that, silt is the next contributor to non-exchangeable K in soil. A negative correlation was obtained between non-exchangeable K and sand (r = 0.90**).

IV.9.2.4. Lattice K :

This fraction of K is associated in the crystal lattice of various K bearing minerals and is released to the soil solution by weathering. The release of K from this source depends upon the particle size of the mineral, bonding energy of K in the crystal lattice, the intensity of weathering etc. Since equilibrium exists between non-exch. and lattice-K the depletion of non-exch.K permits more of the K to be released from the lattice to non-exch. source. Lattice-K in surface layers varied from 580 mg/kg in profile-1, to 1840 mg/kg in profile-5 and gradually increased with depth attaining the maximum value of 2260 mg/kg at the last layer of profile-3. It constituted 52.8% to 73.0% of the total-K. Lattice-K increased with increase in clay content in soil and a highly significant positive 'r' value of 0.83** was obtained (Fig. 14). This value was reduced to 0.50** when correlated with silt. It was negatively correlated with sand (r = -0.84**). These observations showed that most of the K bearing minerals have been weathered to clay sized fraction and some of the resistant minerals are left in silt fraction. The slope value of 32.73 of the regression equation between lattice-k and clay indicated that for one unit increase in clay there was 32.73 unit increase in lattice-K in soil.

Table : 16 K-release pattern in soil as extracted by boiling in HNO_3

Profile	Depth (Cm.)	K-released ($mg.kg^{-1}$) at different extractions									
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
II	0-11	645	240 (885)	180 (1065)	136 (1201)	80 (1281)	40 (1321)	28 (1349)	8 (1357)	4 (1361)	4 (1365)
	11-52	820	400 (1220)	220 (1440)	180 (1620)	112 (1732)	112 (1844)	92 (1936)	24 (1960)	24 (1984)	24 (2008)
	52-88	860	480 (1340)	260 (1600)	204 (1804)	164 (1968)	84 (2052)	72 (2124)	40 (2164)	32 (2196)	32 (2228)
	88-115	850	520 (1370)	300 (1670)	228 (1889)	164 (2062)	156 (2218)	104 (2322)	64 (2386)	40 (2426)	40 (2466)
	115-150	925	520 (1445)	320 (1765)	232 (1997)	168 (2165)	108 (2273)	84 (2357)	68 (2425)	40 (2465)	40 (2505)
III	0-14	600	320 (920)	160 (1080)	92 (1172)	64 (1236)	36 (1272)	24 (1296)	20 (1316)	16 (1332)	16 (1348)
	14-42	945	400 (1345)	220 (1565)	148 (1713)	124 (1837)	92 (1929)	76 (2005)	32 (2037)	24 (2061)	24 (2085)
	42-90	1100	560 (1660)	260 (1920)	228 (2148)	180 (2328)	144 (2472)	128 (2600)	64 (2664)	56 (2720)	56 (2776)
	90-172	1130	640 (1770)	280 (2050)	228 (2278)	212 (2490)	120 (2610)	92 (2702)	60 (2762)	60 (2822)	60 (2822)
IV	0-14	675	280 (955)	200 (1155)	109 (1264)	96 (1360)	24 (1384)	20 (1404)	12 (1416)	8 (1424)	8 (1432)
	14-27	765	280 (1045)	180 (1225)	116 (1341)	108 (1449)	56 (1505)	48 (1553)	28 (1581)	24 (1605)	24 (1629)
	27-60	830	520 (1350)	240 (1590)	156 (1746)	144 (1890)	60 (1950)	56 (2006)	36 (2042)	32 (2074)	32 (2106)
	60-150	1045	560 (1605)	280 (1885)	192 (2077)	180 (2257)	140 (2397)	112 (2502)	72 (2581)	64 (2645)	64 (2709)
V	0-14	505	280 (785)	80 (865)	60 (925)	56 (981)	40 (1021)	24 (1045)	24 (1069)	20 (1089)	20 (1109)
	14-32	570	400 (970)	100 (1070)	80 (1150)	60 (1210)	44 (1254)	40 (1294)	32 (1326)	32 (1358)	32 (1390)
	32-84	775	520 (1295)	140 (1435)	104 (1539)	72 (1611)	56 (1667)	60 (1727)	20 (1747)	20 (1767)	20 (1787)
	84-155	885	640 (1525)	160 (1685)	144 (1829)	100 (1929)	84 (2013)	76 (2089)	32 (2121)	32 (2153)	32 (2185)

* Figures in parenthesis indicate the cumulative K-released after the end of the extraction.

IV.9.2.5. Total - K :

It includes all the forms of K as discussed above. Total-K content in the surface layers varied from 1100 mg/kg in profile-1 to 2200 mg/kg in profile-2 and increased with soil depth attaining the maximum value of 3500 mg/kg at the last layer of profile-3. Total-k in soil increased with increase in clay content and a highly significant positive 'r' value of 0.91** was obtained (Fig. 14). This value was reduced to 0.51** when it was correlated with silt. Total-K was negatively correlated with sand (r = - o.91**). These observations showed that, total-K in soil is mainly contributed by clay fractions and to a less extent by silt. The slope value of the regression equation establishing relationship between total-K and clay indicated that for 1 unit increase in clay content there was 48.46 unit increase in total-K in soil.

IV.9.3. Change in the per cent of various forms of K in the soil profiles :

IV.9.3.1. Water soluble-K % :

Water soluble-K% was maximum in the surface layers of different profiles (Table 16) and gradually decreased with increase in soil depth. This is due to the decrease in water soluble-K and simultaneous increase in total K with soil depth. Water soluble K per cent was positively correlated with sand (r = 0.83**), negatively correlated with silt (r = -0.49*) and clay (r = -0.82**). Positive correlation with sand may be the indirect effect of the negative relationship between sand & clay. Water soluble K% was positively correlated with water soluble K (r=0.85**). This is due to negative relation bewteen watersoluble K and total K. It was negatively correlated with non-exch. K (r=-0.77**), lattice K (r = -0.84**) and total K(r = -0.88**). Water soluble K % was negatively correlated with lattice K% (r = -0.50**) thus indicating that with increase in the fractions of lattice K to total K, there was decrease in the fraction of water soluble to total K.

IV.9.3.2. Exchangeable K % :

Exch. K% in surface layers varied from 2.8% in profile- 5 to 4.0% in profile-4 with an inconsistent change with soil depth. Exch. K% varied from 3.2 to 3.6% in different layers of profile-1 , 3.1 to 4.0% in profile-2, 2.8 to 3.0% in profile-3, 2.1 to 4.0% in profile-4 and 2.8 to 3.9% in profile-5. These observations showed that there was little variation in the exch. K% in soil profiles.

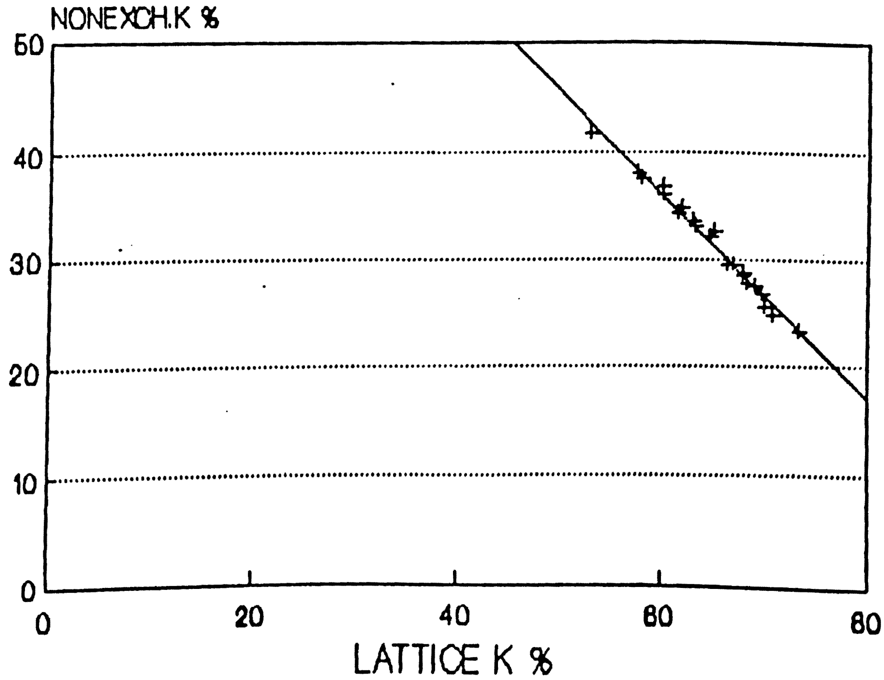
IV.9.3.3. Non-exchangeable K% :

Non-exchangeable K% in surface layers varied from 24.8 mg/kg in profile-2 to 41.8 mg/kg in profile-1 and changed irregularly with soil depth. Non-exchangeable K% showed a significant negative relationship with lattice K (r=-0.67**) thus showing that with increase in lattice K, the fraction of non-exchangeable K to total K, decreased. This might be due to the fact that with increase in lattic-K, the fraction of lattice-K to total-K increased (r=0.73**) and consequently the fraction of exch. K to total K decreased. Non-exchangeable K% also showed a negative relationship with total K (r=-0.51*). It was negatively correlated with lattice K% with a highly significant 'r' value of -0.99** (Fig. 15). The slope value of the corresponding regression equation indicated that with one unit increase in the percent of lattic K, there was 0.95 unit decrease in the percent of non-exchangeable K. Non-exchangeable K% was significantly correlated with non-exchangeable/lattic K with a positive 'r' value of 0.98**.

