I

PEDOTRANSLOCATION IN PLANOSOLS AND ITS MANAGEMENT IMPLICATIONS IN KINANGOP AREA, KENYA.

BY

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DECLARATION

THIS THESIS IS MY ORIGINAL WORK AND HAS NOT BEEN PRESENTED FOR A DEGREE IN ANY OTHER UNIVERSITY.

Sign ______________ Date 4th Sept. 1995

OSIYO J.O. RICHARD (Candidate).

THIS THESIS HAS BEEN SUBMITTED WITH MY APPROVAL AS THE UNVERSITY SUPERVISOR.

Sign ______________ Date 4th Sept. '95

PROF. J.P. MBUVI (University Supervisor).

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DEDICATION

This thesis is dedicated to my parents, Mr and Mrs Osiyo and to my brother, Cephas and Sisters, Eucabeth, Alice, Nora, Penny and Dorcas.

ABSTRACT

In this study transfer of clay and other soil constituents was evaluated using soil samples from Kitiri Scheme in the Kinangop plateau. The total area covered by the study which is based on pedotranslocation in Planosols of the area is about 100 hectares. The approach used was basically physical and chemical laboratory analyses. Parameters used include CEC, exchangeable base, bulk density, pH, water retention, particle size analysis, mineralogical composition and geochemical composition. Depth of the slowly permeable layer and related management constraint was noted in the field so as to provide a scientific basis for the rational use of the soils.

The area was divided into 3 transects based on position in slope before the Planosols were characterized. Samples were obtained from representative profiles of each transect and analyzed at the University's Soil Science laboratory ;Geology Department and Ministry of Natural Resources.

The parameters mentioned indicated the possibility of clay translocation in the soil sola of the entire area since there were significant differences in the values in adjacent horizons especially between Bt and E horizons. The silt/silt + clay ratios of adjacent horizons of the 3 transects especially between E and Bt horizons were significantly different indicating either clay accumulation or differences in parent material which would release clays at different rates resulting into the disparity observed. However, despite the textural breaks observed in the pedons studied, mineralogical tests provided evidence of parent material uniformity hence differences in ratios reflect

clay accumulation. Textural breaks observed in sand and silt fractions in E and B horizons is likely due to leaching of soil components which has resulted to the slowly permeable layer (Bt horizon).

The slowly permeable layer occurs at an average depth of 4: cm in the three transects. Imperfect drainage observed in the field is due to the compact Bt-horizon. The horizon allows shallow rooted crops to be grown but drainage conditions and low temperatures restrict crop choice to mainly potatoes and cabbages which are grown in relatively better drained sites. Otherwise much of the area is under grass for grazing, land use which is rational for the small scale farmers in the area.

CHAPTER ONE

1.0 INTRODUCTION

The selected study area is in Nyandarua District. The site is part of the Kinangop plateau and is bound by longitudes 36° 34' 27.5"E and 36° 33' 22.7"E and latitudes 0° 34' 9.5"S and 0° 33'4.2"S and is sandwitched between river Engare Kenja and Engineer-Ndunyu Njeru murram road. The area is about 5 km from Ndunyu-Njeru Southwards and is about 100 hectares.

The geology of the Kinangop plateau comprises rocks of volcanic origin, some of which date back to Miocene period. The site under study is covered by pyroclastic rocks and sediments of upper middle Pleistocene periods .

The study area is at an altitude range of 2500m in the North to 2680m in the South. It receives about 1064 mm (mean annual rainfall) and has a mean monthly temperature range of 12 to 15 °C. The area falls within rain shadow side of Aberdare mountains and its low temperature is associated with night frosts in most months. The frost arises due to cold wind which falls from the Aberdares during clear nights. Therefore growing of certain crops which are sensitive to frost especially maize, sunflower and potatoes may be risky if extended beyond warm months. Maize which requires at least 10 months to maturity cannot be easily adopted to the area. The rather low mean temperatures are also not conducive to growing of warmth requiring crops such as beans, sorghum, sweet potatoes, bananas, pawpaws and coffee. Crops that could be considered for the area include pyrethrum, potato, cabbage, kale, carrot, onion and wheat. (Nyandat, 1984, Rachilo, 1978).

Specifically, the study site is mainly used as grazing plots. Both dairy animals and sheep are kept. Crops (potatoes and cabbages) are mainly grown on relatively flat areas whereas grazing concentrates in relatively steeper sections of farms. Pennisetum schimperi is the dominant grass species. It tolerates waterlogging conditions.

The area is covered by Planosols (Nyandat, 1984 and Rachilo, 1978). These are soils marked by migration and accumulation processes, that is clay migration and accumulation. The morphology of these soils is characterized by a dark coloured surface horizon overlying an equally impoverished, light coloured, clay and iron poor horizon, which in turn overlies a horizon in which clay,oxides of iron and aluminium,soluble cations and humus have accumulated. The upper horizon(s) with relatively low clay content, abruptly overly a deeper horizon with considerably more clay. This may have been caused by translocation of clay and/or by overwash of coarse material onto a clay layer or by particular
soil forming process called ferrolysis (seasonal destruction and translocation of clay in alternating dry and wet seasons (FAO, 1991).

Planosols occur in water receiving sites on flat to gentle undulating terrain, with a natural climax vegetation of grasses or open forest.

planosols world wide cover about 130 million hectares with important concentration in Brazil (Rio Grandle do sul), northern Argentina, South Africa, Eastern Australia and Tasmania, (FAO, 1991).

The main problem encountered in these soils is hydromorphism. The hydromorphism is due to impoverishment of materials rich in fine clays (oxides of iron and alumina, organic matter etc) other than quartz, a process which leads to a loss of colour in the surface horizon and formation of an albic E horizon. Their very ephemeral surface water tables are formed which in certain circumstances favour redox processes in the residual iron (Duchaufour, 1982).

Pedotranslocation is defined as movement of materials during profile development. It is an essential observation in the genesis of moderately to strongly developed soils for in young soils clay movement cannot be quantified or qualified. Thus the process plays a role leading to formation of diagnostic features of profiles which are important in soil taxonomy (Mackeage and Arnand, 1968).

From recent studies (Jongerius, 1970, Roose, 1968 1970a, 1970b, Targulian, 1971), cited in Rutherford (1973),it is known that particles of any size can be translocated in suspension through the soil and can be deposited in the soil after being sorted or unsorted. Results of translocation can be seen both in the field as well as in a thin section as residuum in areas of dispersion (called also areas of accumulation). Evidence suggesting that lessivage, or clay translocation, occurs in many freely draining soils, originally came from micromorphological study of soil thin sections from B-horizon. These microscopic studies indicate that fine clay particles were deposited in layers or skins around soil particle surfaces and as coatings, (cutans) in voids. Coatings composed of fine translocated clay are called argillans. By studying the texture characteristics of whole profiles containing Bt horizons, one can deduce that clay is mobilized in A horizons, perhaps by weathering processes, transported downprofile and deposited in B horizons (Ross, 1989). Wang and McKeague (1982),cited in Ross (1989) reported sustained losses of clay and of mobile iron and aluminium (as measured by pyrophosphate extraction) from A/E horizons of a series of sandy podzol, with relative enrichment of all these components in B horizons. Thus argillic B horizons or Bt horizons are cited as evidence of both translocation and in some cases for illuviation.

Pedotranslocation, eluviation, illuviation in soils is generally conceived to lead to formation of E horizon, transition horizons as BE, E/B and B/E and to form Bt horizons with argillans which are usually best developed in lower B horizons or even upper C horizons, though exact mechanism of clay eluviation and illuviation are rather poorly understood (Fanning, 1989).

Studies of pedotranslocation has involved quantification of oxides of iron and aluminium in A E Bt and C horizons of a profile. Amount in B (illuvial horizon) exceed those of both overlying and underlying horizons especially in clay fraction. If deposition has not occurred on a site of uniform parent material, then the disparity in oxide contents can be attributed to downward translocation especially as iron-silicate clay complex or by chelating agents in organic matter rich soils (Rutherford, 1973).

Soil genesis studies involve analysis of parent material. Jenny (1941; In Fitzpatrick, 1986) defines parent material as "the initial state of the soil system". Quantitative mineral analysis techniques have been developed by various workers to determine weight gains and losses of both clay and nonclay (or primary) minerals within the profile; these techniques can be used to assess clay formation in place from a clay distribution due to translocation, but they can only be used for soils in which the parent material is uniform throughout the profile.

All changes within the soil are based on comparisons with unweathered parent material, which might be either rock or unconsolidated deposits at depth (Birkeland, 1974). Parent material generally establishes the outline of clay mineral distribution and pedogenic weathering produces some modification in kinds and amounts. Heterogeneous parent material leads to a variety of clay minerals (Holmes, 1965).

For firm conclusions to be drawn on quantitative changes in Soils profile, uniformity of horizons with regard to their parent material has to be demonstrated; second, an immobile constituent has to be chosen, then used as the basis for quantitative comparisons; third, the kinetic study of process needs to be undertaken (Marshall, 1977).

The objectives of this study include:-

1. To show that pedotranslocation occurs in Planosols of the study area through:
   (a) Physical and chemical laboratory analysis of Cation Exchange Capacity (CEC), bulk density, exchangeable bases, clay content, moisture retention in both eluvial and illuvial horizons
   (b) Mineralogical tests to establish uniformity of parent material so that material ratios can be explained by translocation and not parent material layering.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The net changes in clay content in various horizons of a profile include both translocation and formation. Although it is not very easy to differentiate translocated and sedentary clay, Barshads's procedure (Brewer,1964) of relating net loss of non clay to net gain in clay for the whole profile is useful. Clay movement together with translocation of other soil components lead to profile development (pedogenesis). Magnitude of their effect is governed by interaction of factors defining the initial state of soil formation (parent material, relief), the environment (climate, organisms) and the extent of reaction (time), (White, 1987). The main controls on the occurrence of clay migration are soil physical properties as tortuosity of the pore space and hence magnitude of saturated and unsaturated hydraulic conductivities. Soil environmental conditions of pH and Redox potential (Eh) determine the solubility and hence mobility of migrating species thus the two control lessivage too.

2.2 ELUVIATION

Eluviation refers to movement of materials out of a portion of a soil profile as in albic horizon. Such a movement leaves behind minerals which are more resistant to weathering processes (Buol et al. 1980). White (1987) used the term lessivage to describe the mechanical eluviation of clay particles from the A horizon without chemical alteration: but in the 1982 translation by T.R Paton the term pervection is substituted for lessivage.

The clay is washed progressively downwards in the percolating water to be deposited in oriented films (argillans)on ped faces and pore walls, gradually forming a horizon of clay accumulation (Bt).

Eluviation occurs when water is added to the soil so as to disrupt the fabric. The disturbed fabric ends up in a dispersed state where clay sized particles move freely in a suspension. The particles remain in isolation and can move downwards due to gravity through cracks or pores of capillary size. Dispersion and subsequent eluviation occur mainly in soils of dry and wet climates. Dispersion is at its maximum in soils which were initially dry, a fact which explains why dry spell is a necessity for eluviation to occur (USDA, 1975). Eluviation occurs because clay particles or colloidal particles disperse in aqueous media thus allowing free movement. Dispersion and suspension stability thus play important roles in clay migration in soils (Marshall, 1977). Differential peptization of fine clay is not the only important phenomenon in clay translocation but suspension stability also plays an important role in determining the extent to which clay moves. Rapid flocculation leads to deposition fast below A or E horizon. The longer the dispersed phase remains stable the greater the depth of illuvial horizon (Ermolenko, 1972). Verwey and Overbeck (1948) attributed suspension stability to several forces which include electrical repulsing forces, specific attraction forces (Van der waals forces), water molecules which continually collide with particles and gravitational force. Thus suspension stability can be viewed as a product of interaction between repulsive and attractive forces in a colloidal system. In Marshall, (1977), the Derjaguin , Landaw . Verwey and Overbeek theory advanced independently by Verwey and Overbeek (1948) has been used to quantitatively evaluate balance of repulsive and attractive forces when particles approach each other. According to the theory, energy of interaction is obtained by summation of the attraction and repulsive energies.

Lessivage, or clay translocation is unlikely to occur in calcareous soils or neutral soils that retain high proportion of exchangeable calcium ions because clay remains flocculated. Under acid conditions, if exchangeable aluminium ions and hydroxy-aluminium ions are predominant on clay surfaces, the clay should also remain flocculated. However, when iron and aluminium are complexed by soluble organic compounds ,they do not flocculate the clay which can then be transported (White, 1987).

Clay particles are charged on their surfaces. The charges arise from either isomorphous substitution or preferential adsorption of certain ions on their surfaces. They are mainly negatively charged. The charges lead to interparticle interaction observed in colloidal suspensions. The negative charges contribute to repulsive forces between particles which counteract Van der Waals attractive forces thus determine whether a system is dispersed or flocculated. The former phenomenon is a requirement for eluviation process (Van Olphen, 1963).

Dickson and Weed (1977) describes another source of charge which does contribute to eluviation. The charge develops on hydroxylated surfaces through amphoteric dissociation of surface hydroxyl groups or by adsorption of hydrogen ions or hydroxyl ions. Parks (1967), cited in Dickson and Weed (1977), shows that these reactions can be written as follows, where the underscored symbol refer to species forming part of the surface:

$\underline{M}OH = MO^- + H^+_{(aq)}$

$\underline{M}OH = \underline{M}^+ + OH^-_{(aq)}$

$\underline{M}^+H_2O = MOH_2^+{}_{aq}$

Soils dominated by colloidal particles which have pH dependent charge can only show signs of pedotranslocation if pH is within range of 5.5 to 8.5.

Greenland and Hayes, (1978) compares the phenomenon of clay dispersion to diffuse double layer (DDL) of Gouy and Chapman of 1910 and 1913 respectively. If an electrode is introduced into a clay suspension with minimal electrolyte content, there's a shift in colloidal particles movement towards or away from the electrode. Colloidal particles tend to move towards the anode with gradual decrease in colloidal concentration with distance from the anode. However, a cathode leads to a reverse of the above. In nature, colloidal systems behave as if a cathode has been introduced into the systems especially in low salt soils. Thus upon wetting after a dry spell, colloidal particles (0.2µm-5A°) became dispersed as much as possible allowing individual particle translocation (Antipov and Isyurupa 1961).

Dispersion of colloidal systems consist of creating a condition for maximum repulsion of colloidal particles; that is a low salt concentration in the pore water, monovalent exchangeable ions, high pH to prevent positive charges and high water content to increase interparticles distance.

The factors above determine the extent of dispersion.

