SOIL MAPPING AND SOIL CHARACTERIZATION STUDIES IN THE ZARIA AREA, NIGERIA.

by

I

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Dedicated to Kemi and Femi

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INTRODUCTION

Zaria ($11^{\circ}07'N$, $07^{\circ}44'E$) lies in the Zaria-Kano Plain, a vast gently undulating peneplain of Mid-Tertiary age (Thorp, 1970) occurring at an elevation of about 730m above sea level in northern Nigeria. It is about 640 km away from the sea.

The development of soil survey in northern Nigeria started with the publication of the maiden issue of the Samaru Soil Survey Bulletin by Higgins (1957). Soil surveys of various kinds and scales have been conducted in northern Nigeria since Higgin's initial work in 1957. The North Zonal Soil Correlation Committee has listed the major survey works that have been undertaken in the region to date.

Even though the soil surveys of many parts of northern Nigeria were initiated from Samaru, Zaria, no systematic soil survey of the Samaru-Zaria environ has so far been undertaken (Klinkenberg, 1970; Hope, 1979). Consequently only little information is available on soils around Samaru-Zaria area itself.

The importance of soil mapping and characterization, especially in an environment such as the Samaru-Zaria area cannot be over-emphasized as it forms the basis for all enterprises and researches that have the soil as base. It is in a dire desire to provide soil information in this vital area that the present study is undertaken.

It is hoped that this will be a useful contribution to the collection of vital information about the soil condition of Nigeria in general.

REVIEW OF LITERATURE

The soil, like many other natural formations, represents a dynamic system - a system where a series of changes or processes operate constantly affecting its composition, properties and energy conditions (Rode, 1961). All these changes or processes pattern the soils overall characteristics. The changes (processes) are the result of the integrated effects of climate, parent material/rock, vegetation and associated organisms, relief of the land and time (Crompton, 1962).

Geology of the Zaria-Kano Plain

The Zaria-Kano plain is underlain by Basement complex rocks which in Nigeria have been put at about precambrian by several workers (Pugh and King, 1952; Russ, 1959; and Furon (1963) as reported by Oyawoye (1965). The rocks are mainly granites and gnesses. Other rock types such as migmatites, schists and quartzite also occur in the area. Fig. 1 shows the distribution of rocks in the central part of the plain.

There is agreement among many workers on the Nigerian

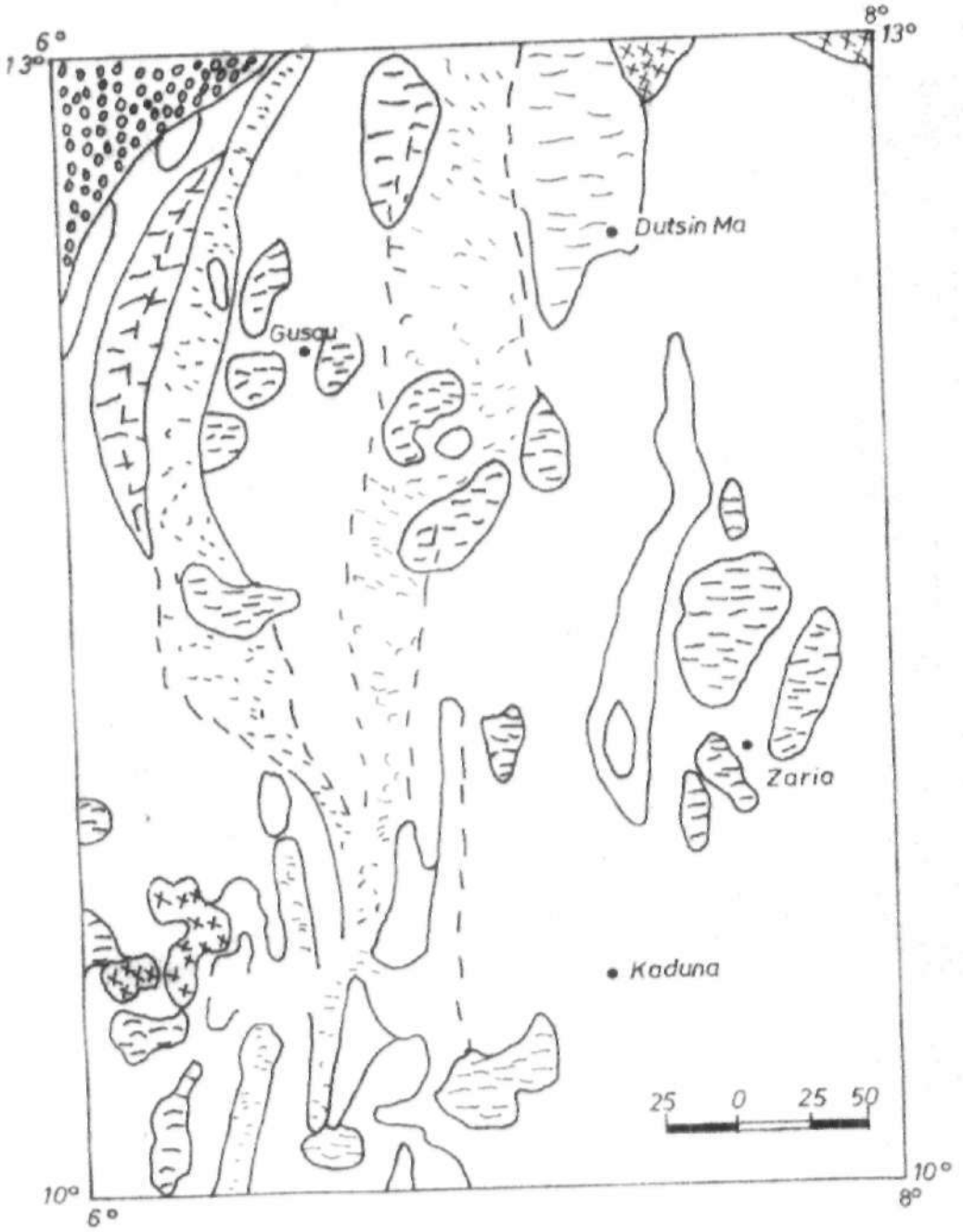


Fig 1 Geology of part of the Zaria–Kano plain.

Basement Complex, that it is part of a more extensive African basement complex (Oyawoye, 1964; Grant, 1969; Truswell and Cope, 1964, Wright and McCurry, 1970; McCurry, 1970). This is partly due to the whole continent being involved in a single orogeny, the Pan-African orogenic movement (du Preez, 1956).

The upper layer of the Basement rocks in the area has been highly weathered and has been generally referred to as the weathered mantle (du Preez, 1956; du Preez and Barber, 1965; Olowu, 1967; Wright and McCurry, 1970 and Tokarski, 1972). It is generally so highly decomposed that it is difficult to determine whether it is derived from gnesses or granites (Akpoborie, 1972).

On top of this weathered mantle is a network of superficial deposits (De Swardt, 1946; Folster, 1969; Durotoye, 1976) whose deposition has been influenced by landforms as well as alternating wet and dry seasons. De Swardt, (1946) recognized the presence of aeolian drift among the superficial deposits on the Zaria-Kano plain. According to Turner, (1975) the aeolian drift covers the surface, becoming thinner and finer in texture from the north-east to the south-west on the plain. The usual thickness of the aeolian drift is 0.5 to 2m although Kowal, (1968) refers to depths up to 5m. The thickest of the drift deposits are found in valleys where the drift accumulations have been protected from the actions of erosion. On exposed surface remnants, only a thin veneer of the

drift materials remain today. Pugh and King, (1952) speculated that the source of the aeolian deposits lay to the north of the area somewhere within the confines of the present Sahara.

Geomorphology

The vastly undulating Zaria-Kano plain is thought to be a mid-Tertiary surface (Thorp, 1970) which extends almost unbroken from Sokoto in the west to Lake Chad in the east and from south of Kaduna to Agades in Niger Republic in the north (McCurry, 1973). From its higher part in the vicinity of Zaria-Funtua area the plain slopes south and southwestwards towards the Niger and northeastwards towards Lake Chad. It ranges in altitude from 900 to 100m (Russ, 1959).

The landforms include a series of mature erosion surfaces (pedisediments) with scattered inselbergs. The inselbergs are nearly bare domes of granitic gneisses and migmatite. Pugh and King (1952) grouped the landforms into the "African landscapes" which evolved during the mid-Tertiary cycle of erosion.

The plain is for the most part deeply weathered as mentioned earlier and thickly alluviated especially around Zaria (McCurry, 1973), where a monotonous relief is broken only by occassional granite inselbergs, whalebacks and low quartzite ridges. Typically, the inselbergs rise to about 200m above the surrounding surface or

from more or less level platform of the same rock. The flanks of the larger inselbergs are precipitious. North of Funtua, the topography becomes more rugged being characterized by migmatites and quartzite ridges and well exposed elliptical granite bodies (McCurry, 1970). Uplift, warping and northerly tilting may have had some effect on the present configuration of the plain (Falconer, 1911). Pugh and King (1952), reported that this phenomenon led to the alteration of drainage from the high Zaria plains. As a result, some stream courses have been severed, while some have markedly incised courses, and some others have winding courses due to decreased gradients.

The presence of several terrace levels along some of the more important rivers, and infilled and re-escarvated erosion gullies suggest the occurence of a number of erosional and depositional cycles since Pleistocene time (Wright and McCurry, 1970) which may possibly be related to pluvial and interpluvial stages recorded elsewhere in West Africa (Grove and Warren, 1968; Anderson and Bruckner, 1965; Burke et. al. 1969).

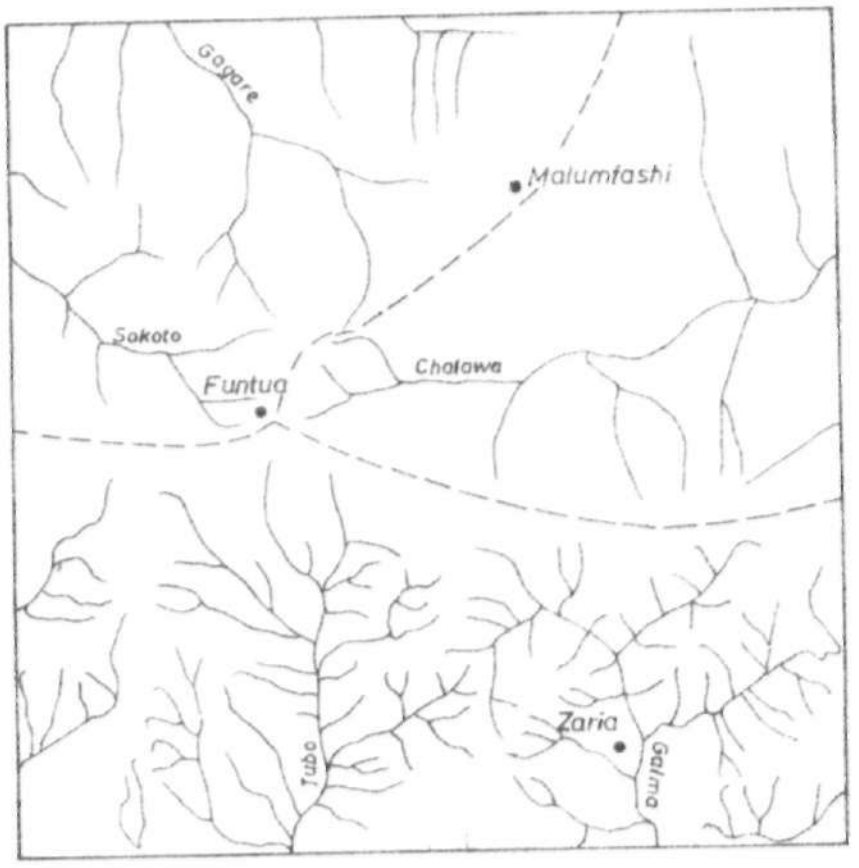
The superficial cover on the plain falls into two main groups: the loessial alluvial deposits and laterite. There are probably several generations of both alluvial and laterite development although only two types of laterite the Older Laterite and the Younger Laterite have been identified in the area (McCurry, 1973).

The Older Laterite forms prominent mesas along watersheds where they are being reduced by active headwater erosion. Such mesas are common features throughout the north of Nigeria, and are believed to be erosional remnants of an extensive laterite peneplain described by du Preez (1956) as being of possible Pliocene age. The Younger Laterite is often found along present river valleys and pediment slopes. This is partly derived from the Older Laterite as a gravelly re-cemented detrital deposit (du Preeze, 1948).

Drainage

The rivers which rise in the plain belong to three major catchment areas (Fig. 2). The southward-flowing rivers emptying into the Kaduna River which is a left-bank tributary of the Niger, drain the entire southern half of the area. The northwestern part is drained by the Sokoto/Rima and Gagare river systems. The northeast is drained by the Kano river and its major tributary, the Chalawa, to the inland basin of Lake Chad. Most of the rivers, including the large ones are silted in their upper reaches, and flow only during the rainy season.

The river divides especially between the northern and southern basins, are marked by prominent laterite plateaux and escarpments. The focal point of the river divides is centered on



SCALE 1:1000,000

Fig 2 A portion of the Zaria – Kano plain showing drainage patterns and density of the three main catchments

Funtua (Fig. 2) falling on a major east-west axis of the divide or watershed. (Russ, 1957).

Slopes along river profiles while attaining comparatively steep gradients in certain restricted areas, are generally low, varying between ½% and 4% (Thorp, 1970).

Land Use in Kaduna State

In discussing man's activities, it is befitting to start with his agricultural activity because it has the most effect on the course of soil development (Fagbami, 1976).

The following is an outline of the land use types actively pursued on the plain especially in Kaduna State.

1. Arable farming (Plate 1)
2. Forestry
3. Firewood/Timber exploitation
4. Road construction
5. Urban expansion and the associated gravel digging and quarrying activities.
6. Traditional crafts and industries
7. Industrial development.

Arable farming, forestry and firewood exploitation have led to the development of three major types of land use similar to that described around Zaria by Davies (1970). Immediately around

Plate 1. Arable farming around Zaria, Kaduna State.

the settled areas (villages and urban areas) cultivation is intense, with little land under rotation. Further away, the pressure on land is less intense, large areas are under rotation cropping and patches of woodland increase in number and extent. Further away still, the cultivated areas become isolated clearings in the savanna. It is in the latter land use type that most of the firewood used in urban areas comes from. Thus man's effect in modifying the soilscape decreases in extent from the settled areas.

Arable farming consists of subsistence farming through a system of bush fallowing where population is not dense. Small parcels of land are cleared and planted to annual crops. Main food crops include maize, millet, rice, sorghum and yams. Minor crops include cabbage, carrot, onions, potatoes, and tomatoes. Cash crops include cotton, groundnuts, and tobacco. There are government agencies that buy and market the cotton and the groundnuts while the Nigerian Tobacco Company is responsible for buying all the tobacco. Tobacco as a crop is widely grown throughout the state as both a wet and a dry season crop. Most of the crop is used for cigarette production within the country. Zaria and Ikarra Local Government areas are leading growers of the crop.

Tree-felling for firewood is vastly modifying the soilscape through soil compaction by log-carrying trucks and exposure of soils

to erosion owing to removal of vegetative cover. The lack of coal or natural oil for home use by the increasing population will obviously promote further tree-felling on the plain. Thulin, (1965) has estimated that the average firewood consumption in the Zaria area is 22.3 cubic feet per head per annum and by 1980 his projections indicate an increase of over 20% in consumption. Tree-felling is already telling on the land, the effects of which manifest in soil erosion and land degradation. To arrest the situation, the government set up a number of forest reserves for controlled tree felling, but it appears these are inadequate.

Previous Soil Studies

References to the soils of Zaria can be found in the studies by Lawes (1962; 1964) Kowal (1968; 1970), Higgins (1963) and Bennett et. al., (1977). Valette has carried out recently, a reconnaisance soil survey of Kaduna-Samaru-Kano area, but the report is still under preparation. Ojanuga, (1979b) reported some physical and mineralogical characteristics of the soils of the Kaduna-Zaria area. Malgwi (1979) carried out a detailed soil survey of an area on the left bank of the stream in the survey area (Fig. 3). These studies provide the only literature available on soils around Zaria. However, most of these studies are not on the scale of a

soil survey and therefore the information provided on soils is scanty.

SITE INFORMATION

Location

The project area is located at the northwestern corner of the Ahmadu Bello University farm situated along the Zaria-Funtua road. The site is directly behind the water dam (Fig. 3). The farm is about 8 km. northwest of Samaru and serves as a research base for both staff of the Faculty of Agriculture and the Institute for Agricultural Research. The project area covers about 160,000 m^2.

Geology

Reference to the geology of the Samaru-Zaria area can be found in the studies by Olowu, (1967), McCurry (1970), Wright and McCurry (1970), Tokarski (1972), Karofi (1972), and Akpoborie (1972). Briefly, the Zaria area is underlain by low-lying and often deeply weathered biotite gneisses. Porphyroblastic granites form the prominent inselbergs of Kufena Hill and several smaller hills in the area. The gneisses form part of a crystalline complex. Occuring within the gneisses and alternating with them in places are schists. Close examinations of these schists showed

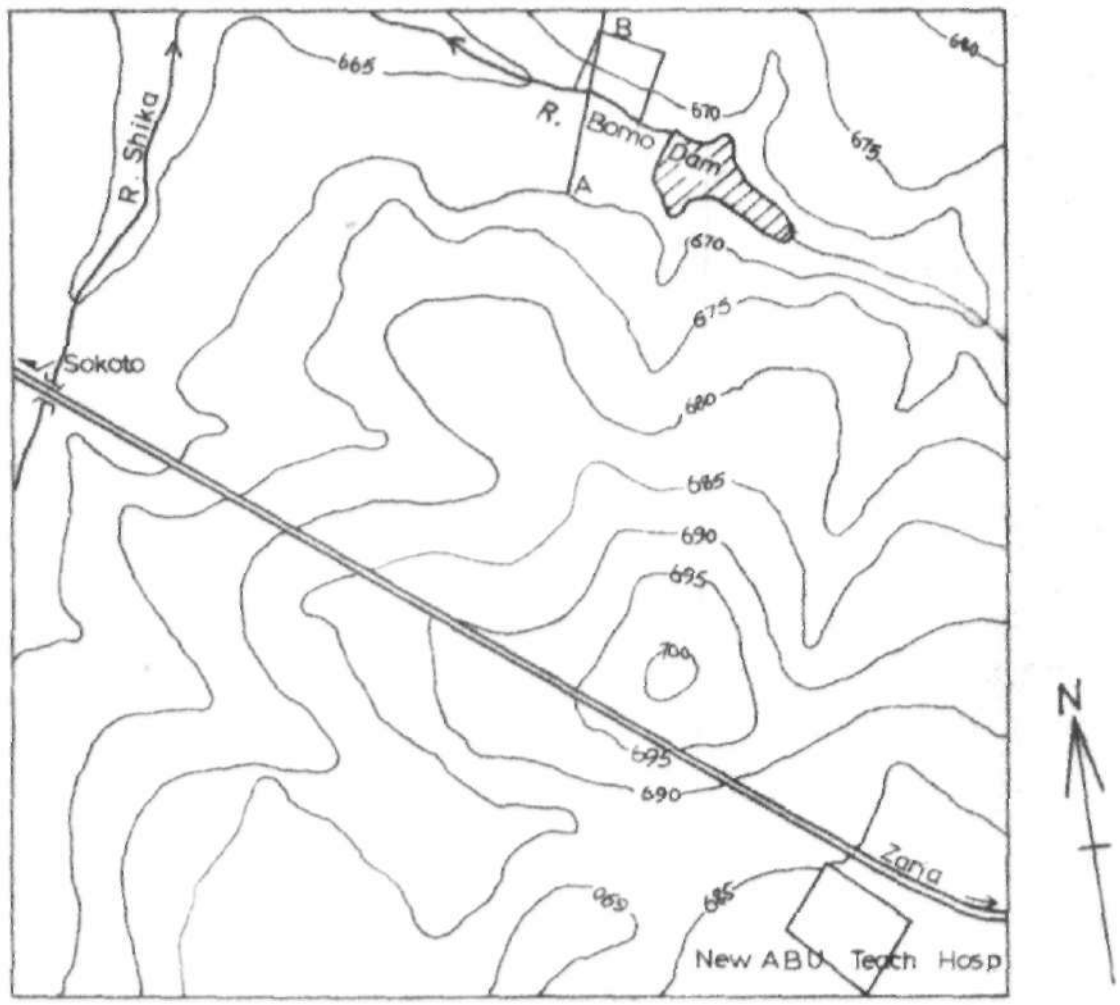


Fig 3 Topographic map of the study area
The boxed area is the "site" and transect AB is a cross profile through the "site"

that they contain muscovite, quartz, feldspars and traces of biotite (Akpoborie 1972).

No bare rock is exposed within the study area but quartz veins and mica shists traverse the rotted rock in places as evident in burrow pits near the project site (Plate 2). There is a distinct juncture between weathered rock material (residua) and fresh rock in places (Plate 3). As has been mentioned earlier, the mantle of residua is overlain by aeolian deposits. (Plate 4).

Climate

Rainfall is the most important climatic variable and it is its seasonality, intensity and amount which are of overriding importance in pedological studies. From about October to March, the area is subject to cool, dry northeasterly winds which yield virtually no rain. Over these months, vegetative growth decreases to a minimum, the solum dries out and pedogenetic processes are slowed down. From April to May, the seasons change; the moist southwesterly winds bring rains, vegetative activities start again and the processes that develop the solum are at work again.

The seasonal distribution of mean monthly rainfall for Samaru is given in table 1. From the table it can be seen that the peak rainfall months in the area are July, August and September when about 67% of the rain falls. Over 25% of rainfall in the area

Plate 2. Mica schist in saprolite in the vicinity of the project site.



Plate 3. Quartz veins traversing saprolite in the vicinity of the project site.