IV.9.3.4. Lattice K% :

Lattice K% in different layers varied from 52.8 to 70.8% and no specific trend of change could be obtained. Lattice K% possessed a highly significant positive correlation with lattice K (r=0.73**) indicating an increase in the fraction of lattice K to total K with increase in lattice K. Lattice K increased alongwith increase in total K in soil. But the proportion at which lattice K increased was greater than the proportion of increase of total K in most of the cases. This might be the possible reason of the positive relationship between lattice K% and lattice K in soil.

Fig.15 Relationship of nonexch.K% with lattice K%



IV.9.4 Variation in the ratio of different forms of K in the soil profile:

IV.9.4.1. Watersoluble/Exchangeable K :

This ratio indicates the fraction of exch. K that comes to the soil solution. This ratio was highest at the surface layers and gradually decreased with soil depth in all the profiles. The decrease in the ratio of water soluble K to exch. K in sub-surface layers might be due to greater specific adsorption of K with clay content and simultaneous low release of water soluble K. This ratio was positively correlated with water soluble K% (r=0.97**) indicating that, with increase in the fraction of water soluble to total K there was an increase in the fraction of water soluble K to exchangeable K. Water soluble to exch. K ratio was positively correlated with sand (r=0.79**), negatively correlated with silt (r = -0.44*) and clay (r = -0.80**). Water soluble/exch. K was negatively correlated with non-exch. K (r = -0.87**), lattice-K (r = -0.83**) and total K (r = -0.85**). This may be the effect of the negative co-rrelation of water soluble K with non-exch. K, lattice K, total K and possitive correlation of exchangeable K with all those forms of K.

IV.9.4.2 Exch. K/ Non-exch. K:

This ratio signifies the fraction of non-exchangeable K coming to the exchangeable form. Smaller is the ratio greater is the capacity of the soil to reserve K and the soil is more resistant to K depletion. This ratio varied from 0.08 to 0.15 with very little change in different layers. It was correlated negatively with non-exchangeable K% (r = -0.70**) and positively with lattice K (r=0.61**).

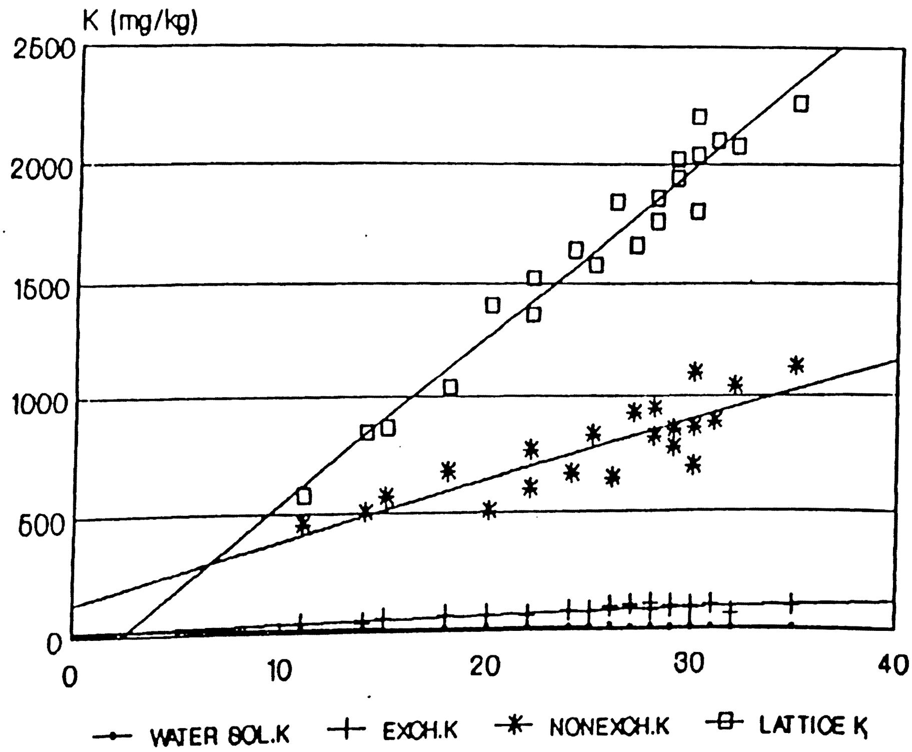
IV.9.4.3. Non-exch.K/ Lattice K :

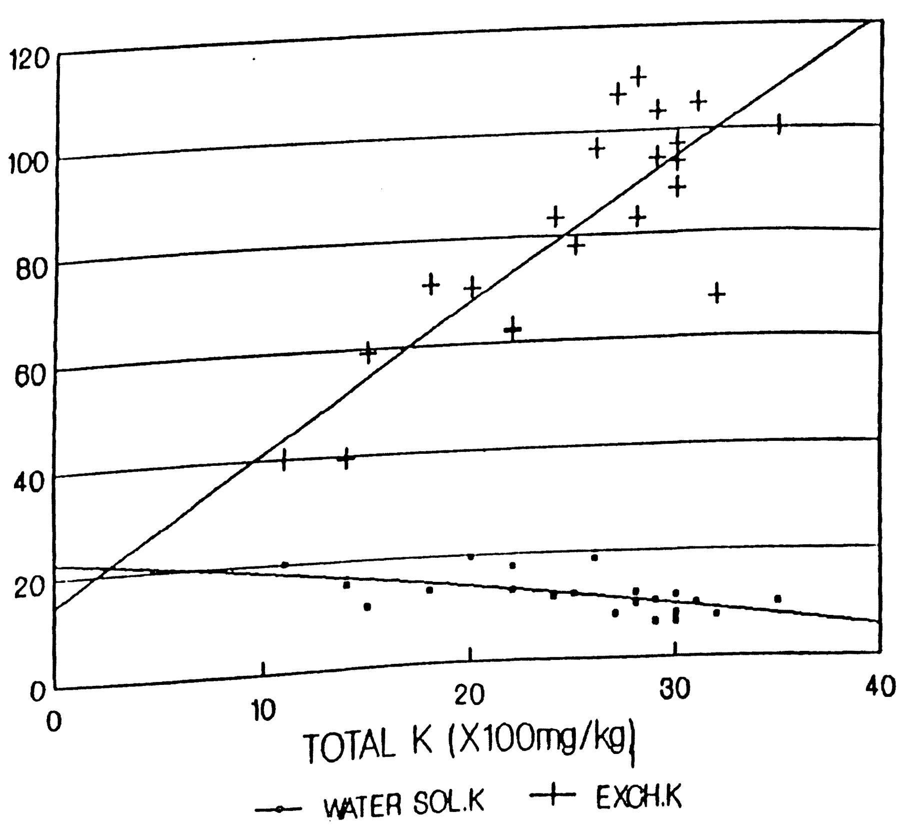
This ratio indicated the fraction of lattice-K coming to non-exchangeable form. It varied from 0.32 to 0.79 with an inconsistent change in different layers in the profiles. It showed a highly significant negative correlation with lattice K (r = -0.71**) indicating that with increase in lattice K there was decrease in the fraction of non-exchangeable K to lattice K. This ratio was negatively correlated with lattice K% with a highly significant 'r' value of -0.99**, indicating that with increase in lattice K% there was decrease in non-exch. K/ lattice K in all the cases. This might be due to slow release of K from lattice to the non-exchangeable sources. The slope value of -0.023 of the corresponding regression equation indicated that, with one unit increase in lattice K% there was -0.023 unit decrease in the ratio of non exch. K to lattice K.