2.2.1 Electrolyte Content: Soils high in electrolyte content have limited clay movement. The reason being that electrolytes favour flocculation of colloidal systems as they decrease forces of repulsion. The precipitated clay fraction seals soil pores which leads to restricted drainage in such soils (USDA, 1975, Ross, 1989 and Yong, 1975).

Concentration of specific cations influence extent of Diffuse Double Layer. Cations of lower valence have greater average distance from the clay surface since they have lower charge density than multivalent cations. Thus higher levels of multivalent cation limits clay migration hence pedotranslocation (Dickson and Weed 1977 and Yong, 1975).

2.2.2 pH: pH is defined as the negative logarithm of hydrogen

ion concentration (Black, 1965). Soil pH affects charge density of soil particles. High pH favours formation of positive charges which counteract repulsive forces as stated previously. pH below 4 favours liberation of aluminium which is dislodged from adsorption phase to exchange phase, where it hydrolyses and goes into solution. The trivalent ion has strong flocculating powers and also behaves as a weakly acid exchange as shown in the equation below (Bolt and Bruggenwert, 1976).

$$Al(H_2O)_6^{3+}{}_{(aq)} = Al(H_2O)_5OH^{2+}{}_{(aq)} + H^+{}_{(aq)}$$

Cation Exchange Capacity (CEC) is high within pH range of 5.5 and 8.5 in soils dominated by pH dependent charge. The high CEC is due to increased negative sites on colloidal surface which also leads to greater repulsion. Deprotonation is also very likely within such pH range causing further increase in charge density (Bolt and Bruggenwert 1976).

2.2.3 Yong (1975), shows that swelling of clays on wetting is attributed to water molecules forcing adjacent particles apart since water molecules are attracted to the particles. Presence of large water molecules favour interparticle interaction thus free particle movement in any direction.

2.3 ILLUVIATION

Illuviation refers to the movement of materials into a portion of soil profile as in argillic or spodic horizon (Greenland and Hayes, 1978). Such horizons have an accumulation of translocated materials. While biochemical processes play a major part in the accumulation of complexes, in contrast the movement of clay being mechanical its accumulation is controlled particularly by physical factors. The percolation experiments of Melnikova and Kovenya (19"1) in Greenland and Hayes (1978), showed that the speed of movement of clay particles mechanically translocated by water is proportional to, but clearly less than the speed of water flow: thus any decrease in the speed of water flow leads to a deposition of clay which is the basis for the formation of argillans.

Bartelli and Odell (1960) in Wilding et al. (1983) attributed the build up of clay in lower B horizon of profiles to discontinuity in moisture flow at the boundary between two contrasting parent materials. The flow of water is arrested at the boundary for long periods of time because of differential moisture tensions. Colloidal materials contained in suspension precipitates as the water is subjected to evaporation. Also, high calcium ion concentration in such horizons would enhance the precipitation of colloidal materials. Soil Taxonomy (USDA, 1975) shows that deposition of clay together with other translocated materials can be attributed to several phenomena operating in illuvial horizons. Deposition occurs when colloidal suspension flocculates due to moisture withdrawal into soil matrix thus leaving suspended clay and its constituents to plaster on voids.

Coagulation which leads to deposition on walls of non capillary voids can be due to increased electrolyte concentration in the illuvial horizon (Antipov, et al., 1961 and USDA, 1975). With respect to clay, illuvial horizons have higher ratio of fine clay to total clay than overlying or underlying horizons. This has been taken to be an evidence of clay translocation (USDA, 1975, and Birkeland, 1974).

In certain cases, accumulation of clay in the Bt horizon fills up the pores of horizon. This leads to reduced permeability of the horizon which then develops signs of waterlogging, such as the segregation of iron in better aerated zones as rusty patches or concretions (hydromorphic argillic horizons, often symbolized as (Btg). Lateral loss of fine clay is common once Btg horizons are choked with clay (Duchaufour, 1982).

2.4 MINERALOGY

Knowledge of clay minerals is necessary in understanding the structure of soils and nutrients exchanged or extracted from them (Moore and Reynolds , 1989). Cox et al. (1967) indicates that mineral analysis of sand and silt fraction is also important in the determination of homogeneity of parent material and its identification in the laboratory. Within a specific sand or silt fraction , minerals that are relatively resistant to weathering should show an increase in abundance from parent material to the surface, whereas more weatherable minerals should show a relative decrease from parent material to the surface. The trends indicate homogeneity of parent material. Brewer (1964) shows that ratio of a resistant to a nonresistant mineral in horizons of a profile indicate homogeneity of parent material if the ratio decreases down the profile.

Soils contain silicate clay minerals but the use of estimations of clay minerals for studies of uniformity of parent material throughout the soil profiles is complicated because new clay minerals species can be formed during sedimentation and by weathering during soil formation besides inheritance from parent material. Hence more reliable tests are based on size fractions greater than 2 microns (Brewer , 1964).

In illuviation process,the breakdown of primary weatherable minerals and their translocation leaves a residue high in silt and sand particles. An increase relative to the underlying horizon in amounts of stable minerals such as tourmaline, Zircon and rutile in the sand fraction and an increase of quartz in the silt fraction and increase in Kaolinite in the clay fraction may be taken as evidence of eluviation (Hallsworth , 1965).

2:1 clay minerals have higher charge density than 1:1 minerals. Since the charge density determine strength of bond formed between cations adsorbed on adjacent particles, it does also influence the Van der Walls forces in clay suspension.

2:1 clays thus have a stronger bonding which leads a stable flocculated system when positive cation are attracted to the clay surface. Such flocculated clays do not migrate. 1:1 clays with less bonding strength remain dispersed hence migrate (Hallsworth , 1965). Duchaufour (1982) however shows that resistance to clay movement by water varies according to the type of clay minerals and amount of negative charge: Montmorillonites are most easily transported.They are practically the only ones that migrate in slightly acid conditions ,together with iron that cover them like a skin.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 FIELDWORK AND SAMPLING

The study area , which was just over 100 hectares, was first divided into three transects based on position in the slope. Transect A ran along the lower part of the slope (lower slope) and had profile numbers 2,4,7 and 12. The profile pits were adjacent to river Engare Kenja. Transect B ran along middle slope and comprised profile numbers 1,6,11 and 14. Transact C covered the crest of the area study area and profiles 3,5,8, 9, 13 and 15 were made along it. The location of the profile pits is shown in Fig. 1

In each transect, representative profiles were selected for detailed analysis. The selected profiles had similar macro and micro relief hence those selected in each transect are replicates. The profiles selected in each transect are as follows:

Transect A - 2, 4, and 7

Transect B - 1 and 11

Transect C - 3, 5, 8 and 15

Rachilo (1978) shows that the Kinangop plateau is mainly covered by Planosols. The present work involved the identification of units of Planosols found in the area together with features and characteristics indicative of pedotranslocation process.

All disturbed samples were taken from the profile pits. The transect sampling carried out ran perpendicular to drainage way. Samples of about 2kg were taken starting with the lower horizon to avoid contamination. Each sample was taken midway between each of the horizon boundaries to reduce bias towards either of the adjoining horizons. The samples were put in polythene bags and labelled both inside and outside. Rock samples were also collected for analysis.

Core samples were also taken for determination of bulk density and water holding characteristics.

3.2 LABORATORY ANALYSIS

Pre-treatment: All samples (disturbed samples) were air dried then ground to pass through a 2mm sieve prior to laboratory analysis. Except for total nitrogen and organic carbon, all other samples used were of a particle size less than 2mm.

CEC and exchangeable bases: For this determination 2.5grams of air dried 2mm soil samples were leached using 100 ml of ammonium acetate (1N NH_4OAC, 25 ml at a time at pH 7.0). The leachates, collected in 100 ml volumetric flasks were used for determination of exchangeable bases: sodium, calcium, magnesium and potassium. Calcium and magnesium were determined through titration using EDTA (Ethylenediamine-tetraacetic acid) Potassium and sodium were determined using flame photometer (Black, 1965).

The leached samples were then washed with ethyl alcohol to wash off ammoniated organic constituents from them. After alcohol washing, samples were leached with 1N potassium chloride at pH 2.5 to recover adsorbed ammonium ions which was determined by distillation. Amount of ammonia recovered was used to calculate CEC.

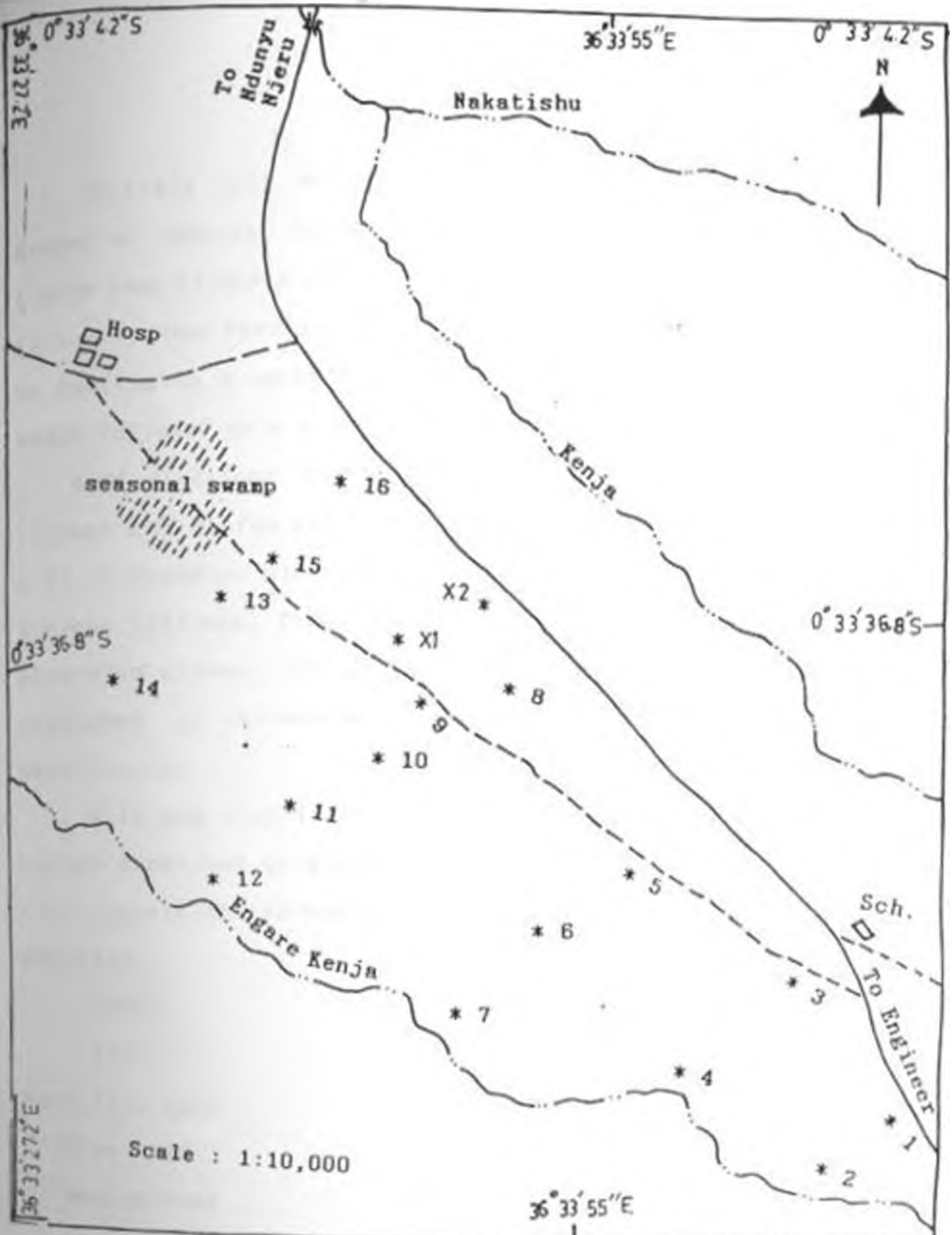
Total Nitrogen (Kjedahl procedure): 0.5 grams of samples <0.5 mm were weighed then digested using concentrated sulphuric acid and selenium mixture to convert nitrogen into ammonium - nitrogen. The ammonium-nitrogen was then steam distilled using aliquots of the 250 ml digestion product (digest) and trapped in an accurately measured boric acid from where it was titrated using dilute sulphuric acid. Calculation procedure is obtained in Klute(1982).

Organic Carbon: Walkley - Black method. 0.5 grams of <0.5 mm samples were oxidized using mixture of concentrated sulphuric acid and 1N potassium dichromate. Excess dichromate was then back titrated using standard ferrous sulphate (0.51N). The percentage organic carbon was calculated as follows:

% organic Carbon = $(m.e.K_2Cr_2O_7 - m.e.FeSO_4)\ 0.3f\ /$g. of water free soil.

where f = Correction factor (1.33). m.e: milliequivalents which is given by ml x normality of the solution used.

Fig 1: LOCATION OF PROFILE PITS



KEY

Hosp ------ hospital
Sch ------- school
------ loose surface road
----- main track
----- minor track
----- River
* 8 ----- profile pit

Base map derived from Topographical map No. 134/1

Particle size analysis (pipette method): A portion (10 grams) of <2mm air dried sample was weighed in 500 ml conical flasks then aliquots of 10 ml of 30% hydrogen peroxide were added till no further reaction occurred. Excess peroxide was evaporated by heating on a sanbath. Sodium hexametaphosphate (20 ml) was added followed by a 6-hour reciprocating shaking.

Sand fraction: The suspension, after shaking was poured through a 63 micron sieve into a 1 litre sedimentation cylinder. A 20 cm diameter sieve was put on a funnel held by a stand to prevent spillage. Trapped sand was then collected in weighed aluminium dishes, put in the oven at 105°C for 12 hours then reweighed to calculate weight of sand in each sample by substraction.

Silt and clay fractions were determined according to the method described in Klute, (1986). The USDA system of particle size classification was used as shown below:

Particle	diameter in mm
Clay	< 0.002
Silt	0.002 - 0.05
Very fine sand	0.05 - 0.1
Fine Sand	0.1 - 0.25
Medium Sand	0.25 - 0.5
Coarse Sand	0.5 - 1.0
Very coarse sand	1.0 - 2.0

source: Birkeland, (1984).

Sand mineralogy: Sand fraction obtained as described above was cleaned with 2N HCl and boiled with 30% H_2O_2. The sand fractions were mounted on glass slide (1" x 3") with Canada balsam and covered with a cover glass (1" x 2"). The mineralogical identification was done with a standard petrographic microscope.

Water holding characteristics was determined following the method in Klute ,(1982).

Bulk density determination involved oven drying core samples at 105°C for 12 hours followed by weighing of the samples.

ρ_b = (dry weight of samples / volume of core samples

where ρ_b is the bulk density (g/cc). Volume of samoles was obtained by calculating volume of core ring.