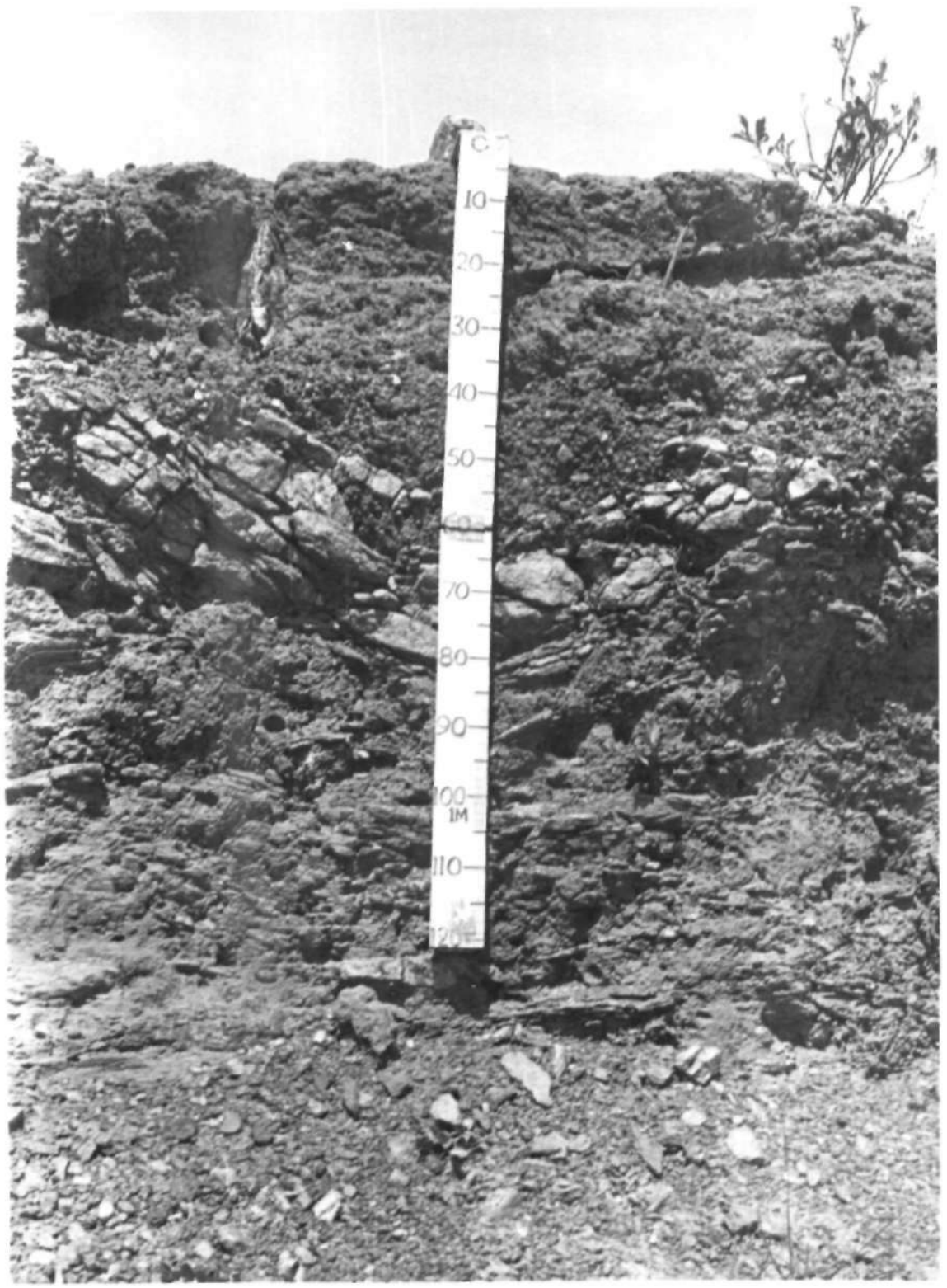
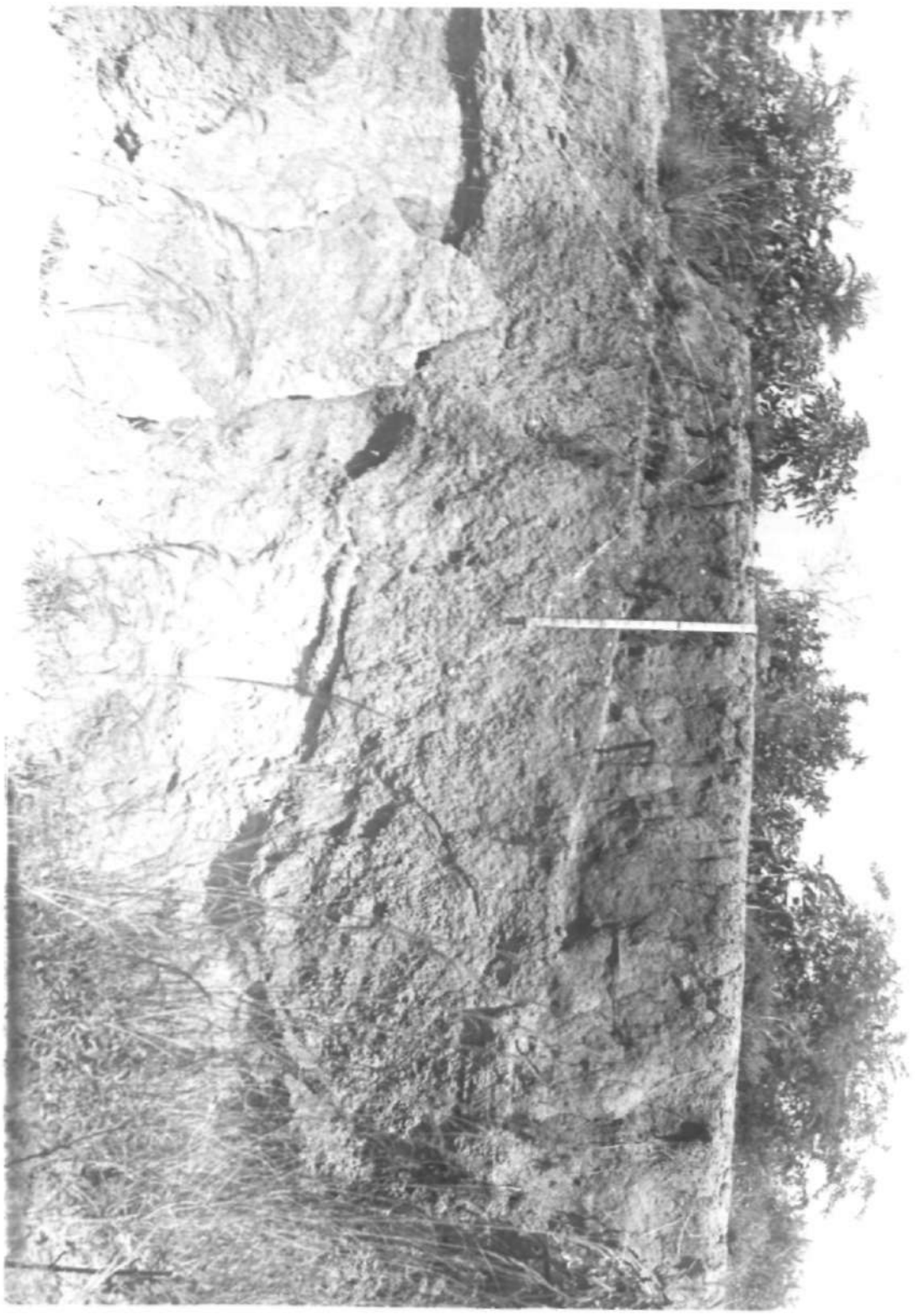
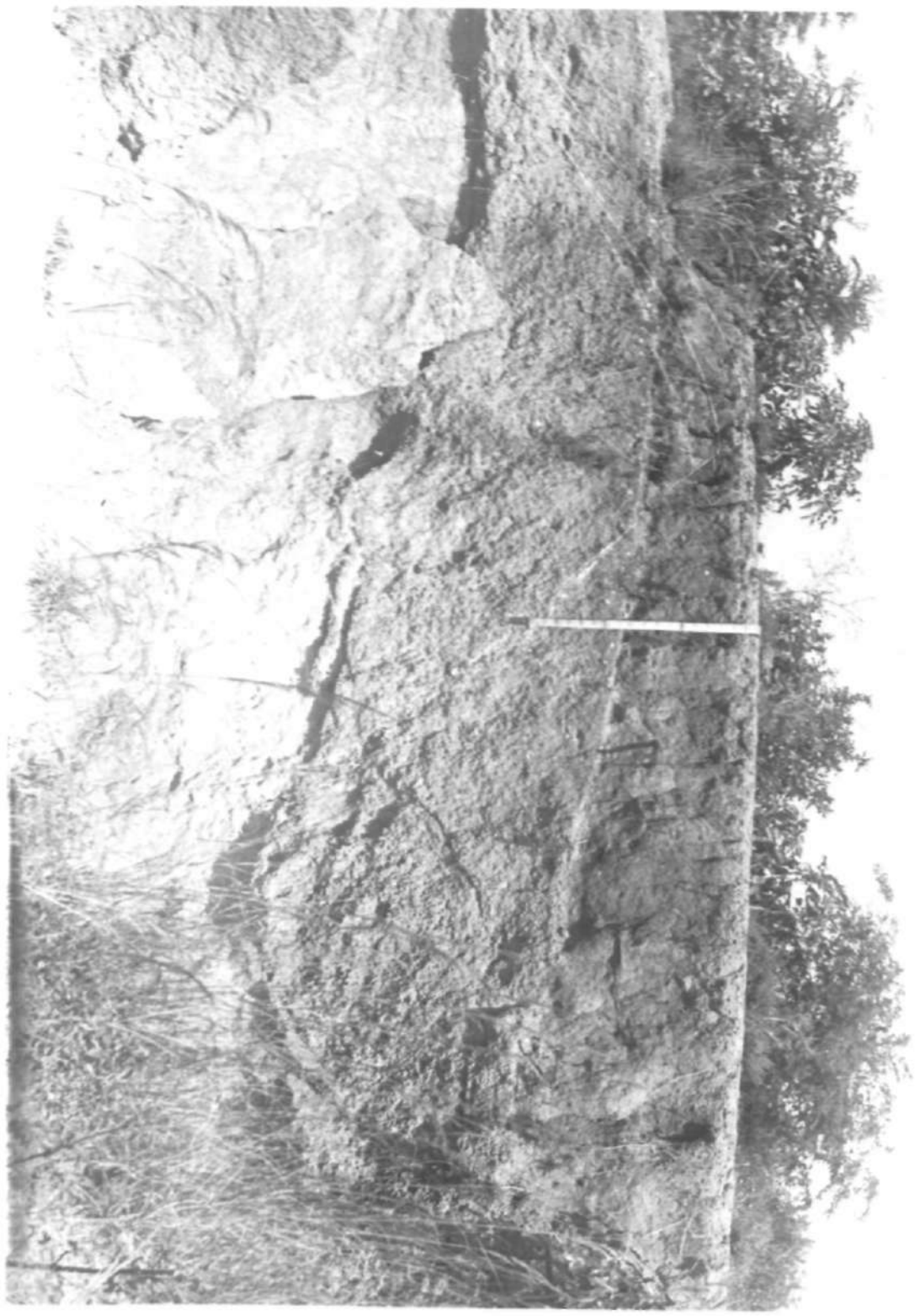
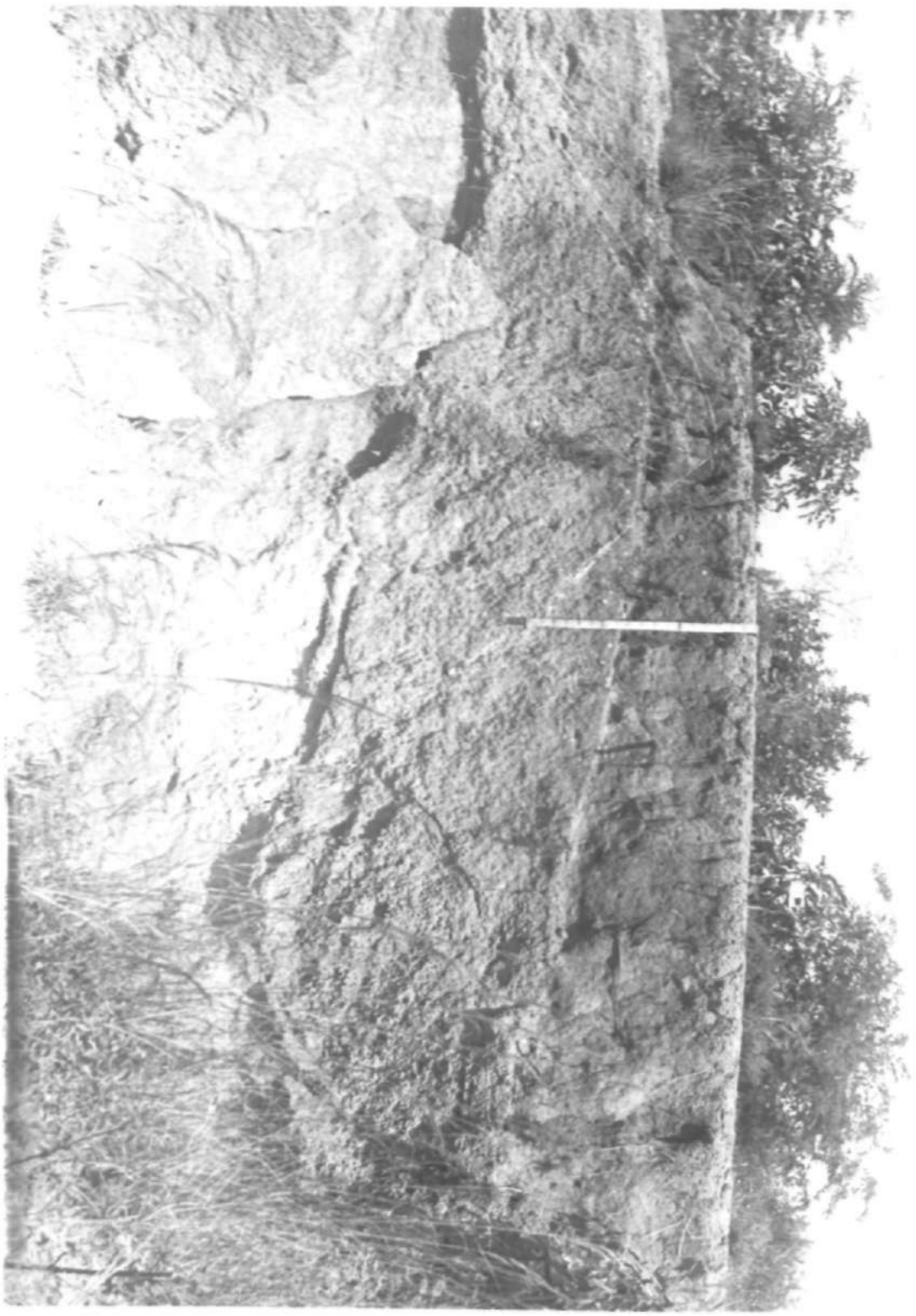

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1M
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Plate 4. Loess over saprolite in Zaria area.





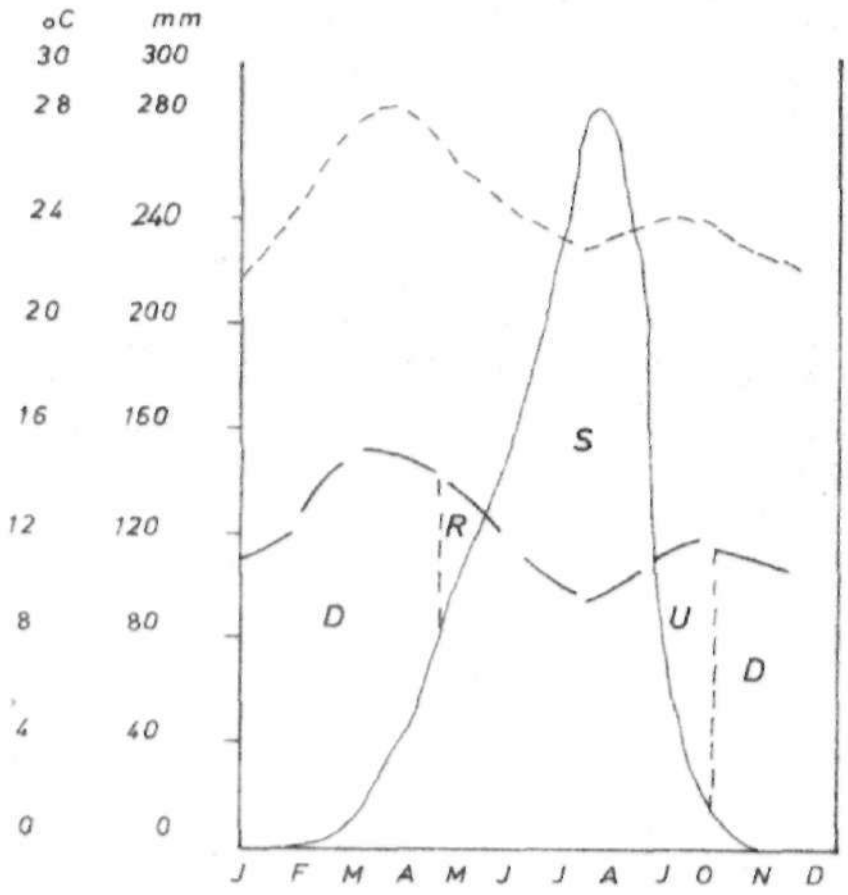


comes in August alone. This is illustrated by the rainfall distribution curve for Samaru, using the 50 year mean (Fig. 4). Much of the rainfall, particularly in July and August, is associated with storms of high intensity (Ologe, 1972).

The rainy season which can be defined as the number of days between the first and last rainy days of the year when precipitation is equal or greater than 1mm varies greatly in length. Benoit (1976) illustrates this feature with records over the period 1965 to 1971 from Samaru when the number of days ranged from 164 to 231.

Rains et. al., (1977) estimated from the work of Kowal and Knabe (1972) that the mean date of start of rains and the mean date of end of rains in Samaru are May 24th and October 8th respectively. Mean date of start of rains is defined as the 10-day period in which rainfall is greater than 25.4mm followed by two subsequent 10-day periods when rainfall is greater than half evapotranspiration, while the mean date of end of rains is defined as the last 10-day period in the rainy season with at least 12.7mm rain and with evapotranspiration in the previous 10-day period not less than precipitation. The computed date for start of rainy period varies between 26th April and 1st June, whereas the end of rains occurs during October in a much more abrupt manner.

From this rainfall distribution pattern, the soil moisture regime for the Samaru area is inferred to be USTIC. This is



Rainfall

Evapotranspiration

Temperature

U , Utilization

D , Deficit

R , Recharge

S , Surplus

Fig 4 Distribution of rainfall, evapotranspiration and temperature at Samaru

because the soil dries in some or all parts for more than 90 cumulative days during the period Dec. - early April in most years, but the soil moisture control section is continously moist in some part for at least 90 consecutive days during the period June to October.

The rainy period is considered to be that of a positive water balance in the soil. From a soil formation point of view, it is a period of intense chemical, biological and even physical pedogenetic activity, whereas during the dry season, such activity becomes attenuated.

The energy component of the rainfall systems (intensity) is known to be large as has been pointed out earlier. This, together with the amount of water they hold and the generally high rate of precipitation implies a great erosive potential (Rains et. al., 1977). The rainfall erosivity degrades the soil and is thought to be the reason for the high rate of occourrence of erosion by surface wash and of gullying in the area (Ologe, 1972; Rains et. al., 1977).

Average rainfall in Samaru is 1108mm per annum. It however has its relatively dry and wet years. The driest year during the 50-year period 1927 to 1978 was 1961 with 817mm and the wettest year during the same period was 1954 with 1469mm.

Pattern of radiation and temperature

Mean daily number of sunshine hours per annum in the study area is about 8 hours (Kowal and Knabe, 1972; Table 1) although the mean day length per annum is about 12.5 hours (Rains et. al., 1977). This is due to the fact that clouds in the rainy season, and harmattan dust in the dry season greatly modify the pattern of radiation and reduce the annual daily average by about 5 hours.

Table 1 shows evapotranspiration (mm), mean monthly air temperature (°C) and mean monthly soil temperature (°C) at Samaru.

Temperature is high in the area and annual range is small (Table 1; Fig 4). The thermal conditions are of Sahelo-Sudanese type (Maignien,1961). Monthly and seasonal variations in temperature are pronounced. The range of maximum mean 10-day temperature is 27.3°C to 35.7°C. The maximum mean daily temperature drops during the dry season which also coincides with the period of harmattan, and increases in March, reaching the major peak in April, just before the rains. It then drops to its lowest value in August. It rises again to its secondary peak in October. The range of minimum mean 10-day temperature is 13.1°C to 22.1°C. It rises from its lowest value in December/January to its highest value in April.

The mean monthly temperature shows a marked seasonal effect, being relatively high in the dry season. The lowest mean monthly

Table 1: Temperature, rainfall and other meteorological information at Samaru.

11°11'N, 07°38'E; 685m altitude.

Observation	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total or Daily Mean	Years of record
Air temp. (°C)	21.9	23.9	26.9	28.4	27.3	24.8	23.7	23.3	23.9	24.3	23.2	22.1	24.5	50
Soil temp. (°C)	26.2	29.5	34.0	35.1	33.4	29.7	27.6	26.7	28.3	29.0	27.2	26.1	29.4	10
Rainfall (mm)	0.2	2.2	7.2	36.0	126	165	221	281	230	36	2.2	0.1	1106.9	50
Sunshine (hr)	9.4	8.9	8.6	8.0	8.1	7.3	6.5	6.0	7.6	7.0	9.5	8.8	8.0	15
Evapotranspiration (mm)	115.6	120.7	146.5	153.2	153.7	125.4	107.6	97.1	106.9	119.6	108.8	106.4	1461.5	15

temperature (22°C) occurs in December/January owing to the cooling effect of the harmattan. Mean annual temperature is 24.5°C.

The mean monthly soil temperature at the 5cm depth in Samaru is high (Table 1). It varies between 26.1°C in December to 35.1°C in April with an annual mean value of 29.4°C, and is usually higher than the corresponding air temperature. Soil temperatures at deeper depth are higher still, and the range is less. At the 50cm depth, the mean hot season (summer) and cool season (winter) soil temperature differ by less than 5°C (Malgwi, 1979). An isohyperthermic soil temperature regime is therefore inferred. The high soil temperature speeds up all chemical and biological processes, more so during the rainy season when percolating water complements high temperatures.

Evapotranspiration

Evapotranspiration is a good measure of the depletion of soil water. Data on evapotranspiration in Samaru is given in Table 1. The mean monthly values varied between 97.1 and 153.7mm with an average of 121.8mm. The factors responsible for such high evapotranspiration rates are the high rates of solar radiation, lack of adequate vegetal cover, and wind action. The annual evapotranspiration (1461mm) is in excess of annual rainfall (1107mm). There are however, periods of the year when rainfall is in excess of evapotranspiration (Fig 4). This is the four-month period from about late May to September (Table 1). Over most of the remaining eight months, there is a water deficit in the soil.

Vegetation

Keay, (1953) classified the vegetation of the study area into the Northern Guinea Savanna type. It is an open sub-humid broad-leaved savanna woodland with short to medium grasses. Isoberlinia doka, I. tomentosa, Monotes kerstingii, Daniellia oliveri and Uapaca togoensis are characteristic woody species of this vegetation zone. Undisturbed, a single-story savanna woodland with a light canopy is formed. In the project area, as is the case in most parts of northern Nigeria, the savanna woodland has been disturbed by burning, tree-felling for firewood and timber, and cultivation. As a result of a combination of these factors, the characteristic vegetation one sees in the area is one of open shrub woodland in varying stages of regrowth. In more intensely cultivated zones around towns and villages, an open park-like landscape of large trees set in cultivated fields has evolved. (Plate 5).

A little savanna woodland still remains, however, in isolated places where population is not dense.

There are many fire-resistant species, all of them part of the woody vegetation. Appendices 1, 2 and 3 list the vegetative species collected from the project area.

The floodplain (fadama) usually carry a characteristic

Plate 5. Park-like landscape of Ceiba pentandra set in cultivated fields around Zaria.



grassland vegetation. Trees and shrubs are usually absent, although widely scattered low trees of species such as Mitragyna inermis and Terminalia glaucescens may occur in some fadamas. (Rains et. al. 1977).

The typical fadama grassland population in the study area are Elionorus pobeguinii and Paspalum orbiculare. They generally constitute an extremely important source of dry season fodder.

METHODS AND MATERIALS

Field Studies

The project site, almost $(400m)^2$ in the Ahmadu Bello University farm was selected and a detailed soil survey was carried out. The area is northwest of the main dam and is on the right bank of the Bomo river (Fig. 3). This area, henceforth referred to as the "site" occupied the upper to lower slope positions between the contours 665m and 675m above sea level.

Traces 50m apart were cut in alignment with the general slope of the land and the soils were examined along these. By this procedure the soils of the area were mapped. In order to characterize each of the soil units detected by mapping, at least two soil profiles were dug in each of the soil units.

The soil profiles were described. Following their descriptions bulk soil samples were collected from each horizon and analysed in the laboratory for their physical and chemical characteristics. Undisturbed soil clods were also taken from the soil profiles for bulk

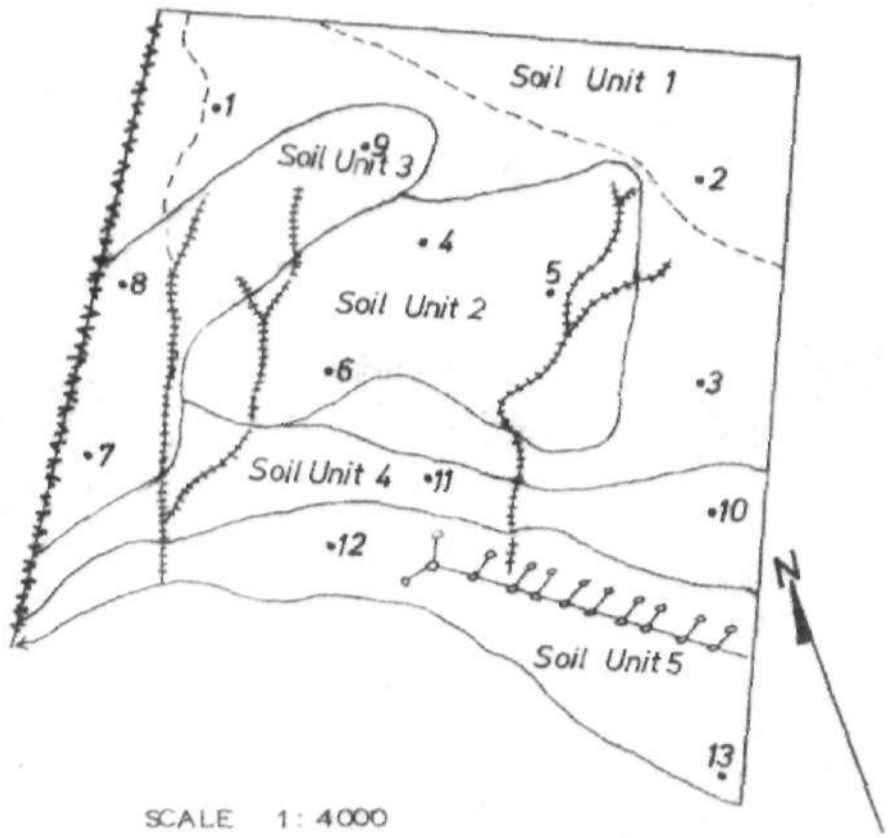


Fig 5 Detailed Soil survey map of the project site

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density studies. Fig. 5 shows the extent of each soil unit and the general layout of the profiles.