IV.9.4.4. Lattic K/ Total-K :

This indicates the fraction of total K present in the crystal lattice of various K bearing minerals in soil. This ratio varied from 0.52 to 0.73 in different layers with

Fig.16 Relationship of other forms of K with total K.





an irregular change with depth. Lattice K/total K was positively correlated with lattice K (r = 0.73**).

IV.9.5. Inter-relationships among various forms of K:

Various forms of K were significantly correlated with each other (Table 20). Water soluble-K was negatively correlated with exch.K (r=-0.60**), non-exch. K (r=-0.68**), lattice K (r = -0.62**) and total K (r=-0.68**). Exch. K was positively correlated with non-exch. K (r=0.60**), lattice K (r=0.82**) and total K (r = 0.82**). Non-exch. K was positively correlated with lattice K (r=0.72**) and total K (r=0.84**). Lattice-k was positively correlated with total k with a highly significant 'r' value of 0.98** in addition to its relationship with other forms of k. Significant correlations among various forms of K indicated that they are in dynamic equilibrium with each other. The slope values of the regression equations of water soluble, exchangeable, non-exchangeable and lattice K with total K indicated that with one unit increase in total K, there was an increase of 0.72 units in lattice K, 0.25 unit in non-exchangeable K, 0.03 unit in exchanbeale K and a decrease of 0.004 unit in water soluble K (Fig. 16).

IV.10. K Releasing phenomenon :

K release characteristics from the non-exchangeable sources were studied for profile 2,3,4 and 5 by repeated

Fig.17 Successive extraction of K from different layers

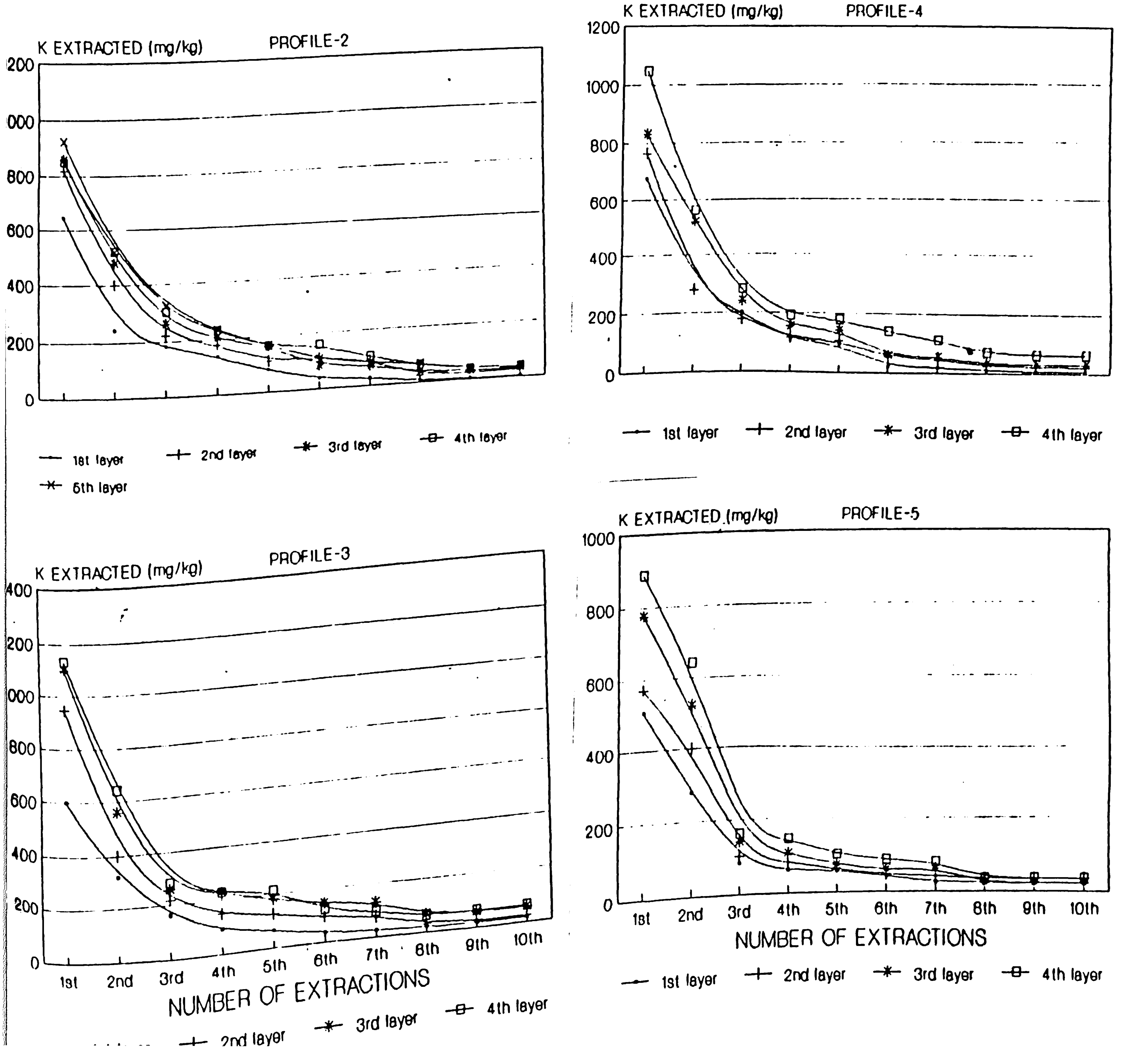


Fig. 10 Cumulative release of K from different layers.