Differences in cation Exchange capacity ,bulk density,total bases ,and clay content in top and Bt horizons and in E and B. horizons were tested statistically using a t-test at both 5 and 10 percent levels.

CHAPTER FOUR

4.0 RESULTS

4.1 SOILS OF TRANSECT A:

4.1.1 Soils General:

Transect A which formed lower slope of the study area has soils with A E Bt horizons. The profiles are typical of planosols. A-horizons are generally poor in bases, silty loam to silty clay loam in texture and of subangular blocky structure. The E horizon of these soils is base poor and has a gravelly silty clay loam to silty clay texture. The Bt-horizons are clayey and base rich (more than 30% clay and above 50% base saturation) (Tables 1 2 and 3). The soils are deep to very deep but imperfectly drained. The transect is underlain by pyroclastic rocks (tuff) and the vegetation type is grassland.

4.1.2 Profile P_4

Parent material: Tuffs, which are indurated pyroclastic rocks of grain generally finer than 4mm that is, they represent the consolidated equivalent of volcanic ashes.

Meso and macro relief: Around the soil profile , there are cumbered beds and termite mounds. The site is gently undulating with slopes ranging from 3 to 4%.

Vegetation and land Use: Grassland/grazing:

Colour: The top horizon (A horizon) is of brown/dark brown (10YR 4/3, moist) whereas the E-horizon has relatively lighter colour, (10YR 5/3, moist) brown. The Bt horizon has brown/dark brown colour (10 YR 4/3, moist).

Texture: Top horizon has silty clay loam texture, gravelly silty clay loam for the albic E and clay for the Bt horizon.

Silt: clay ratios are 1.9, 1.0 and 0.1 for 'top horizon, E and Bt horizons respectively.

Structure:The top horizon has medium to course weak subangular blocky structure while Bt-horizon has fine strong subangular blocky structure.

Consistence: Friable when moist and slightly sticky when wet in top horizon. Bt-horizon has a friable to firm consistence when moist but plastic and sticky consistence when wet.

Chemical properties: Organic carbon ranges from 4.6% in top horizon to 0.7% in the subsoil, pH-H_2O is 5.7 in top horizon but increases down the profile to 6.3 in Bt horizon. Cation Exchange Capacity increases down the profiles. Top horizon has CEC of 22 cmol/kg but Bt has 48 cmol/kg: Percent base saturation of top horizon is 21 but that of E horizon is 73%. Bt horizon has 66%.

Calcium is the dominant cation with quantities ranging from 2.2. cmolkg^{-1} in top horizon to 25.4 cmol/kg in Bt horizon. Magnesium follows calcium in quantity, ranging from 1.8 cmol/kg in top horizon to 2.2 cmol/kg in the Bt horizon. Potassium and Sodium found in top horizons are 0.4 and 0.3 cmol/kg respectively while sub soil has 2.1 and 1.7 cmol/kg respectively.

4.1.3 Profile P_7

Parent material: Tuffs, indurated pyroclastic rocks.

Macro and meso relief: Flat to gently undulating with slopes ranging from 3 to 4%: Cumbered beds and termite mounds around profile location.

Vegetation and land use: Grassland/grazing:

Colour: The top horizon is greyish brown (10YR 5/2, moist) while the subsoil is light brownish grey (10 YR 6/2, moist) to dark yellowish brown (10 YR 3/4, moist).

Texture: The top horizon has silty loam texture. E horizon has gravelly silty clay texture but B has a clay texture.

Structure: Medium, moderate subangular blocky structure in the top horizon. Bt_1 has strong angular blocky structure.

Consistence: Friable when moist and slightly sticky and plastic when wet in the top horizon. Bt horizon has a plastic and sticky consistence when wet but friable when moist.

Chemical properties: Percent organic carbon is 3 in the top horizon, 2.4% and 0.3% in AE and Bt_1 horizons respectively. pH-H_2O increases down the profile, 5.5 at the top and 6.9 in the Bt_1 horizon. Bt_1 and Bt_2 horizons have CEC of 37 . cmol/kg and 23 cmol/kg respectively. The top horizon has CEC of 9 cmol/kg. Percent base saturation increases down the profile. The topsoil has 57% while Bt_2 has 88% with AE horizon having 83 percent.

Calcium is the dominant cation in the entire profile. The top horizon has 3.6 cmol/kg while Bt_1 and Bt_1 horizons have 24 and 16.4 cmol/kg respectively.

Magnesium is highest in AE horizon, 3.4 cmol/kg. Bt_1 and Bt_2 horizons have 1.8 cmol/kg and 2.0 cmol/kg respectively but top horizon has 0.8 cmol/kg. Both potassium and sodium quantities increases down the profile but potassium is higher in quantity. The top horizon has 0.5 cmol/kg of potassium but 0.5 cmol/kg of sodium while the subsoil has 2 cmol/kg and 0.7 cmol/kg of potassium and sodium respectively.

4.1.4 Profile P_2

Parent material: Tuffs, indurated pyroclastic rocks.

Macro and meso relief: Flat to gently undulating with a slope range of 1-2%. Cumbered beds and termite mounds.

Vegetation and land use: grassland/grazing:

Colour: The top horizon is dark brown (10 YR 3/3, moist) while the subsoil is black (10 YR 2/1, moist).

Texture: The texture ranges from silty loam at the top to clay at the lower horizon (Bt horizon). The E horizon has gravelly silty clay texture.

Structure: Fine subangular blocky structure at the top horizon and strong fine to medium subangular blocky structure in Bt horizon.

Consistence: Top horizon is friable when moist but slightly sticky and plastic when wet. However, the Bt horizon is firm when moist but sticky and plastic when wet.

Chemical properties: Organic carbon percent is 4.7 % in the top horizon, but declines to 0.8% in the subsoil. The topsoil has a pH-H_2O of 5.7 whereas that of the subsoil is 6.4. Cation Exchange Capacity increase down profile: top horizon has 27 cmol/kg but Bt horizon has 30 cmol/kg. The E horizon has 10.0cmol/kg.

The base saturation of the Bt horizon is 69% while that of the top horizon is 25%. Calcium is the most abundant base followed by magnesium. Their quantities increase with depth from 4.2 to 16.2 cmol/kg and 1.2 to 2.2 cmol/kg for calcium and magnesium respectively. Potassium and sodium occur in small quantities although they show the same trend as calcium and magnesium.

Table 1. Physical data and weathering indices for 3 selected pedons of transect A

Depth centimetres	Particle size distribution (diameter of particles) 0.05-2mm	0.002-0.05	Less than 0.002mm	Bulk density g/cc	$\frac{Silt}{Silt+clay}$	$\frac{Silt}{clay}$	$\frac{sand}{silt}$	Textural class
	Percent	Percent	Percent					
PEDON 2:								
0-17 A	2	83	15	0.8	0.9	5.5	0.02	Sil
30-43 Bt1	4	56	40	1.4	0.6	1.4	0.07	SiC
71-102 Bt2	3	37	60	1.3	0.4	0.6	0.08	C
PEDON 4:								
0-15 A	13	57	30	1.1	0.7	1.9	0.2	SiCl
15-24 Eg	19	41	40	1.3	0.5	1.0	0.5	SiCl
24-40 BEcs	20	40	40	1.3	0.5	1.0	0.5	Cl
40-75 Bt	9	11	80	1.4	0.12	0.1	0.8	C
PEDON 7:								
0-20 Ag	20	70	10	1.2	0.8	7.0	0.3	Sil
20-27 AEg	19	41	40	1.3	0.5	1.0	0.5	SiC
34-68 Bt1cs	7	13	80	1.2	0.1	0.1	0.5	C
68-94 Bt2cs	9	21	70	1.2	0.2	0.3	0.4	C

TABLE 2: CHEMICAL DATA FOR 3 SELECTED PEDONS OF TRANSECT A

DEPTH IN CM	PH H_2O	CARBON %	NITROGEN %	C/N	EXCHANGEABLE BASES (CMOl/KG) Ca	Mg	K	Na	CEC (CMOl/KG)	%BS
PEDON 2										
A 0-17	5.7	4.7	0.2	23	4 2	1 2	1 0	0 6	27	25
Bt_1 30-34	5.9	2.9	0.2	15	3 2	2 4	0 6	0 6	10	66
Bt_2 71-102	6.4	0.8	0.1	8	16 2	2 2	1 9	0 8	30	69
PEDON 4										
A 0-15	5.7	4.6	0.2	23	2.2	1.8	0 4	0 3	22	21
Eg 15-24	5.7	1.8	0.3	6	3 2	2.4	0 6	0 5	10	73
BEcs 24-40	5.8	2.7	0.2	9	6 0	3 0	1 0	0.5	27	39
Bt 40-75	6.3	0.7	0.2	4	25 4	2 2	2 1	1.7	48	66
PEDON 7										
Ag 0-20	5.5	3.0	0 3	10	3 6	0 8	0.[illegible]	0.5	9.0	57
AEg 20-27	5.5	2.4	0 3	8	7 8	3 4	0.6	0.4	14	83
Bt_1ca 34-68	6.5	0.8	0.1	8	24	1 8	1.8	1.0	37	77
Bt_2ca 68-94	6.9	0.3	0.1	3	16 4	2 0	2.0	0 7	23	88

TABLE 3: WEATHERING INDICES FOR 3 SELECTED PEDONS OF TRASECT A

DEPTH IN CM	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O	Ca/Mg	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
			MINERALOGY - PER CENTAGES						
PEDON 2									
A-0-17	61.8	4	11.2	0 38	0 27	2.33	2.04	3.5	4.0
Bt_1 30-43	68.9	4.4	12.0	0.40	0 26	2.62	2.34	1.3	4.7
Bt_2 71-102	55.9	8.8	18.7	0.6	0 46	1.73	1.25	7.4	2.0
PEDON 4 A 0-15	55.3	5.2	11 2	0.55	0 23	2 68	2.54	1.2	3.1
Eg 15-24	•	•	•	•	•	•	•	•	
BEcs 24-40	41.7	25.3	14 4	0.35	0.29	2 06	1 80	2.0	1.1
Bt 40-75	45.0	14.7	28.6	0.55	0.53	1 72	0.97	11.5	1.0

4.2.0 SOILS OF TRANSECT B:

Transect B formed the middle slope of the study area. Profiles 1 and 11 were among those opened in the transect. The soils have the A, E, Bt, horizons, also typical of Planosols. Bt horizons are rich in bases, clay in texture and have an angular blocky structure. The soils are imperfectly drained and moderately deep to deep. The transect is underlain by pyroclastic rocks. The transect is covered by grass.

4.2.1 Profile P_1

Parent material: Tuffs. The parent material is similar to that of transect A. The welded tuffs are composed mainly of feldspar minerals and iron ores, haematite and magnetite, but only a small quantity of quartz.

Meso and macro relief: Very gently undulating with a slope range of 1-2%. Cumbered beds and termite mounds are also present.

Vegetation and land use/grazing and grassland

Colour: Very dark greyish brown (10 YR 3/2, moist) top horizon dark greyish brown (10 4/2, moist), AE horizon and very dark brown (10 YR 5/2, moist) Bt, horizon.

Texture: Texture changes from silty loam through silty clay loam to clay from the topsoil to the subsoil.

Structure: The top horizon has fine to medium subangular blocky structure. The transition has medium to coarse, moderate subangular blocky structure but the Bt horizon has a strong coarse angular blocky structure.

Consistence: Bt horizons are friable when moist and sticky and plastic when wet. Top horizon has a slightly sticky and slightly plastic wet consistence but friable moist consistence.

Chemical properties: Organic carbon ranges from 3.2% at the top soil to 0.2% in the subsoil.

pH_{H_2O} is 5.7 in the top horizon but slightly higher, 6.7 in the Bt_1 horizon. Cation exchange capacity increase down the profile. Horizon A has a CEC of 9.8 cmol/kg whereas that of Bt_1 is 28.6 cmol/kg. The per cent base saturation follows a similar trend with the top horizon having 41% while that of the subsoil is over 50%. Soluble bases tend to concentrate in Bt horizons. Calcium is the dominant cation followed by magnesium . Sodium and potassium are present but in small quantities. Calcium content in top soil is 2 cmol/kg but very high, 24.2 cmol/kg in Bt_1 horizon. The quantity of magnesium in Bt_1 is 3.2 cmol/kg but much less, 1.2 cmol/kg, in top horizon

4.2.2 Profile P_{11}

Parent material: Tuff.

Meso and macro relief: Cumbered beds and termite mounds: The site is gently undulating.

Vegetation and land use: grassland/grazing:

Colour: Brown/dark brown (10 YR 4//3, moist) at the top horizon. Bt horizon has very dark greyish brown (10 YR 3/2, moist).

Texture: Texture ranges from silty loam at the top horizon through gravelly loam texture to clay in E and Bt horizons respectively.

Structure: The top horizon has subangular blocky structure but Bt horizon has angular blocky structure.

Consistence: The top horizon is friable when moist but slightly sticky and plastic when wet. However Bt horizon is friable when moist but sticky and very plastic when wet.

Chemical properties: The top horizon has 2.5% carbon content, whereas Bt has 0.4%. pH_{H_2O} does increase down the profile, being 5.9 at the top but 6.2 in Bt horizon. Cation Exchange Capacity of top horizon is 9.8 cmol/kg whereas that of the Bt_1 is 33.6 cmol/kg. Base saturation is 99% in Bt but only 63% at the top horizon. Calcium is dominant cation followed by magnesium. Potassium and sodium are less than 1.0 cmol/kg in both top and E horizons except in Bt horizon where the quantities are is 1.6 and 1.0 respectively.

Table 4 Physical data and weathering indices for 2 selected pedons of transect B.