Laboratory Studies

The bulk soil samples were air-dried for several days. Those intended for physical and chemical analysis were fractionated into two separates, gravel ($\geq$ 2mm) and fine earth ($<$ 2mm). Undisturbed clods for bulk density were kept intact until needed.

Particle size distribution

Particle size distribution was determined by the method described by Day (1965). Stones and gravel were first determined by direct sieving followed by weighing. Sand, silt and clay were determined by the Bouyoucos hydrometer using sodium hexametaphosphate as dispersant and determining sizes and amounts of particles settling by employing progressive time intervals. Sand fraction was collected, dried and sieved into the different size ranges using 1000, 500, 250 and 53μm seives in series (Day, 1965).

Bulk density

Bulk density was determined by the method described by Blake (1965) with the modification that the paraffin-coated clod

was immersed in water and reweighed. The volume of clod plus paraffin was then calculated by employing the data of the density of water at the temperature of determination and the weight of water displaced by the clod and paraffin. The volume of paraffin was calculated from its density and weight. The volume of soil was then obtained by difference.

Particle density

Samples for particle density were further ground and passed through a 210 µm mesh sieve. Particle density was then determined in water after the expulsion of air bubbles in a 50-ml pycnometer (Blake, 1965).

Porosity

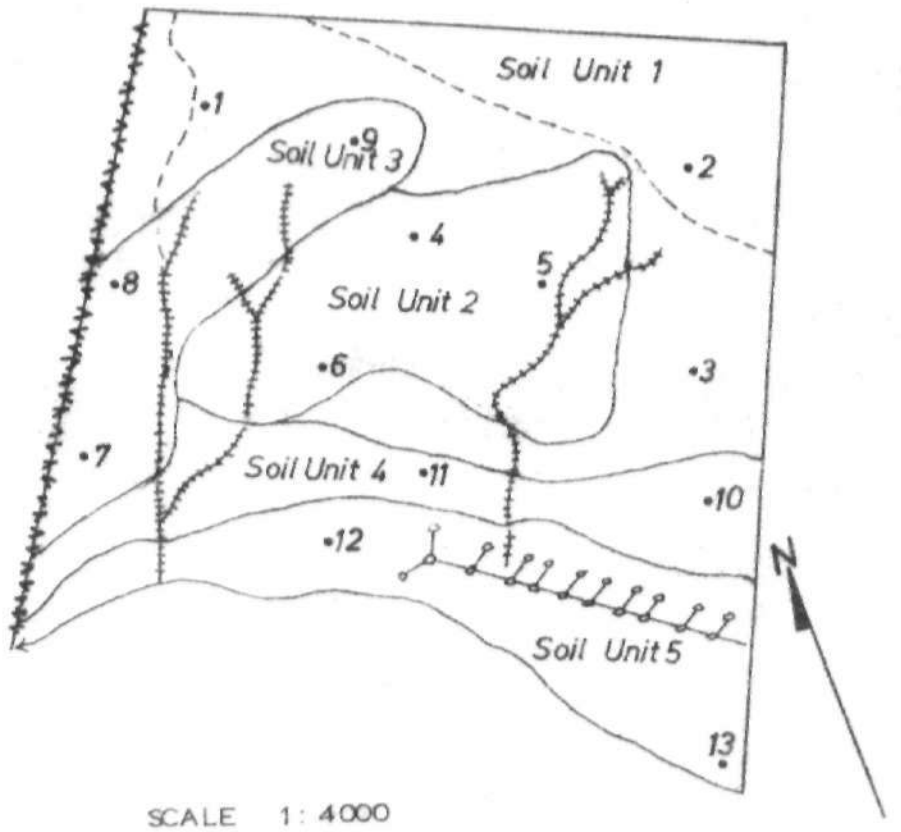
Porosity was calculated mathematically from the results of bulk and particle density (Vomocil, 1965) using the relation

$$P = 100\ (1-Db/Dp)$$

where P is porosity;

Db is bulk density and

Dp is particle density.



SCALE 1 : 4000

40 0 40 80 120 160 metres

Fence
Soil boundary
Erosion courses (rills)
Drainage channel (Agric Eng. project)
Footpath
Stream
•1,2,3..13. Profile pit

Fig 5 Detailed Soil survey map of the project site

Organic carbon

Organic carbon was determined by the Walkley-Black method (Jackson, 1958; Allinson, 1965). The method involved the digestion of the soil organic matter by potassium dichromate ($K_2 Cr_2 O_7$) using concentrated sulphuric acid to increase the temperature and hasten reaction.

The soil was finely gound and sufficient sample was weighed to contain 10-15 mg of carbon. Generally, the sample weights varied between 1g for the topsoils and 2gms for the subsoils. The sample was placed in 500ml conical flask and 10 mls of 1 N $K_2 Cr_2 O_7$ added. 20 ml of concentrated sulphuric acid were then added and the contents of the flask mixed by gentle rotation. The reaction was left on for 30 minutes after which the mixture was diluted to 250 mls with distilled water. Excess dichromate was back-titrated with ferrous ammonium sulphate using barium diphenylamine sulphonate as indicator.

Soil pH

Soil pH was determined on 1:1 soil: water pastes using a Coleman Metrion IV pH meter.

Cation exchange capacity

Cation exchange capacity was determined using three analytical procedures, namely; neutral acetate saturation followed by displacement of the adsorbed NH_4^+ by the acid-NaCl method described by Chapman (1965), sum of exchangeable metallic cations plus $BaCl_2$-TEA exchange acidity (Chapman, 1965), and sum of exchangeable metallic cations plus 1N KCl extraction of exchangeable H and Al by the titration procedure outlined by McLean (1965).

Exchangeable cations

Exchangeable K, Na, Ca and Mg were extracted with 1N NH_4OAc (pH 7) using a 1:10 soil solution ratio. K and Na in the filtered extracts were determined with a Gallenkamp Flame Analyzer while Ca and Mg were determined with a Parkin-Elmer Model 290B atomic absorption spectrophotometer (Chapman, 1965).

Extractable acidity

Extractable acidity was determined by successive leaching of soil with 1N KCl using a 1:10 soil solution ratio . The amounts of exchangeable H and Al in the leachates were determined by the titration procedure outlined by McLean (1965).

Exchange acidity

Exchangeable acidity or total exchange acidity was determined by two methods, viz the ammonium acetate method described by Peech (1965), and the leaching method described by Peech et. al., (1962) using $BaCl_2$-Triethanolamine solution adjusted to pH8

Total free iron oxide

The extraction procedure outlined by Olsen, (1965) was used. Samples were ground to pass through a .21mm mesh sieve in order to ensure complete extraction. The Fe was reduced and removed from the soil with sodium dithionite ($Na_2 S_2 O_4$). The suspension was then adjusted to pH 3.5-4.0 to dissolve any ferrous sulphides formed, and the excess $Na_2 S_2 O_4$ was later destroyed with $H_2 O_2$. Excess $H_2 O_2$ was removed by addition of NH_4OAc with boiling. The Fe^{3+} was then reduced to Fe^{2+} with $Sn Cl_2$ and the excess $Sn Cl_2$ oxidized by addition of $Hg Cl_2$. The Fe^{2+} was then titrated with $K_2 Cr_2 O_7$ using barium diphenylanie sulphonate as indicator.

Statistical Analysis

Where possible, differences in soil properties among the soil mapping units were tested by the analysis of variance using chemical and physical data. Statistical significance was tested at the 0.1% and 1% levels of significance.

RESULTS AND DISCUSSION

Soils around Zaria are formed in loess (a silty aeolian deposit) underlain by basement complex rocks. In most cases, the loess forms the main parent material.

The loess was once a thick extensive deposit which was pedimented in more recent times. At lower slope and other shielded positions where erosion was not drastic, thicker loess often occur; however in areas that have been actively pedimented, a thin loess usually mantles rock, saprolite or ironpan. Lithologic discontinuities mark the juncture between loess and underlying material. Such lithologic discontinuities are common within the upper 300 cm of the soil surface in the upper slope positions. Plates 2, 3 and 4 show the general relationship of soil parent materials in the study area.

Soil parent material in the fadama is usually an admixture of sediments of varying composition.

Soil Morphology

Five soil units were identified during the field survey (Fig 5). Fig 6 shows the topographic relationship of the five soil units. A representative profile was described in each of the five soil units below.

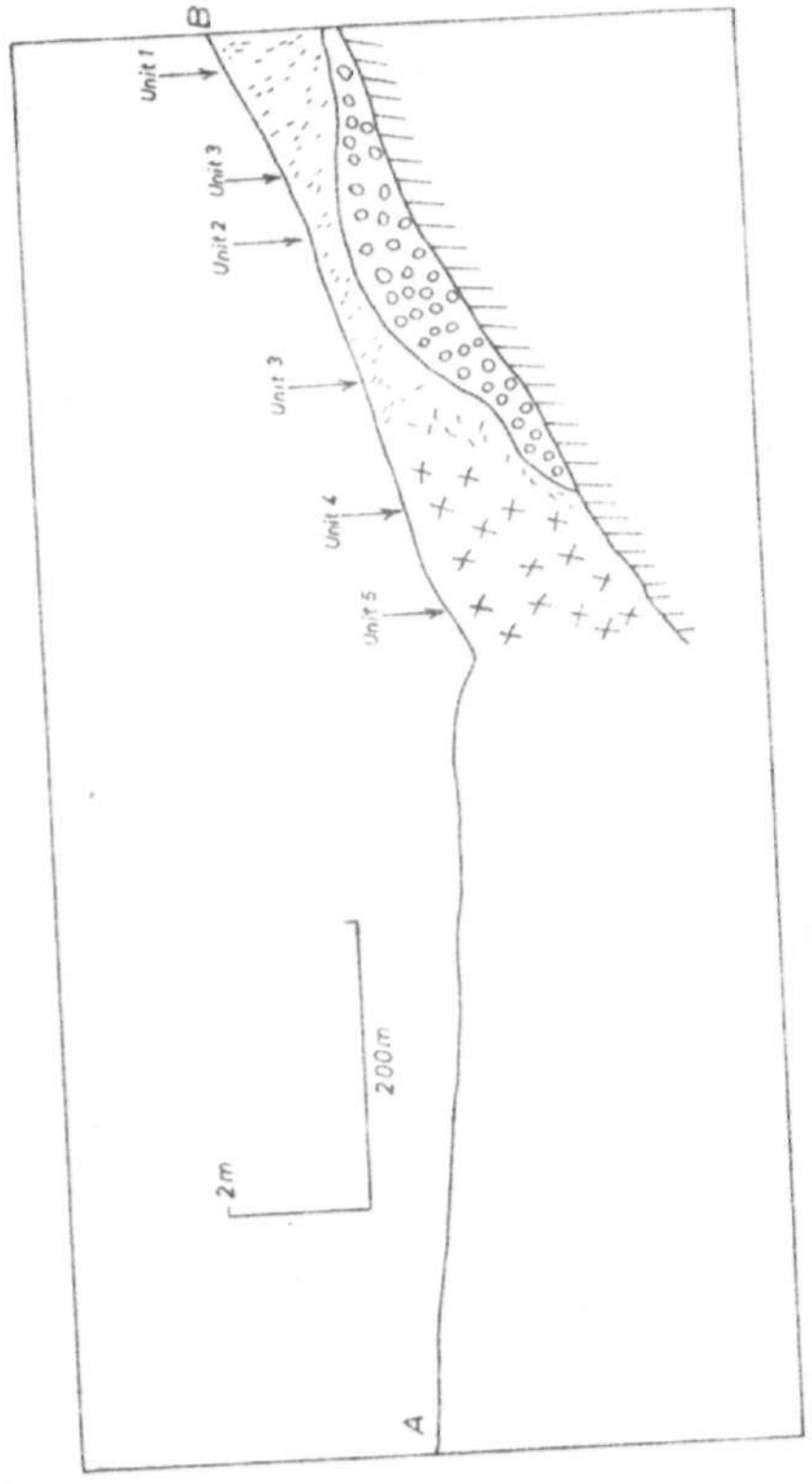


Fig 6 Topographic relationship of the five soil units

Soil descriptions follow the pattern described in the Soil Survey Manual (Soil Survey Staff, 1951) as revised in 1962. Soil descriptions are for the moist soil state unless otherwise stated.

Soil unit 1

Soil unit 1 includes well drained yellowish red (5YR 4/6) clay soils with thin (about 12cm) brown (10YR hue) loam surface horizons. The soils are deep, and occupy midslope positions. Typical profiles show a lithologic discontinuity at about 200cm.

The soils exhibit strong structural development, and there is evidence of clay lessivation as indicated by the occurence of clay skin on ped surfaces. Argillic horizons are diagnosed in the soils on the field.

A soil profile (profile 1) typifying the soils of the unit is described as follows:

Profile 1

Parent material	:	Thick loess over saprolite.
Topography	:	1% slope; mid-slope position.
Drainage	:	Well drained
Vegetation	:	Isoberlinia doka with tall Hyparrhenia and Ctenium newtonii grasses.
Depth of water table:		Water table below 200cm

Horizon	Depth	Description
A1	0 - 14cm	Brown (10YR 5/3) sandy loam; moderate fine and medium crumb structure; friable; common very fine vertical and oblique pores; abundant fine roots; pH 5.6; clear smooth boundary.
$B21_t$	14 - 25cm	Yellowish red (5YR 4/8) clay; strong medium to coarse subangular blocky structure; friable; common fine pores; many voids and channels having thin clay films and ped surfaces having thin yellowish brown clay films; abundant fine to coarse roots; pH 5.6; gradual smooth boundary.
$B22_t$	25 - 60cm	Yellowish red (5YR 4/6) clay; strong medium to coarse subangular blocky structure; friable; many fine and medium pores; thin cutans on some ped surfaces and in root channels; frequent fine to coarse roots; pH 5.8; diffuse smooth boundary.
$B23_t$	60 - 100cm	Yellowish red (5YR 4/6) clay; strong medium to coarse subangular blocky structure; friable; many fine and medium pores;

continous thick cutans on ped surfaces and root channel walls; few medium roots; pH 6.1; diffuse smooth boundary.

$B2l_t$	100 - 130cm	Yellowish red (5YR 5/8) clay; moderate medium subangular blocky structure; friable; few fine pores; clay coatings on ped surfaces; few medium roots; pH 6.1; diffuse smooth boundary.
B3	130 - 170cm	Yellowish red (5YR 5/8) clay; moderate medium subangular blocky structure; friable; few fine pores; thin clay films on ped surfaces; few medium roots; pH 6.0

Soil unit 2

Members of this soil unit are well drained gravelly concretionary clay loam soils. The colour of the surface horizon is dark brown (10YR 4/3). The colour of the subsoil horizons is strong brown (7.5 YR 5/6) tending to reddish yellow (7.5YR 6/8) towards the C horizon. The soils commonly occur at the break of slopes where erosion processes are actively at work and have eroded the superficial loess to a thin layer. A lithologic discontinuity marks the juncture of the loess and colluvial

material which commonly occurs within 60cm of the soil surface and contains moderate to abundant gravelly materia .s.

The coarse fractions are dominantly nodular iron oxide bodies. Small amounts of quartz also occur in the gravel fraction of the soils. The iron oxide nodules are thought to have been inherited from past erosional phenomena. The gravelly horizons begin from about 30cm depth and extend to about 160cm depth. The gravel content increases in amount with depth with maximum value attaining about 20% by volume of the horizon materials.

Structural development is weak and white patches occur in the soil matrix from about 100cm depth, increasing in abundance with depth.

Soil profile 5 which is a representative of this soil unit is described below.

Profile 5

Parent material	:	Thin loess over gravelly colluvial material over saprolite.
Topography	:	2% slope; midslope position.
Drainage	:	Well drained.
Vegetation	:	Isoberlinia doka with Hyparrhenia grasses.
Depth of water table	:	Water table below 200cm

Horizon	Depth	Description
A1	0 - 10cm	Dark brown (10YR 4/3) sandy clay loam; moderate fine and medium crumb structure; friable; many fine pores; common fine roots; pH 6.1; clear smooth boundary.
B21	10 - 25cm	Strong brown (7.5YR 5/6) slightly gravelly sandy clay loam; weak medium subangular blocky structure; friable; common fine to medium pores; gravel consisted of abundant small rounded hard iron oxide nodules and few small quartz gravels; common medium roots; pH 5.8; abrupt smooth boundary.
$IIB22_{ton}$	25 - 60cm	Strong brown (7.5YR 5/6) slightly gravelly clay loam; weak medium to coarse subangular blocky structure; friable; many fine and medium pores; gravel (about 10% by volume) consisted of abundant small rounded hard unzoned iron oxide nodules, and few small quartz gravel; few medium roots; pH 5.9; gradual smooth boundary.
$IIB23_{ton}$	60 - 90cm	Reddish yellow (7.5YR 6/8) slightly gravelly clay loam; with few fine distinct white

(7.5YR 8/0) patches; weak moderate to coarse subangular blocky structure; friable; many fine to medium pores; gravel (about 15% by volume) consisting of abundant medium rounded hard iron oxide nodules and few quartz gravel; few fine roots; pH 6.1; gradual smooth boundary.

$IIB24_{tcn}$ 90 - 120cm Reddish yellow (7.5YR 6/8) slightly gravelly clay loam; with few fine distinct white (7.5YR 8/0) patches; weak medium subangular blocky structure; friable; many fine and medium pores; gravel content and composition similar to that in $B23_{tcn}$ above; few fine roots; pH 6.1; gradual smooth boundary.

$IIB25_{tcn}$ 120 - 140cm Reddish yellow (5YR 6/8) gravelly clay loam; with many distinct white (7.5YR 8/0) patches; weak medium subangular blocky structure; friable; many fine pores; gravel (about 20% by volume) has composition similar to that in the overlying horizons; few fine and medium roots; pH 6.1; gradual smooth boundary.

$IIB3_{ton}$	140 - 180cm	Reddish yellow (7.5YR 6/8) gravelly clay; common medium distinct wh_te (7.5YR 8/0) patches; weak fine to medium subangular blocky structure; friable; many fine pores; gravel content and composition similar to those in the above horizon; few fine roots; pH 6.1.

Soil unit 3

These are moderately deep well drained clay loam soils. The loess in this soil unit is distinctly thin as in soil unit 2. The gravelly horizons are deep and the gravel is rather diffused through the horizons.

Colour in the surface horizon is characteristically yellowish brown (10YR 5/4). In the subsurface B horizons, colour ranges between dark brown (7.5YR 4/6) and strong brown (7.5YR 5/6). The C horizons are either reddish yellow (7.5YR 6/8) or yellowish brown (10YR 6/8) and are appreciably mottled white (10YR 8/0). Soft iron nodules may be found in some of the soils (e.g. profile 9).

Sheet erosion is actively at work on these soil surfaces and some soils have developed rills (Fig 5). Profile 9 is described as the representative of the soil unit.

Profile 9

Parent material : Loess over colluvium and saprolite.

Topography : 2% slope; midslope position.

Drainage : Well drained

Vegetation : Tall and short Hyparrhenia ctenium grasses with Butyrospermum woody species.

Depth tp water table : Water table below 200cm

Horizon	Depth	Description
Ap	0 - 22cm	Yellowish brown (10YR 5/4) clay loam; moderate fine to medium subangular blocky structure; friable; many fine vertical and oblique pores; few fine roots; pH 6.0; clear smooth boundary.
$B21_t$	22 - 42cm	Dark brown (7.5YR 4/4) clay loam; strong medium subangular blocky structure; friable; many fine pores; few fine and medium roots; pH 5.8; abrupt smooth boundary.
$B22_t$	42 - 75cm	Strong brown (7.5YR 5/6) clay; strong medium to coarse subangular blocky structure; friable; many fine and medium pores; few fine and medium roots; pH 5.6;

gradual smooth boundary.

$B23_{tcn}$ 75 - 100cm Strong brown (7.5YR 5/6) clay; moderate medium to coarse subangular blocky structure; friable; many fine and medium pores; few soft red iron concretions; few fine roots; pH 6.1; abrupt smooth boundary.

$B24_{tcn}$ 100 - 130cm Strong brown (7.5YR 5/6) slightly gravelly clay loam; with few fine white (7.5 YR 8/0) patches exhibiting a clear boundary with the surrounding matrix; moderate fine to medium subangular blocky structure; friable; many fine pores; gravel consisting of small hard brownish iron oxide nodules and quartz gravel; few medium and coarse roots; pH 6.1; clear smooth boundary.

$B31_{tcn}$ 130 - 150cm Reddish yellow (7.5YR 6/8) slightly gravelly clay loam; with few fine diffuse white (7.5YR 8/0) patches; weak fine to medium subangular blocky structure; friable; common fine pores; gravel content and composition as in $B24_{tcn}$ above; few medium and coarse roots; pH 6.1; clear smooth boundary.

$B32_t$	150 - 180cm	Yellowish brown (10YR 6/8) slightly gravelly clay loam; with white patches as in the horizons above; weak fine to medium subangular blocky structure; friable; common fine pores; (about 15% by volume) gravel consisting of large soft iron oxide nodules; few medium roots; pH 6.7.

Soil unit 4

These soils are deep, somewhat imperfectly drained clay loam soils at the edge of the fadama. The parent material is loess admixed with fine colluvial material. The colour in the surface horizon is dark yellowish brown (10YR 4/2). The colour changes in hue to 7.5YR in the subsurface horizons where the characteristic colour is reddish yellow (7.5YR 6/8) to brownish yellow (7.5YR 6/6).

Water table rises to 60cm or higher the solum in the rainy season and drops to below 200 cm in the dry season. This fluctuating water table has led to mottling in the subsurface horizons and gleying in the C horizon. The mottles are white (10YR 8/1).

Structural development is weak, but a weakly developed argillic horizon is present in the soils. Profile 11 differs in texture from the other soils in the unit, but it shares all other properties in

common with them. Consequently, it may be regarded as a variant or an inclusion.

Profile 10 which is representative of this soil unit is described below.

Profile 10

Parent material	:	Loessial - colluvial material.
Topography	:	2% slope; lower slope position.
Drainage	:	Somewhat imperfectly drained.
Vegetation	:	Tall Hyparrhenia and Elionurus grasses with some Borassus aethiopum.
Depth of water table:		Water table at 200cm

Horizon	Depth	Description
A1	0 - 18cm	Dark yellowish brown (10YR 4/2) loam; weak fine to medium crumb structure; friable; common fine vertical and oblique pores; common fine roots; pH 6.0; clear smooth boundary.
$B1_t$	18 - 35cm	Yellowish brown (10YR 5/6) clay loam; weak medium to coarse subangular blocky structure; friable; many fine pores; common fine roots; pH 5.9; gradual smooth boundary.

$B21_t$	35 - 60cm	Reddish yellow (7.5YR 6/8) clay loam; weak medium subangular blocky structure; friable; common fine pores; few fine and medium roots; pH 5.7; gradual smooth boundary.
$B22_t$	60 - 110cm	Reddish yellow (7.5YR 6/8) clay loam; weak medium to coarse subangular blocky structure; friable; many fine pores; few fine and medium roots; pH 5.7; clear smooth boundary.
$B23_t$	110 - 135	Brownish yellow (10YR 6/6) clay; weak medium subangular blocky structure; friable; many fine pores; few small rounded soft iron oxide nodules; few medium roots; pH 5.5; clear smooth boundary.
$B3_{tg}$	135 - 180cm	Brownish yellow (10YR 6/8, wet) clay; abundant (10% by volume) coarse white (10YR 8/0) mottles exhibiting diffuse boundary with the surrounding matrix; massive; slightly firm, wet; few fine pores; few fine and medium roots; pH 5.8.