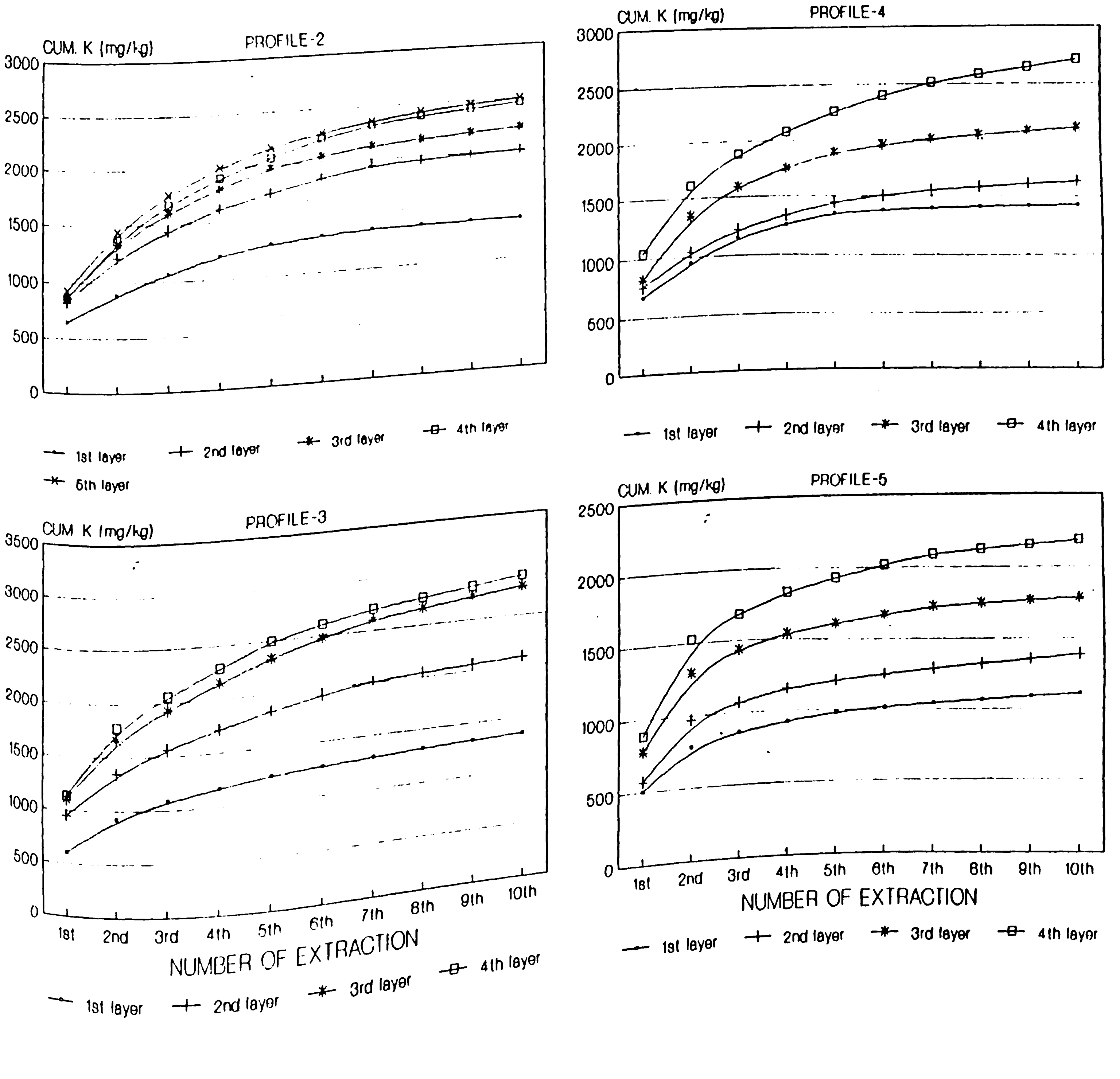
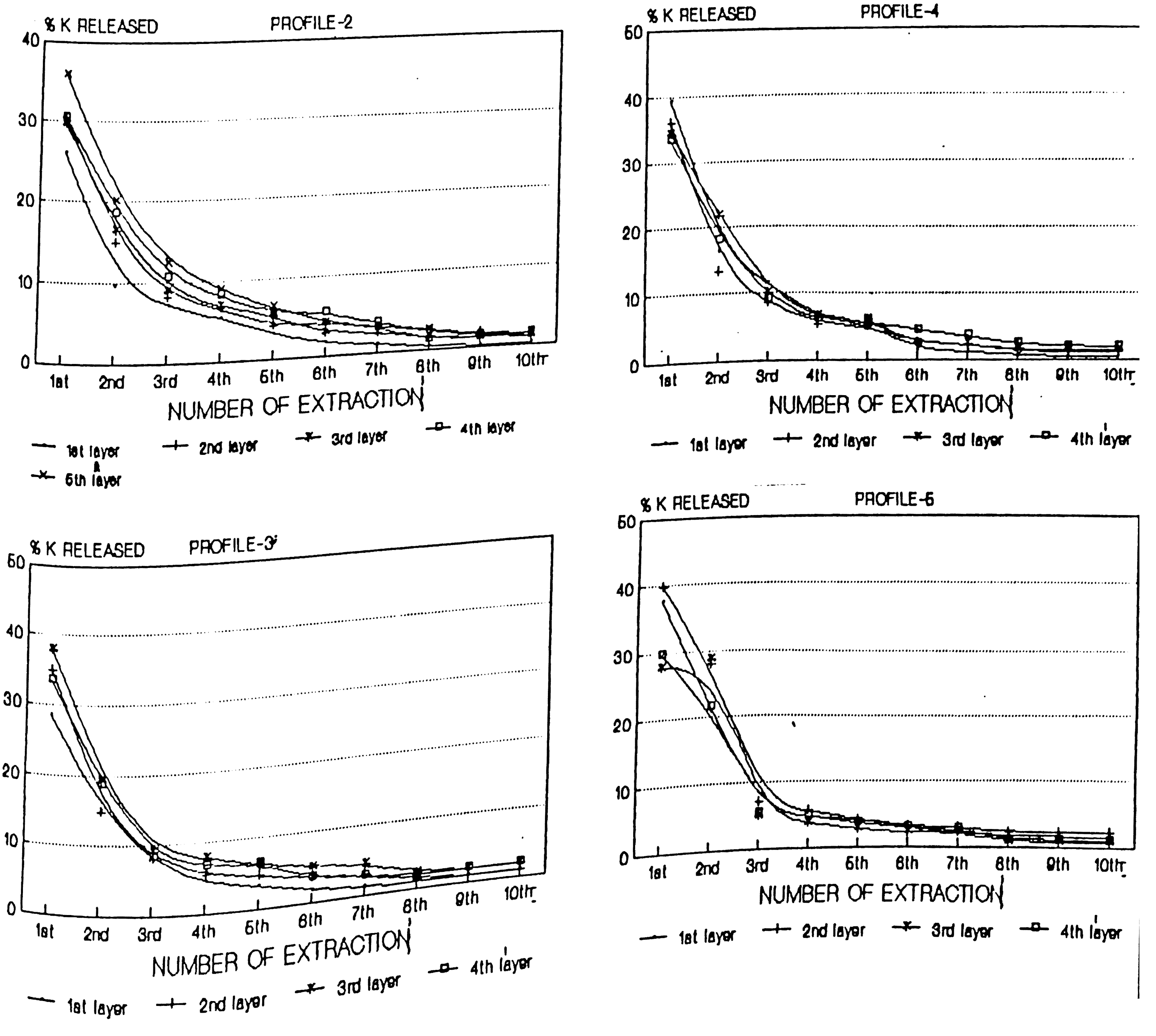


Fig.19 Per cent (nonexch.+lattice)-K released at successive extractions



extractions with boiling 1N HNO_3. Release behaviour of potassium in different layers of the profiles and the relationship of the K-release paramenters with some basic soil properties and forms of K were investigated.

IV.10.1. Release pattern within the profile :

K-release pattern in different layers of the profiles has been presented in table 16 and Fig. 17. The maximum amount of K was released in the first extraction and decreased gradually with successive extractions to attain a constant value after 7th/8th extractions. Cumulative K released at the end of each extraction increased with depth in all the profiles (Fig. 18). The total amount of K released varied from 1348 to 2822 mg kg^{-1} at different layers. The initial higher release of K might be due to removal from less resistant minerals and the lower release towards the end might be due to removal from resistant minerals. 67.7 to 80.7% of the total K extracted was released in the initial three extractions, 12.9 to 20.4% was released in the next three extractions and 3.3 to 11.5% was released in the last four extractions (Table 17). It was observed that 26.0 to 39.9% of the non-exch. and lattice K was released at the first extraction which was gradually reduced to 0.2 to 1.8% in the tenth extraction (Table 18 and Fig. 19).

Table : 17 Per cent of the (non-exchangeable + lattice)-K released at different extractions.

Profile	Depth (Cm.)	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	Total
II	0-11	26.0	9.6	7.2	5.5	3.2	1.6	1.1	0.3	0.2	0.2	54.9
	11-52	34.3	14.9	8.3	6.7	4.2	4.2	3.4	0.9	0.9	0.9	78.7
	52-88	29.6	16.5	9.0	7.0	5.6	2.9	2.6	1.4	1.1	1.1	76.8
	88-115	30.5	18.6	10.7	8.2	5.8	5.6	3.7	2.3	1.4	1.4	88.4
	115-150	35.8	20.1	12.4	9.0	6.5	4.3	3.2	2.6	1.5	1.5	96.9
III	0-14	28.3	15.1	7.5	4.3	3.0	1.7	1.1	0.9	0.8	0.8	63.6
	14-72	34.9	14.8	8.1	5.5	4.6	3.4	2.8	1.2	0.9	0.9	77.1
	42-90	37.9	19.3	9.0	7.9	6.2	5.0	4.4	2.2	1.9	1.9	95.7
	90-172	33.3	18.8	8.3	6.7	6.3	3.5	2.7	1.8	1.8	1.8	85.0
IV	0-14	39.4	16.3	11.6	6.3	5.6	1.4	1.3	0.7	0.4	0.4	83.4
	14-27	36.0	13.2	8.5	5.5	5.1	2.6	2.3	1.3	1.1	1.1	76.7
	27-60	34.4	21.6	10.0	6.05	6.0	2.5	2.3	1.5	1.3	1.3	87.4
	60-150	33.4	18.0	9.0	6.1	5.8	4.5	3.6	2.3	2.0	2.0	86.7
V	0-14	37.5	20.8	5.9	4.5	4.2	3.0	1.8	1.8	1.5	1.5	82.5
	14-32	39.9	28.0	7.0	5.6	4.2	3.1	2.8	2.2	2.2	2.2	97.2
	32-84	27.7	18.6	5.0	3.7	2.6	2.1	2.1	0.7	0.7	0.7	63.9
	84-155	29.6	21.4	5.4	4.8	3.6	2.8	2.6	1.0	1.0	1.0	73.2

The per cente of non-exch. + lettice K released at each extraction was observed to change irregularly with soil depth. This might be due to the variation in the proportions of weatherable to resistant minerals at different layers. The total per cent of non-exch + lattice K released after all the ten extractions varied from 54.9 at the first and layer of profile 2 to 97.2 at the second layer of profile 5. Lower per cent of K removal in the former indicated that, this soil can maintain K supply for a longer period and will take long time to get exhausted and vice versa in the latter case.