Depth centimetres	Particle size distribution (diameter of particles)			Bulk density g/cc	$\frac{Silt}{Silt+clay}$	$\frac{Silt}{clay}$	$\frac{sand}{silt}$	Textural class
	0.05-2mm	0.002-0.05	Less than 0.002mm					
	Percent	Percent	Percent					
PEDON I:								
0-25 A	13	57	30	1.1	0.7	1.9	0.2	SiCl
25-38 AEg	16	59	25	1.3	0.7	2.4	0.2	SiCl
50-85 Bt1cs	7	38	55	1.4	0.4	0.7	0.2	C
85-101 Bt2cs	29	16	55	1.3	0.2	0.3	1.8	C
PEDON II:								
0-17 Ag	20	60	20	0.9	0.8	3.0	0.3	Sil
17-35 Ecsg	46	44	10	1.4	0.8	4.4	1.1	L
35-63 Btcs	31	9	60	1.4	0.13	0.2	3.4	C

TABLE 5: CHEMICAL DATA FOR TWO SELECTED PEDONS OF TRANSECT B

DEPTH IN CM	PH H_2O	CARBON %	NITROGEN %	C/N	EXCHANGEABLE BASES (CMOl/KG) Ca	Mg	K	Na	CEC (CMOl/KG)	%BS
PEDON I										
A 0-25	5.7	3.2	0.3	10	2.0	1.2	0.6	0.2	9.8	41
AEg 25-38	5.7	1.9	0.3	6	4.4	3.8	0.5	0.2	10	89
Bt_1ca 50-55	6.4	0.4	0.1	4	26.4	3.2	2.0	1.4	33	100
Bt_2Ca 85-101	6.7	0.2	0.1	2	24.2	0.4	1.8	1.0	26.6	96
P										
PEDON II										
Ag 0-17	5.9	2.5	0.2	11.2	3.6	1.6	0.6	0.3	9.8	63
Ecag 17-35	6.0	1.4	0.18	8	6.6	0.8	0.8	0.3	12.8	66
Btca 35-63	6.2	0.4	0.2	2	28.4	2.6	1.6	1.0	33.6	99

TABLE 6: WEATHERING INDICES FOR 2 SELECTED PED

	S_1O_2	Fe_2O_3	AL_2O_3	CaO
PEDON I				
A 0-25	72.1	2.46	11.7	0 43
AE_g 25-38	•	•	•	•
Bt_1 cs 50-85	56.0	12.9	13.2	0.37
Bt_2cs 85-105	45.9	10.6	18.7	0 63
PEDON II				
Ag 0-17	63.2	5.84	12.1	0.4
Ecsg 17-35	47.4	16.90	11.6	0.44
Btcs 35-63	34.9	22.5	11.1	0.55

ONS OF TRANSECT B

MgO	K_2O	Na_2O	Ca/Mg	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$
0.24	3.25	3.05	2	5.1
*	*	*	*	*
0.27	2.96	2.78	8	2.1
0.65	1.67	1.14	60	1.6
0.22	2.99	2.76	2.3	3.5
0.24	2.41	2.27	8.0	1.6
0.33	1.67	1.40	11.0	1.0

4.3.0 SOILS OF TRANSECT C:

Transect C is the summit of the entire area taken for study. Soils have A E Bt horizons and are covered by grass though profile 5 was opened at a cultivated site. Top horizons are either silty loam or silty clay loam while B- horizon of the profiles are all clay. The B horizon which is also base rich, has higher PH_{H_2O} than overlying horizons. Table 7 8&9 Volcanic rocks present are mainly the pyroclastic rocks (tuff) which is the parent material. The soils are imperfectly drained.

4.3.1 Profile P_3

Parent material: Tuffs

Meso and macro relief: Flat to gently undulating with a slope range of 1-2%.

Vegetation and land use: grassland and grazing

Colour: The top horizon is dark brown (10 YR 3/3, moist). The transition, AE- horizon is dark greyish brown (10 YR 4/2 moist) while Bt_1 horizon is very dark brown (10 YR 2/2, moist).

Texture: Top horizon has a silty loam texture while the transition has a gravelly silty loam. B-horizon is clay.

Structure: Top horizon has medium, moderate subangular blocky structure whereas the B-horizons have angular blocky structures.

Consistence: Friable when moist but sticky and plastic when wet. The B-horizon has friable moist consistence but very sticky and very plastic wet consistence.

Chemical properties: Organic carbon ranges from, 4.6% at the top soil to 0.3% in the subsoil.

pH_{H_2O} of top horizon is 5.7 but increases to 6.5 in the B horizon. CEC increases down the profile. The top horizon has CEC of 11.8 cmol/kg but the B-horizon has a CEC ranging from 39.8 to 40.8 cmol/kg. The percent base saturation follows a similar trend. The top horizon has 46% whereas Bt_1 and Bt_2 have 82% and 75% respectively. Calcium is the dominant cation followed by magnesium. The top horizon has 3.2 $cmolkg^{-1}$ of calcium but 0.8 cmol/kg of magnesium. The B horizons have between 24 and 28 $cmolkg^{-1}$ of calcium but 1.8 and 2.8 cmol/kg of magnesium. Potassium and sodium are also present but in smaller quantities although their quantities reflect deposition in the B horizons.

4.3.2 Profile P_{15}

Parent material: Tuffs, indurated pyroclastic rocks.

Macro and meso relief: Gently undulating, cumbered beds and termite mounds are present.

Vegetation and land use: grassland/grazing:

Colour: Dark greyish brown (10 YR 4/2, moist) at the top while the E horizon has a lighter colour, grey (10 YR 5/1, moist). The B-horizons have colour ranging from very dark greyish brown (10 YR 3/3, moist) to dark brown (10 YR 3/3, moist).

Texture: Texture changes from silty loam through gravelly silty loam to clay from the top through the E-horizon to the B-horizons.

Consistence: Friable when moist but slightly sticky and slightly plastic when wet for the top horizon. The B-horizon has a very friable consistence when most but is sticky and plastic when wet.

chemical Properties: The top horizon has between 3.7% to 2.2% carbon but the subsoil has a range of 0.2% to 0.3%. pH_{H_2O} rises down the profile with the subsoil having a pH ranging from 6.7 to 6.9 while that of the topsoil is 5.4. The CEC of the top horizon is 15 cmol/kg while that of the E-horizon is 12 cmol/kg. The B-horizons have higher CEC, 33 cmol/kg and 32 cmol/kg for Bt_1 and Bt_2 respectively. The higher CEC values reflect the higher clay content in the horizons. The base saturation increases with depth. The top horizon has a base saturation of 42%, E horizon has 22% but Bt_2 has 76%. Calcium is the dominant cation in all the horizons, ranging from 5 cmol/kg at the top to 22 cmol/kg in Bt_2 horizon. Magnesium is second in abundance, followed by potassium. Sodium is negligible.

Table 7. Physical data and weathering indices for 2 selected pedons of transect C.

Depth centimetres	Particle size distribution (diameter of particles) 0.05-2mm	0.002-0.05	Less than 0.002mm	Bulk density g/cc	$\frac{Silt}{Silt+clay}$	$\frac{Silt}{clay}$	$\frac{sand}{silt}$	Textural class
	Percent	Percent	Percent					
PEDON 3:								
0-20 Ag	10	79	11	1.2	0.9	7.2	0.13	Sil
20-39 AEcs	30	60	10	1.5	0.9	6.0	0.5	Sil
39-64 Bt1	5	35	60	1.4	0.4	0.6	0.14	C
64-82 Bt2	9	51	40	1.3	0.6	1.3	0.2	SiCl
PEDON 15								
0-10 Ag	29	46	25	1.1	0.6	1.8	0.6	Sil
10-25 Ecsg	37	48	15	1.4	0.8	3.2	0.7	Sil
25-57 Bt1cs	10	10	80	1.3	0.1	0.1	1.0	C
57-74 Bt2cs	8	52	40	1.3	0.6	1.3	0.2	SiC
74-110 Bt3	10	50	40	1.2	0.6	1.3	0.2	Sil

TABLE 8 CHEMICAL DATA FOR 2 SELECTED PEDONS OF TRANSECT C

	DEPTH IN (cm)	pH_{H_2O}	CARBON %	NITROGEN %	C/N	EXCHANGEABLE bases (Cmol/kg) Ca	Mg	K	Na	CEC (Cmol/KG)
	Peden 3									
Ag	0 - 20	5.7	4.6	0.2	23	3.2	0.8	1.2	0.2	11.8
AEcs	20 - 39	5.8	1.6	0.1	16	2.4	1.0	1.0	0.5	20.8
Btcs	39 - 64	6.0	1.0	0.1	10	28	1.8	1.7	1.0	39.8
Bt2cs	64 - 82	6.5	0.3	0.03	10	24	2.8	2.4	1.4	40.8
	Peden 15									
Ag	0 - 10	5.4	3.7	0.2	19	5	0.6	0.6	0.2	15
Ecsg	10 - 25	5.7	2.2	0.2	11	1.4	0.6	0.6	0.2	12
Btcs	25 - 57	6.0	0.7	0.1	7	18	3.0	1.8	1.0	31
Bt2cs	57 - 74	6.7	0.3	0.1	3	20	2.0	1.6	1.0	32
Bt3	74 - 110	6.9	0.2	0.1	2	22	4.0	1.8	1.0	33

TABLE 9 WEATHERING INDICES FOR 2 SELECTED PEDONS OF TRANSECT C

	DEPTH IN (cm)	MINERALOGY S_1O_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	Ca/mg	$\frac{S_1O_2}{Al_2O_3+Fe_2O_3}$
	PEDON 3									
Ag	0 - 20	59.4	4.3	10.8	0.50	0.43	2.49	2.01	4	3.9
Ecs	20 - 39	76.50	3.8	12.7	0.45	0.24	3.29	3.48	2.4	4.6
Btcs	39. - 64	52.20	12.30	21.0	0.87	0.69	1.12	1.81	1.5	1.5
Bt2cs	64 - 82	*	*	*	*	*	*	*	*	*
	PEDON 15									
Ag	0 - 10	57.0	9.6	12.1	0.5	0.24	2.85	2.88	8	2.6
Ecs	10 - 25	55.3	13.5	13.0	0.43	0.25	2.82	2.89	2	2.0
Btcs	25 - 57	58.0	11.5	12.9	0.89	0.78	1.59	2.13	6	1.8

Table [10] Water release data and bulk densities of horizons of representative Pedons of 2 transects:

		Transect A			Transect B		
		Horizons			Horizons		
	Bars	A	E	Bt	A	E	Bt
Water release %	0.3	76.0	59.2	51.8	66.4	51.7	50.4
	0.6	65.2	60.5	51.0	66.3	51.3	47.4
	0.9	62.9	59.1	49.9	64.7	51.0	46.9
Bulk density		0.9	1.2	1.5	0.9	1.4	1.4

CHAPTER FIVE

5.0 DISCUSSION

5.1 Soil classification and development:

Soils in the study area were classified according to the FAO/UNESCO (1991) 'Revised legend of the soil map of the world'. The FAO/UNESCO classification is based on mainly measurable and observable characteristics which result largely from soil formation. The pedons have albic E horizon, overlying an impermeable layer (compacted B horizon) within 125 cm from the surface. There is abrupt textural change from E or AE to the impermeable layer. The base saturation in the entire Bt horizon is above 50%. Hence the soils are classified as Eutric Planosols.

Soil development

Many processes act together to form any one soil profile. It is difficult therefore to discuss soil formation as a function of a specific process. The formation of a soil profile is viewed by Simonsom, cited in Birkeland, (1974), as the combined effect of additions to the ground surface, transformations within the soil, vertical transfers (up or down) within the soil and removals from the soil. For any one soil, the relative importance of these processes varies, and the result is a variety of profiles in any landscape (Birkeland, 1984). According to Jenny, as quoted in Birkeland (1984), soil or soil property is a function of five factors which define the state of the soil system.

S or s = f(cl, o r, p, t, ...)

Where S denotes the soil, s any soil property, o biotic factor, cl the climatic factor, p the parent material, r the topographic factor, and the dots after t represent unspecified factors. Therefore soil properties used in the study to evaluate pedotranslocation in Planosols of the Kinangop plateau are themselves results of the factors of the soil formation.

5.1.1 Role of climate

Many of the soil properties used in transect A to indicate material translocation in the profiles are climate controlled. Moisture and temperature are the two aspects of climate most important in controlling the soil properties. Cation exchange capacity (CEC): Percolating water carries with it soil materials. Exchangeable bases are normally carried down the profile and deposited when downward movement stops. CEC values increases down the profile in the 3 pedons of transect A. Maximum CEC are observed in Bt horizons of the profiles. CEC of top horizons are higher than those of eluvial horizons (E horizons) in pedons 3 and 4. The significant differences (at 10% level of significance) is attributed to organic matter which is higher in top horizons than in E horizons. Wilding et al. (1983) indicates that exchange sites in mineral soils are mainly provided by clay particles and commonly only a small percentage of CEC traceable to included organic materials - these mostly in the A horizon. However depending upon the amount of organic carbon and the base status of the soil the organic contribution may be much higher.

The higher carbon content can be traced from the grassland vegetation which continually enriches the top soil with organic materials. Low temperatures and continued presence of water on the soil surface for reasonably long periods reduce the rate of mineralization of organic matter. The high C/N ratio observed in top horizons (Table 2) indicate the presence of much partially decomposed organic matter.

The CEC of the Bt horizons are higher than those of the overlying horizons. The significant difference (at 10% level) is apparently due to high clay content. Differences in CEC can be explained exclusively by organic carbon and clay contents. Bonneau and Souchier (1979) indicates that clay fraction provides vast surlace area with enormous charge which is satisfied by cations. The leached bases thus get adsorbed onto the vast surface provided by the deposited clay in the Bt horizon. Since Bt horizons have over 1.2 times as much clay as in the overlying horizons (Table 1) the higher CEC values thus reflect clay accumulation in these horizons, which could be due to illuvial or sedentary formation.