Soil unit 5

Members of this soil unit are the fadama soils. They are generally poorly drained loam soils and are water-logged during the rainy season and for a considerable part of the dry season. Water recedes from the soil surface in late February to early March to about 100 cm in May/June when the rainy season begins. Gleying is a common characteristic of the soils. The typical colour of the subsoil horizons is light brownish gray (10YR 6/2). At deeper depths, the colour is predominantly gray (10YR 7/1). The soils are mottled reddish brown (2.5YR 4/4) from the surface downwards.

Depressions and slightly raised levees are common occurences in the fadama. The depressions receive more fine materials as sediments while the levees receive less of the sediments. Consequently, texture varies considerably in this soil unit. All the soils are however lumped in the same unit as they cannot be mapped separately.

The soils are thought to be developing in a mixed loessial - alluvial material as reflected by the high contents of fine sand and silt.

Profile 13 is described below:

Profile 13

Parent material	:	Mixed fine loessial-alluvial deposits.
Topography	:	Flat; valley bottom position.

Drainage : Poorly drained; seasonally water-logged.

Vegetation : Paspalum and Elionurus grasses mainly.

Depth to water table: Water table at 100cm at peak of dry season.

Horizon	Depth	Description
A1	0 - 12cm	Dark gray (10YR 4/1) loam; mottled reddish brown (2.5YR 3/4); weak fine and medium crumb structure; friable; many fine pores; common fine roots; pH 5.5; abrupt smooth boundary.
B1	12 - 30cm	Light yellowish brown (10YR 6/4) loam; with few fine distinct dark brown (10YR 4/3) mottles; moderate medium subangular blocky structure; firm, moist; few fine pores; few fine roots; pH 5.4; abrupt smooth boundary.
B21	30 - 50cm	Light yellowish brown (10YR 6/4) clay loam; common distinct reddish brown to red - (2.5YR 4/4) to (2.5YR 4/8) - mottles; weak fine to medium subangular blocky structure; firm, moist; many fine pores; few fine roots; pH 5.4; abrupt smooth boundary.

B22	50 - 100cm	Gray (10YR 7/1, wet) silty clay loam; common fine distinct sharp brownish yellow (10YR 6/6) mottles; massive; sticky and plastic, wet; few fine pores; few fine roots; pH 5.8; gradual smooth boundary.
B31g	100 - 130cm	Gray (10YR 7/1, wet) clay loam; common fine distinct dark brown (10YR 4/3) mottles; massive; sticky and plastic, wet; few fine pores; few fine roots; pH 5.8.
B32g	130cm+	Water table.

Physical Characteristics

Texture, bulk density, particle density and total porosity were determined for the soils. Each characteristic is discussed in detail below.

Texture

The particle-size distribution data are presented in table 2.

Coarse fragments (>2mm separates) are negligible in soil units 1, 4 and 5. Soil units 2 and 3 have slight iron oxide nodules of fine gravel size randomly distributed in their profiles, particularly

Table 2. Particle-size distribution of units 1 - 5 soils.

Horizon	Depth	Particle-size analysis								
		Gr+ >2mm	VCS* 2000-1000 µ	CS[1] 1000-500 µ	MS[2] 500-250 µ	FS[3] 250-100 µ	VFS[4] 100-50 µ	Total Sand	Silt 50-2 µ	Clay <2 µ
Soil Unit 1	cm	%	—— % of <2mm soil separate ——							
Profile 1	(OXIC PALEUSTALF/EUTRIC NITOSOL)									
A1	0-14	-	1	3	14	7	30	55	35	10
$B21_t$	14-29	-	1	2	9	2	10	24	31	45
$B22_t$	29-60	-	1	2	8	2	9	22	29	49
$B23_t$	60-100	-	1	2	8	2	7	20	28	52
$B24_t$	100-130	-	1	3	9	2	7	22	30	48
$B3_t$	130-170	-	2	3	8	3	10	26	26	48
Profile 2	(OXIC PALEUSTALF/EUTRIC NITOSOL)									
A1	0-12	-	1	3	13	6	25	48	30	22
$B1_t$	12-25	-	1	2	9	2	11	25	28	42
$B21_t$	25-50	-	1	1	5	2	8	17	29	54
$B22_t$	50-80	-	1	0	5	2	9	17	30	53
$B23_t$	80-110	-	2	1	7	3	10	23	29	48
B3	110-150	-	1	1	5	1	9	17	32	51
IIC_{cn}	150-190	-	3	1	7	2	10	23	27	50
Profile 3	(OXIC HAPLUSTALF/CHROMIC LUVISOL)									
A1	0-10	-	3	2	16	5	19	45	27	28
$B1_t$	10-25	-	3	1	11	4	11	30	28	42
$B21_t$	25-40	-	3	2	12	4	13	34	21	45
$B22_t$	40-70	-	2	1	11	4	10	28	32	50
$B23_t$	70-120	-	3	1	10	4	9	27	31	42
B3	120-160	-	3	2	10	8	11	34	27	39
IIC_{cn}	160-195	20	4	7	13	6	9	35	28	37

+ Gravel
* Very Coarse Sand
1 Coarse Sand
2 Medium Sand
3 Fine Sand
4 Very Fine Sand

Table 2 (Contd.): Particle-size distribution of units 1 - 5 soils.

Horizon	Depth	Particle-size analysis Gr+ >2mm	VCS* 2000 - 1000 µ	CS[1] 1000 - 500 µ	MS[2] 500 - 250 µ	FS[3] 250 - 100 µ	VFS[4] 100 - 50 µ	Total Sand	Silt 50 - 2 µ	Clay < 2 µ
Soil Unit 2	cm	%	% of <2mm soil separate							
Profile 4	(OXIC PALEUSTALF/EUTRIC NITOSOL)									
A1	0–8	-	5	3	13	6	21	48	25	27
$B1_t$	8–30	2	5	4	8	5	12	34	21	45
$IIB21_t$	30–50	13	5	7	11	3	12	38	22	40
$IIB22_{tcn}$	50–90	22	9	6	11	4	10	40	18	42
$IIB23_{tcn}$	90–130	30	11	8	10	4	13	46	16	38
$IIB24_{tcn}$	130–165	35	10	7	11	5	10	43	19	38
Profile 5	(OXIC PALEUSTALF/EUTRIC NITOSOL)									
A1	0–10	-	3	5	13	6	4	50	28	22
B1	10–25	5	8	7	13	6	16	52	25	23
$IIB21_{tcn}$	25–60	16	6	8	12	3	12	41	19	40
$IIB22_{tcn}$	60–90	16	9	6	11	3	11	40	20	40
$IIB23_{tcn}$	40–120	12	9	6	10	3	14	42	21	37
$IIB24_{tcn}$	120–140	26	7	5	10	4	12	38	23	39
$IIB25_{tcn}$	140–180	20	4	3	9	3	11	32	22	48
Profile 6	(OXIC PALEUSTALF/EUTRIC NITOSOL)									
A1	0–15	-	3	7	16	6	18	50	33	17
$B21_t$	15–40	-	3	7	15	5	18	48	24	28
$B22_t$	40–70	-	4	6	15	6	17	48	27	25
$B23_t$	70–110	-	1	3	10	5	18	37	25	38
$B24_t$	110–160	2	6	5	12	5	12	40	19	41
$B25_t$	160–195	7	4	3	8	5	12	32	22	46
$IIB3_{gcn}$	195–215	30	10	9	15	3	14	51	19	30

\+ Gravel
* Very Coarse Sand
1 Coarse Sand
2 Medium Sand
3 Fine Sand
4 Very Fine Sand

Table 2 (Contd.): Particle-size distribution of units 1 - 5 soils.

Horizon	Depth	Particle-size analysis								
		Gr+ >2mm	VCS* 2000-1000µ	CS[1] 1000-500µ	MS[2] 500-250µ	FS[3] 250-100µ	V.S[4] 100-50µ	Total Sand	Silt 50-2µ	Clay <2µ
Soil Unit 3	cm	%	——% of <2mm soil separate ——							
Profile 7	(OXIC HAPLUSTALF/CHROMIC LUVISOL)									
A1	0-4	-	-	3	15	8	23	49	32	19
B1	4-30	-	6	17	23	6	15	67	14	19
$B21_t$	30-60	-	1	2	11	4	15	33	34	33
$B22_t$	60-85	-	1	3	10	4	12	30	26	44
$B23_t$	85-100	16	4	4	10	5	12	35	29	36
$B24_t$	100-135	-	2	3	10	6	13	34	27	39
$B3_g$	135-180	-	1	3	12	6	13	35	30	35
Profile 8	(OXIC PALEUSTALF/DYSTRIC NITISOL)									
A1	0-8	1	3	5	15	5	23	51	32	17
$B1_t$	8-20	-	4	5	9	6	16	40	21	35
$B21_t$	20-40	-	3	4	9	7	13	36	24	40
$B22_t$	40-75	-	5	5	10	5	15	40	24	36
$B23_t$	75-105	-	3	4	9	7	13	36	28	36
$B24_t$	105-160	-	1	4	10	6	15	36	25	39
Profile 9	(OXIC HAPLUSTALF/CHROMIC LUVISOL)									
Ap	0-22	9	4	4	9	6	11	34	30	36
$B21_t$	22-42	-	3	3	9	7	12	34	28	38
$B22_t$	42-75	-	1	3	6	4	10	24	28	48
$B23_t$	75-100	2	2	3	7	3	12	27	26	47
$B24_t$	100-130	30	9	6	9	3	9	36	25	39
$B31_t$	130-150	16	2	5	10	5	10	32	32	36
B32	150-180	16	7	6	10	4	13	40	31	29

\+ Gravel
* Very Coarse Sand
1 Coarse Sand
2 Medium Sand
3 Fine Sand
4 Very Fine Sand

Table 2 (Contd.): Particle-size distribution of units 1 - 5 soils

Horizon	Depth	Particle-size analysis								
		Gr+ >2mm	VCS* 2000-1000 µ	CS[1] 1000-500µ	MS[2] 500-250µ	FS[3] 250-100µ	VFS[4] 100-50µ	Total Sand	Silt 50-2 µ	Clay <2 µ
Soil Unit 4	cm	%	——— % of <2mm soil separate ———							
Profile 10 (OXIC PALEUSTALF/EUTRIC NITOSOL)										
A1	0-18	-	1	4	14	8	23	50	35	15
$B21_t$	18-35	-	1	3	14	8	19	45	16	39
$B22_t$	35-60	-	1	3	10	6	17	37	26	37
$B23_t$	60-110	-	1	2	10	4	17	34	27	39
$B24_t$	110-135	-	1	2	11	4	15	33	21	46
$B25_{tg}$	135-180	-	3	4	11	5	13	36	23	41
Profile 11 (TYPIC PALEUSTALF/DYSTRIC NITOSOL)										
A1	0-12	-	-	1	8	5	14	28	44	28
B1	12-30	-	1	2	10	4	18	35	38	27
B21	30-60	-	2	3	10	6	19	40	38	22
B22	60-100	-	2	3	12	7	19	43	35	22
B3	100-140	-	-	2	12	7	20	41	43	16
C1	140-180	-	1	3	13	6	16	39	31	30

+ Gravel
* Very Coarse Sand
1 Coarse Sand
2 Medium Sand
3 Fine Sand
4 Very Fine Sand

Table 2 (Contd.): Particle-size distribution of units 1 - 5 soils

Horizon	Depth	Particle-size analysis								
		Gr+ >2mm	VCS* 2000-1000μ	CS[1] 1000-500μ	MS[2] 500-250μ	FS[3] 250-100μ	VFS[4] 100-50μ	Total Sand	Silt 50-2μ	Clay <2μ
Soil Unit 5	cm	%	—— % of <2mm soil separate ——							
Profile 12 (TYPIC TROPAQUEPT/EUTRIC GLEYSOL)										
A1	0-10	2	4	6	17	7	21	55	36	9
B1	10-20	-	1	3	13	7	21	45	38	17
B2	20-50	-	-	1	12	5	20	38	40	22
IIC1	50-100	-	1	4	12	6	22	45	52	3
IIC2	100	-	1	5	14	6	25	50	47	3
Profile 13 (TYPIC TROPAQUEPT/EUTRIC GLEYSOL)										
A1	0-12	-	-	1	9	5	19	34	50	16
B1	12-30	-	-	-	8	4	14	26	49	25
B21	30-50	-	-	1	5	4	11	21	48	31
B22	50-100	-	-	1	5	2	9	17	43	40
$B31_g$	100-130	-	1	4	9	3	8	25	43	32
$B32_g$	130-160	-	-	1	4	1	7	13	43	44

\+ Gravel
* Very Coarse Sand
1 Coarse Sand
2 Medium Sand
3 Fine Sand
4 Very Fine Sand

in their B horizons. Some angular quartz fragments are included in the coarse fragments of these horizons. The iron oxide nodules seem to be inherited features derived through past erosion cycles.

The absence of gravel in soil unit 1 in the upper 200cm of the soils seem to indicate the aeolian origin of the soil parent material. Soil units 4 and 5 on the other hand occupy lower slope to valley bottom positions where mixed aeolian material and fine alluvial materials form the soil parent material.

The particle-size data show other marked textural variations among the different soil units. Generally, textures vary only slightly within a soil profile except in cases where the parent material of the soil is layered. In profile 1 of soil unit 1 (table 2) for an example, apart from clay deficiency in the A1 horizon, all other horizons have a clay texture. Within each soil unit, textural differences are also slight. The wide variation in texture among the fadama soils (unit 5 soils) has already been mentioned.

Total sand content in the soils range from 13-55%. The A horizons usually have the highest sand content as they are devoid of clay. In soil units 1 and 3, fine sand (250-50μm) predominates over the other sand fractions supporting the aeolian source of the soil parent material.

A noteworthy feature in all the five soil units is the high silt content. Soils in unit 5 contain the highest amount of silt with a mean value of 44% (36 - 52% range), followed by soils in unit 4 which have a mean silt content of 31% (16-44% range). Soil unit 1 has a mean silt content of 29% with a 21-35% range while soils of units 2 and 3 have mean silt contents of 22 and 27% respectively.

The silt content further points to the aeolian origin of the soil parent material of the upland soils in the study area. The soil units in the low-lying areas (soil units 4 and 5) contain more silt in their profiles than associated upper to mid-slope soils due to the fine sediments they inherited from the latter slope positions through erosion.

The high silt content of the soils ranks the soils in the Zaria area among the most silty in Nigeria. The high silt content distinguishes these soils from the soils of the humid tropical lowlands of southwestern Nigeria (Wessel, 1965; Ojanuga, 1969; 1975). The high silt content also compares favourably with the silt content in soils forming in basaltic parent material on the Jos Plateau (Ojanuga and Awujoola, 1979). Values obtained agree with findings on soils in the Zaria area (Ojanuga, 1979; Malgwi, 1979).

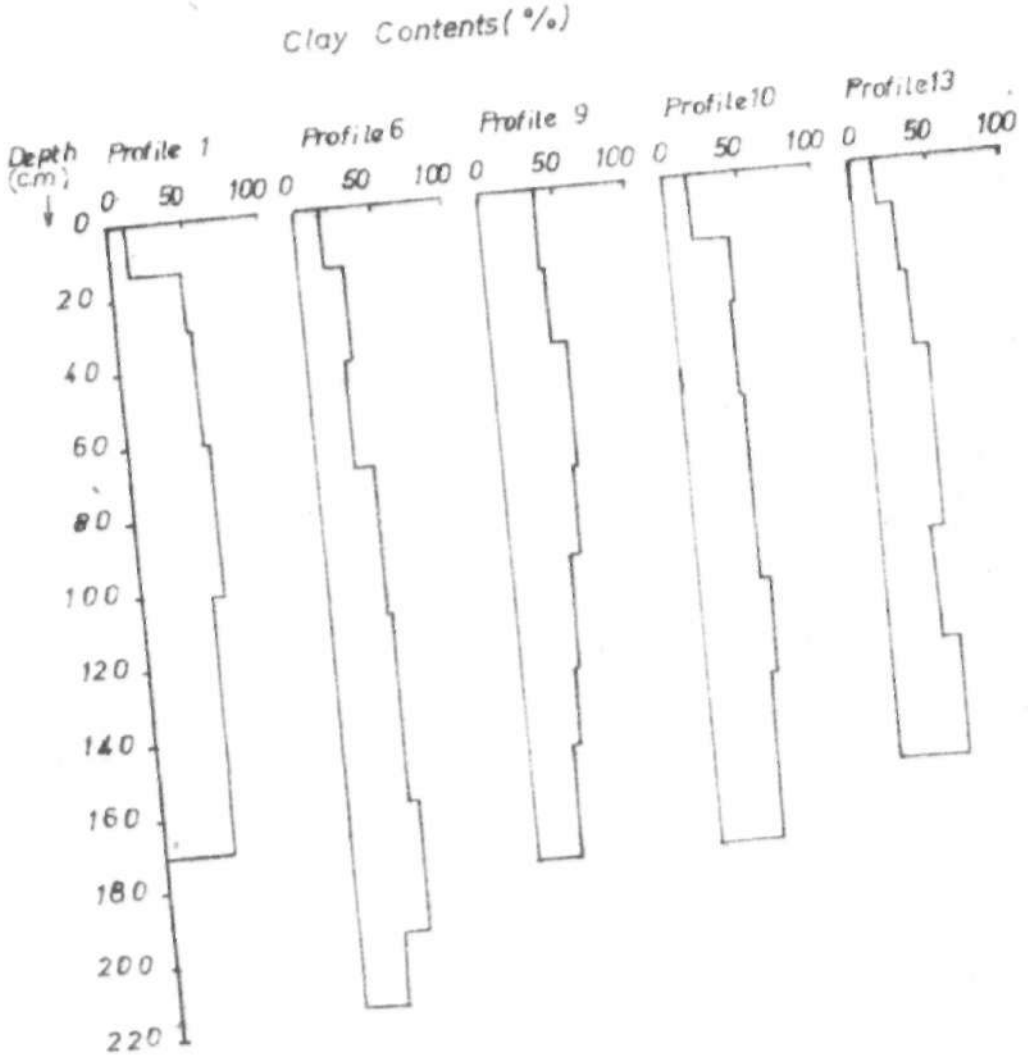


Fig 7. Clay-- depth distribution for selected profiles

Clay content increases from the A horizons to the B2 horizons and then decreases in the underlying B3 and C horizons. Clay maxima values in the B2 horizons range from 38-54%. The high clay contents in the B horizons relative to the A or C horizons confirm the presence of argillic horizons in soil units 1, 2, 3 and 4.

Clay depletion in the A1 horizon is a characteristic feature of all the soil units. This characteristic is shared with most soils in Nigeria (Ojanuga, 1969; Ojanuga and Awujoola, 1979; Malgwi, 1979). The clay impoverishment of the surface horizon is thought to be due to biological (termite) sorting of soil materials, clay eluviation, and erosional activities. Where the A horizon has been disturbed by cultivation, a high clay content is often recorded as in profile 9 (table 2). This is due to the mixing of soil materials by the cultivation practices.

The depth distribution of clay for selected profiles is presented in Fig 7. From the figure, the presence of argillic horizons in most of the soils can be confirmed.

On the whole, the particle-size distribution data confirm the aeolian nature of the parent material of most of the soils, and the sedimentational history of the fadama soils.

Bulk density

Bulk density, particle density and total porosity data for the soil units are presented in table 3.

Table 3: Bulk density, particle density and porosity of units 1 - 5 soils.

Horizon	Depth	Db *	Dp +	Porosity
	cm	g/cc		%
Soil Unit 1				
Profile 1	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
A1	0–14	1.60	2.60	38
$B21_t$	14–29	1.55	2.61	41
$B22_t$	29–60	1.45	2.62	45
$B23_t$	60–100	1.47	2.62	44
$B24_t$	100–130	1.47	2.63	44
$B3_t$	130–170	1.48	2.64	44
Profile 2	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
A1	0–12	1.56	2.60	40
$B1_t$	12–25	1.46	2.62	44
$B21_t$	25–50	1.48	2.63	44
$B22_t$	50–80	1.41	2.63	46
$B23_t$	80–110	1.49	2.64	43
B3	110–150	1.50	2.65	43
IIC_{cn}	150–190	1.54		42
Profile 3	(OXIC HAPLUSTALF/CHROMIC LUVISOL)			
A1	0–10	1.54	2.61	41
$B1_t$	10–25	1.52	2.59	42
$B21_t$	25–40	1.32	2.58	49
$B22_t$	40–70	1.34	2.61	49
$B23_t$	70–120	1.34	2.61	49
B3	120–160	1.48	2.62	44
IIC_{cn}	160–195	1.79	2.67	43

* Bulk density
\+ Particle density

Table 3 (Contd.): Bulk density, particle density and porosity of units 1 - 5 soils.

Horizon	Depth	Db*	Dp+	Porosity
Soil Unit 2	cm	g/cc		%
Profile 4	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
A1	0-8	1.65	2.61	37
$B1_t$	8-30	1.51	2.61	43
$IIB21_t$	30-50	1.52	2.61	42
$IIB22_{ton}$	50-90	1.56	2.62	41
$IIB23_{ton}$	90-130	1.78	2.66	33
$IIB24_{ton}$	130-165	2.14	2.65	19
Profile 5	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
A1	0-10	1.58	2.59	39
B1	10-25	1.65	2.61	37
$IIB21_{ton}$	25-60	1.85	2.62	29
$IIB22_{ton}$	60-90	1.74	2.66	35
$IIB23_{ton}$	90-120	1.71	2.67	36
$IIB24_{ton}$	120-140	1.88	2.66	29
$IIB25_{ton}$	140-180	1.65	2.63	37
Profile 6	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
A1	0-15	1.60	2.60	38
$B21_t$	15-40	1.52	2.62	42
$B22_t$	40-70	1.63	2.64	38
$B23_t$	70-110	1.52	2.60	42
$B24_t$	110-160	1.57	2.64	41
$B25_t$	160-195	1.46	2.61	44
$IIB3_{gcn}$	195-215	1.79	2.71	34

* Bulk density
\+ Particle density

Table 3 (Contd.): Bulk density, particle density and porosity of units 1 - 5 soils

Horizon	Depth	Db*	Dp+	Porosity
Soil Unit 3	cm	g/cc		%
Profile 7	(OXIC HAPLUSTALF/CHROMIC LUVISOL)			
A1	0-4	1.33	2.59	49
B1	4-30	1.55	2.61	41
$B21_t$	30-60	1.50	2.59	42
$B22_t$	60-85	1.65	2.62	37
$B23_t$	85-100	1.51	2.61	43
$B24_t$	100-135	1.63	2.63	38
$B3_g$	135-180	1.69	2.64	36
Profile 8	(OXIC PALEUSTALF/DYSTRIC NITOSOL)			
A1	0-8	1.56	2.61	40
$B1_t$	8-20	1.56	2.59	40
$B21_t$	20-40	1.41	2.63	46
$B22_t$	40-75	1.51	2.64	43
$B23_t$	75-105	1.61	2.64	39
$B24_t$	105-160	1.67	2.62	36
Profile 9	(OXIC HAPLUSTALF/CHROMIC LUVISOL)			
Ap	0-22	1.38	2.58	47
$B21_t$	22-42	1.39	2.60	47
$B22_t$	42-75	1.41	2.59	46
$B23_t$	75-100	1.57	2.63	40
$B24_{ts}$	100-130	1.60	2.63	39
$B31_{ts}$	130-150	1.62	2.65	39
$B32_s$	150-180	1.76	2.66	34

* Bulk density
\+ Particle density

Table 3 (Contd.): Bulk density, particle density and porosity of units 1 - 5 soils.