The total extractable K increased along with clay content and a highly significant positive correlation (r=0.95**) was obtained (Fig. 20). This indicated that, K supplying capacity of the soil increased along with the increase in clay content down the depth. The slope value of 45.3 of the corresponding regression equation indicated that for one unit increase in clay content there was 45.3 unit increase in total extractable K. It was negatively correlated with sand (r=-0.89**) and did not show any significant relationship with silt. This observation also indicated that the K bearing minerals in soil are mainly associated with the clay fraction in soil. Total extractable K was negatively correlated with water soluble K (r=-0.74**) and positively correlated with exch-K (r=0.58*), non-exch. K (r=0.96**), lattice K (r=0.73**) and total-K (r=0.84**). The highly

Table : 18 Per cent of the total cumulative K released at the end of different extractions.

Profile	Depth (Cm.)	1st+2nd+3rd extractions	4th+5th+6th extractions	7th+8th+9th+10th extractions
I	0-14	62.5	16.08	21.42
	14-40	79.1	12.6	8.3
	40-72	79.4	16.6	4.0
	72-150	76.4	19.0	4.6
II	0-11	78.0	18.7	3.3
	11-52	73.0	19.1	7.9
	52-88	71.8	20.4	7.8
	88-115	67.7	22.3	10.0
	115-150	70.4	20.3	9.3
III	0-14	80.1	14.2	5.7
	14-42	75.1	17.4	7.5
	42-90	69.2	19.9	10.9
	90-172	71.1	19.5	9.4
IV	0-14	80.7	16.0	3.3
	14-27	75.2	17.2	7.6
	27-60	75.5	17.0	7.5
	60-150	69.6	18.9	11.5
V	0-14	77.9	14.1	8.0
	14-32	77.0	13.2	9.8
	32-84	80.1	12.9	7.0
	84-155	77.0	15.0	8.0

Table : 18 Per cent of the total cumulative K released at the end of different extractions.

Profile	Depth (Cm.)	1st+2nd+3rd extractions	4th+5th+6th extractions	7th+8th+9th+10th extractions
I	0-14	62.5	16.08	21.42
	14-40	79.1	12.6	8.3
	40-72	79.4	16.6	4.0
	72-150	76.4	19.0	4.6
II	0-11	78.0	18.7	3.3
	11-52	73.0	19.1	7.9
	52-88	71.8	20.4	7.8
	88-115	67.7	22.3	10.0
	115-150	70.4	20.3	9.3
III	0-14	80.1	14.2	5.7
	14-42	75.1	17.4	7.5
	42-90	69.2	19.9	10.9
	90-172	71.1	19.5	9.4
IV	0-14	80.7	16.0	3.3
	14-27	75.2	17.2	7.6
	27-60	75.5	17.0	7.5
	60-150	69.6	18.9	11.5
V	0-14	77.9	14.1	8.0
	14-32	77.0	13.2	9.8
	32-84	80.1	12.9	7.0
	84-155	77.0	15.0	8.0

significant positive correlation between non-exch. K and total extractable K indicated that non-exch. K can serve as a good index of the total K supplying capacity of the soil. The slope value of 2.91 of the corresponding regression equation indicated that for one unit increase in non-exch. K there was 2.91 units increase in the total extractable K. It was negatively correlated with water soluble K% (r=-0.85**) and water soluble K/exch. K (r=-0.74**).

The per cent of the non-exch + lattice K released at the end of all the ten extractions was positively correlated with non-exch. K% (r=0.79**) and negatively correlated with lattice K% (r=-0.76**) (Table 21). It was observed that, although total extractable K was positively associated with lattice K but its per cent as non-exch. + lattice K was negatively correlated with lattice K. This indicated that, with increase in lattice K the total extractibility of K increases but the per cent extractibility decreases. It was positively correlated with non-exch. K/ lattice K (r=0.79**) and negatively correlated with lattice K/total K (r=-0.74**).

IV.10.2 Step-K :

Step-K and constant rate-K (CR-K) provide estimates of K availability from non-exchangeable and mineral lattice sources respectively (Haylock, 1956). Conceptually step-K is a measure of the more available part of the non-exchangeable

Fig.20 Relationship of K release parameters with clay%

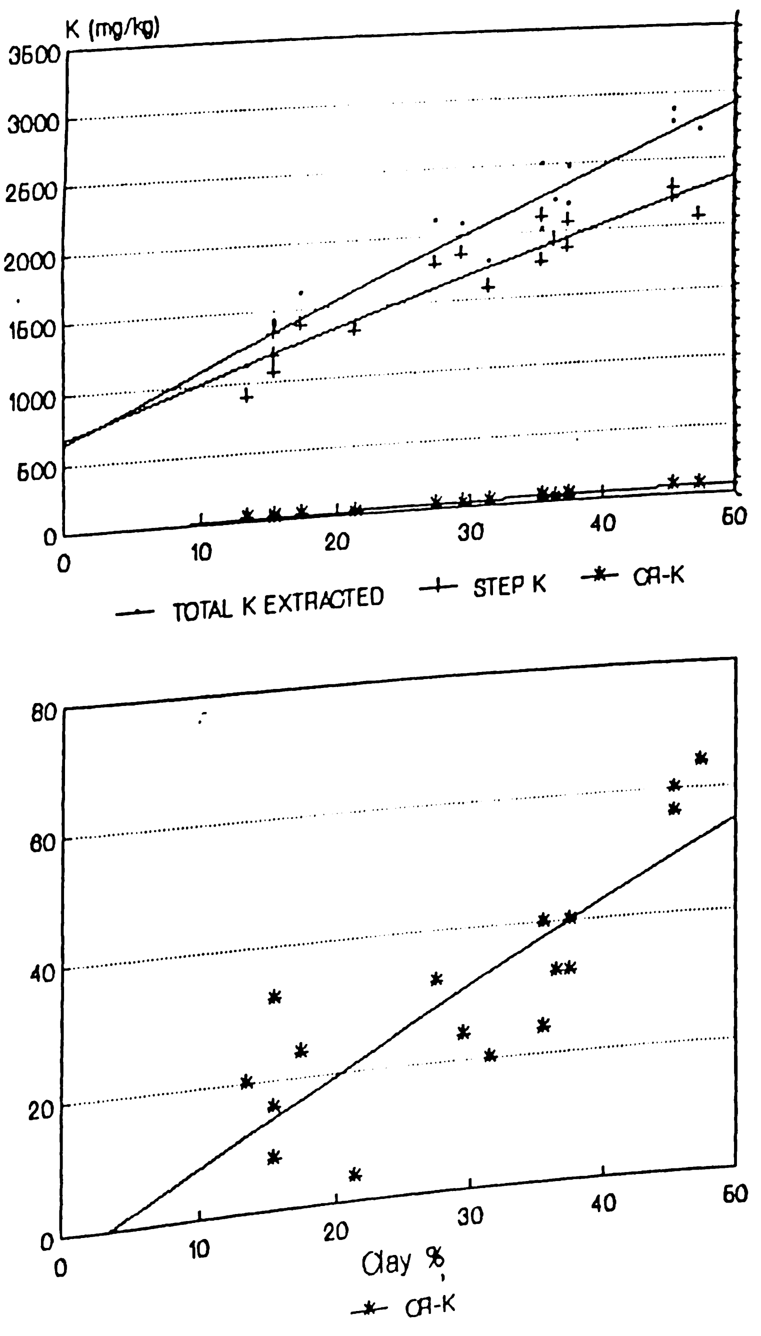
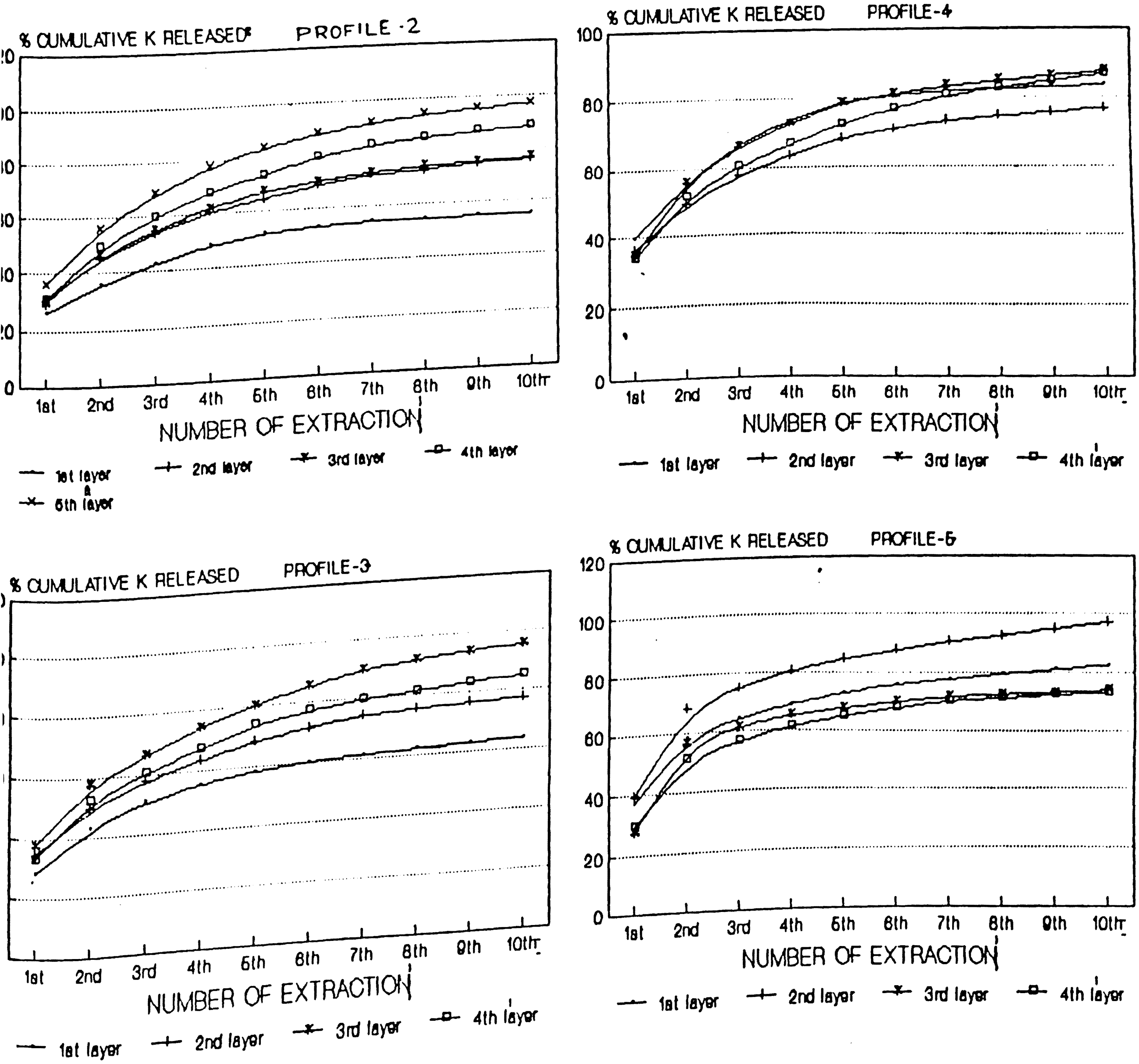