Topsoils of the two pedons 2 and 4 have low base saturation (less than 50%). However subsoils have higher values (Table 2). The trend indicates deposition of bases in the subsoil such that exchange sites of soil colloids get saturated with the bases. The top horizons have a lower base saturation percent probably due to combined effect of organic matter and clay content. The two influence CEC positively thus lowering percent base saturation. The eluvial horizons which are clay and organic matter poor, have few available exchange sites occupied by the available bases. There is a possibility of the bases moving with percolating water saturating the limited sites. The phenomenon leads to a higher base saturation in E horizons than the A horizons. Movement of soil ma erials, clay and organic matter from E-horizons leave such horizons with higher base saturation,

Wilding et al. (1983) shows that as B-horizon texture becomes finer due to clay illuviation, permeability is reduced, therefore less leaching occurs, a higher base saturation develops and clays with swelling characteristics are formed. All the Bt horizons have base saturation more than 50% (Table 2). This is likely due to leaching of bases from E-horizon with eventual deposition in the horizons. The leaching of bases, is further evidenced by distribution of individual bases in the profiles. Exchangeable Calcium: Magnesium ratios range from 1.2 to 13.3 in the three pedons. The ratio show that more calcium than magnesium is available in the soil. The soils also show a stronger affinity for calcium than magnesium. The ratio is least in top horizons but greatest in the illuvial horizons of the three pedons. Wilding et al. (1983) points out that where base saturations increase in or below the lower solum, the calcium/magnesium ratio may be controlled largely by the weatherable minerals in these zones. The soils were found to be rich in alkali feldspar rather than ferromagnesium minerals thus the higher calcium content in the Bt horizon. The calcium rich sub-strata may promote deposition of clay as the change in

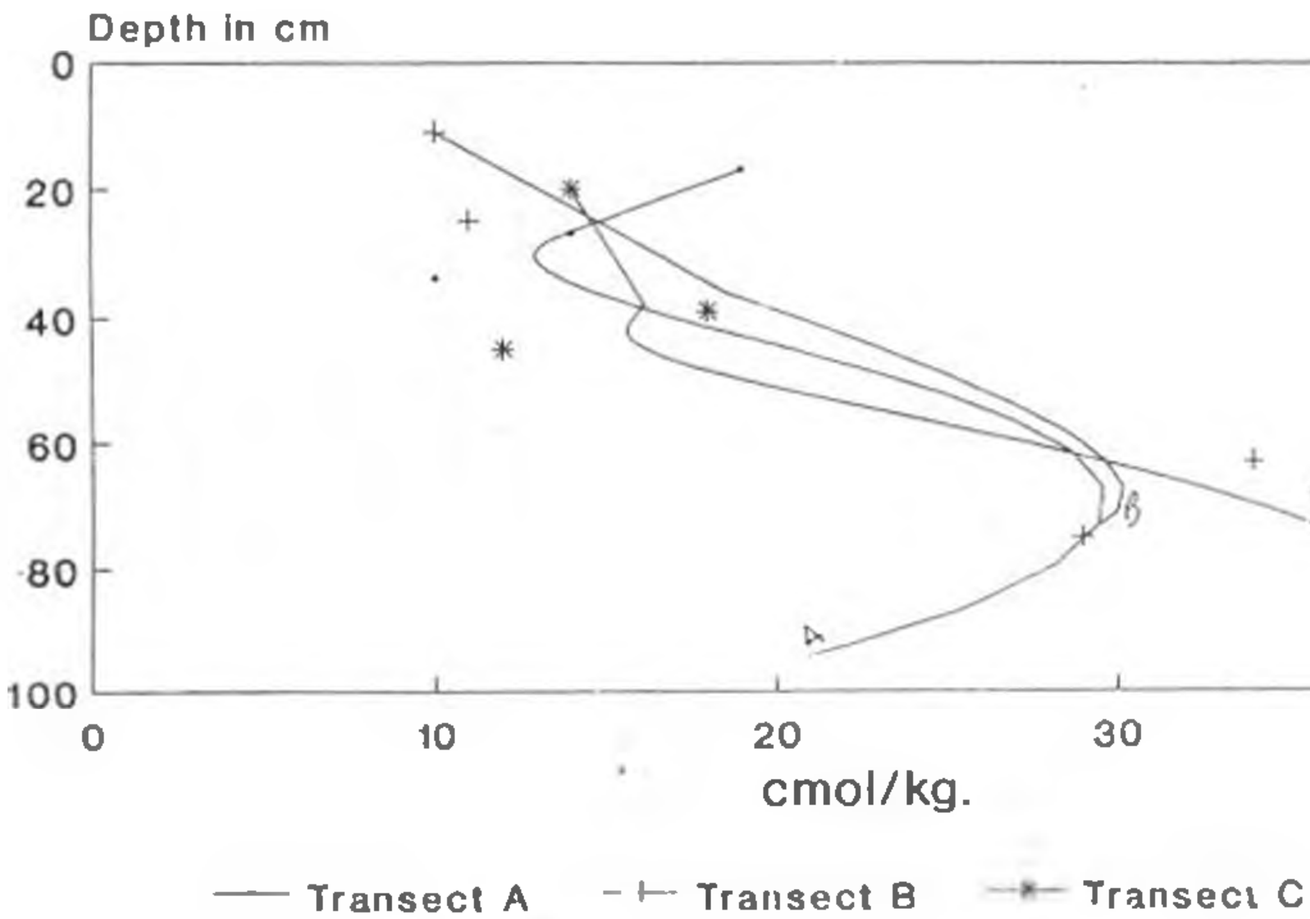


Fig 2: Variation with depth in CEC for selected pedons of the three transects.

electrolyte content leads to flocculation of dispersed systems.

In transect B, the CEC, total bases and base saturation percent all indicate downward transfer of soil materials and subsequent deposition in the B-horizon. Bases concentrated in B-horizons giving a base saturation percent of over 50% in the entire Bt horizons (Table 5). The higher base saturation percent of Bt horizons reflect higher clay content in such horizons than overlying horizons. The clay distribution in the solum of pedons of transect B, shown in figure 4, supports the preceeding statement. Thus the higher CEC observed in Bt horizons relative to the overlying horizons is most likely due to higher clay content in the former.

In transect C, trends similar to those of pedons in transect A and B are observed with respect to CEC, base saturation percent and exchangeable bases. The three parameters are thus indicators of material transfer from top horizons to B-horizons in the three transects. Thus the higher clay content in B-horizons relative to overlying horizons is apparently due to illuviation which is favoured by the climate of the area.

In moderately to strongly developed profiles there is relatively more clay in the B horizon than in either A or C horizons. One of the processes which leads to the distribution is transfer of the clay in downward percolating water which eventually accumulates in B horizon (Birkerland ,1984).

In the three pedons of transect A, clay content increases down the profile. (Fig. 4). The B horizons have more clay than

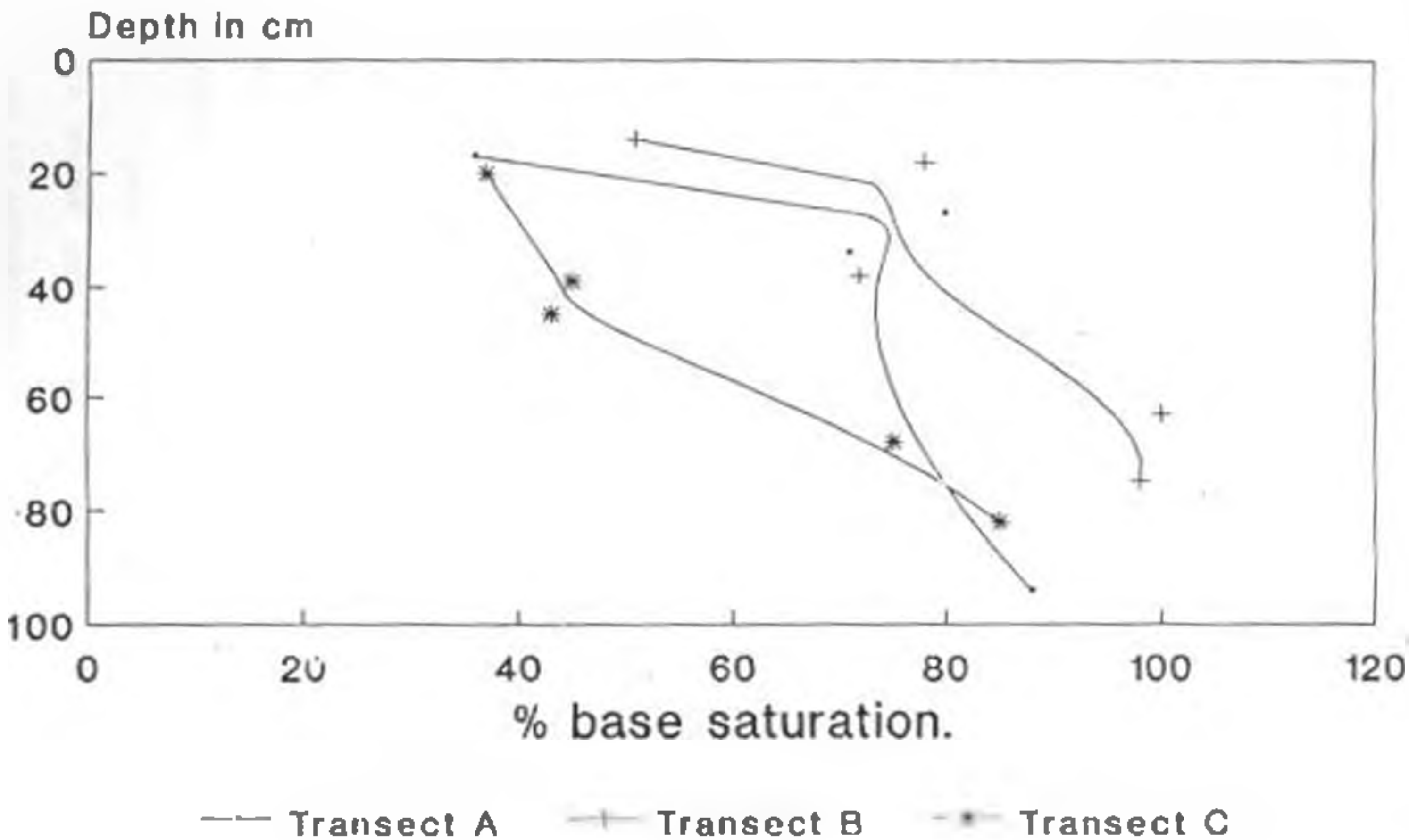


Fig 3:Variation with depth in % base saturation for selected pedons of the three transects.

the overlying horizons. They have over 1.5. times as much clay as the overlying horizons and twice the thickness of such horizons. From field morphological studies, peds and pores of the argic horizons had silicate clay coatings (cutans). The cutans concentrated in lower parts of the argic horizons. According to the Soil Taxonomy (USDA,1975), the thickness of illuvial horizons should be at least one tenth of that of the overlying horizons. If overlying horizons are very thin, an argillic horizon at least 7.5 cm thick is needed to indicate significant illuviation. Thus in all the pedons there had been significant illuviation of clay size particles. The results also indicate a sharp increase in clay with depth from E to B horizons. The foregoing discussion thus shows that clay transfer by water formed part of the processes leading to the development of slowly permeable layer in the Planosols.

The silt/silt + clay ratios are very low (less than 1.0) for both the surface and subsurface horizons showing an that large proportion of silt had weathered to clay. The ratios decline down the profile showing an increase in clay content down the profile which could be due to translocation . The percentage difference in sand in horizons BE and Bt is 11. While that between E and BE is 1. The top horizon and E horizon have a difference of 6%. Thus the results indicate a textural break in pedon 4 between horizons BE and B and between A and E. However this wide differences can also be due to transfer of soil components by downward percolating water since it is an important profile development process in the area.

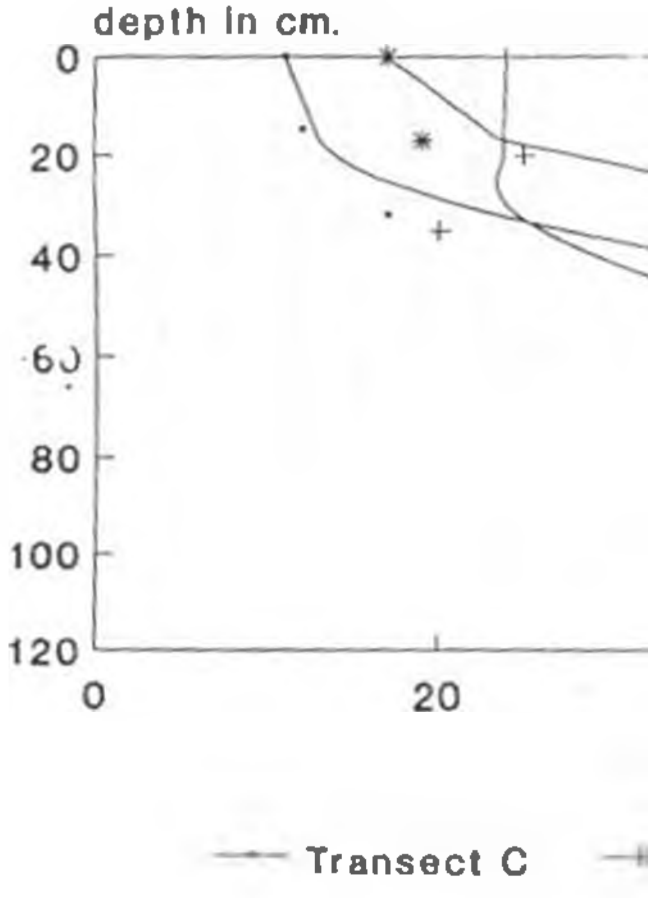
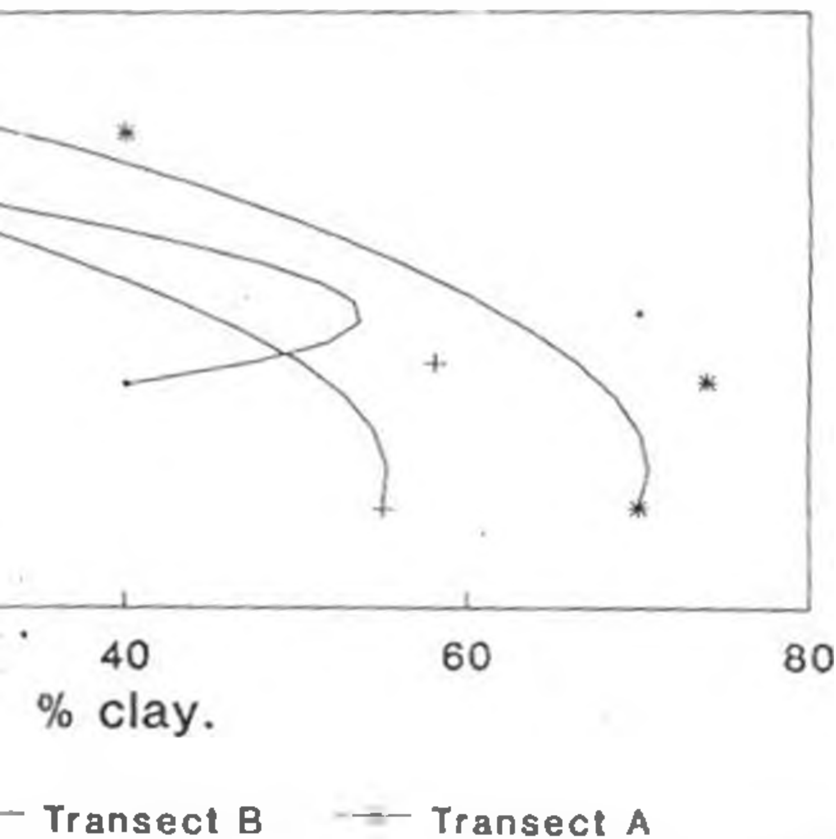


Fig 4: Distribution with deph of % clay less than 2 microns in representative pedons of the three transects.



40
60
80
% clay.
Transect B
Transect A

The textural breaks reflect the occurrence of more than one parent material in the profile which could also lead to the clay distribution pattern shown in figure 4.