Horizon	Depth	Db *	Dp +	Porosity
Soil Unit 4	cm	g/cc		%
Profile 10	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
A1	0-18	1.63	2.58	37
$B21_t$	18-35	1.57	2.62	40
$B22_t$	35-60	1.57	2.62	40
B23t	60-110	1.59	2.63	40
$B24_t$	110-135	1.67	2.63	37
$B25_{tg}$	135-180	1.71	2.64	35
Profile 11	(TYPIC PALEUSTALF/DYSTRIC NITOSOL)			
A1	0-12	1.44	2.55	44
B1	12-30	1.51	2.56	41
B21	30-60	1.47	2.55	42
B22	60-100	1.52	2.55	40
B3	100-140	-	2.57	-
C1	140-180	-	2.58	-

* Bulk density
\+ Particle density

Table 3 (Contd.): Bulk density, particle density and porosity of units 1 - 5 soils.

Horizon	Depth	Db*	Dp+	Porosity
Soil Unit 5	cm	g/cc		%
Profile 12 (TYPIC TROPAQUEPT/EUTRIC GLEYSOL)				
A1	0-10	1.57	2.55	38
B1	10-20	-	2.56	-
B2	20-50	-	2.57	-
IIC1	50-100	-	2.60	-
IIC2	100	-	2.62	-
Profile 13 (TYPIC TROPAQUEPT/EUTRIC GLEYSOL)				
A1	0-12	1.37	2.52	46
B1	12-30	1.55	2.56	39
B21	30-50	1.55	2.55	39
B22	50-100	-	2.56	-
$B31_g$	100-130	-	2.57	-
$B32_g$	130-160	-	2.56	-

* Bulk density
\+ Particle density

Bulk density values varied widely both among soil units and even within units. The general pattern is a high value in the surface horizon, a decrease in the B horizons and then an increase to maximum values in the B3 or C horizons.

The surface horizon in the project area is heavily trekked by cattle, sheep and goats (Plate 6). This animal trekking has led to the compaction of the soil surface and this is the cause of the high bulk density values recorded in the A1 horizons. Areas sheltered from cattle trekking have low bulk density values in the surface horizon.

Surface horizon bulk density values range from 1.33 g/cc in the uncompacted areas to 1.65 in compacted areas. In the subsurface horizon, bulk density ranges from 1.32g/cc to 1.65g/cc. A notable exception to this trend is profile 5 of soil unit 2 (table 3) which has a high gravel content. Bulk density values in its B horizons ranged between 1.65 and 1.88 g/cc. This is because the gravel content is made up dominantly of iron oxide nodules which have high densities.

The low bulk density values obtained in the subsurface B horizons may be attributed to the good structural developments in these zones.

High bulk densities also occur in zones of lithologic discontinuities that have appreciable amounts of heavy particles

such as iron oxide nodules (profiles 3, 5, 6 and 10, table 3), and in the C horizons. The high bulk density values in the latter horizons may be due to poor structural development, low content of organic matter and increasing contents of heavy minerals.

In general, the values of bulk density agree with those obtained by earlier workers in the Zaria area (Lawes, 1964; Kowal, 1968; Malgwi, 1979).

Particle density

Particle density values show slight variations between different soil units, and with depth within each soil profile. The general trend is an increase in value from the surface horizon to the C horizon. Profile 10 (table 3) has a particle density-depth distribution of 2.58-2.64 g/cc for example. The surface horizons though zones of clay deficiency and sand concentration, have the highest organic matter contents. This is thought to be the reason for their low particle density values. The intermediate particle density values in the argillic horizons are thought to be due to their higher clay contents and lower contents of organic matter, while the high particle density values in the C horizons are due to decreased pedogenetic activities in these horizons with resultant high contents of heavy primary minerals. Zones of lithologic discontinuities which are also zones of accumulation

of heavy iron oxide nodules have high particle density values (e.g. profiles 3 and 6, table 3).

Total porosity

Total porosity (table 3) varied between 19 and 49%. Very low porosity values (29%) were recorded in very gravelly horizons with poor structural development such as in profile 5 (table 3), and in regions of lithologic discontinuities as for example in profiles 4, 5 and 6 (table 3). The low porosity in the vicinity of the discontinuities in these soils is due to the higher content of coarse fragments, and hence, a higher occurence of non-capillary pores. Outside the gravelly and discontinuity zones, porosity values range from 33 to 49%.

The surface horizons generally have low porosity values because of the compaction mentioned earlier. The range of values for the surface horizons is 37 to 49% with a mean value of 41%. The subsoil B horizons have the highest total porosity values due to their high clay content and the good structural development. Porosity values in these B horizons ranges from 39 to 49%, with a mean value of about 43%. The C horizons generally have the lowest porosity values.

Chemical Characteristics

Tables 4, 5, 7, 8 and 10 show the results of the soil chemical

characteristics including organic carbon, pH, exchangeable cations, cation exchange capacity, base saturation and free iron oxide.

Organic carbon

The soils are generally low in organic carbon content (table 4). The range is 0.09 to 1.86%. Organic carbon is highest in the Ap or A1 horizons where the mean organic carbon content is 1.04% with a range of 0.52 to 1.86%. Where the surface horizon has been truncated or disturbed by cultivation recently as in profile 9 (table 4) organic carbon content in the A horizon is generally very low (0.33%).

Organic carbon decreases rapidly below the 14cm depth in all the soil units. Fig 8 shows the depth distribution of organic carbon for solected profiles.

The poorly drained soils of unit 5 recorded the highest organic carbon in the A1 horizon with values of 1.02% for the loam soils and 1.86% for the clay loam soils. The relatively slower rate of biological decomposition of residues in these soils is the principal factor responsible for the higher organic carbon values.

The annual bush burning during field preparation in the Zaria area around December/January minimizes litter addition to the well drained soil units 1, 2, 3 and the somewhat imperfectly drained soil

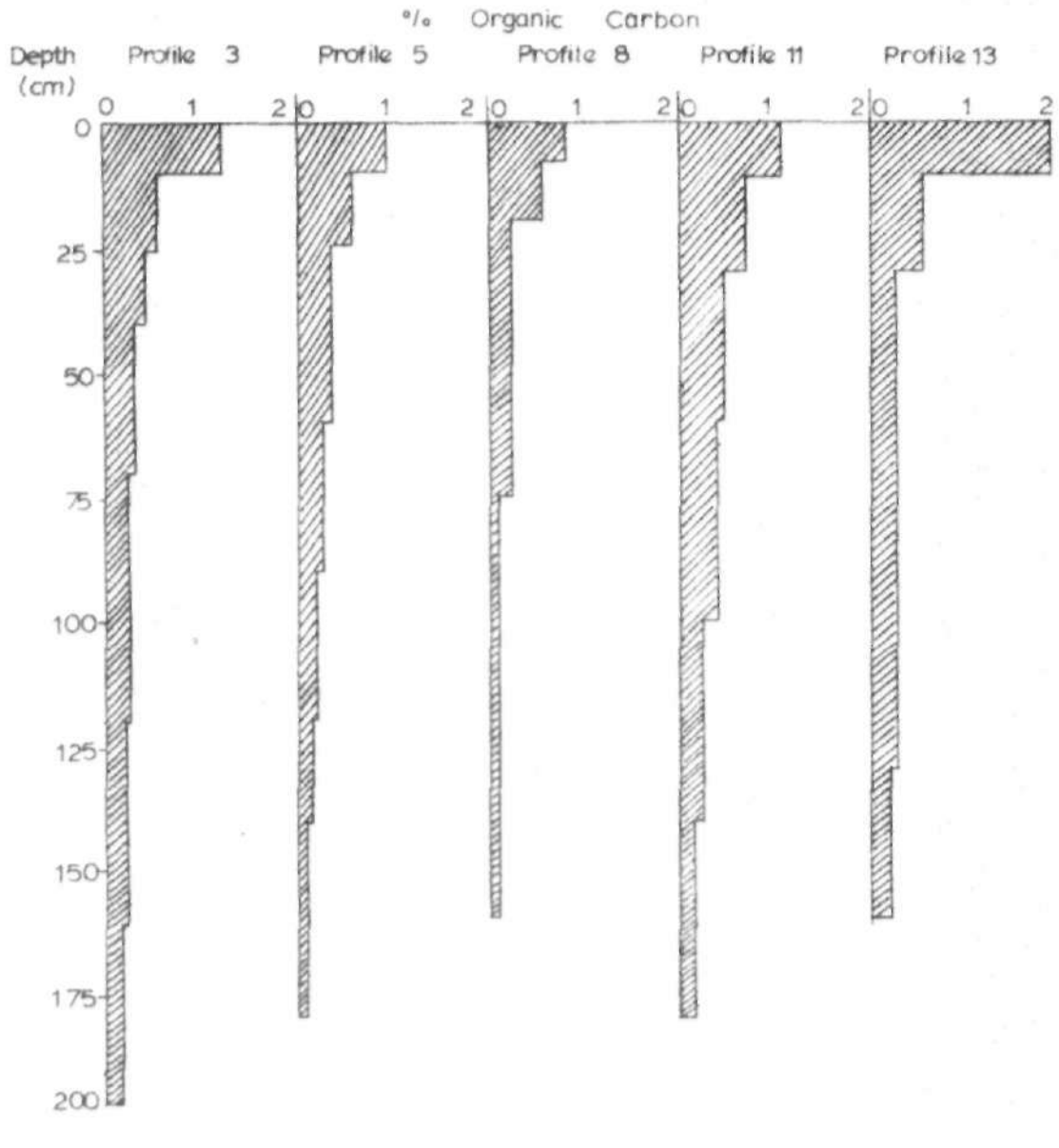


Fig 8 Organic carbon - depth distribution for selected profiles

unit 4. However, soils of unit 5 are not affected due to waterlogging and therefore their vegetation remains lush at the peak of the dry season.

The generally low organic carbon content in the units 1, 2, 3 and 4 soils is also promoted by the fast microbial mineralization of the little litter that is added, as temperatures are high all the year.

The organic carbon-depth distribution of unit 1 soils contrasts with those for soil units 2, 3 and 4. The organic carbon tends to be relatively more evenly distributed in unit 1 soils. These may be due to translocation of organic matter in these strongly structured soils as organo-metallic complexes. This phenomenon is thought to have been involved in the movement of clay from the surface horizons and its deposition in the subsurface horizons with characteristic coating of ped surfaces with clay skin.

Perhaps it is true as summarized by Ojanuga (1971) that the major decomposition product of organic matter in tropical soils is fulvic acid as claimed by Dochuafor and Dommergues(1963). The phenomenon may be another important factor responsible for the generally low organic carbon contents of all the soils because fulvic acid is mobile in soils, and is therefore easily leached out of the soil system.

Table 4. Organic carbon, pH and exchangeable cations of units 1 - 5 soils.

Soil Unit	Horizon	Depth	OC[1]	pH	Exchangeable Cations Ca	Mg	K	Na	Exch. Acidity	TEB[2]
		cm	%		meq/100g soil					
1	Profile 1		(OXIC PALEUSTALF/EUTRIC NITOSOL)							
	A1	0-14	0.84	5.6	1.5	0.99	0.17	0.07	3.6	6.3
	$B21_t$	14-29	0.62	5.6	2.69	1.86	0.5	0.1	3.7	8.8
	$B22_t$	29-60	0.44	5.8	3.27	2.14	0.68	0.09	3.8	11.0
	$B23_t$	60-100	0.26	6.1	3.24	2.29	0.69	0.09	3.9	10.2
	$B24_t$	100-130	0.28	6.1	3.94	2.117	0.69	0.09	3.8	10.7
	$B3_t$	130-170	0.27	6.0	2.45	2.17	0.63	0.9	3.7	9.0
	Profile 2		(OXIC PALEUSTALF/EUTRIC NITOSOL)							
	A1	0-12	1.1	5.9	1.97	1.27	0.38	0.07	3.3	7.0
	$B1_t$	12-25	0.6	5.6	3.14	1.73	0.38	0.09	3.9	9.3
	$B21_t$	25-50	0.37	5.9	2.99	2.94	0.60	0.07	3.7	10.3
	$B22_t$	50-80	0.35	5.9	3.61	2.23	0.46	0.1	4.1	10.5
	$B23_t$	80-110	0.37	6.0	3.67	2.7	0.55	0.1	4.1	11.1
	B3	110-150	0.27	6.1	3.29	2.89	0.63	0.15	3.9	10.9
	IIC_{cn}	150-190	0.29	6.4	2.73	2.94	0.5	0.08	3.7	10.0
	Profile 3		(OXIC HAPLUSTALF/CHROMIC LUVISOL)							
	A1	0-10	1.24	5.8	2.02	1.47	0.38	0.07	3.6	7.5
	$B1_t$	10-25	0.55	5.5	1.7	1.11	0.38	0.07	3.9	7.2
	$B21_t$	25-40	0.47	5.6	1.66	1.48	0.38	0.06	3.9	7.5
	$B22_t$	40-70	0.32	5.7	1.78	1.55	0.63	0.11	3.5	7.6
	$B23_t$	70-120	0.25	5.9	1.05	0.95	0.86	0.14	3.5	6.5
	B3	120-160	0.28	6.0	1.12	0.71	0.86	0.11	4.0	6.8
	IIC_{cn}	160-195	0.23	6.2	1.3	0.71	0.95	0.19	3.8	7.0

1 OC = Organic Carbon
2 TEB = Total Exchangeable Bases

Table 4 (contd.). Organic carbon, pH and exchangeable cations of units 1 - 5 soils.

Soil Unit	Horizon	Depth	OC[1]	pH	Exchangeable Cations Ca	Mg	K	Na	Exch. Acidity	TEB[2]
		cm	%		meq/100g soil					
Profile 4 (OXIC PALEUSTALF/EUTRIC NITOSOL)										
	A1	0–8	1.1	5.7	2.02	1.12	0.38	0.07	3.8	7.5
	$B1_t$	8–30	0.54	5.4	1.86	0.79	0.38	0.04	3.9	7.0
	$IIB21_t$	30–50	0.48	5.6	1.72	0.79	0.31	0.05	3.6	6.5
	$IIB22_{tcn}$	50–90	0.34	5.7	2.35	1.07	0.35	0.06	3.7	7.5
	$IIB23_{tcn}$	90–130	0.28	5.9	2.67	1.3	0.31	0.07	3.7	8.1
	$IIB24_{tcn}$	130–165	0.26	6.1	2.92	1.41	0.31	0.06	3.7	8.4
Profile 5 (OXIC PALEUSTALF/EUTRIC NITOSOL)										
	A1	0–10	0.9	6.1	1.95	1.19	0.22	0.05	3.7	7.1
	B1	10–25	0.62	5.8	1.40	0.79	0.38	0.04	3.8	6.4
	$IIB21_{tcn}$	25–60	0.38	5.9	2.40	1.24	0.38	0.08	3.9	8.0
	$IIB22_{tcn}$	60–90	0.26	6.1	2.62	1.15	0.46	0.05	3.7	8.0
	$IIB23_{tcn}$	90–120	0.2	6.1	2.62	1.05	0.5	0.06	3.6	7.8
	$IIB24_{tcn}$	120–140	0.19	6.1	2.74	1.06	0.46	0.04	3.7	8.0
	$IIB25_{tcn}$	140–180	0.18	6.1	2.64	0.92	0.74	0.04	3.7	8.0
Profile 6 (OXIC PALEUSTALF/EUTRIC NITOSOL)										
	A1	0–15	0.52	6.0	1.5	0.87	0.18	0.02	3.3	5.9
	$B21_t$	15–40	0.41	5.5	1.42	0.85	0.26	0.03	3.3	5.9
	$B22_t$	40–70	0.21	5.8	1.26	0.9	0.22	0.03	3.3	5.7
	$B23_t$	70–110	0.26	5.6	1.62	1.19	0.28	0.04	3.5	6.6
	$B24_t$	110–160	0.14	5.7	1.49	1.07	0.28	0.1	3.8	6.7
	$B25_t$	160–195	0.15	5.5	1.33	1.06	0.38	0.08	3.9	6.8
	$IIB3_{gcn}$	195–215	0.09	5.4	1.12	0.98	0.35	0.02	3.5	6.0

1 OC = Organic Carbon
2 TEB = Total Exchangeable Bases

Table 4 (contd.): Organic carbon, pH and exchangeable cations of units 1 - 5 soils.

Soil Unit	Horizon	Depth	OC[1]	pH	Exchangeable Cations Ca	Mg	K	Na	Exch. Acidity	TEB[2]
		cm	%		meq/100g soil					
3										
	Profile 7 (OXIC HAPLUSTALF/CHROMIC LUVISOL)									
	A1	0-4	1.08	6.1	2.54	1.59	0.18	0.03	3.4	7.7
	B1	4-30	0.58	6.0	1.55	0.89	0.41	0.03	3.5	6.4
	$B21_t$	30-60	0.30	5.6	2.54	1.6	0.35	0.1	3.7	8.3
	$B22_t$	60-85	0.21	6.0	2.37	1.6	0.38	0.05	3.7	8.1
	$B23_t$	85-100	0.19	5.8	1.77	1.3	0.38	0.05	3.2	6.7
	$B24_t$	100-135	0.14	5.9	1.4	1.12	0.38	0.05	3.2	6.2
	$B3_g$	135-180	0.19	6.1	1.85	1.07	0.35	0.02	3.7	7.0
	Profile 8 (OXIC PALEUSTALF/DYSTRIC NITOSOL)									
	A1	0-8	0.76	5.7	1.39	1.03	0.38	0.1	1.7	4.6
	$B1_t$	8-20	0.52	5.9	1.34	0.88	0.28	0.06	4	6.6
	$B21_t$	20-40	0.23	5.7	1.74	0.75	0.22	0.04	4	6.8
	$B22_t$	40-75	0.30	5.5	1.77	0.79	0.28	0.04	3.2	6.1
	$B23_t$	75-105	0.14	5.8	2.13	0.99	0.46	0.04	3	6.6
	$B24_t$	105-160	0.12	6.0	2.74	1.28	0.72	0.04	3.7	8.5
	Profile 9 (OXIC HAPLUSTALF/CHROMIC LUVISOL)									
	Ap	0-22	0.33	6.0	2.23	1.07	0.41	0.04	4.5	8.3
	$B21_t$	22-42	0.36	5.8	2.95	1.71	0.41	0.1	4	9.2
	$B22_t$	42-75	0.23	5.6	3.31	2.34	0.51	0.05	3.7	9.9
	$B23_t$	75-100	0.11	6.1	2.9	1.67	0.51	0.04	3.7	8.8
	$B24_t$	100-130	0.23	6.1	3.25	1.6	0.5	0.04	3	8.4
	$B31_t$	130-150	0.15	6.1	3.05	1.52	0.45	0.04	3	8.1
	B32	150-180	0.14	6.7	4.05	1.6	0.51	0.05	2.7	8.9

1 OC = Organic Carbon
2 TEB = Total Exchangeable Bases

Table 4 (contd.): Organic carbon, pH and exchangeable cations of units 1 - 5 soils.

Soil Unit	Horizon	Depth	OC[1]	pH	Exchangeable Cations Ca	Mg	K	Na	Exch. Acidity	TEB[2]
		cm	%		meq/100g soil					
4										
Profile 10 (OXIC PALEUSTALF/EUTRIC NITOSOL)										
	A1	0–18	1.02	6.0	2.78	1.25	0.28	0.03	2.5	6.8
	$B21_t$	18–35	0.44	5.9	2.41	1.58	0.28	0.04	2.7	7.0
	$B22_t$	35–60	0.21	5.7	2.82	1.94	0.37	0.05	3	8.2
	$B23_t$	60–110	0.11	5.7	2.83	2.17	0.45	0.07	2.7	8.2
	$B24_t$	110–135	0.12	5.5	2.37	1.55	0.35	0.07	2.7	7.0
	$B25_t$	135–180	0.18	5.8	2.5	2.0	0.38	0.07	2.7	7.7
Profile 11 (TYPIC PALEUSTALF/DYSTRIC NITOSOL)										
	A1	0–12	1.06	5.8	2.83	1.16	0.51	0.19	3.2	7.9
	B1	12–30	0.69	5.5	2.24	0.71	0.41	0.19	3.2	6.8
	B21	30–60	0.48	5.4	1.44	0.43	0.35	0.18	3.2	5.6
	B22	60–100	0.42	5.2	0.7	0.14	0.28	0.17	2.8	4.1
	B3	100–140	0.27	5.4	0.6	0.13	0.28	0.20	2.2	3.4
	C1	140–180	0.22	5.7	1.42	0.54	0.41	0.26	2.2	6

1 OC = Organic Carbon

2 TEB = Total Exchangeable Bases

Table 4 (contd.): Organic carbon, pH and exchangeable cations of units 1 - 5 soils.

Soil Unit	Horizon	Depth	OC[1]	pH	Exchangeable Cations Ca	Mg	K	Na	Exch. Acidity	TEB[2]
		cm	%		meq/100g soil					
5										
	Profile 12 (TYPIC TROPAQUEPT/EUTRIC GLEYSOL)									
	A1	0–10	1.02	5.4	0.76	0.08	0.6	0.5	3.7	5.6
	B1	10–20	0.5	5.5	0.7	0.03	0.45	0.36	3.0	4.6
	B2	20–50	0.34	5.4	1.15	0.19	0.31	0.2	2.5	4.4
	IIC1	50–100	0.2	5.5	0.37	0.12	0.26	0.16	1.5	2.4
	IIc2	100	0.14	5.4	0.58	0.15	0.35	0.27	1.4	2.8
	Profile 13 (TYPIC TROPAQUEPT/EUTRIC GLEYSOL)									
	A1	0–12	1.86	5.5	2.55	0.78	0.61	0.33	5.5	9.8
	B1	12–30	0.54	5.4	1.9	0.38	0.56	0.36	6.2	9.4
	B21	30–50	0.26	5.4	1.81	0.35	0.54	0.32	5.5	8.5
	B22	50–100	0.37	5.8	3.03	1.01	0.72	0.4	5.2	1.04
	$B31_g$	100–130	0.40	5.8	3.44	1.14	0.86	0.41	6.7	12.6
	$B32_g$	130–160	0.24	6.0	3.44	1.37	1.06	0.85	6.2	12.9

1 OC = Organic Carbon
2 TEB = Total Exchangeable Bases

pH

The pH of the soil horizons (table 4) ranged between 5.4 and 6.7 indicating strongly acid to neutral soil reactions (U.S.D.A., 1951). However, most of the soils are moderately to weakly acid in reaction.

In general, the soils exhibit relatively higher pH values (pH 5.6 - 6.0) in the surface horizon than in the B horizons. There is a slight increase of pH in the C horizons. Exceptions to the general pH trend in the A horizons are profile 5 (soil unit 2) and profile 7 (soil unit 3) where pH is slightly acid (pH 6.1) in the surface horizon. The poorly drained fadama soils of unit 5 have a strongly acid (pH 5.4) surface horizon (e.g. profile 12).

As mentioned earlier, the B horizons have lower pH values than either the A or the C horizons. pH values in the B horizons are in the 5.6 to 6.0 range as with the A horizons, but within each profile the B horizons have relatively lower values. Exceptions to this general pH trend in the B horizons are profile 5 (soil unit 2) which is slightly acid (pH 6.1) from the B22 horizon downward; profiles 6 and 9 (soil units 2 and 3 respectively); and the imperfectly drained soil units 4 and 5, which are strongly acid (pH 5.4 to 5.5) in their B horizons.

The B3 and C horizons generally have higher pH values than the overlying B horizons.

The exchangeable cations' data showed that the surface horizons are richer in exchangeable Ca (propably by plant root action and from surface decomposition of litter), Mg and in some cases K. This concentration of cations in the surface horizons is thought to be responsible for their relatively higher pH values compared with the underlying B horizons. The surface accumulation of exchangeable Ca and Mg is thought to be due to plant root and litter decomposition as mentioned earlier, while the K is partly contributed by ash from grass burning.

The lower pH values in the B horizons reflect more the state of leaching of the soils through drainage.

The relatively lower pH values of the poorly drained fadama soils of unit 5 are due probably to the accumulation of reduction products and dissociation of strongly acid functional groups in their organic matter.

In general, the pH values of the soils tend to confirm the assertion of Forth and Turk (1972) that the pH of most agricultural soils in the tropics range between 5 and 6.8.

Exchangeable cations

Relatively low amounts of exchangeable Ca, Mg, K and Na are

present in the soils (table 4), with Ca being the principal saturating cation. The amounts and distribution of exchangeable cations show marked randomness with depth, but in general, maximum values occur in B horizons, a distribution which is possibly related to the clay content. The amounts of exchangeable cations present in well drained soil units 1, 2 and 3 are less than the amounts in the poorly drained units 4 and 5 soils. This is probably due to the fact that weathering, and leaching in particular, are more pronounced in the well drained soils than in the poorly drained soils.