Fig.21 Cumulative % of (nonexch.+lattice)-K released at successive extractions



and lattice K. The values of step K released at different extractions have been presented in table-19. Step-K gradually decreased with successive extractions to attain a zero value after 7th/8th extractions in different layers and showed a general trend of increase with increase in depth of the profile (Fig. 19). The total amount of step-K released at the end of all the extractions varied from 905 to 2282 mg kg^{-1} with a regular increase with depth (Fig. 22). Total step-K calculated as per cent of non-exch. + lattice K varied from 53.3 to 81.9%.

Total step-K increased along with the increase in clay content down the profile and a highly significant positive correlation with the 'r' value of 0.94** was obtained. The slope value of 33.9 of the corresponding regression equation indicated that with one unit increase in clay content there was 33.9 unit increase in total step-K. Total step-K was negatively correlated with sand (r=-0.89**) and showed a nonsignificant relationship with silt. It was positively correlated with exch. K (r=0.70**), non-exch. K (r=0.95**), lattice K (r=0.79**) and total K (r=0.89**). The slope value of 2.2 of the corresponding regression equation between sept K and non exchangeable K co-efficient indicated that with one unit change in the value of non-exch. K, there was 2.2 units change in the value of total step-K. It was negatively correlated with water soluble K (r=-0.71**) and

Table : 19 *Depth-wise change in Step-K and CR-K in the Soil profiles*

Profile	Depth(Cm.)	Step-K at the extractions (Mg Kg^{-1}) 1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	Total(mg.K^{-1})	CR-K	Percent of(Non-exch+lattic)-K released as: Total Step	CR-K
II	0-11	641	236	176	132	76	36	24	4	-	-	1325	04	53.3	0.2
	11-52	896	376	196	156	88	88	68	-	-	-	1868	24	69.7	0.9
	52-88	828	448	228	172	132	52	40	8	-	-	1908	32	65.7	1.1
	88-115	810	480	260	188	124	116	64	24	-	-	2066	40	74.0	1.4
	115-150	885	480	280	192	128	68	44	28	-	-	2105	40	81.4	1.5
III	0-14	584	304	144	76	48	20	8	4	-	-	1188	16	56.0	0.7
	14-42	921	376	196	124	100	68	52	8	-	-	1845	24	68.2	0.9
	42-90	1044	504	204	172	124	88	72	8	-	-	2216	56	81.9	2.1
	90-172	1070	580	220	168	152	60	32	-	-	-	2282	60	67.3	1.8
IV	0-14	667	272	192	101	88	16	12	4	-	-	1352	08	78.8	0.5
	14-27	741	256	156	92	84	32	24	4	-	-	1389	24	65.3	1.1
	27-60	798	488	208	124	112	28	24	4	-	-	1786	32	74.1	1.3
	60-150	981	496	216	128	116	76	48	8	-	-	2069	64	66.2	2.0
V	0-14	485	260	60	40	36	20	4	-	-	-	905	20	67.2	1.5
	14-32	538	368	68	48	28	12	8	-	-	-	1070	32	74.8	2.2
	32-84	755	500	120	84	52	36	40	-	-	-	1587	20	56.8	0.7
	84-155	853	608	128	112	68	52	44	-	-	-	1865	32	62.5	1.1

Table : 20 Relationship of various forms of K with soil properties and among themselves.

x	y	Correlation Coefficient values 'r'	Intercept and slope values of the regression equation y = a + bx: a	b
1. Water sol.K	sand	0.76	-1.077	0.211
	silt	-0.39NS	-	-
	clay	-0.78	19.354	-0.266
	exch.K	-0.60	21.567	-0.117
	non-exch.K	-0.68	23.137	-0.014
	lattice.K	-0.62	20.818	-5.372
	total.K	-0.68	22.849	-4.322
2.Exch.K	sand	-0.67	140.564	-0.952
	silt	0.29NS	-	-
	clay	0.71	47.616	1.230
	non-exch.K	0.60	31.213	0.065
	lattice.K	0.82	22.062	0.036
3.Non-exch.K	sand	-0.90	1500.256	-11.718
	silt	0.44	582.798	18.339
	clay	0.92	366.461	14.768
	lattice.K	0.72	297.173	0.291
	total.K	0.84	136.861	0.254
4.Lattice.K	sand	-0.84	3305.337	-26.918
	silt	0.50	1115.514	50.020
	clay	0.83	733.980	32.730
	total.K	0.98	-174.370	0.723
5.Total.K	sand	-0.91	4945.88	-39.38
	silt	0.51	1781.86	69.32
	clay	0.91	1167.49	48.46
6.Water sol.K VS	sand	0.83	-0.78	0.82
	silt	-0.49	0.99	-0.04
	clay	-0.82	1.30	-0.03
	water sol.K	0.85	-0.40	0.08
	non-exch.K	-0.77	1.77	-0.002
	lattice.K	-0.88	1.7	-0.7×10^{-4}
	lattice.K%	-0.50	2.98	-0.04

x	y	Correlation Coefficient values 'r'	Intercept and slope values of the regression equation y = a + bx	
			a	b
7.Non-exch.K% VS	lattice.K	-0.67	42.99	-0.007
	total.K	-0.51	41.40	-0.004
	lattice.K%	-0.99	92.90	-0.95
	non-exch.K / lattice.K	0.98	11.55	40.58
8.Water solable/ exch-K VS	sand	0.73	-0.22	0.006
	silt	-0.44	0.28	-0.011
	clay	-0.80	0.38	-0.008
	non-exch.K	-0.87	0.58	-4.3×10^{-9}
	lattice.K	-0.83	0.50	-2.04×10^{-4}
	total.K	-0.85	0.55	-1.55×10^{-4}
9.Exch./non-exch. K VS	non-exch.K	-0.70	0.21	-0.003
	lattice.K	0.61	0.087	1.23×10^{-5}
10.Non-exch./ lattice.K VS	non-exch.K	0.98	-0.257	0.024
	lattice.K	-0.71	0.786	-1.8×10^{-4}
	lattice-K%	-0.99	1.974	-0.023
11.Lattice/total K VS	lattice.K	0.73	0.512	8.08×10^{-5}

Table : 21 Relationship of different K release parameters with soil properties, forms of K & among themselves