The annual precipitation is responsible for transfer of clay and other soil entities down the soil profile. In the two representative pedons of transect B, the variation in texture from horizon to horizon can be used to decipher the pedogenic processes within the soil solum. In pedon 11, the first two horizons have silty loam texture and loamy texture respectively while the B horizon has a clay texture. In pedon 1, the first two top horizons have silty clay loam texture whereas the Bt_1 and Bt_2 have clay textures. The clay content of 10% in E and 60% in the B horizons of pedon 11 indicates a sharp textural change between the two horizons. There is also a sharp change in texture between AE and Bt_1 horizons of pedon 1. The ratios of percentages of clay in B to that of either AE or E-horizons in both pedons exceed 1.2. Such sharp changes in clay content can be attributed to lithological discontinuities or stratification. However a plot of resistant to non resistant minerals in sand fraction of the horizons show an increase from horizon C to the surface. This indicates uniformity of parent material. Thus the higher ratios reflect significant illuviation of clay in both pedons.

Although migration is not the sole cause of clay bulge in B, field morphological studies indicate presence of clay coatings (cutans) on ped faces. Cutans are themselves an evidence of clay deposition thus migration has played a role in clay bulge in B-horizons.

The silt/silt + clay ratios decrease down the profile. The subsoil has more clay than the top soil possibly due to clay migration. This is true when the parent material give both silt and clay in the same ratio .

In transect C, presence of clay coatings form part of the evidence of clay migration thus forming the impermeable layer. The B-horizons of the two selected pedons have a clay texture while the overlying horizons have silty loam texture. The sharp change in texture from E to B horizons signify clay deposition in the latter. Soil Taxonomy (USDA ,1975) indicates that percent clay ratios of 6 and 2 in E and B horizons of the two pedons reflect significant illuviation.

The silt/silt + clay ratios are high in the top horizons (Table 7) but low in B horizons. There is limited alteration of silt to clay in the top horizons while the process is intense in the B-horizons. There is also a possibility of translocation giving lower ratios in illuvial horizons. Hence eluviation and illuviation are processes responsible for profile development in the Planosols.

The pH $_{(1)}$ of the horizons of all pedons studied correlate with CEC and base saturation. Brady (1984) points out that there is a general relationship between soil pH and cations held by soil colloids. At high pH values the exchangeable bases predominate. pH values above 5 can be associated with excess exchangeable bases over bound hydrogen, exchangeable hydrogen and exchangeable aluminium. In all the three transects, there is a rise in pH with depth, same trend as those of CEC and base saturation. Fitzpatrick (1986) Shows that the presence of an impermeable layer in a pedon limits water percolation which could leach soluble salts to lower horizons and eventually out of the profiles. Based on this argument, soluble bases accumulate in the impermeable layer of the soils and is reflected by the higher pH values.

Perched groundwater levels favour capillary rise which transports bases to surface layers thereby modifying the pH irrespective of the intensity of rainfall (Fitzpatrick, 1986). Planosol of the transects has perched groundwater level at an average depth of 42 cm (0.42m) due to presence of impermeable layer thus there is likely hood of upward transfer of salts during dry seasons hence pH modification.

The water release data(Table 10) indicate reduction in water released for a given suction as horizons become more clayey. The curves also reflect the difficulty with which that subsoil releases water under a particular suction . B horizons retain more water followed by albic E than A-horizon. Hillel (1977) shows that the amount of water retained at relatively low values of matric suction (between 0 and 1 bar of suction) depends primarily upon the capillary effect and pore size distribution, and hence is strongly affected by the structure of the soil. On the other hand, water retention in the higher suction range is due increasingly to adsorption and thus influenced less by the structure and more by the texture and specific surface of the soil material. Apparently the increase in water retention coincide with increase in clay content in the horizons of the pedons studied. The B-horizons ability to release less water at suctions above 1 bar is due to clay content, therefore higher bulk densities relative to top horizons is most likely due to clay deposition or in situ synthesis. The bulk densities of the Bt horizons of the pedons reflect compaction in such horizons relative to top horizons. Clay deposition fills up pores thus the horizons become more dense. Though bulk density of E horizon is the same as Bt horizon of the pedon of transect B, the latter retains more water than the former. The E horizon has gravels which are more dense but have limited absorption capacity than clay. Hence soil-moisture characteristic curves indicate clay distribution in profiles Ceteris paribus.

5.1.2 Role of Vegetation:

The transects are mainly under grass. Roots of vegetation have effect on biochemical cycling of minerals and on the deposition of litter on the surface all of which influence soil formation.

In grass dominated vegetation, roots decomposing annually in situ reduce to a minimum the transport of elements within the profile. Humification is influenced by climate . The low temperatures and imperfect drainage in the study area contribute to slow decomposition resulting in accumulation of organic carbon in the topsoil. (Tables 2, ,5 and 8).

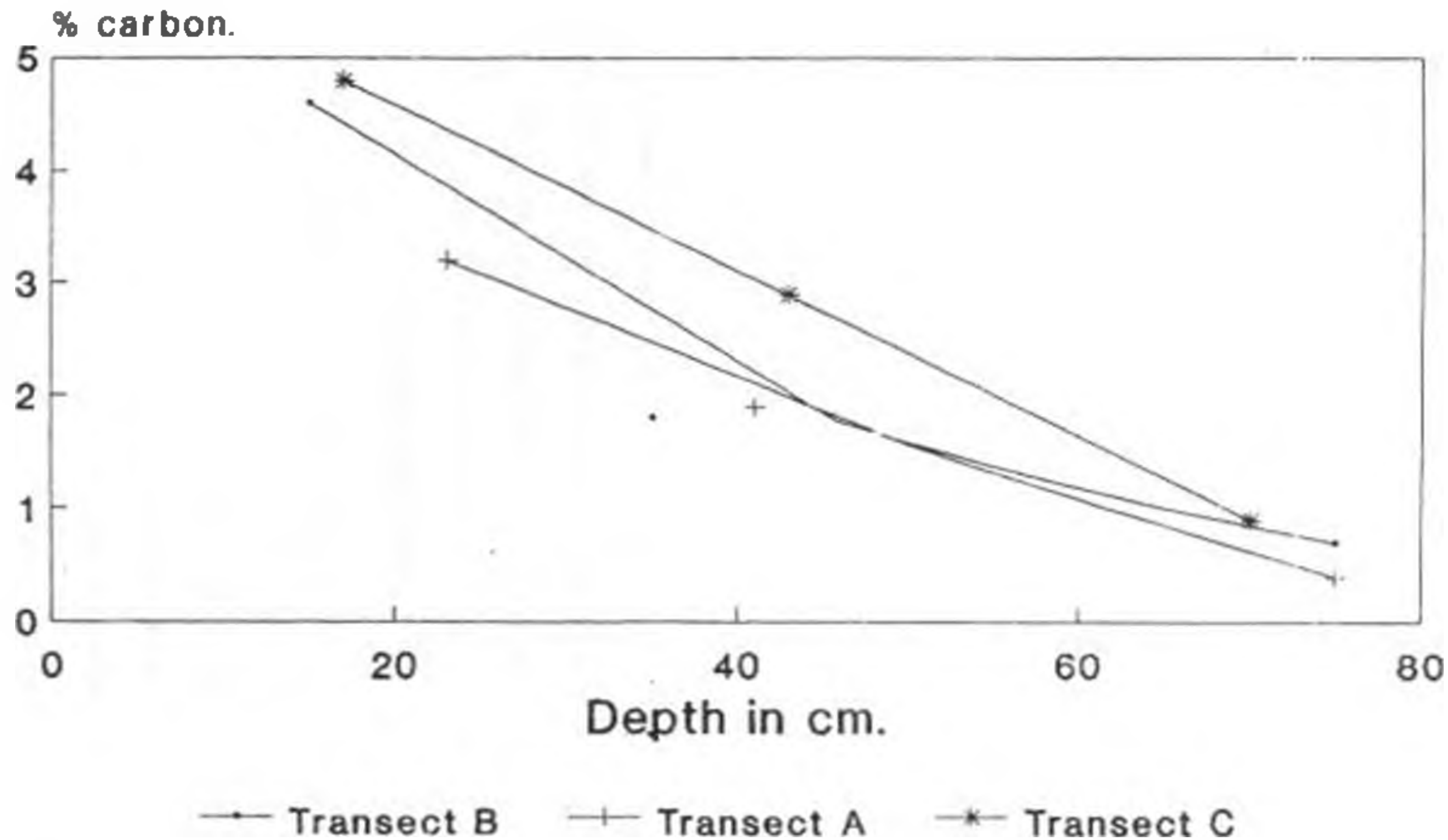


Fig 5: Distribution of organic carbon content with depth in a selected pedon of the three transects.

In the three transects, carbon content decline with depth (Fig. 5). The C/N ratio also decreases down the profile . There is no indication of organic matter accumulation in the Bt horizon. Hence eventhough there might be downward transfer of organic matter by water , the distribution does not provide any indication to that effect. The high C/N ratios at the top horizons reflect presence of much partially decomposed organic materials.

5.1.3 Role of topography:

Topography explains the soil patterns mainly through hydrology because landform determine the pathways of drainage water. The soil patterns are differentiated by means of the geomorphological processes of erosion, deposition and for chemical subsurface migration (Birkeland, 1984).

In the study area, the three transects occupy various slope positions thus different solum depths and horizon thicknesses occur. Transect B is at the transition to lower slope. The area is likely to experience overland flow. There is, therefore a chance of having a shallower pedon and thinner illuvial horizon than in the other two transects. However E-horizon has to be thicker due to both lateral and vertical transfers (Table 11).

Transect C has profiles with the thickest solum. Transect C which occurs at the summit of the area experience predominantly vertical transfer with limited lateral transfer which could remove soil materials. According to Wilding et al. (1983), solum thickness is a function of the permeability of the material and the amount and frequency of rainfall, where materials are very permeable the soils have thicker sola than in comparable soils on adjacent landscape elements. Transect A receives materials from transect B. Therefore it has a thicker sola than the latter.

Table 11 Average Solum depths and B-and E-horizons' thickness of the 3 transects.

Transect	Solum depth Thickness(cm)	B horizon Thickness(cm)	E horizon Thickness(cm)
A	90	42	11
B	58	39	15
C	120	82	12

5.1.4. Role of parent material:

Table 12: Petrographic characteristic of a representative rock sample from the study area.

Mineral	% Composition
Feldspars	85
Iron Ores	15
Quartz	Trace

(Determination: Department of Geology, University of Nairobi, 1993).

Approximate mineralogical composition of the rock sample is shown above. The rock, identified as a welded tuff, is of volcanic origin. The pyroclastic igneous rocks of the three transects are dominated by feldspars with iron ores, especially haematite and magnetite second in abundance.

The tuffs contain feldspars which are indistinguishable. The minerals weather relatively quickly and due to their prominence among minerals of the lithosphere, their disappearance is accompanied by release of significant quantities of bases.

The bases influence the soil pH. Iron ores are present in the parent rock and are likely to be the source of oxide found in the solum. Presence of the minerals both in parent materials and soil sola indicate geogenic type of soil formation. However other primary minerals especially the ferromagnesium type, biotite, olivines and amphiboles are present in soils but not in parent rock. Their synthesis is apparently within the sola hence both pedogenetic and geogenetic processes are responsible for the Planosol formation.

Quartz, among minerals found in the solum as feldspars, amphiboles, olivines, biotites, iron oxides and garnents, is relatively the most resistant mineral. Quantity of quartz increases relatively from parent material upwards to the surface. Feldspars show relative decline in quantity up the profile. The trends indicate parent material uniformity in the soils (Fig. 8).

The graphs of Fig.7 indicate a decline of the ratio of quartz to feldspars with depth in the 3 transect. The sharp interhorizonal boundaries (between B and E) leads to sharp breaks in the curves of the mineral ratios versus depth. Such sharp breaks are due to differences in parent material - that of either differences in conditions of deposition or differences in geological materials if breaks are associated with appearance of

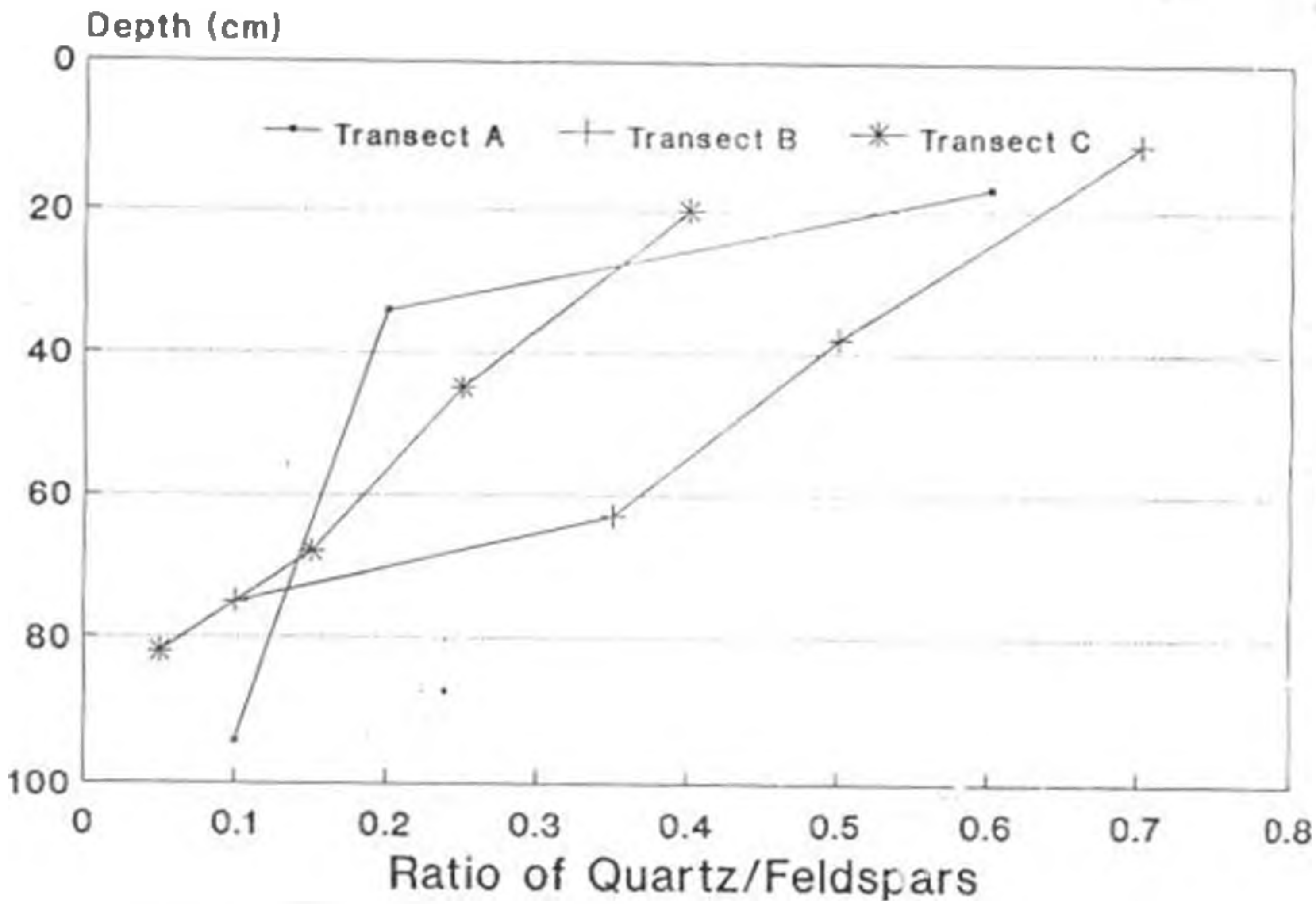


Fig. 6: Variation with depth of average ratios of resistant to non resistant minerals.