The general trend shown by the distribution of the exchangeable cations is Ca > Mg > K > Na. The amounts of exchangeable Ca ranged between 0.37 and 3.94 meq/100g of soil, while exchangeable Mg ranged between 0.03 and 2.94 meq/100g of soil. Exchangeable K varied between 0.17 and 1.06 meq/100g of soil while exchangeable Na varies in value from 0.02 to 0.85 meq/100g of soil.

The low contents of exchangeable cations in these soils may be related to their leaching during the rainy season, and the nature of the soil parent material. The leaching effect is borne out by the fact that the soils contain more cations where drainage is poor or imperfect as in profiles 10 and 13 (soil units 4 and 5 respectively).

The predominance of Ca over the other cations agrees with the assertion of Brady (1974) that of all the exchangeable cations, Ca is least easily lost from soil environments. Another explanation for the predominance of Ca over the other cations may be the occurrence of exchange sites in soils which show specific affinity for Ca (Beckett, 1965). The low levels of exchangeable K and particularly Na, point either to their strong binding forces and their fixation on clay minerals (Beckett, 1965), or to a low content of these cations in the soil parent material.

Cation exchange capacity

For convenience, the CEC determined by the four methods stated earlier will be referred to as NH_4OAc-CEC, EDTA-CEC, sum of cations, and ECEC respectively.

The results presented in table 5 show that the magnitude of the CEC depends upon the method used. Results follow the trend observed by Juo, Ayanlaja and Ogunwale (1976) on some West African soils. In general, the sum of cations gave the highest values (2.4 to 12.9 meq/100g of soil, range) and the ECEC method gave the lowest values (1.0 to 7.0 meq/100g of soil, range). Results obtained by both the NH_4OAc-CEC and EDTA-CEC are comparable, and are a bit lower than results for the sum of cations.

Table 5: CEC and base saturation of units 1 - 5 soils

Soil Unit	Horizon	Depth	Cation Exchange Capacity.			Base Saturation			
			NH_4OAc	EDTA	Cations ECEC	NH_4OAc	EDTA	Cations	ECEC
		cm	meq/100g soil			%			
1									
	Profile 1 (OXIC PALEUSTALF/EUTRIC NITOSOL)								
	A1	0-14	4.8		6.3	2.8	57	43	90
	$B21_t$	14-29	8.1		8.8	5.2	63	58	98
	$B22_t$	29-60	9.5		11.0	6.2	65	56	100
	$B23_t$	60-100	9.2		10.2	6.4	68	62	98
	$B24_t$	100-130	9.8		10.7	6.9	70	64	100
	$B3_t$	130-170	9.1		9.0	5.4	58	59	98
	Profile 2 (OXIC PALEUSTALF/EUTRIC NITOSOL)								
	A1	0-12	5.0	4.8	7.0	3.7	74	78	53	100
	$B1_t$	12-25	9.0	7.6	9.3	5.4	60	71	58	100
	$B21_t$	25-50	9.2	8.7	10.3	6.6	72	76	64	100
	$B22_t$	50-80	9.5	9.1	10.5	6.4	67	70	61	100
	$B23_t$	80-110	10.3	9.3	11.1	7.0	68	75	63	100
	B3	110-150	9.9	8.9	10.9	7.0	71	79	64	100
	IIC_n	150-190	9.7	9.1	10.0	6.3	65	69	63	100
	Profile 3 (OXIC HAPLUSTALF/CHROMIC LUVISOL)								
	A1	0-10	5.7	6.4	7.5	4.0	68	61	52	98
	$B1_t$	10-25	7.7	6.9	7.2	3.6	43	48	46	92
	$B21_t$	25-40	7.4	6.9	7.5	3.8	49	52	48	95
	$B22_t$	40-70	7.0	6.8	7.6	4.2	59	60	54	98
	$B23_t$	70-120	7.2	7.0	6.5	3.2	42	43	46	94
	B3	120-160	6.8	6.8	6.8	3.1	41	41	41	90
	IIC_{cn}	160-195	6.8	6.6	7.0	3.4	47	48	46	94

Table 5 (contd.): CEC and base saturation of units 1 - 5 soils

Soil Unit	Horizon	Depth	Cation Exchange Capacity.				Base Saturation			
			NH_4OAc	EDTA	Cations	ECEC	NH_4OAc	EDTA	Cations	ECEC
		cm	meq/100g soil				%			
2										
	Profile 4		(OXIC PALEUSTALF/EUTRIC NITOSOL)							
	A1	0-8	5.9	7.5	3.7	63		49	100	
	$B1_t$	8-30	6.7	7.0	3.3	46		44	94	
	$IIB21_t$	30-50	7.5	6.5	3.0	39		45	97	
	$IIB22_{ton}$	50-90	7.0	7.5	3.9	54		51	97	
	$IIB23_{ton}$	90-130	7.1	8.1	4.4	62		54	100	
	$IIB24_{ton}$	130-165	7.5	8.4	4.7	63		56	100	
	Profile 5		(OXIC PALEUSTALF/EUTRIC NITOSOL)							
	A1	0-10	5.1	7.1	3.4	67		48	100	
	B1	10-25	5.8	6.4	2.6	45		41	100	
	$IIB21_{ton}$	25-60	7.7	8.0	4.1	53		51	100	
	$IIB22_{ton}$	60-90	7.5	8.0	4.3	57		54	100	
	$IIB23_{ton}$	90-120	7.6	7.8	4.3	55		54	100	
	$IIB24_{ton}$	120-140	7.8	8.0	4.3	55		54	100	
	$IIB25_{ton}$	140-180	7.7	8.0	4.4	56		54	98	
	Profile 6		(OXIC PALEUSTALF/EUTRIC NITOSOL)							
	A1	0-15	4.4	5.9	2.6	59		44	100	
	$B21_t$	15-40	5.1	5.9	2.7	51		44	96	
	$B22_t$	40-70	4.1	5.7	2.5	59		42	96	
	$B23_t$	70-110	5.2	6.6	3.2	60		47	97	
	$B24_t$	110-160	5.1	6.7	3.1	57		43	94	
	$B25_t$	160-195	5.8	6.8	3.1	50		43	94	
	$IIB3_{gon}$	195-215	6.1	6.0	2.7	41		42	87	

Table 5 (contd.): CEC and base saturation of units 1 - 5 soils

Soil Unit	Horizon	Depth	Cation Exchange Capacity.				Base Saturation		
			NH_4OAc	EDTA	Cations	ECEC	NH_4OAc	EDTA	Cations ECEC
		cm	meq/100g soil				%		
3									
	Profile 7		(OXIC HAPLUSTALF/CHROMIC LUVISOL)						
	A1	0-4	5.2	7.7	4.4	83	56	98	
	B1	4-30	3.2	6.4	2.9	91	45	100	
	$B21_t$	30-60	6.7	8.3	4.7	69	55	98	
	$B22_t$	60-85	6.2	8.1	4.6	71	54	96	
	$B23_t$	85-100	7.2	6.7	3.6	49	52	97	
	$B24_t$	100-135	6.1	6.2	3.2	49	48	94	
	$B3_g$	135-180	5.8	7.0	3.5	53	48	94	
	Profile 8		(OXIC PALEUSTALF/DYSTRIC NITOSOL)						
	A1	0-8	4.1	4.6	2.9	71	63	100	
	$B1_t$	8-20	6.1	6.6	2.8	43	42	93	
	$B21_t$	20-40	6.0	6.8	3.0	47	40	93	
	$B22_t$	40-75	5.8	6.1	3.0	50	47	97	
	$B23_t$	75-105	5.7	6.6	3.7	56	55	97	
	$B24_t$	105-160	5.7	8.5	4.9	84	56	98	
	Profile 9		(OXIC HAPLUSTALF/CHROMIC LUVISOL)						
	Ap	0-22	7.2	8.3	3.9	53	46	97	
	$B21_t$	22-42	7.4	9.2	5.3	70	57	98	
	$B22_t$	42-75	7.4	9.9	6.3	84	63	98	
	$B23_t$	75-100	7.0	8.8	5.1	73	58	100	
	$B24_{ts}$	100-130	6.4	8.4	5.4	84	64	100	
	$B31_{ts}$	130-150	6.7	8.1	5.1	76	64	100	
	$B32_s$	150-180	6.2	8.9	6.2	100	70	100	

Table 5 (contd.): CEC and base saturation of units 1 - 5 soils

Soil Unit	Horizon	Depth	Cation Exchange Capacity. NH_4OAc	EDTA Cations	ECEC	Base Saturation NH_4OAc	EDTA Cations	ECEC
		cm	meq/100g soil			%		
4								
Profile 10 (OXIC PALEUSTALF/EUTRIC NITOSOL)								
	A1	0-18	5.0	6.8	4.4	86	63	98
	$B21_t$	18-35	5.3	7.0	4.4	81	61	98
	$B22_t$	35-60	6.6	8.2	5.3	79	63	98
	$B23_t$	60-110	7.3	8.2	5.6	75	67	98
	$B24_t$	110-135	7.2	7.0	4.5	60	61	96
	$B25_t$	135-180	7.4	7.7	5.0	68	65	100
Profile 11 (TYPIC PALEUSTALF/DYSTRIC NITOSOL)								
	A1	0-12	6.6	7.9	4.7	71	59	100
	B1	12-30	7.3	6.8	3.7	49	53	92
	B21	30-60	6.0	5.6	2.6	40	43	92
	B22	60-100	7.4	4.1	1.8	18	32	72
	B3	100-140	7.3	3.4	1.4	16	35	86
	C1	140-180	6.2	6.0	3.9	61	63	97

Table 5 (contd.): CEC and base saturation of units 1 - 5 soils

Soil Unit	Horizon	Depth	Cation Exchange Capacity.			Base Saturation		
			NH_4OAc	EDTA Cations	ECEC	NH_4OAc	EDTA Cations	ECEC
		cm	meq/100g soil			%		
5								
Profile 12		(TYPIC TROPAQUEPT/EUTRIC GLEYSOL)						
	A1	0-10	4.8	5.6	2.2	40	34	86
	B1	10-20	4.8	4.6	1.8	33	35	89
	B2	20-50	6.5	4.4	2.0	29	43	95
	IIC1	50-100	4.4	2.4	1.0	20	38	90
	IIC2	100	3.9	2.8	1.4	36	50	96
Profile 13		(TYPIC TROPAQUEPT/EUTRIC GLEYSOL)						
	A1	0-12	8.8	9.8	4.4	49	44	98
	B1	12-30	7.2	9.4	3.4	44	34	94
	B21	30-50	7.4	8.5	3.4	41	35	88
	B22	50-100	9.7	10.4	5.3	54	50	98
	B31g	100-130	12.6	12.6	6.0	41	47	98
	B32g	130-160	10.0	12.9	6.9	62	52	97

The large difference between the sum of cations and ECEC determinations has been explained by Juo, Ayanlaja and Ogunwale (1976) to be due to increase in pH dependent negative charges measured by $BaCl_2$-TEA at pH 8.0. Consequently, the amount of H^+ exchanged by a soil depends to a great extent upon the pH at equilibrium. The successive H^+ of the soil complex becomes active as pH increases (Schollenberger and Simon, 1945). Barber & Rowell (1972), and Sawney & Norrish (1971), have also shown that soils whose exchange sites are accounted for mainly by Kaolinite, halloysite, and sesquioxides have pH-dependent negative charges. The clay mineralogy of soils in Kaduna - Zaria area has been indicated by Ojanuga (1979) to be dominantly kaolinite. The soils therefore have the capacity to exchange more H^+ at pH 8.0 for the sum of cations method.

The discrepancy between the NH_4OAc-CEC abd ECEC is also attributed to the increase in pH.

Simple correlation and regression analysis between the methods were carried out. Table 6 and Figs 9, 10 and 11 show the statistical relationships between the three methods. The three methods were all significantly different at the 0.1% level of significance. The highest correlation was between values obtained by ECEC and sum of cations. One important aspect of the regression lines between the methods is that knowing the value by one method, the CEC value of

Table 6. Statistical comparison of three methods for determining CEC

Variables	Correlation Coefficient	Regression line
NH_4OAc-ECEC	0.7191***	NH_4OAc = 3.3319+0.8619 ECEC
NH_4OAc-sum of cations	0.787***	NH_4OAc = 1.7022+0.6804 sum of cations
ECEC-sum of cations	0.9161***	ECEC = -0.9136+0.6607 sum of cations

the same soil by the other two methods could be calculated.

Because CEC is pH dependent as mentioned earlier, and because a pH of 7 or above is hardly ever recorded in the soils, Juo, Ayanlaja and Ogunwale (1976) suggested that the sum of cations may not give true positions of the CEC in tropical soils. Juo, Ayanlaja and Ogunwale (1976) further suggested that ECEC may be a more realistic measure of CEC because according to them, values obtained by this method are much closer to the CEC under field conditions. But as has been noticed earlier, values obtained by this method are so low that they are unlikely to represent field conditions adequately. ECEC also represents CEC under soil pH conditions. Soil pH conditions are likely to change with water content or saturation of the soils. On the basis of all these, it is suggested than an underestimation of the CEC of soils is likely

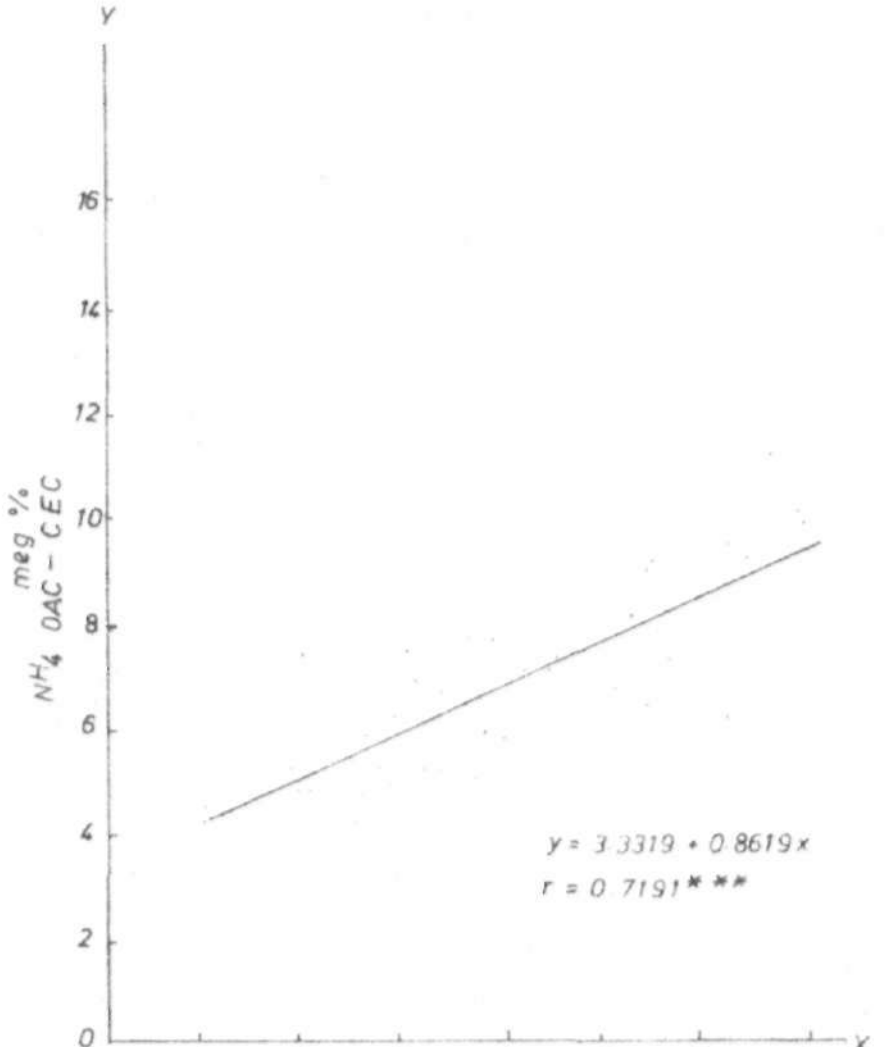


FIG. 9: Regression line of NH_4OAc- CEC upon ECEC

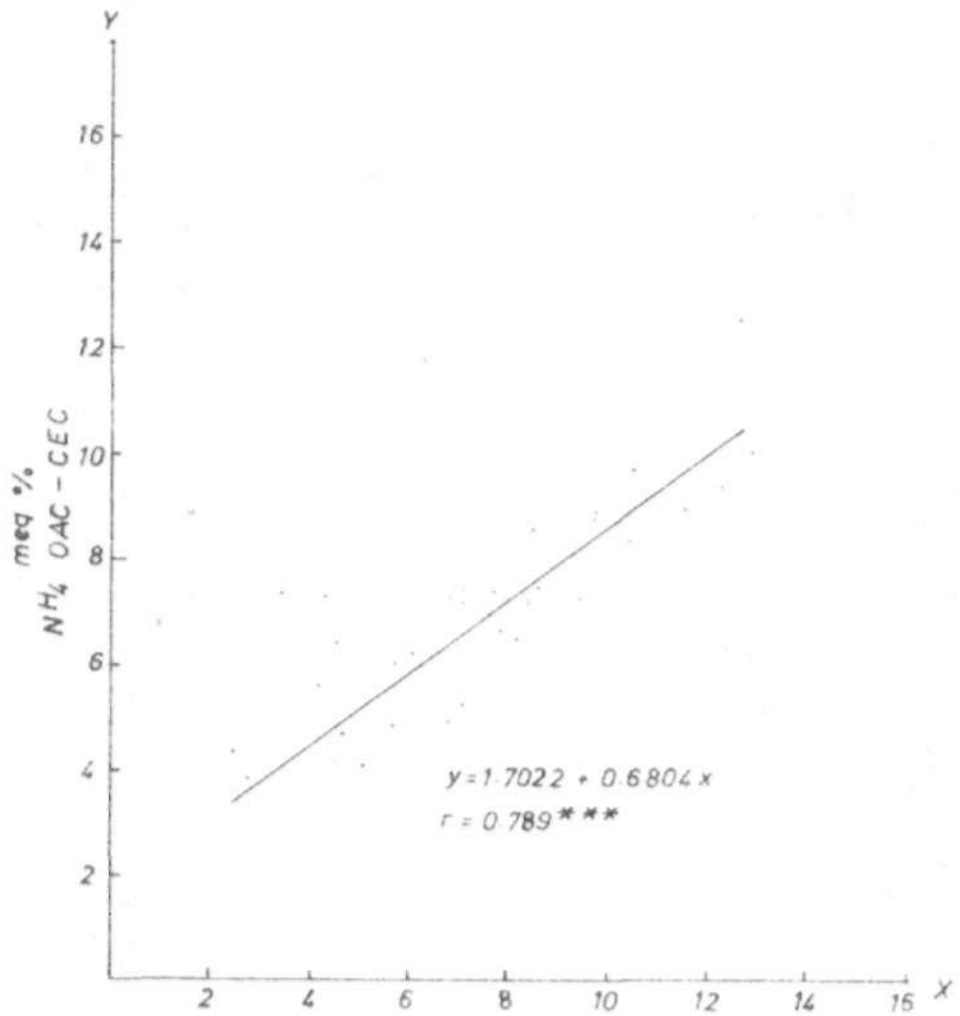


FIG.10: Regression line of NH_4OAc-CEC upon sum of cations

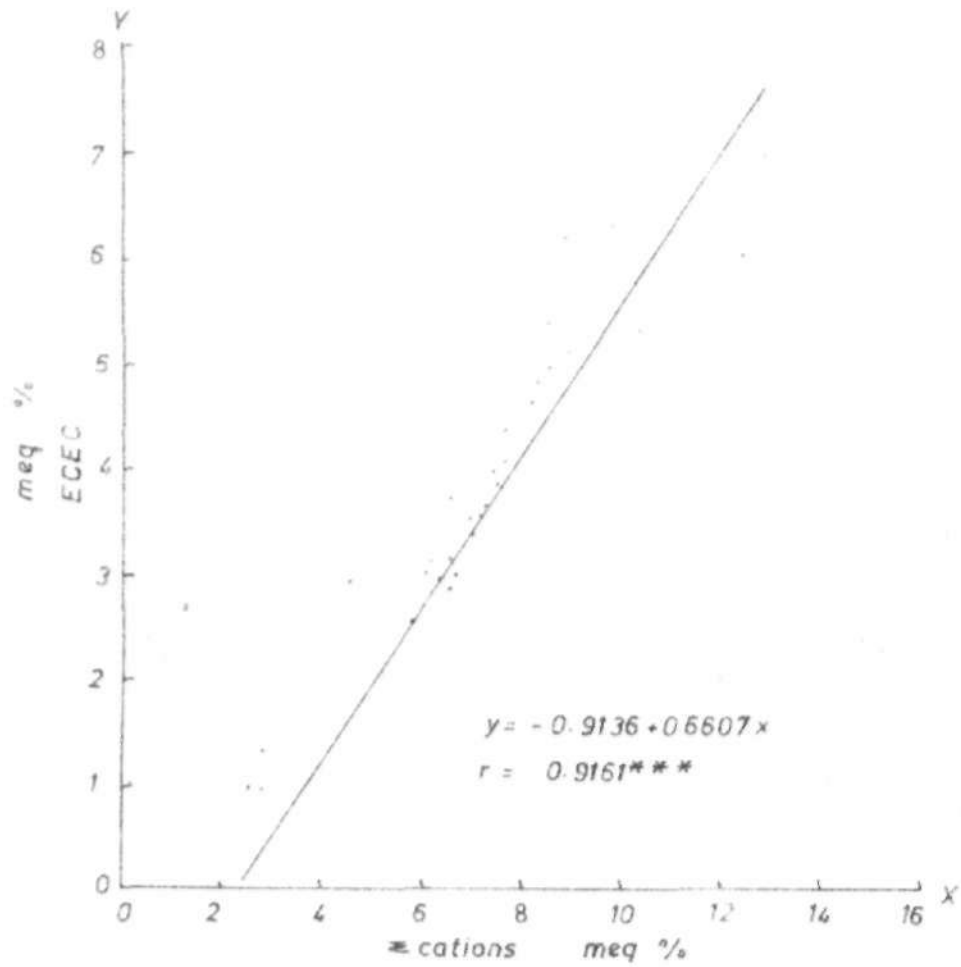


FIG.11. Regression line of ECEC upon sum of cations

to result if the ECEC method is used in routine analysis for soil classification purposes.

While the sum of cations may have genuine limitations in use for determining the CEC of soils in the Zaria area as pointed out earlier, the NH_4OAc-CEC method can be used effectively because it gives near approximate CEC values for the soils. It appears that the soils are low in 2:1 layer silicate clays like montmorillonite and vermiculite that fix the NH_4^+ ions, resulting in underestimation of CEC for soils of the temperate regions.

For comparison purposes, the CECof some of the soils (profiles 2 and 3) were also determined using EDTA-CEC method as mentioned earlier. Values (tables 5) were very comparable with the NH_4OAc-CEC method indicating that any of the two analytical procedures will be good for determining the CEC of these and similar soils.

The lowest CEC values were recorded in the surface horizons owing to their low clay and perhaps low organic matter contents. CEC values increased in the B horizons due to the high clay contents in such horizons. Exceptions to this general trend are profiles 12 and 13 of the poorly drained fadama soil unit 5 where the lowest CEC values occur in the subsoil B horizons. This discrepancy is perhaps partly due to the high content of organic matter in the surface horizon of the soils, and NH_4^+ fixation by mica and other 2:1 layer silicate clays which may be present in these poorly drained

environments (Ojanuga, 1979). Another exception to the general rule is profile 7 of soil unit 3 where the lowest CEC value was recorded in the A3 horizon having a sand lens.

There is close agreement between CEC and clay content. Data for profile 6, soil unit 2 (table 5)substantiate the relationship clearly. The $B22_t$ horizon which contained less clay than the overlying or underlying horizons showed a decrease in CEC value by all the three methods used. The fact that the surface horizons which usually contain the lowest clay content, have the lowest CEC values may be indicative of the prominence of clay over organic matter, in influencing the CEC of these soils.

Soil units 2 and 3 (table 5) have relatively low CEC values in their B horizons as a result of the high gravel, and low clay contents per unit volume of soil.