Parameters	Diff. forms & properties	'r'	'a'	'b'
(1) Total extractable K VS.	Sand	-0,89	4066.711	-34.733
	Silt	0,33 NS	-	-
	Clay	0,95	648.889	45.283
	non-exch. K	0,96	-390.545	2.914
	lattice.K	0,73	433.497	0.981
	total-K	0,84	-29.239	0.781
(2) Per cent K release after tenth extraction VS.	non-exch.K	0,79	5.3673	2.3415
	non-exch. K/lattice.K	0,79	30.601	99.772
	lattice.K/total.K	-0,74	218.643	-216.036
(3) Step.K VS.	Sand	-0,89	3259.510	-26.348
	Silt	0,36 NS	-	-
	Clay	0,94	680.403	33.893
	non-exch.K	0,95	-113.198	2.200
	lattice.K	0,79	410.504	0.761
	total.K	0,89	71.112	0.623
	CR-K	0,75	1113.569	18.542
	Cumulative-K after tenth extraction.	0,98	204.640	0.743
(4) Per cent total step.K of the total non-exch + lattice.K	non-exch.K %	0,79	15.610	1.645
	lattice.K %	-0,76	172.271	-1.621
	non exch.K/lattice.K	0,80	32.510	71.775
	lattice.K/total.K	-0,78	170.752	-160.043
(5) CR-K VS.	Sand	-0,73	83.207	-0.875
	Silt	0,21 NS	-	-
	Clay	0,81	-4.056	1.179
	non-exch.K	0,80	-30.250	0.074
	lattice.K	0,73	433.497	0.930
	total-K	0,84	-29.239	0.781

water soluble K/ exch.K (r=-0.80**). A highly significant positive relationship was obtained between step-K and total extractable-K (r=0.98**). The slope value of 0.74 of the corresponding regression equation indicated that for one unit increase in the total extractable K there was 0.74 unit increase in the value of step-K.

Total step-K although was positively correlated with lattice K but the per cent total step-K of the non-exch. + lattice K was negatively correlated with lattice K% (r=-0.79**). It was also positively correlated with non-exch. K% (r=0.79**) and non-exch. K/ lattice K (r=0.80**).

IV.10.3. Constant rate-K (CR - K) :

CR-K is a measure of the difficultly available K from the crystal lattice of the minerals (Haylock, 1956). It varied between ; to 64 mg kg^{-1} at different layers with an increasing trend from surface downward (Table 19 and Fig. 22). CR-K calculated as the per cent of non-exch. + lattice-K varied between 0.2 to 2.1% at different layers. CR-K% was observed to increase with depth in all the profiles except profile-5.

CR-K was negatively correlated with sand (r=-0.73**) and positively with clay (r=0.81**). It was negatively correlated with water soluble K (r=-0.66**) and positively

FIG.22 Relationship of K release parameters with depth.

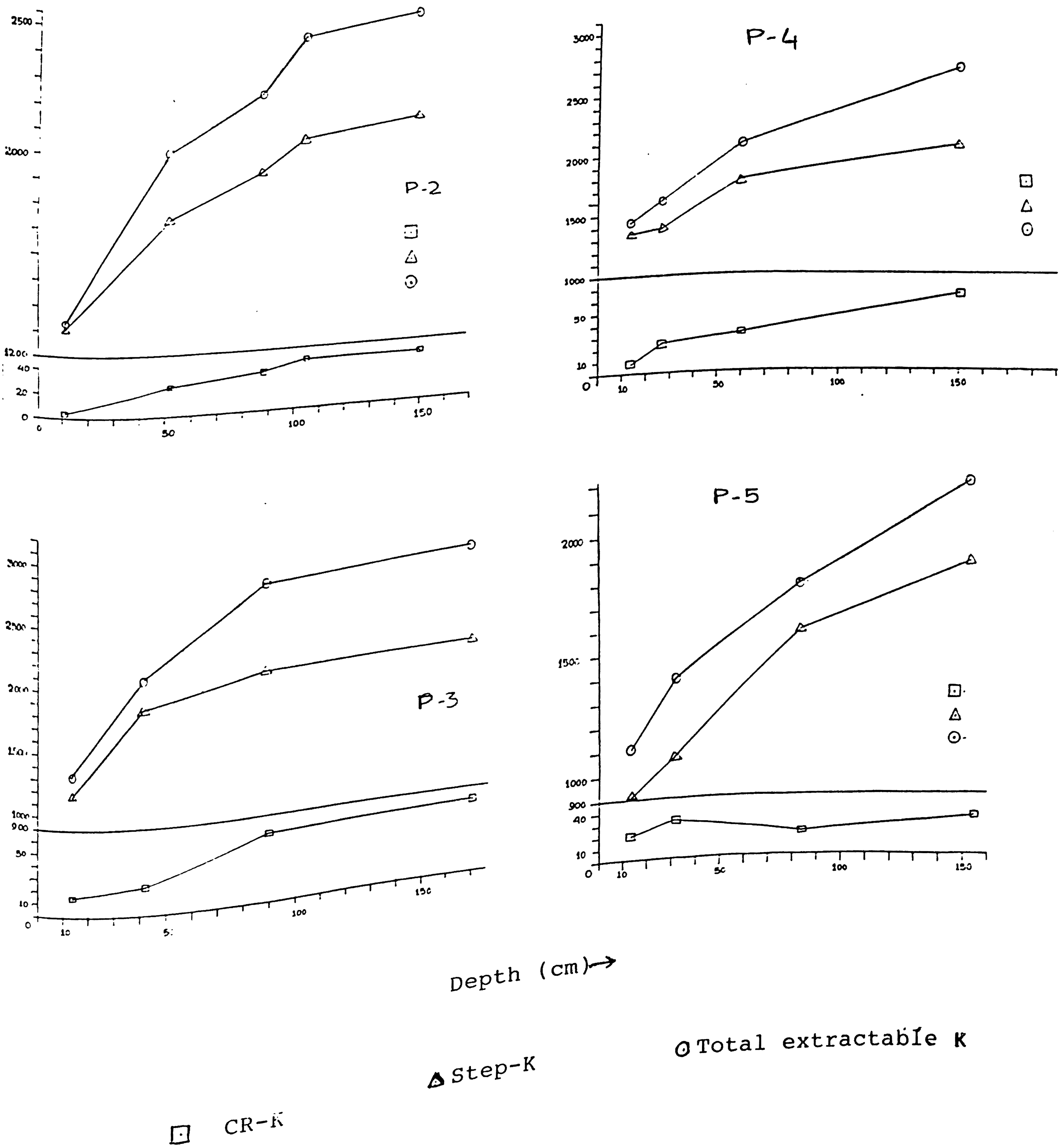
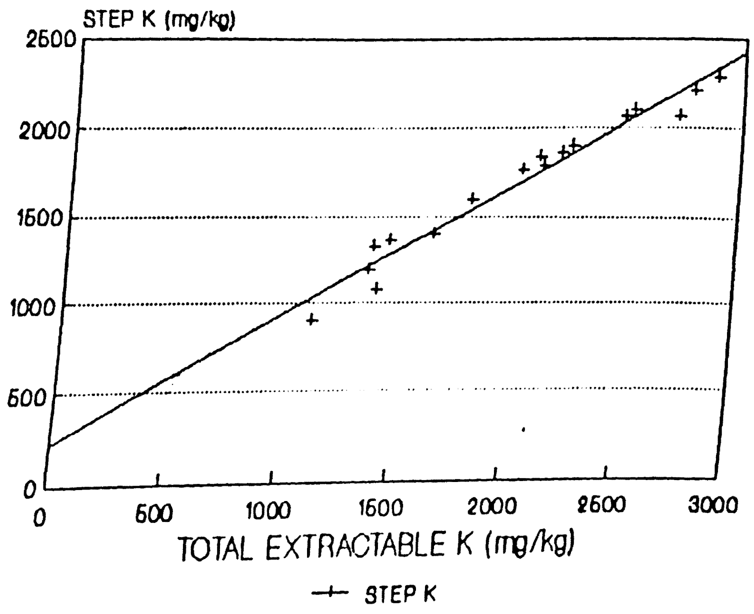


Fig.23 Relationship between step K and total extractable K



with non-exch. K (r=0.80**) and total-K (r=0.58**). The slope value of 0.80 in the regression equation between CR-K and non-exch. K indicated that with one unit change in non-exch. K there was 0.80 unit change in CR-K.

CR-K was negatively correlated with water soluble-K (r=-0.60*) and positively correlated with total sept-K (r=0.75**) and total exctractable-K (r=0.98**).