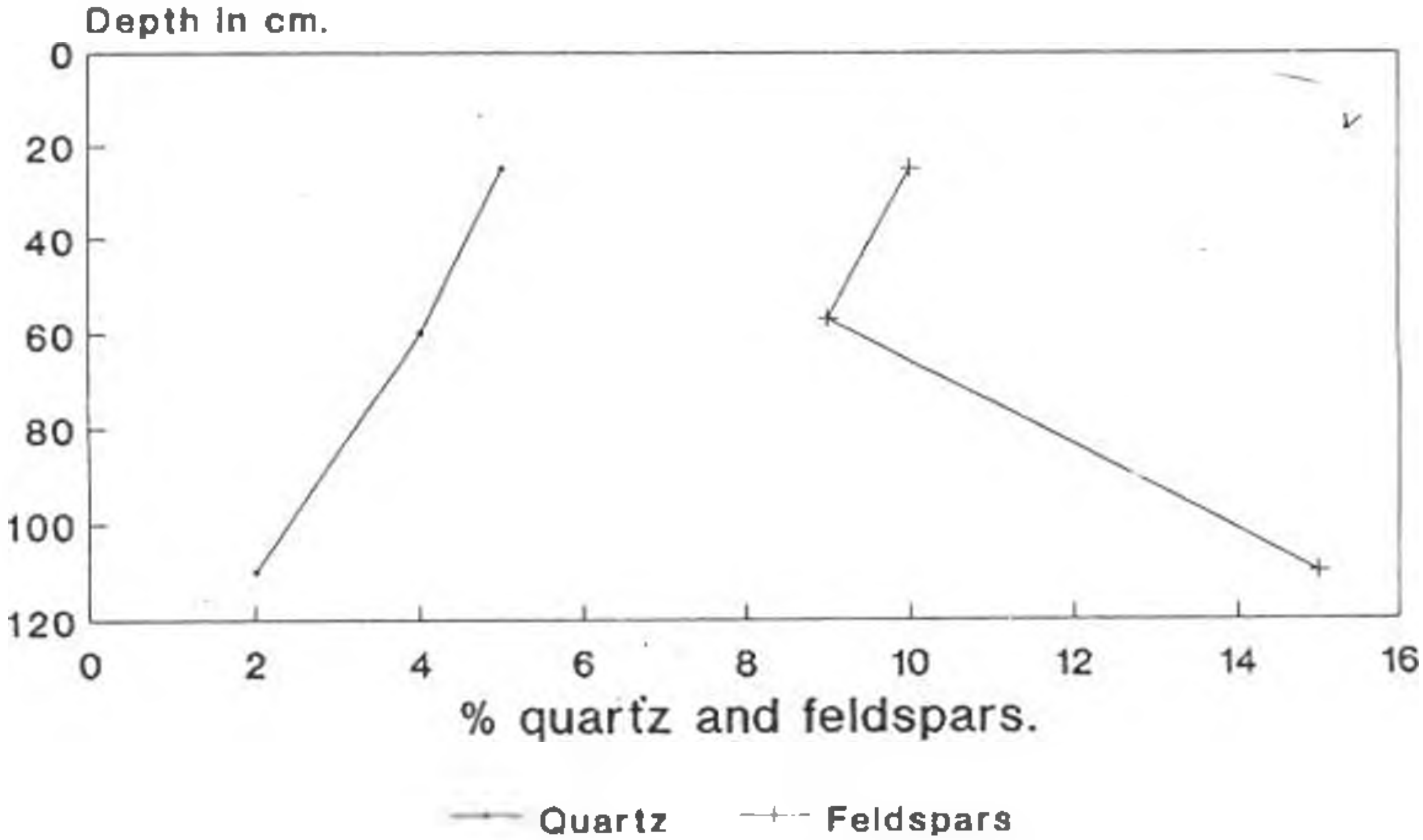


Fig 7: Variation of quartz and feldspars with depth in pedon 16 in transect C.

different mineral species. However profiles with sharp interhorizonal boundaries as in Planosols experience sharp differences in weathering which could lead to wide disparity in mineral composition even if parent material is uniform (Brewer,1964).

The geochemical data provided in Tables 2, 4 and 6 show that the soils are rich in iron (III), silica, aluminium, potassium and sodium oxides but poor in calcium and magnesium oxide. The ratio of $SiO_2/Fe_2O_3+Al_2O_3$ decline with depth from the top soil to the B-horizon. The trend in the three transects indicate relative enrichment of silica with the loss of iron and aluminium oxides. The ratios are minimal in B horizons reflecting deposition and accumulation of iron and aluminium in E-horizons.

5.2 Land Use:

Much of the area under study is under grass. In each farm within the transects only about 0.08 ha is spared for arable crops. Crops most common are Irish potatoes and vegetables. The two are grown both for domestic and commercial purposes.

The main limitations of crops in the area are poor drainage and low temperature. The soils are fertile and rainfall is adequate for crop growth. Temperatures are low for a good part of the year thus crops taking over 3 months do not do well due to chilly conditions. Also crops which do not tolerate waterlogging cannot do well because of imperfect drainage. The drainage condition is due to impermeable layer which exist at about 42cm depth in the three transects.

The impermeable layer is formed as a result of clay accumulation in the B-horizon thus sealing off soil pores. Besides the crops grown, much of the land in the three transects is under grass and grazing is the main land use in the area. Dairy animals are reared and milk is sold locally. Dairying happens to be the most economical land use currently since most commercial crops cannot do well in the area.

Cumbered beds are normally constructed to reduce the drainage menace. This has proved fruitful especially in crop growing sites. However the only major drawback is the formation of a hard pan beneath the soil surface due to induration of the exposed E-horizon at depths between 15 and 30 cm. The indurated pan inhibits root penetration thus further limiting the choice of crops. Future remedies would then become quite expensive. An alternative approach would therefore be a shallow cultivation preferably to depths above 15 cm or just above the E-horizon or alternatively the fields should be left under pasture.

CHAPTER SIX

6.0 SUMMARY AND CONCLUSIONS

The soils of the three transects all classified as Eutric Planosols (FAO, 1991) have undergone pedogenic episodes greatly influenced by the soil forming factors. Climate plays a significant role in modifying the soil properties. Most of the soil properties used in the study to qualitatively evaluate clay migration in the soil are climate controlled. Cation exchange capacity (CEC), percent base saturation and quantities of exchangeable bases all have been used to reflect clay accumulation in B-horizons. The three parameters indicate deposition of clay in situ or synthesis since the parameters and clay content have high correlation coefficients. In the three transects therefore the properties indicate a bulge of clay in B-horizons.

Variation in texture from horizon to horizon can be used to decipher the pedogenic and geological history of a soil. Texture of the soils of the three transects has been influenced by vertical transfer of clay and other inorganic components. Percolating water has over time transferred clay from A and E horizons and deposited the components in B-horizons giving such horizons clayey texture. The fine grained fraction makes the B-horizons to be more chemically active than overlying horizons because of their greater charge per unit volume and their capacity to hold greater amounts of water by adsorption. Thus higher clay content is associated with higher CEC, exchangeable bases, percent base saturation , water retention and pH.

The occurrence of clay coatings in B-horizons provide evidence of clay deposition in the horizon.

Vegetation is a soil forming factor which is linked to soil morphology and soil chemistry. Types of vegetation determine the distribution of organic carbon in profiles. Though organic matter is transported together with clay down profile the results do not give a distribution reflecting such a combined transfer since B horizons have lowest organic carbon percentages.

The three transects are underlain by pyroclastic rocks. The tuffs are mainly composed of feldspar minerals with little iron Oores and traces of quartz. The mineral distribution in the profiles show strong evidence of parent material uniformity in the sola-thus clay accumulation in B-horizon is attributed to migration from overlying horizons. Both soil and rock mineral composition indicate that both geogenic and pedogenic processes are responsible for soil formation and development. Textural breaks are observed in all the three transects. This might indicate parent material layering in the solum. However soil profile developmental processes might sometimes lead to wider variation in silt or sand percent in adjacent horizons.

The physical and chemical data together with field morphological data give strong indications of clay translocation and accumulation within the soil body. Such transfers have led to the formation of the slowly permeable layer which is characteristic of Planosols.

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APPENDIX.

Laboratory data
Transect A
Profile P_4

Soil classification Eutric Planosol

Horizon	A	Eg	BE_{cs}	Bt
Depth (cm)	0-15	15-24	24-40	40-75
pH_H2O	[illegible]	5.7	5.8	6.3
pH_Kcl	4.6	4.6	4.6	4.7
Texture Sand g/100g	[illegible]	19	20	9
Silt	[illegible]	41	40	11
Clay	30	40	40	80
Textural Class	SiCl	SiCl	Cl	C
Exch.Cations Ca cmol/kg	2.2	3.2	6.0	25.4
Mg	1.8	2.4	3.0	2.2
K	0.4	0.6	1.0	2.1
Na	0.3	0.5	0.5	1.7
CEC cmol/kg	22.0	9.0	27.0	48
Base Saturation %	21.00	73.0	39.0	66.0
Carbon %	4.6	1.8	1.7	0.7
Nitrogen %	0.2	0.3	0.2	0.2
C/N	23	6	9	0.4
Bulk density g/cc	1.1	1.3	1.3	1.4
Soil minerals Ab.	-	-	•	Fe_{ox}
Comm.	Fe_{ox} F	Fe_{ox}	•	-
Few	G B A Q	F Q A B	•	F
Tr.	-	-	•	QA

Explanatory notes for the mineralogical results.

1. Soil minerals

Alphabetical key

A. Amphibole
B. Biotite
F. Feldspar
F_{ox} Iron oxide
G Garnet
Q. Quartz

Quantities

Ab.	Abundant	> 60%
Comm.	Common	20 - 60%
Few.	Few	5 - 20%
Tr.	Trace	< 5%

profile description and laboratory data:

Transect A

Profile no P_4

Area/Date	: Nyandarua District: 24/10/92
Soil classification(FAO.1990)	: Eutric Planosol
Ecological zone	: II
Geological formation	: Pyroclastic rocks
Local petrograp'y	: Tuffs
Physiography	: Plateau
Relief-macro	: gently undulating, 2-6%
Relief-macro/meso	: Cumbered beds, termite mounds
Vegetation/Land Use	: grazing, grassland
Erosion	: Nil
Surfae stoniness	: Nil
Salinity and alkalinity	: Nil
Drainage class	: Imperfectly drained; slow permeability
Depth of slowly permeable layer	: 40 cm

Profile description

Horizon	depth (cm)	description
A	0-15	Brown to dark brown (10YR 4/3, moist) silty clay loam; weak medium to coarse subangular blocky structure friable moist; slightly sticky and slightly plastic wet;many fine & common course pores; and abundant fine roots;clear and smooth transition to:
Eg	15-24	Brown (10YR 5/3, moist); red many, medium and prominent mottles; gravelly silty clay loam; moderate to medium subangular blocky structure; friable moist, slightly sticky and plastic wet; many fine and common coarse pores; common fine roots; clear and smooth transition to:
BEcs	24-40	Dark yelloyish brown (10YR 4/6, moist); gravelly clay loam; weak fine subangular blocky structure; friable moist, slightly sticky and slightly platic wet; few to common fine pores; very few roots; fine, 80% iron and manganese concretions; abrupt and wavy transition to:
Bt	40-75	Brown to dark brown (10YR 4/3, moist); clay;weak fine subangular blocky structure; friable to firm moist,sticky and plastic wet; broken thick clay cutans; few fine pores; abrupt and wavy transition to:
C	75+	Weathering parent material.

Laboratory data

Transect A

Profile P_1

Soil classification: Eutric Planosol

		A	AEg	Bt_{1ss}	Bt_{2ss}
Depth (cm)		0-20	20-27	34-68	68-94
pH H_2O		5.5	5.5	6.5	6.9
pH Kcl		4.4	4.3	4.9	5.4
Texture	Sand	20	19	7	9
$g100g^{-1}$	Silty	70	41	13	21
	Clay	10	40	80	70
Textural Class		SiI	SIC	C	C
Exch.Cations	Ca	3.6	7.8	24	16.4
$cmolkg^{-1}$	Mg	0.8	3.4	1.8	2.0
	K	0.5	0.4	1.0	0.7
	Na	0.5	0.4	1.0	0.7
CEC $cmolkg^{-1}$		9.4	13.8	37.0	23
Base Saturation %		57.0	83.0	77.0	88.0
Carbon %		3.0	2.4	0.8	0.3
Nitrogen %		0.3	0.3	0.1	0.1
C/N		10	8.0	8.0	3.0
Bulk density g/cc		1.2	1.3	1.2	1.2
Soil minerals	Ab.	-	-	Fe_{ox}	Fe_{ox}
	Comm.	Fe_{ox} F	Fe_{ox} F	-	-
	Few	G B A Q	F Q A B	F	FA
	Tr	-	-	QA	Q

Explanatory noted for the mineralogical results.