Soil unit 1 has relatively higher CEC values in the B horizon than the other soil units possibly as a result of a high silt plus clay content.

Unit 5 soils as typified by profile 13 have relatively higher CEC values compared to the other soil units. CEC values in these soils ranged from 7.2 to 12.6 meq/100g of soil (by NH_4OAc). The relatively high CEC values in these soils may be related to the high organic matter content, and the presence of montmorillonitic

type of clays since the soils are poorly drained, and are environments conducive to the formation of 2:1 lattice clay minerals as has been mentioned earlier (Ojanuga, 1973; Young, 1976). The CEC of this soil unit may even be higher than these apparent values as the fadama soils in the Kaduna - Zaria area have been reported to contain mica (illite) (Ojanuga, 1979) which could fix NH_4^+

The CEC of the soils per 100g of clay was calculated. Values (table 7) are moderate to high being 12 - 146 meq/100g, (by NH_4OAc). Most of the soils have CEC/100g of clay in the range of 16-27 meq. Profile 12 of soil unit 5 has 130 to 147 meq/100g of clay in the subsurface horizons. Since kaolinite has a CEC of between 3 and 15 meq/100g (Grim, 1968), it is suggested that the soils contained some amounts of 2:1 silicate clays as pointed out by Ojanuga (1979).

CEC per 100g clay shows an increase with depth within each profile. It also shows an increase from well drained to poorly drained sites. These may be due to increases in the amount of 2:1 layer silicate clay minerals in the subsurface horizons and in poorly drained environments. The subsoil and the poorly drained soil environments can be considered as closed systems where bases are available for recombination with silica and alumina for the synthesis of these layered silicate clays (Ojanuga, 1973).

Table 7: A comparison of CEC % clay and CEC % silt + clay

Soil Unit	Horizon	Depth	CEC% clay	CEC % silt + clay
		cm	meq %	
Profile 1	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
	A1	0–14	48.0	10.6
	$B21_t$	14–29	18.0	10.7
	$B22_t$	29–60	19.3	12.2
	$B23_t$	60–100	17.7	11.5
	$B24_t$	100–130	20.4	12.6
	$B3_t$	130–170	19.0	12.3
Profile 2	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
	A1	0–12	22.7	9.6
	$B1_t$	12–25	19.1	12.0
	$B21_t$	25–50	17.0	11.1
	$B22_t$	50–80	17.9	11.4
	$B23_t$	80–110	21.5	13.4
	B3	110–150	19.4	11.9
	IIC_{cn}	150–190	19.4	12.6
Profile 3	(OXIC HAPLUSTALF/CHROMIC LUVISOL)			
	A1	0–10	20.9	10.4
	$B1_t$	10–25	18.3	11.0
	$B21_t$	25–40	16.4	11.2
	$B22_t$	40–70	17.5	9.7
	$B23_t$	70–120	17.1	9.9
	B3	120–160	17.4	10.3
	IIC_{cn}	160–195	18.4	10.5

Table 7 (Contd.): A comparison of CEC % clay and CEC % silt + clay

Soil Unit	Horizon	Depth	CEC% clay	CEC % silt + clay
2		cm.	meq %	
Profile 4	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
	A1	0–8	21.9	11.3
	$B1_t$	8–30	14.9	10.2
	$IIB21_t$	30–50	18.8	12.1
	$IIB22_t$	50–90	16.7	11.7
	$IIB23_{ten}$	90–130	18.7	13.1
	$IIB24_{ten}$	130–165	19.7	13.2
Profile 5	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
2	A1	0–10	23.2	10.2
	B1	10–25	25.2	12.1
	$IIB21_{ten}$	25–60	19.3	13.1
	$IIB22_{ten}$	60–90	18.8	12.5
	$IIB23_{ten}$	90–120	20.5	13.1
	$IIB24_{ten}$	120–140	20.0	12.6
	$IIB25_{ten}$	140–180	16.0	11.3
Profile 6	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
	A1	0–15	25.9	8.8
	$B21_t$	15–40	18.2	9.8
	$B22_t$	40–70	16.4	7.9
	$B23_t$	70–110	13.7	8.3
	$B24_t$	110–160	12.4	8.5
	$B25_t$	160–195	12.6	8.5
	$IIB3_{gen}$	195–215	20.6	12.4

Table 7 (Contd.): A comparison of CEC % clay and CEC % silit + clay

Soil Unit	Horizon	Depth	CEC% clay	CEC % silt + clay
3		cm	meq %	
Profile 7	(OXIC HAPLUSTALF/CHROMIC LUVISOL)			
	A1	0–4	27.4	10.2
	B1	4–30	16.8	9.7
	$B21_t$	30–60	20.3	10.0
	$B22_t$	60–85	14.1	8.9
	$B23_t$	85–100	20.0	11.1
	$B24_t$	100–135	15.6	9.2
	$B3_g$	135–180	16.6	8.9
Profile 8	(OXIC PALEUSTALF/DYSTRIC NITOSOL)			
	A1	0–8	24.0	8.4
	$B1_t$	8–20	15.6	10.2
	$B21_t$	20–40	15.0	9.4
	$B22_t$	40–75	16.1	9.7
	$B23_t$	75–105	15.8	8.9
	$B24_t$	105–160	14.6	8.9
Profile 9	(OXIC HAPLUSTALF/CHROMIC LUVISOL)			
	Ap	0–22	20.0	10.9
	$B21_t$	22–42	19.5	11.2
	$B22_t$	42–75	15.4	9.7
	$B23_t$	75–100	14.9	9.6
	$B24_t$	100–130	16.4	10.0
	$B31_t$	130–150	18.6	9.9
	$B32_t$	150–180	21.0	10.3

Table 7 (Contd.): A comparison of CEC % clay and CEC % silt + clay

Soil Unit	Horizon	Depth	CEC% clay	CEC % silt + clay
4.		cm	meq %	
Profile 10	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
	A1	0–18	33.3	10.0
	$B21_t$	18–35	13.6	9.6
	$B22_t$	35–60	17.8	10.5
	$B23_t$	60–110	18.7	11.1
	$B24_t$	110–135	15.6	10.7
	$B25_{tg}$	135–180	18.0	11.6
Profile 11	(TYPIC PALEUSTALF/DYSTRIC NITOSOL)			
	A1	0–12	23.6	9.2
	B1	12–30	27.0	11.2
	B21	30–60	27.3	10.0
	B22	60–100	33.6	13.0
	B3	100–140	45.6	12.4
	C1	140–180	20.7	10.2

Table 7 (Contd.): A comparison of CEC % clay and CEC % silt + clay

Soil Unit	Horizon	Depth	CEC% clay	CEC % silt + clay
5		cm	meq %	
Profile 12	(TYPIC TROPAQUEPT/EUTRIC GLEYSOL)			
	A1	0-10	53.3	10.7
	B1	10-20	28.2	8.7
	B2	20-50	29.5	10.5
	IIC1	50-100	146.7	8
	IIC2	100+	130.0	7.8
Profile 13	(TYPIC TROPAQUEPT/EUTRIC GLEYSOL)			
	A1	0-12	55.0	13.3
	B1	12-30	28.8	9.7
	B21	30-50	23.9	9.4
	B22	50-100	24.3	11.7
	B31	100-130	39.4	16.8
	B32	130-160	22.7	11.5
6				

Kaolinite, quartz and illite have been reported as the dominant clay minerals in the well drained soils of the study area (Ojanuga, 1979b).

The above calculations may be an overestimation of the activity of the clay in these soils as a considerable part of the CEC may come from the silt-size (2 - 50μm) fraction. Martini (1970) and Ojanuga, (1971; 1975) have reported appreciable charged sites on silt-size particles and the occurrence of silt-sized kaolinite respectively. CEC was therefore calculated per 100g silt + clay (table 7). The range of values was 7.9 to 16.8 meq % with a mean value of 10.7 meq %. Values are not too far apart as with CEC per 100g clay, and this may be a better representation of CEC for these soils.

Exchange acidity

Exchange acidity values determined by three methods are given in table 8. Values generally follow the same trend as those for CEC. The high value got by both the $BaCl_2$-TEA (pH 8.0) and the neutral 1N NH_4OAc methods may possibly be ascribed to weakly dissociated organic acid groups and oxyhydrates of Fe and Al on exchange sites (Ojanuga, 1971). Extractable acidity (unbuffered 1N KCl extraction) values are generally low, being 0.1 to 0.49 meq/100 g of soil. This is probably due to the effect of

Table 8: Exchange acidity (meq/100g soil) by three methods.

Soil Unit I

Profile 1 (OXIC PALEUSTALF/EUTRIC NITOSOL)

Horizon	Depth (cm)	NH_4OAc pH7	$BaCl_2$-TEA pH8	KCl
A1	0-14	2.07	3.6	0.07
$B21_t$	14-29	2.97	3.7	0.07
$B22_t$	29-60	3.32	3.8	0.05
$B23_t$	60-100	2.89	3.9	0.04
$B24_t$	100-130	2.91	3.8	0.03
$B25_t$	130-170	3.76	3.7	0.04
Profile 2	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
A1	0-12	1.31	3.3	0.02
$B1_t$	12-25	3.63	3.9	0.07
$B21_t$	25-50	2.60	3.7	0.02
B22t	50-80	3.1	41	0.03
B23t	89-110	3.28	4.1	0.02
B3	110-150	2.94	3.9	0.03
IIC_{cn}	150-190	2.45	3.7	0.02
Profile 3	(OXIC HAPLUSTALF/CHROMIC LUVISOL)			
A1	0-10	1.76	3.6	0.02
$B1_t$	10-25	4.44	3.9	0.03
$B21_t$	25-40	3.82	3.9	0.20
$B22_t$	40-70	2.93	3.5	0.11
$B23_t$	70-120	4.2	3.5	0.24
B3	120-160	4.0	4.0	0.26
IIC_{cn}	160-195	3.65	3.8	0.21

Table 8 (Contd.): Exchange acidity (meq/100g soil) by three methods

Soil Unit 2

Profile 4 (OXIC PALEUSTALF/EUTRIC NITOSOL)

Horizon	Depth (cm)	NH_4OAc pH7	$BaCl_2$-TEA pH8	KCl
A1	0–8	2.23	3.8	0.03
$B1_t$	8–30	3.63	3.9	0.21
$IIB21_{cn}$	30–50	4.63	3.6	0.16
$IIB22_{tcn}$	50–90	3.17	3.7	0.04
$IIB23_{tcn}$	90–130	2.75	3.7	0.04
$IIB24_{tcn}$	130–165	2.80	3.7	0.03
Profile 5	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
A1	0–10	1.69	3.7	0.02
B1	10–25	3.19	3.8	0.02
$IIB21_{tcn}$	25–60	3.60	3.9	0.06
$IIB22_{tcn}$	60–90	3.22	3.7	0.01
$IIB23_{tcn}$	90–120	3.37	3.6	0.02
$IIB24_{tcn}$	120–140	3.50	3.7	0.03
$IIB25_{tcn}$	140–180	3.36	3.7	0.03
Profile 6	(OXIC PALEUSTALF/EUTRIC NITOSOL)			
A1	0–15	1.83	3.3	0.02
$B21_t$	15–40	2.50	3.3	0.07
$B22_t$	40–70	1.69	3.3	0.06
$B23_t$	70–110	2.07	3.5	0.11
$B24_t$	110–160	2.16	3.8	0.12
$B25_t$	160–195	2.95	3.9	0.21
$IIB3_{gcn}$	195–215	3.63	3.5	0.20

Table 8 (Contd.): Exchange acidity (meq/100g soil) by three methods

Soil Unit 3

Profile 7 (OXIC HAPLUSTALF/CHROMIC LUVISOL)

Horizon	Depth (cm)	NH_4OAc pH7	$BaCl_2$-TEA pH8	KCl
A1	0-4	0.86	3.4	0.01
B1	4-30	0.32	3.5	0.03
$B21_t$	30-60	2.11	3.7	0.13
B22t	60-85	1.80	3.7	0.23
B23t	85-100	3.70	3.2	0.08
B24t	100-135	3.15	3.2	0.22
$B3_g$	135-180	1.51	3.7	0.21
Profile 8	(OXIC PALEUSTALF/DYSTRIC NITOSOL)			
A1	0-8	1.20	1.7	0.02
$B1_t$	8-20	3.54	4.0	0.23
$B21_t$	20-40	3.25	4.0	0.28
$B22_t$	40-75	2.92	3.2	0.09
$B23_t$	75-105	2.08	3.0	0.04
$B24_t$	105-160	0.92	3.7	0.12
Profile 9	(OXIC HAPLUSTALF/CHROMIC LUVISOL)			
Ap	0-22	3.45	4.5	0.14
$B21_t$	22-42	2.23	4.0	0.11
$B22_t$	42-75	1.19	3.7	0.04
$B23_t$	75-100	1.88	3.7	0.02
$B24_{ts}$	100-130	1.01	3.0	0.02
$B31_{ts}$	130-150	1.64	3.0	0.02
$B32_s$	150-180	0.0	2.7	0.02

Table 8 (Contd.): Exchange acidity (meq/100g soil) by three methods

Soil Unit 4

Profile 10 (OXIC PALEUSTALF/EUTRIC NITOSOL)

Horizon	Depth (cm)	NH_4OAc pH7	$BaCl_2$-TEA pH8	N KCl
A1	0–18	0.66	2.5	0.02
$B21_t$	18–35	0.99	2.7	0.04
$B22_t$	30–60	1.41	3.0	0.08
$B23_t$	60–110	1.78	2.7	0.06
$B24_t$	110–135	2.86	2.7	0.12
$B25_{tg}$	135–180	2.45	2.7	0.04

Profile 11 (TYPIC PALEUSTALF/DYSTRIC NITOSOL)

A1	0–12	1.91	3.20	0.03
B1	12–30	3.75	3.2	0.11
B21	30–60	3.60	3.2	0.19
B22	60–100	6.11	2.8	0.49
B3	100–140	6.09	2.2	0.19
C1	140–180	2.36	2.2	0.1

Table 8 (Contd.): Exchange acidity (meq/100g soil) by three methods

Soil Unit 5

Profile 12 (TYPIC TROPAQUEPT/EUTRIC GLEYSOL)

Horizon	Depth (cm)	NH_4OAc pH7	$BaCl_2$-TEA pH8	N KCl
A1	0-10	2.86	3.7	0.23
B1	10-20	3.21	3	0.25
B2	30-50	4.65	2.5	0.17
IIC1	50-100	3.49	1.5	0.05
IIC2	100	2.55	1.4	0.06

Profile 13 (TYPIC TROPAQUEPT/EUTRIC GLEYSOL)

A1	0-12	4.53	5.5	0.08
B1	12-30	4.0	6.2	0.15
B21	30-50	4.38	5.5	0.42
B22	50-100	4.54	5.2	0.12
$B31_g$	100-130	6.75	6.7	0.1
$B2_g$	130-160	3.28	6.2	0.21

low pH in repressing the dissociation of weakly acidic groups present in the soil complex.

Base saturation

Base saturation as calculated for the three methods is variable and is dependent on the method used (table 5). As will be expected, the base saturation by ECEC gave the highest values (72-100% range) with most values falling between 91 and 100%. The sum of cations gave the lowest values (32-70% range). Base saturation by NH_4OAc gave values slightly higher than those obtained by sum of cations in most cases. Values ranged from 16 to 100% by NH_4OAc method. Table 9 shows the statistical relationships between the three methods, while Figs 12, 13 and 14 show the regression lines between methods. The highest correlation was between values obtained by NH_4OAc and sum of cations.

Table 9. Statistical relationship between base saturation as computed by three methods.

Variable	Correlation Coefficient	Regression line
NH_4OAc-ECEC	0.6945**	NH_4OAc = -184.7154+2.5163 ECEC
NH_4OAc-sum of cations	0.7902**	NH_4OAc = -13.8778+1.3978 sum of cations
ECEC-sum of cations	0.7065**	ECEC = 78.7203+0.3449 sum of cations.

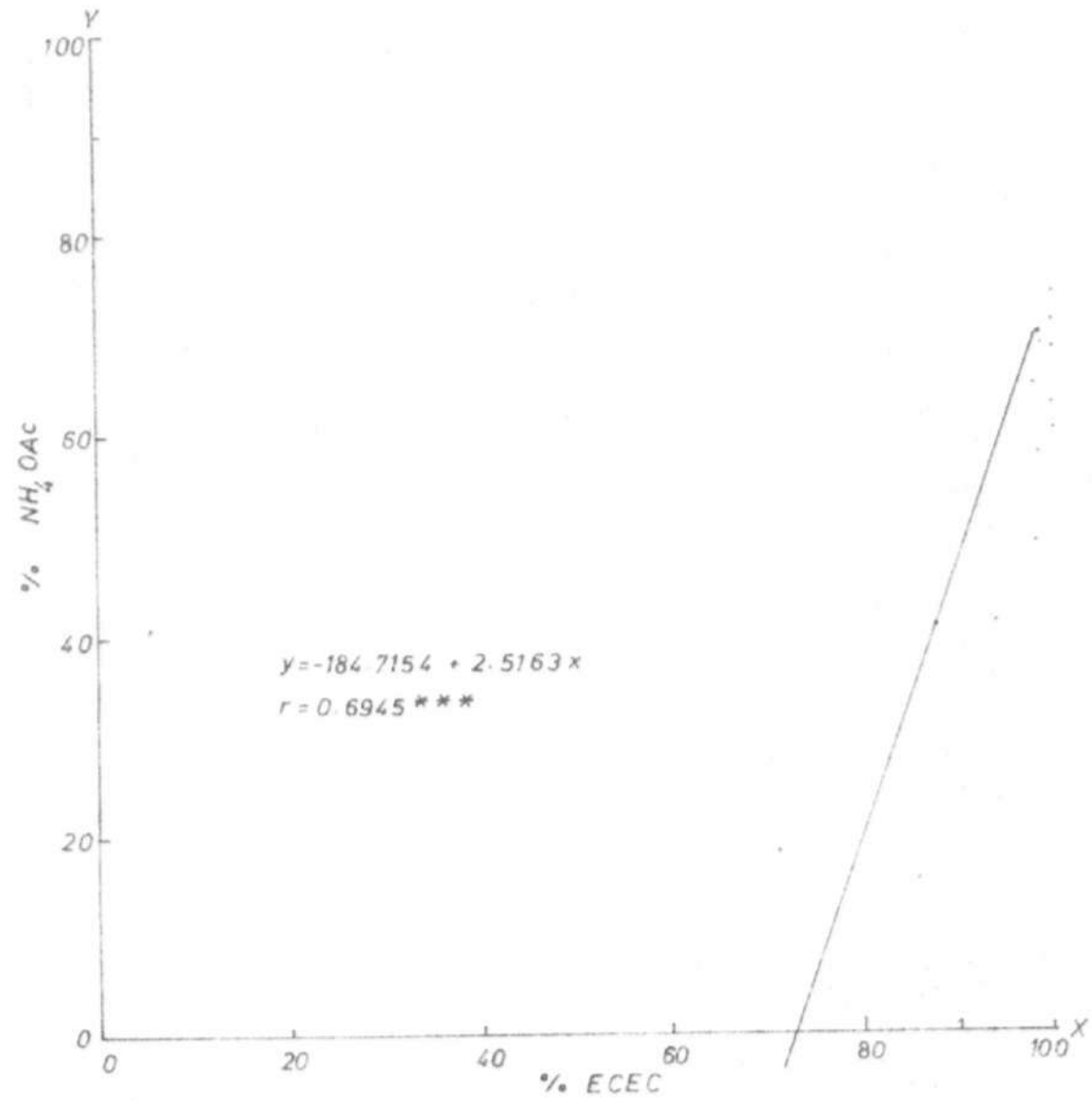


FIG.12 Regression line of NH_4OAc base saturation upon ECEC base saturation

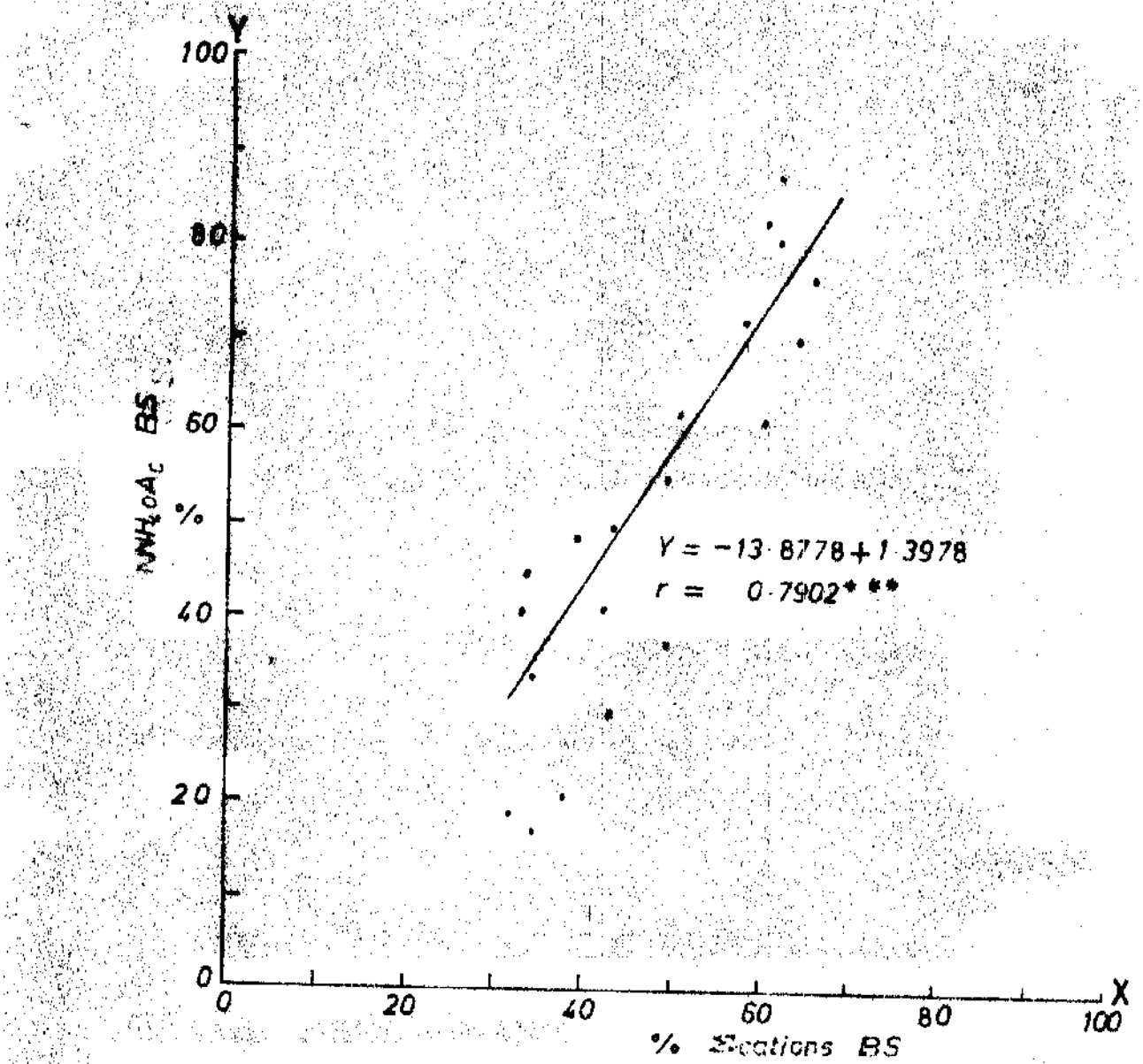


Fig 13 *Regression line of NH_4 OAc base saturation upon sum of cation base saturation*

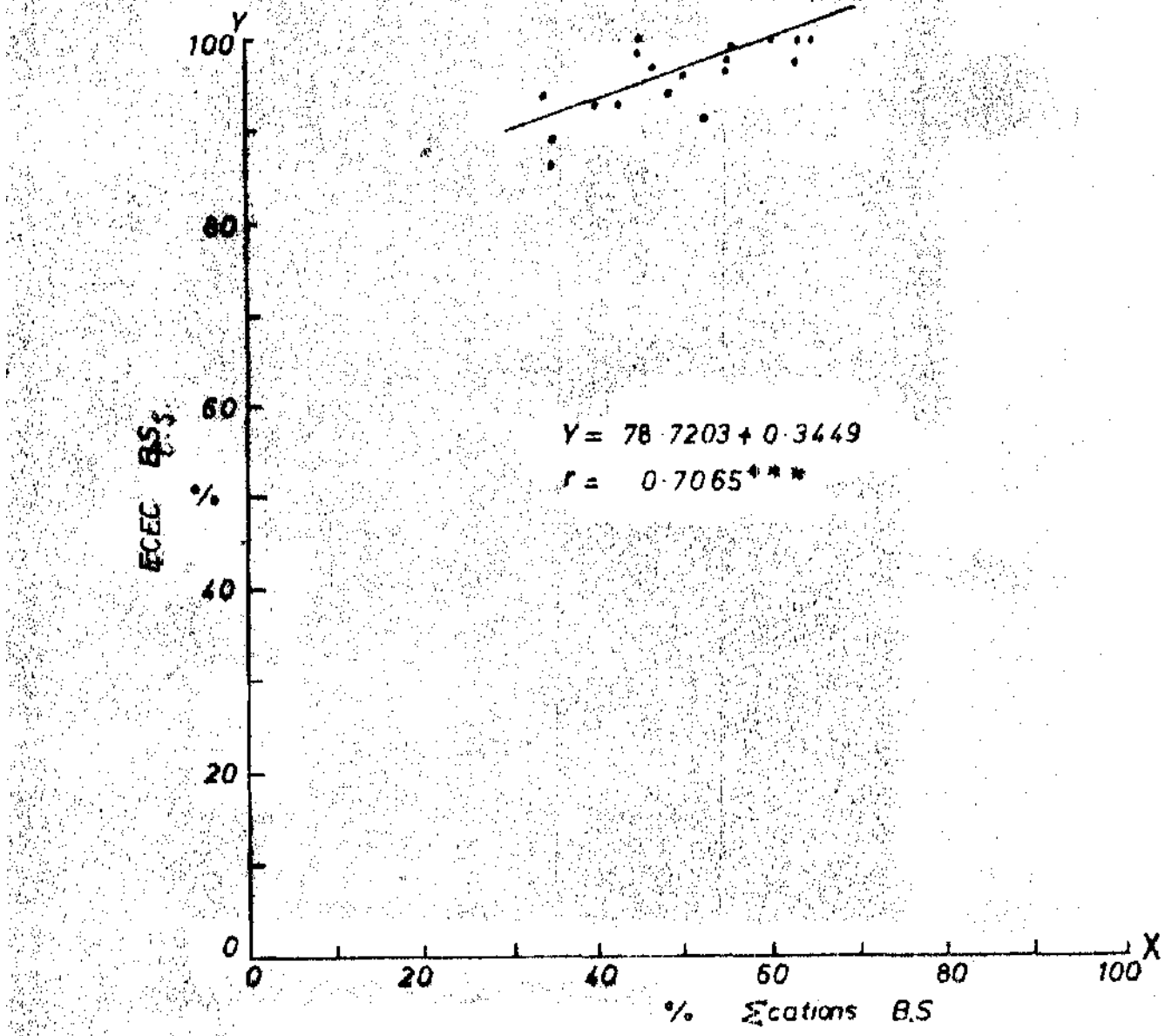


Fig 14 Regression line of ECEC base saturation upon sum of cations base saturation

By knowing the percent base saturation by one method, the percent base saturation of the same soil by the other two methods can be calculated. This method can prove very useful in soil correlation work, as conversion of base saturation from one "scale" to the other is rendered easy.