K release behaviour of the soils provides vital information regarding the period, extent and rate of K-supply to plants. K-supplying capacity of the soil at the 3rd layer of P-1 was highest as observed from the maximum value of total extractable K, but this soil can not maintain K-supply for a longer period and will be soon exhausted due to maximum removal of K (95.7%) at the end of tenth extraction. The value of step-K at different extractions indicated that this soil can maintain adequate K-supply at the initial stage which will be reduced subsequently after some cropping seasons.

Total extractable-K was lowest in the first layer of profile-1 indicating that the lowest K-supplying capacity of this soil. Removal of only 54.9% K at the end of this extraction indicated that this soil can supply K for a longer period. The value of step K at different extractions indicated that this soil can supply K adequately for some initial cropping seasons only. The low CR-K value of 4 mg kg^{-1} indicated that, although this soil can supply K for a longer period but it was too inadequate to sustain the plant growth. Hence application of potassium from external source will be required for a successful crop production.

SUMMARY AND CONCLUSION

A detail soil survey was taken up in the Nedisahi Nalla mini-watershed (ORM-3-8-5-1) to study the soil morphology and genesis of the tract and classify them as per Soil Taxonomy. Different forms of potassium and their release characteristics were also studied to know the correlation amongst them. Two adjacent villages namely Sidingi and Nedisahi were taken up for the present study comprising the total geographical area of 265.7 ha.

The study area is within the I.W.D.P. project of Phulbani and is situated in the district of Kandhamal. The general slope of the terrain was 8-15% and the slope of 3-5% within different physiographic units was observed. Five physiographic units namely; foot hills, upper ridges, mid upland, mid medium land and medium valley land were demarcated and one profile each from these physiographic units designated from P-1 to P-5 respectively, alongwith 4 to 5 composite surface samples were collected and studied. The first four physiographic units are under Sidingi village and the fifth one is under Nedisahi. The blacktopped metaled road from Bisipada to Khajuripada streches between P-2 and P-3 and one sub-canal of Pilasalki M.I.P. stretches between P-4 and P-5 interfering with normal run-off in the slopy terrain.

The area is situated in 20° 28'N latitude and 84° 21'E longitude and cames under sub-tropical monsoonic climate. The climate is hot and sub-humid with average annual rainfall of 1280 mm. The mean maximum and mean minimum temperatures are 37°C and 10.4°C respectively.

Morphological characteristics were studied in the field in November 1994. The laboratory estimations included mechanical composition, physical properties and chemical characteristics consisting of pH, organic carban, CEC, exchange composition, exchange acidity, free oxides, lime requrement, avilable N.P.K. Different forms of K like water soluble, exchangeable, non-exchangeable, lattice and total K, their release characteristics within the profiles and correlation amongst them were also studied.

1. Soil colour on the surface varied from reddish brown through reddish yellow to light reddish brown from upper ridges down the slope but the colour of the sub-surface horizons were mostly yellowish red.
2. The profiles were deep to very deep throughout the study area.
3. Surface texture of the foot hills was sandy which gradually changed to sandy clay loam and loam down the slope.

4. Within the profiles of Sidingi area the clay content increased down the depth with presence of thin patchy clay cutans in the sub-surface horizons forming argillic horizon. This was attributed to the eluviation of finner particles from the surface because of high rainfall and well drained conditon of the sub-stratum. But in the Nedisahi series which was situated in medium valley position, moderately well drained condition prevailed and removal of free oxides was restricted resulting in structural development, Fe, Mn concretionary formation and qualified for the presence of cambic horizon.

5. The soil pH values usually increased down the depth with some variations resulting in medium to slightly acid reaction. The surface soils were usually medium acid in reaction.

6. The organic carbon content was low (less than 0.5%) in all the horizones throughout all the profiles. The value generally decreased gradually down the depth in all the pedons.

7. The CEC values were low in all the profiles. In general, the CEC value increased down the depth and there was a positive correlation between CEC Vs clay content. This indicated that clay was mainly responsible for CEC of soil as the organic carbon content was very negligible. The exchange complex in all the profiles were dominated by Ca^{++} followed by Mg^{++}, K^{+} and Na^{+}.

8. The percentage base saturation of the soil increased down the profile and along the slope except very few deviation and was positively correlated with the pH values.

9. Free iron oxide in all the profiles of the study area was found to increase down the slope as well as down the depth showing a significant positive correlation with clay content (r=0.991**). The gradual increase of the free oxide content in the lateritic zones was attributed to the intermittent wet and dry season. In the Sidingi area, water table was very low and the eluviated free oxides leached downwards without enriching the sub-surface layers.

10. The available nutrient status was, in general, low in case of nitorgen and medium in case of phosphorous and potash.

11. From the study of different forms of K and their release characteristics, the following conclusion could be drawn:

a) Water soluble K decreased where as exchangeable, non- exchangeable, lattice and total K increased with increase in clay content from surface downward.

b) The highly positive relationship of exchangeable, non- exchangeable, lattice and total K with clay content revealed that these forms of K were mainly associated with the clay fractions in soil.

c) Water soluble K% decreased, exch. K% changed with a little variation, non-exch. K% and lattice K% changed irregularly from surface downward.

d) Exch., non-exch., lattice and total K were negatively correlated with water soluble K but positively correlated among themselves indicating that they were in a dynamic equilibrium with each other.

e) The amount of water soluble K in different layers varied from 6.5 to 20 mg/kg constituting 0.2 to 1.8% of total K. Exch. K content varied from 39.5 to 107 mg/kg forming 2.1 to 4 % of total-K, non-exch. K varied from 460 to 1130 mg/kg constituting 23.2 to 41%, lattice K varied from 580 to 2260 mg/kg constituting 52.8 to 73.3% of total K and total K varied between 1100 to 3500 mg/kg inside the profiles.

f) K release parameters like total extractable K, step K and CR-K increased along with the increase in clay content from surface down the profile. This indicated that k supplying capacity of the soil is mainly controlled by the clay fraction in soil.

g) The higher step K values in the initial extraction and the lower CR-K values indicated that these soils can supply K adequately in the initial cropping seasons but later on deficiency will arise and application of fertilizers will be needed.

h) The highly significant positive correlation of total extractable K, step K, and CR-K with non exchangeable K can serve a better index of the K supplying capacity in soil.

12. The soils of foot-hills, upper ridges, mid-up-land and mid-medium land (Sidingi series) under study were classified under *Haplustalfs*. The medium valley land of the study area (Nedisahi series) was classified *Ustochrepts* as per Soil Taxonomuy.

CONCLUSION :

The Nedisahi Nallah miniwatershed (area of investigation) has a number of problems which were the main barrier of the development. Out of them the following were the major problems :

a) Erosion in upland.

b) Erosion on hills.

c) Erosion on cultivable and uncultivable waste lands

d) Stream bank erosion etc.

To boostup the development of the watershed in an integrated manner, the watershed should be treated properly. Some suggestions are categorised below :

1) On-farm lands :

The on-farm lands include all available lands cultivated presently such as upland (high land), medium land and low land. These lands belong to cultivators. The conservation measures and other developmental programmes in these types of land will be as follows :

i) Planting of vetiver on contour.

ii) Replacing earthen bunds with vetiver plantation.

iii) Contour cultivation.

iv) Conservation farming.

v) Adoption of cropping system like;

a) For upland:

Short duration paddy/ragi/millets in *Kharif* and pulses/groundnut/vegetables in *Rabi*. In all the cases application of lime should not be avoided.

b) For low land :

Here the moisture storage capacity of the soil was more because of high clay content (48%) at a depth below 60 cm and high water table. So the above cropping programme with a slight modification should be followed i.e. medium duration paddy/ragi/ sugarcane in Kharif and oil seed/ pulses/ vegetables in *Rabi*.

2. Off-farm land :

Off farm land includes all non-available lands such as hills, pediment, village forest, reserve forest, culturable waste land, unculturable waste land etc. In these type of lands the following programmes may be taken up.

i) Plantation of timber species.

ii) Plantation of fodder, fuel and non-sal sps.

iii) Rehabilitation of degraded forest.

iv) Horticultural plantations.

3. Natural drainage line :

The following measures may be taken up for the development of natural drainage lines.

i) Diversion channel.

ii) Gully control measures.

iii) Runoff storage structure i.e. W.H.S.

iv) Stream bank erosion control.

Future research is needed on incubation studies of organic matter, Q/I study on Potassium, Phosphate fixation, sulphur status, clay mineralogy, sand mineralogy, quantification of different forms of ferruginous and aluminium compounds as a source of soil acidity.

This type of study may be extended to different similar topographic situations in order to evolve a uniform crop management programme for the complete watershed, which may ultimately lead to higher productivity potentialities of the areas under lateritic zones of Orissa in a sloping terrain.

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