1. Soil minerals
   Alphabetical key
   - A. Amphibole
   - B. Biotite
   - F. Feldspar
   - F_{ox} Iron oxide
   - G. Garnet
   - Q. Quartz
2. Quantities
   - Ab. Abundant > 60%
   - Comm. Common 20 - 60%
   - Few: Few 5 - 20%
   - Tr. Trace < 5%

Transect A
Profile no P_1

Area/Date	: Nyandarua District: 24/10/92
Soil classification (FAO, 1990)	: Eutric Planosol
Ecological zone	: II
Geological formation	: Pyroclastic rocks
Local petrography	: Tuffs
Physiography	: Plateau
Relief-macro	: Flat to almost flat, 0-2%
Relief-meso, micro	: Cambered beds, termite mounds
Vegetation/Land Use	: grassland/grazing
Erosion	: Nil
Surface stoniness	: Nil
Alkalinity & Salinity	: Nil
Drainage class	: Imperfect; slow permeability
Depth of slowly permeable layer	: 34 cm

Profile description

Horizon	depth (cm)	description
Ag	0-20	Greyish brown (10YR 5/2, moist); Common, medium and prominent red mottles; Silty loam; moderate medium subangular blocky structure; sticky and slightly plastic wet; Many fine and Common medium pores; abundant fine and common medium roots; gradual and wavy transition to:
AEg	20-27	Browm (10YR 5/3, moist); red common, medium and distinct mottles; gravelly silty clay; moderate, medium subangular blocky structure; friable moist, sticky and plastic wet; Common fine and few medium pores; few fine roots; clear and wavy transition to:
E_{cs}	27-34	Light brownish grey (10YR 6/2, moist); gravelly silty clay; weak, fine subangular blocky structure; friable moist, sticky, plastic wet; Common medium and fine pores; 15%, Iron and manganese concretions; abrupt and smooth transition to:
Bt_{1cs}	34-68	Dark brown (10YR 3/3, moist); clay; strong coarse angular blocky structure; friable moist, very sticky and very plastic wet; broken, thick clay cutans; few fine pores; 40%, Iron and manganese concretions; gradual and smooth transition to:
Bt_{2cs}	68-94	Dark yellowish brown (10YR 3/4, moist); clay; moderate fine angular blocky structure; very plastic wet; Continuous, thick clay cutans; few fine pores; 50% Iron and manganese concretions; clear and smooth transition to:
C	94+	Weathering parent material.

Laboratory Data

Transect B
Profile no P_1

Soil classification: Eutric Planosol

Horizon	A	AEg	Bt_{1ss}	Bt_{2ss}	
Depth (cm)	0-25	22-38	50-85	85-101	
pH H_2O	5.7	5.7	6.4	6.7	
KCl	4.7	4.6	4.9	4.5	
Texture Sand	13	16	7	29	
$100g^{-1}$ Silt	57	59	38	16	
Clay	30	25	55	55	
Textural class	SiL	SiL	C	C	
Exch. Cations Ca	2.0	4.4	26.4	24.2	
$cmolkg^{-1}$ Mg	1.2	3.8	3.2	0.4	
K	0.6	0.5	2.0	1.8	
Na	0.2	0.2	1.4	1.0	
CEC $cmolkg^{-1}$	9.8	10	33	28.6	
Percent Base Saturation	41	89	100	96	
Carbon %	3.2	1.9	0.4	0.2	
Nitrogen %	0.3	0.28	0.14	1.7	
C/N	10.0	6.0	4.0	2.0	
Bulk density g/cc	1.1	1.4	1.3	1.3	
Soil minerals: Ab.	-	-	-	-	Fe_{ss}
Comm.	QFe_{ss}	Fe_{ss}	$Fe_{ss}F$	-	
Few	AF	AQF	AG	-	
Tr.	BG	BG	Q	-	

Key : Same as for profiles 4 and 7.

Transect B
Profile no P_1

Area/Date:	Nyandarua District: 23/10/92
Soil classification:FAO/1990):	Eutric Planosol
Ecological zone:	II
Geological formation:	Pyroclastic rocks
Local petrography:	Tuffs
Phyiography:	Plateau
Relief macro:	Gently undulating: 2-6%
Relief micro/meso:	Cumbered beds, termite mounds
Vegetat on/land use:	Grassland/grazing
Erosion:	Nil
Surface stoniness:	Nil
Salinity & alkalinity:	Nil
Drainage class:	imperfect; slow permeability
Depth of slowly permeable layer:	50 cm

Profile description:

Horizon	depth (cm)	description
A	0-25	Very dark greyish brown (10YR 3/2, moist); silty loam; moderate, fine to medium subangular blocky structure; friable moist, slighly stickly and slightly plastic wet; many fine and medium pores; abundant fine roots; clear and smooth transition to:
AEg	25-38	Dark greyish brown (10YR 4/2, moist); many distinct fine, red mottles; silty clay loam; moderate, medium to coarse subangular blocky structure; friable moist, sticky and plastic wet; many fine and coarse pores; common fine roots; clear and wavy transition to:
E_{cs}	38-50	Greyish brown (10YR 5/2, moist) gravelly silty clay; friable moist, slightly sticky and sligtly plastic wet; many fine and coarse pores; few fine roots; 15%, Iron and manganese concretions; abrupt and irregular transition to:
Bt_{1cs}	50-85	Very dark brown (10YR 2/2. moist); clay; strong medium angular blocky structure; friable moist, sticky and plastic wet; broken thick clay cutans; few fine pores; 15%,Iron and manganese concretions; gradual and smooth transition to:
Bt_{2cs}	85-101	Dark greyish brown (10YR 3/4, moist); clay; strong medium subangular blocky structure; friable moist, sticky and plastic wet; continuous thick clay cutans; few fine pores; 50%, Iron and manganese concretions; abrupt and smooth transition to:
C	101 +	weathering parent material

Laboratory data

Transect B
Profile no P_{11}

Soil classification: Eutric Planosol.

		A	E_{cg}	Bt_{cn}
Horizon		A	E_{cg}	Bt_{cn}
Depth (cm)		0-17	17-35	35-63
pH H_2O		5.9	6.0	6.2
Kcl		4.8	4.9	4.9
Texture	Sand	20	46	31
$g100g^{-1}$	Silt	60	44	9
	Clay	20	10	60
Textural Class		SiI	L	C
Ech. Cations cmol/kg	Ca	3.6	6.6	28.4
	Mg	1.6	0.8	2.6
	K	0.6	0.8	1.6
	Na	0.3	0.3	1.0
CEC.cmolkg		9.8	12.8	33.6
Base saturation %		63	66	99
Carbon %		2.5	1.4	0.4
Nitrogen %		0.2	0.18	0.2
C/N		11.2	8.0	2.0
Bulk density.g/cc		0.9	1.4	1.4
Soil minerals:	Ab.	-	-	Fe_{ox}
	Comm.	Fe_{ox} FB	Fe_{ox}	FB
	Few	A	QFA	-
	Tr.	Q	B	Q

Key: Same as for profiles 4 and 7.

Transect B
Profile no P_{11}

Area/Date:	Nyandarua District: 25/10/92
Soil classification:(FAO/1990):	Eutric Planosol
Ecological zone:	II
Geological formation:	Pyroclastic rocks
Local petrography:	Tuffs
Physiography:	Plateau
Relief macro:	Gently undulating: 2-6%
Relief micro/meso:	Cumbered beds, termite mounds
Vegetation/land use:	Grassland/grazing
Erosion:	Nil
Surface stoniness:	Nil
Salinity & alkalinity:	Nil
Drainage class:	imperfect; slow permeability
Depth of slowly permeable layer:	35 cm

Profile description:

Horizon	depth	description
Ag	0-17	Brown to dark brown (10YR 4/3,moist); many fine, distinct red mottles; silty loam; moderate medium subangular blocky structure; friable moist, slightly sticky, slightly plastic wet; many fine and medium pores; abundant fine roots; clear and irregular transition to:
E_{css}	17-35	Brown (10YR 5/3, moist); few fine, faint red mottles; gravelly loam texture; weak fine subangular blocky structure; friable moist, slightly sticky, slightly plastic wet; many fine and medium pores; few fine roots; 15%, Iron and manganese concretions; abrupt and irregular transition to:
Bt_{sc}	35-63	Very dark greyish brown (10 YR 3/2, moist); clay; strong medium angular blocky Structure; friable moist, sticky, plastic, common, thick clay cutans, few fine pores; 70%, Iron and manganese concretions; very few fine roots; clear and irregular transition to:
C	63+	Weathering material.

Laboratory Data

Transect C
Profile no P_1

Soil classification: Eutric Planosol.

Horizon		Ag	AE_{x}	Bt_1	Bt_2
Depth(cm)		0-20	20-39	39-64	64-82
pH H_2O		5.7	5.8	6.0	6.5
Kcl		4.5	4.4	5.0	5.3
Texture g/100g	Sand	10	30	5	9
	Silt	79	60	35	51
	Clay	11	10	60	40
Textural class		SiL	SiL	C	SiC
Ech. Cations cmol/kg	Ca	3.2	2.4	28	24
	Mg	0.8	1.0	1.8	2.8
	K	1.2	1.0	1.7	2.4
	Na	0.2	0.5	1.0	1.4
CEC.cmol/kg		11.8	20.8	39.8	40.8
Base saturation %		46.0	24.0	82.0	75
Carbon %		4.6	1.6	1.0	0.3
Nitrogen %		0.2	0.1	0.1	0.03
C/N		23	16	10	10
Bulk density. g/cc		1.2	1.5	1.4	1.3
Soil minerals	Ab.	Fe_{ox}	-	Fe_{ox}	•
	Comm.	-	Fe_{ox}A	-	•
	Few	AFB	QFB	Q	•
	Tr.	Q	-	AF	•

Key: Same as for profiles 4 and 7.

Transect C
Profile no Ps

Area/Date:	Nyandarua District: 25/10/92
Soil classification: (FAO/1990):	Eutric Planosol
Ecological zone:	II
Geological formation:	Pyroclastic rocks
Local petrography:	Tuffs
Physiography:	Plateau
Relief macro:	Gently undulating: 2-6%
Relief micro/meso:	Cambered beds, termite mounds
Vegetation/land use:	Grassland/grazing
Erosion:	Nil
Surface stoniness:	Nil
Salinity & alkalinity:	Nil
Drainage class:	imperfect; slow permeability
Depth of slowly permeable layer:	39 cm

Profile description:

Horizon	depth (cm)	description
Ag	0-20	Dark brown (10YR 3/3, moist); common, medium and distinct brown mottles; silty loam; moderate medium subangular blocky structure; friable moist, slightly stickly, slightly plastic wet; many fine and medium pores; abundant fine roots; clear and smooth transition to:
AE_{cs}	20-39	Dark greyish brown (10YR 4/2, moist) gravelly silty loam; weak, fine subangular blocky structure; friable moist, slightly plastic, slightly sticky wet; common fine 10%, Iron and manganese concretions; abrupt and broken transition to:
Bt_{1cs}	39-64	Very dark brown (10YR 2/2, moist); clay; strong medium to coarse angular blocky structure; friable moist, sticky, plastic wet; common, thick clay cutans; few pores; very few fine dead roots; gradual and smooth transition to:
Bt_{2cs}	68-82	Dark brown (10YR 3/3, moist); clay; moderate, coarse angular blocky structure; friable moist, sticky, plastic wet; contineous thin clay cutans; few fine pores; dead roots; clear and smooth transition to:
C	82+	Weathering material.

Laboratory Data

Transect C
Profile no P_{11}

Soil classification: Eutric Planosol

Horizon		Ag	E_{csg}	Bt_{1cs}	Bt_2ca	Bt_3
Depth (cm)		0-10	10-25	25-57	57-74	74-110
pH H_2O		5.4	5.7	6.0	6.7	6.9
Kcl		4.6	5.9	5.3	5.8	5.7
Texture	Sand	29	7	10	8	10
g/100g	Silt	46	8	10	52	50
	Clay	25	5	80	40	40
Textural class		Sil	Sil	C	SiC	Sil
Exch.Cations	Ca	5	1.4	18	20	22
$Cmolkg^{-1}$	Mg	0.6	0.6	3.0	2.0	4.0
	K	0.6	0.6	1.8	1.6	1.8
	Na	0.2	0.2	1.0	1.0	1.0
CEC $cmolkg^{-1}$		15	12	31	32	33
Base saturation %		42	22	76	76	87
Carbon %		3.7	2.2	0.7	0.3	0.2
Nitrogen %		0.2	0.2	0.1	0.1	0.1
C/N		19.0	11.0	7.0	3.0	2.0
Bulk density g/cc		1.1	1.4	1.3	1.3	1.2
Soil minerals	Ab.	Feox	-	Feox	•	•
	Comm.	-	FeoxA	-	•	•
	Few	ABF	QBF	Q	•	•
	Tr.	Q	-	AF	•	•

Transect C
Profile no P_{11}

Area/Date:	Nyandarua District: 27/10/9
Soil classification:(FAO/1990):	Eutric Planosol
Ecological zone:	II
Geological formation:	Pyroclastic rocks
Local petrography:	Tuffs
Physiography:	Plateau
Relief macro:	Gently undulating: 2-6%
Relief micro/meso:	Cumbered beds,termite mounds
Vegetation/land use:	Grassland/grazing
Erosion:	Nil
Surface stoniness:	Nil
Salinity & alkalinity:	Nil
Drainage class:	imperfect; slow permeability
Depth of slowly Permeable layer:	25 cm

Profile description:

Horizon	depth (cm)	description
Ag	0-10	Dark brown (10YR 4/2, moist); common, medium and distinct brown mottles; silty loam; moderate medium subangular blocky structure; friable moist, slightly sticky,slightly plastic wet; many fine and medium pores; abundant fine roots; clear and smooth transition to:
E_{gw}	10-25	Gray, (10YR 5/1, moist); Common, fine faint red mottles; gravelly silty clay; weak, fine subangular blocky structure; friable moist, slightly sticky, slightly plastic wet; many pores; 20%, Iron and manganese concretions; abrupt and smooth transition to:
Bt_{1cs}	25-57	Very dark greyish brown (10 YR 3/3, moist); clay; moderate medium to coarse angular blocky structure; friable moist, sticky, plastic wet; broken thick clay cutans; few fine pores; 50%, Iron and mangan(?)e concretions; dead roots; gradual and smooth transition to:
Bt_{2cs}	57-74	Dark brown, (10YR 3/3, moist); clay; moderate to strong fine to medium subangular blocky structure; friable moist, sticky, plastic wet; continous thick clay cutans; Very few fine pores; 80% Iron and manganese concretions; gradual and smooth transition to:
Bt_3	74-110	Yellowish brown (10YR, moist); clay; moderate to strong, fine angular blocky structure; very friable, sticky, plastic wet ; broken thick clay cutans; few fire pores; clear and wavy transition to:
C	110	Weathering material.

Explanatory notes for the mineralogical results.

1. Soil minerals

Alphabetical key:

A Amphibole
B Biotite
F Feldspar
Feox Iron Oxide
G Garnet
Q Quartz.

2. Quantities

Ab.-	aboundant	> 6 %
Comm.	Common	20- 0%
Few	Few	5-2 %
Tr.	Trace	< 5

• not analysed

NB: Percentage ranges reobtainable in Greenland, (1981).