The general pattern of base saturation by the three methods for all the soils is that of a high value in the surface horizon, a decrease in the underlying A3 and B1 horizon , and a gradual increase in value with depth.

The higher base saturation in the surface horizon is due to accumulation of exchangeable cations from plant litter decomposition coupled with low clay content and consequent low CEC. Malgwi (1979) also attributed the high base saturation of the surface horizons in the Samaru area to cation addition to the soil surface through the harmattan dust. The limited available exchange sites are therefore almost base saturated.

The underlying A3 and B1 horizons represent regions of maximum eluviation and this is why they tend to have low base saturation generally.

Maximum base saturation were recorded in the deeper subsoil horizons. This is possibly as a result of the accumulation of leached cations in these horizons.

Base saturation is highest in units 3 and 4 soils where mean values are about 75%, and lowest in unit 5 soils where mean value is about 40%. The units 1 and 2 soils which occupy relatively higher topographic positions have intermediate base saturation values of about 60%. The lower base saturation of the poorly drained unit 5 soils may be due to H^+ saturation of their exchange complex, while the moderate to high base saturation of the units 1 to 4 soils may be due to their low CEC.

Base saturation by ECEC is hardly ever less than 90 for all the soil units. This is due to the very low CEC values obtained with the method. This may be an overestimation of the saturation of these soils, and on this basis, it is suggested that base saturation by NH_4OAc is a better indication of the capacity of these soils for cations.

Dithionite-extractable Fe_2O_3

Results of the total free iron oxide determined for the soils are presented in table 10.

The surface horizons generally contain the lowest total free iron oxide, while the C horizons contain the highest. The trend indicates a translocation of dissolved Fe from the surface horizons to the subsoil horizons. Malgwi (1979) observed a similar trend in the depth distribution of Fe_2O_3 in the soils from an area adjacent

Table 10: Free iron oxide content of units 1 - 5 soils

Soil Unit	Horizon	Depth (cm)	Free Fe_2O_3 (%)
1			
Profile 1	(OXIC PALEUSTALF/EUTRIC NITOSOL)		
	A1	0-14	0.95
	$B21_t$	14-29	2.3
	$B22_t$	29-60	2.4
	$B23_t$	60-100	2.3
	$B24_t$	100-130	2.3
	$B3_t$	130-170	2.5
Profile 2	(OXIC PALEUSTALF/EUTRIC NITOSOL)		
	A1	0-12	1.0
	$B1_t$	12-25	2.3
	$B21_t$	25-50	3.0
	$B22_t$	50-80	2.8
	$B23_t$	80-110	2.6
	B3	110-150	2.9
	IIC_{cn}	150-190	2.7
Profile 3	(OXIC HAPLUSTALF/CHROMIC LUVISOL)		
	A1	0-10	1.5
	$B1_t$	10-25	2.3
	$B21_t$	25-40	2.2
	$B22_t$	40-70	2.5
	$B23_t$	70-120	2.5
	B3	120-160	2.9
	IIB_{cn}	160-195	2.9

Table 10: (Contd.): Free iron oxide content of units 1 - 5 soils

Soil Unit	Horizon	Depth (cm)	Free Fe_2O_3 (%)
2			
Profile 4	(OXIC PALEUSTALF/EUTRIC NITOSOL)		
	A1	0–8	2.8
	$B1_t$	8–30	2.7
	$IIB21_t$	30–50	3.3
	$IIB22_{tcn}$	50–90	4.0
	$IIB23_{tcn}$	90–130	5.2
	$IIB24_{tcn}$	130–165	4.5
Profile 5	(OXIC PALEUSTALF/EUTRIC NITOSOL)		
	A1	0–10	1.4
	B1	10–25	2.5
	$IIB21_{tcn}$	25–60	3.9
	$IIB22_{tcn}$	60–90	4.7
	$IIB23_{tcn}$	90–120	5.2
	$IIB24_{tcn}$	120–140	4.8
	$IIB25_{tcn}$	140–180	4.4
Profile 6	(OXIC PALEUSTALF/EUTRIC NITOSOL)		
	A1	0–15	1.3
	$B21_t$	15–40	1.5
	$B22_t$	40–70	1.8
	$B23_t$	70–110	2.1
	$B24_t$	110–160	2.9
	$B25_t$	160–195	3.2
	$IIB3_{gcn}$	195–215	7.0

Table 10 (Contd.): Free iron oxide content of units 1 - 5 soils

Soil Unit	Horizon	Depth(cm)	Free Fe_2O_3(%)
3			
Profile 7	(OXIC HAPLUSTALF/CHROMIC LUVISOL)		
	A1	0-4	1.0
	B1	4-30	1.2
	$B21_t$	30-60	2.3
	$B22_t$	60-85	2.8
	$B23_t$	85-100	3.3
	$B24_t$	100-135	3.9
	$B3_g$	135-180	3.9
Profile 8	(OXIC PALEUSTALF/DYSTRIC NITOSOL)		
	A1	0-8	1.4
	$B1_t$	8-20	2.1
	$B21_t$	20-40	2.8
	$B22_t$	40-75	3.5
	$B23_t$	75-105	3.3
	$B24_t$	105-160	3.4
Profile 9	(OXIC HAPLUSTALF/CHROMIC LUVISOL)		
	Ap	0-22	2.4
	$B21_t$	22-42	2.3
	$B22_t$	42-75	2.5
	$B23_t$	75.100	3.7
	$B24_{ts}$	100.130	3.9
	$B31_{ts}$	130-150	4.0
	$B32_s$	100-180	4.4

Table 10 (Contd.): Free iron oxide content of units 1 - 5 soils

Soil Unit	Horizon	Depth (cm)	Free Fe_2O_3 (%)
4			
Profile 10	(OXIC PALEUSTALF/EUTRIC NITOSOL)		
	A1	0-18	0.9
	$B21_t$	18-35	1.3
	$B22_t$	35-60	1.4
	$B23_t$	60-110	1.4
	$B24_t$	110-135	1.9
	$B25_{tg}$	135-180	3.6
Profile 11	(TYPIC PALEUSTALF/DYSTRIC NITOSOL)		
	A1	0-12	1.4
	B1	12-30	7.3
	B21	30-60	6.0
	B22	60-100	7.4
	B3	100-140	7.3
	C1	140-180	6.2

Table 10 (Contd.): Free iron oxide content of units 1 - 5 soils

Soil Unit	Horizon	Depth (cm)	Free Fe_2O_3 (%)
5			
Profile 12	(TYPIC TROPAQUEPT/EUTRIC GLEYSOL)		
	A1	0–10	1.7
	B1	10–20	1.2
	B2	20–50	1.3
	IIC1	50–100	1.4
	IIC2	100	1.7
Profile 13	(TYPIC TROPAQUEPT/EUTRIC GLEYSOL)		
	A1	0–12	1.3
	B1	12–30	1.5
	B21	30–50	1.7
	B22	50–100	2.3
	$B31_g$	100–130	5.5
	$B32_g$	130–160	6.7

to the study area and attributed the high contents in the B horizons of the well drained soils to the same process coupled with increased precipitation of iron oxides during the dry season by ground water recession.

The concretionary soils of units 2 and 3 contained the highest amounts of free iron oxide while the poorly drained soils of units 4 and 5 contained the lowest amounts. The high contents in the units 2 and 3 soils are as a result of the occurrence of iron oxide nodules in the coarse fraction of these soils. The low content of free iron oxide in the poorly drained soils is probably due to the occurrence of iron in the soluble state in these poorly drained soil environments.

There are noticeable accumulations of free iron oxide in the vicinity of discontinuities (profiles 3, 4, 5 and 6) and in gleyed horizons (profiles 6, 10 and 13). Such horizons are usually zones of low porosity where iron-enriched percolating water stagnates and their contents, including the iron, precipitated in the non-capillary pores on drying.

SOIL CORRELATION AND CLASSIFICATION

Soil Correlation

Soil correlation is the scientific method by which the set or combination of all the significant characteristics of each soil is specifically compared with the set of characteristics of the already defined soil..in the natural or taxonomic system of soil classification (Kellog, 1959) to establish relationships. The soils of the present study can be correlated with earlier studies by soil scientists who have worked in the Zaria area.

Vine (1953) classified the soils in the Zaria area as Brown to Red - Brown Compact Silty Fine Sands. Tomlinson (1965), Klinkenberg and Higgins (1968) and D'Hoore (1968) using the Belgian classification system, classified the soils as Ferruginous Tropical Soils. The USDA Soil Map of the World (Ackerson et. al. 1968) referred to by Harpstead (1973) classified the soils in the Zaria area as Alfisols. The FAO (1974) soil map of the world classified the soils as Ferric Luvisols.

Many of the studies that culminated in these classifications were based on exploratory soil surveys at best. Recently, Malgwi (1979) gives the most detailed data on soils in the Zaria area with which meaningful comparisons and correlations can be made.

Malgwi (1979) identified six soil units in an area adjacent to the study area.

Soil unit 1 of this study correlates very well with Malgwi's soil unit 6. Both soils are deep, well drained, strongly structured, yellowish red clay or clay loam soils with sandy loam surface horizons. They show evidence of thick clay skin coatings on ped surfaces in the field, indicating the presence of an argillic horizon in the soils.

Soil unit 2 cannot be correlated with any of Malgwi's six soil mapping units.

Soil unit 3 correlates with Malgwi's soil units 4 and 5. It appears that his soil units 4 and 5 can be mapped together as a soil unit. All the three soils are deep, well drained, and have an argillic horizon. They all tend to be concretionary below 130cm. Base saturation in the soils is high and the CEC per 100g clay is moderately high.

Soil unit 4 correlates with Malgwi's soil unit 2. The two soils are imperfectly drained, occupy gently sloping surfaces on the fringes of the fadama, have light textures and show a weak argillic horizon development. They are also similar in terms of their physical and chemical characteristics.

Soil unit 5 correlates very closely with Malgwi's soil unit 1 in terms of its morphological, physical and chemical characteristics, and with the Bomo series of Higgins (1963). The correlation is summarized in table 11.

Table 11. Correlation of units studied with Malgwi (1979)

Soil Units Studied	Malgwi (1979)
Soil unit 1	Soil unit 6
Soil unit 2	-
Soil unit 3	Soil units 4 and 5
Soil unit 4	Soil unit 2
Soil unit 5	Soil unit 1

Soil Classification

In classifying the soils of the study area, the morphological, physical and chemical characteristics considered important in both Soil Taxonomy (Soil Survey Staff, 1975) and the FAO/UNESCO Soil Legend (1974) were employed.

Classification according to Soil Taxonomy

In classifying the soils according to Soil Taxonomy (1975), the lowest category into which the soils were fitted is the SUBGROUP.

In the Zaria area the soil moisture regime is USTIC except in the fadamas. The soil temperature regime is ISOHYPERTHERMIC. Ochric epipedon and argillic horizon are present in soil units 1 to 4. Units 1 to 4 soils also have a base saturation that is higher than 35% (by sum of cations). They fit closely into the suborder of Ustalfs. The U.S.D.A. map of soils of the world (Ackerson et al., 1968) and cited by Harpstead (1973) classifies the soils of the area as Alfisols. The present study is in agreement with that conclusion. Further classification into the great group and subgroup levels is attempted below.

Soils of unit 1 are thick reddish or red Ustalfs lacking plinthite or paralithic contact within 150 cm of the surface. They (expect profile 3) have argillic horizons in which the clay does not decrease by as much as 20% from its maximum value in the B horizon throughout a depth of 150 cm. Unit 1 soils except profile 3 are classified as PALEUSTALFS. They have a CEC (by NH_4OAc) less than 24 meq per 100g clay. Therefore, soil unit 1 with the exception of profile 3 can be classified as OXIC PALEUSTALFS. Profile 3 has a clay distribution which

decreases by more than 20% of the maximum value in the B horizon. It is best classified as an OXIC HAPLUSTALF. Profile 3 can be regarded as an inclusion within the unit 1 soils especially owing to its higher content of coarser materials.

Unit 2 soils are similar in characteristics with unit 1 soils but for the abundant amounts of concretionary iron oxide nodules they contained. They are best classified as OXIC PALEUSTALFS.

Unit 3 soils have (except profile 8) clay distributions that decrease by 20% or slightly higher from its maximum in the argillic horizon. CEC (by NH_4OAc) per 100g clay in these soils is less than 24 meq. Soil unit 3 (except profile 8) is consequently classified as an OXIC HAPLUSTALF. Profile 8 of this soil unit has characteristics of an OXIC PALEUSTALF, and has been classified accordingly. It can be regarded as an inclusion in soil unit 3.

Soil unit 4 are Ustalfs where the clay decreases by less than 20% of the maximum value in the argillic horizon. They are therefore classified as PALEUSTALFS. Profile 10 of this soil unit has a CEC (by NH_4OAc) less than 24 meq per 100g clay and is classified as an OXIC PALEUSTALF. Profile 11 has a CEC more than 24 meq/100g clay in most parts of its B horizon and is classified as a TYPIC PALEUSTALF.

Soils of unit 5 typified by profiles 12 and 13 show minimum horizon development indicative of INCEPTISOLS. They have an ochric epipedon and a cambic horizon and are classified as INCEPTISOLS. They are poorly drained. Ground water table is at the surface for a considerable part of the year. They have a gray surface horizon and characteristically mottled subsurface horizons, and are consequently classified as AQEPTS. Because of the iso-hyperthermic soil temperature indicated for the Zaria area earlier, this soil unit is further classified as a TROPAQUEPT. Low chroma is dorminant in all subsoil horizons in these soils, and the pH of 1:1 soil: water paste is greater than 4. Soil unit 5 is therefore classified as a TYPIC TROPAQUEPT.

Classification according to the FAO/UNESCO Soil Legend.

Soil units 1, 2 and 4 have argillic horizons which have a clay distributing pattern where the percentage of clay does not decrease by as much as 20% within 150cm of the surface except profile 3 (soil unit 1). All the three soil units (except profile 3 of soil unit 1) therefore classify as NITOSOLS. Soil unit 3 and profile 3 of soil unit 1 have clay distribution patterns in which the clay decreases by more than 20% of the maximum value in the argillic horizon. Base saturation (by NH_4OAc) in these soils is greater than 50%. Profile 3 of soil unit 1 and soil unit 3 therefore classify as LUVISOLS. The

fadama soils of unit 5 which have an ochric epipedon, a cambic horizon and show hydromorphic properties within 50cm of the surface are classified as GLEYSOLS. A more detailed classification is given below.

Soils of units 1, 2 and 4 (except profile 3 of soil unit 1 and profile 11 of soil unit 4) are basically EUTRIC NITOSOLS because they have a base saturation of 50% and more (by NH_4OAc) throughout the argillic horizon.

Profile 3 of soil unit 1 is a CHROMIC LUVISOL because it has a strong brown to red argillic B horizon. Profile 11 of soil unit 4 can be classified as a DYSTRIC NITOSOL because it has a base saturation of less than 50% ($_{by}$ NH_4OAc) in some parts of the argillic horizon.

Soils unit 3 with the exception of profile 8 can be classified as a CHROMIC LUVISOL because it has a strong brown to red argillic B horizon. Profile 8 of this soil unit is classified as a DYSTRIC NITOSOL because it has an argillic horizon with a clay distribution where the percentage of clay does not decrease from its maximum amount by as much as 20% within 150cm of the surface. It also has a base saturation less than 50% (by NH_4OAc) in some parts of the argillic horizon.

Soils of unit 5, represented by profiles 12 and 13, are further classified as EUTRIC GLEYSOLS. This is because these poorly drained soils have a base saturation (by NH_4OAc) of more than 50% throughout their profiles.

Table 12 shows a summary of the classification of the soils according to the two systems.

Table 12. Summary of soil classification.

Soil Unit/ Profile	Soil Taxonomy	FAO/UNESCO
Soil Unit 1		
Profiles 1 and 2	OXIC PALEUSTALF	EUTRIC NITOSOL
Profile 3	OXIC HAPLUSTALF	CHROMIC LUVISOL
Soil Unit 2		
Profile 4, 5 and 6	OXIC PALEUSTALF	EUTRIC NITOSOL
Soil Unit 3		
Profile 7 and 9	OXIC HAPLUSTALF	CHROMIC LUVISOL
Profile 8	OXIC PALEUSTALF	DYSTRIC NITOSOL
Soil Unit 4		
Profile 10	OXIC PALEUSTALF	EUTRIC NITOSOL
Profile 11	TYPIC PALEUSTALF	DYSTRIC NITOSOL
Soil Unit 5		
Profile 12 and 13	TYPIC TROPAQUEPT	EUTRIC GLEYSOL

SUMMARY AND CONCLUSION

Particle size data seem to indicate the aeolian origin of the parent material of the upper - to mid-slope soils. Fine sand (250 - 50μ) predominates over the other sand fractions. This, coupled with the high silt content, are the pointers to the aeolian origin of the soil parent materials. The high silt content ranks the soils in the Zaria area among the siltiest in Nigeria. The surface horizons are clay deficient.

The particle size data also confirms the sedimentational history of the fadama soils which show layering of contrasting materials.

The bulk density results show marked compaction of some soil surface horizons due to cattle trekking. Porosity in such compacted horizons are usually low.

Organic carbon is low, decreasing rapidly with depth. Where drainage is poor, the level of organic carbon is usually relatively higher.

The reaction of the soils ranges from pH 5.4 to pH 6.7. Lowest pH values were recorded in the B horizons, indicative of leaching of the soils.

The soils contain relatively low exchangeable Ca, Mg, K and Na. The order of abundance of the cations in the soils is Ca > Mg > K > Na. The low levels of cations in the soils may be due to their leaching during the rainy season, or may result from low levels of these bases in the soil parent material.

Cation exchange capacity of soils is highly dependent on method of determination. The trend of CEC values is sum of cations > NH_4OAc > ECEC. The higher correlation is obtained between ECEC and sum of cations.

The surface horizons of the soils recorded low CEC values generally, while maximum CEC values were recorded in the argillic horizons. Also, where drainage is poor or imperfect, CEC values are usually relatively higher. The latter trend is indicative of the presence of 2:1 lattice clay minerals in the soils occupying low topographic sites.

Base saturation is dependent upon the method used for determining the CEC. The general trend of base saturation for all the soils is that of a high value in the A3 and/or B1 horizon, and an increase in value with depth.

Free iron oxide is lowest in the surface horizons and highest in the C horizons. This trend is suggestive of translocation of dissolved iron from the surface horizons to the subsoil horizons

where the iron precipitates and dries during the dry season.

The well drained soils have characteristics of Paleustalfs or Nitosols. The poorly drained fadama soils have the characteristics of Tropaquepts or Gleysols.

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Appendix 1: Trees of the upland soils

Annona	senegalensis
Bridelia	ferruginea
Butyrospermum	paradoxum
Carisa	edulis
Combretum	ghasalense
Cussonia	batteri
Daniella	oliveri
Detarium	macrocarpum
Dichrostachys	glomerata
Ficus	congoensis
Ficus	gnaphalocarpa
Gardenia	erubescens
Guiara	senegalensis
Hymenocardia	acida
Isoberlinia	doka
Nauclea	latifolia
Parkia	clappertonia
Piliostigma	thionningii
Prosopis	africana
Pseudocedrela	kotschyi
Securidaca	longepedunculata

Appendix 2: Climbers, creepers, grasses and shrubs of the upland soils.

A Climbers and Creepers

Ipomoea	agentaurata
Opilia	celtidifolia

B Grasses

Aloe	bateri
Ctenium	newtonii
Hyparrhenia	involucrata
H.	rufa

C Shrubs

Adenodolicros	paniculatus
Cocklospermum	tinctorium
Fadogia	agrestis
Indigofera	capitala
I.	pulchra

Appendix 3: Vegetative population of the fadama soils

Borassus	gethiopum
Elionurus	pubeguinii
Paspalum	orbiculare

A B S T R A C T

Field observations of noils, soil mapping, descriptions of soils and laboratory experiments were carried out in order to characterize and classify the soils of the Samaru - Zaria area in the northern Guinea savanna region of Nigeria,

The field soil survey procedure adopted was the fixed grid survey. In the laboratory, the soil characteristics determined include particle-size distribution, bulk density, particle density, pH, exchangeable cations, exchange acidity, cation exchange capacity and total free iron oxide.

The soils are silty, and have clay-deficient A1 horizons. Bulk density shows that the compacted cattle-trekked surface horizons have low porosity. Particle density in the soils show little variability..

Organic carbon content of the soils is low,, Soil reaction is on the strongly acid to neutral reaction side. Exchangeable cations by NH_4°Ac were low being of the order of 0.37 to 3.94 meq Ca, 0.03 to 2.94 meq Mg, 0.17 to 1.06 meq K and 0.02 to 0.85 meq Na, per 100 g soil.

NH4OAC-CEC, sum of cations and ECEC gave significantly different results. The highest CEC valuse were recorded by sum of cations while ECEC recorded the lowest values. Exchange acidity is low, and base saturation is moderately high.

Criteria that can be used in classifying soils of the Zaria area include kinds and arrangements of diagnostic horizons, cation exchange capacity, base saturation, clay content and age.