A BIO-CLIMOSEQUENCE STUDY OF UPLAND SOILS DEVELOPED ON OLDER GRANITES IN NIGERIA

B Y

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D E C L A R A T I O N

I hereby affirm that this thesis has been undertaken by me and that it is a record of my research work. It has not been accepted in any previous application for a higher degree. All the sources of information are specially acknowledged by means of references.

Mosugu, Mary Eben

7th July, 1989.
D a t e

C E R T I F I C A T I O N

This thesis entitled "A BIO-CLIMOSEQUENCE STUDY OF UPLAND SOILS DEVELOPED ON OLDER GRANITES IN NIGERIA" by Mosugu, Mary Eben meets the regulations governing the award of the degree of MASTER of SCIENCE of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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D E D I C A T I O N

To you, **Mum**; I know it's not what you'd want,
but the tears would just not dry!
I'll be there someday.

And

To my family; so large, yet so linked.

A B S T R A C T

The morphological, physical and chemical properties of soils developed on similar parent rock (older granite rocks), topography (upland middle slope positions) and time (Pre-Cambrian era) were studied in four different bio-climatic zones in Nigeria. The four zones, following a north-south transect, are the Sudan Savanna zone, the Northern and Southern Guinea Savanna zones and the Rainforest zone. In each of the zones, two soil pedons were described in the field and sampled for laboratory analyses.

A general appraisal of the physical setting of the study areas reveals that the soils in the Sudan Savanna, Northern and Southern Guinea Savanna as well as the Rainforest zones have developed in climatic environments presently characterized by mean total annual rainfall of about 884mm, 1114mm, 1275 mm and 1587mm respectively. There are only little variations in mean annual air temperatures between all the zones and these generally range from 24.4 to 26.5°C with a mode of about 26.0°C. The soil pedons representing the three zones within the savanna region have formed under dominantly grassland vegetation types with tree densities increasing from the Sudan to the Southern Guinea Savanna zones. The soils of the Rainforest zone on the other hand, occur under a dominantly woodland type of vegetation.

The soils are generally sandy. Sandy loam surface soils commonly overlie sandy clay cloam or clay loam

subsoils in the savanna zones while sand clay loam surface soils overlie clay subsoils in the Rainforest zones. The soil reaction ranges from being strongly acid in the Rainforest zone to neutral in the Sudan Savanna zone with the soils of the Sudan Savanna zone having a pH of 7.3 which is distinct from the soils of the other three zones with pH values ranging between 5.2 - 5.6. Organic carbon content of the soils is low in all the zones, with values ranging between 0.35 - 0.54%.

Total nitrogen content of the soils is also low. The Rainforest soils recorded the highest mean value (0.053%) of total nitrogen, and the Sudan Savanna zone the lowest value (0.025%). Available phosphorus levels in the soils were also low in all the zones with values, which did not differ significantly from one another, ranging between 1.95 and 5.51mg/kg. Exchangeable Ca values range widely between low to high in the soils. Soils of the Sudan Savanna zone recorded high contents of exchangeable Ca (6.86 meq/100g soil) which was significantly different from the medium to low mean values of 2.87, 1.77 and 0.86 meq/100g soil recorded for the soils in the Northern Guinea, Southern Guinea and Rainforest zones respectively. Medium levels of exchangeable Mg were recorded for the soils in all zones with mean values ranging from 0.42 to 0.92 meq/100g soil, and indicating adequate supply of nutrient Mg in the soils. Mean exchangeable K values of 0.32, 0.13, 0.05 and 0.19 meg/100g of soil were recorded for the Sudan Northern and Southern Guinea Savanna and the Rainforest zones

respectively.

Cation exchange capacity (both by NH_4OA_c and effective) range from low to medium in the soils. The soils of the Sudan and Northern Guinea Savanna zones recorded higher mean values of CEC (4.61, 9.95 and 1.41, 8.18 meq/100g soil for CEC - NH_4OA_c and effective respectively) than the Rainforest and Southern Guinea Savanna zones.

The soils in all the zones were observed to be well supplied with the micronutrient elements studied (Fe, Mn, Zn and Cu) as all values recorded were often above the known critical levels of the elements.

The study also reveals that soils in each of the zones belong to distinct taxonomic classes. However, at the Order level of classification, the soils of the Sudan and Northern Guinea Savanna zones are Alfisols while the soils of the Southern Guinea Savanna and Rainforest zones have developed into Ultisols. According to the criteria of the USDA Soil Taxonomy, the Sudan, Northern and Southern Guinea Savanna as well as the Rainforest soil pedons were classified as Plinthustalfs, Oxic Haplustalfs, Plinthustults and Orthoxic Tropudults respectively. They were classified as Plinthic Luvisols, Dystric Nitosols, Plinthic Acrisols and Orthic Acrisols in the FAO/UNESCO system respectively.

Despite changes in climatic and vegetal regimes between the zones studied, it will appear that both the Southern Guinea and Rainforest zones can be merged together in terms of most of the characteristics of their soils, while those of the Sudan and Northern Guinea Savanna zones can equally

be said to be closely similar. This indicates that from a bio-climosequence stand point, only two distinct zones instead of four can be delineated for soils developed on older granites in Nigeria.

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INTRODUCTION

Soil formation refers to the transformation of rock into soil through a series of changes or processes, the integrated effects of which are manifested in the composition, properties and energy conditions of the resultant soils. These processes are in turn products of soil forming factors namely, parent material, vegetation, associated organism, climate, relief of the landscape and time (Jenny, 1941; Crompton, 1962). Any of these factors could in different locations exert a dominant effect on pedogenesis as an independent variable (Young, 1976). However, the combined roles of two or more of these factors in soil formation have also been recognised. For example, the joint influence of climate and living matter on soil formation is high-lighted by Brady (1974) in his definition of soil as a "collection of natural bodies occupying parts of the earth's surface that support plants and that have properties due to the integrated effects of climate and living matter acting upon parent material as conditioned by topography over a period of time". This reflects the dependence of the characteristics of a soil, to a large extent, on the soil forming factors that dominate pedogenetic processes in an area.

The environmental factors affecting soil formation are highly varied in Nigeria. In any country with such variations, problems of soil fertility are also varied and complex; an understanding of the roles of the factors

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governing its formation is therefore essential for a meaningful interpretation of its properties. The relative roles played by these factors can be assessed by holding one or more of the factors constant while varying the factor(s) under study.

Some studies aimed at such assessments have been carried out in bio - and climo - sequences. Like Topo-sequence studies of soil, which involve the examination of soils along a slope in a gradational manner, biosequence and climosequence studies of soils involve the assessment of the properties of soils under the influence of different organisms (plants and animals) and under different climatic conditions respectively. The differences in the actions of organism and climate in such studies is usually gradational too. Some work has been done outside Nigeria which look at soil properties in a biosequence. These include the work of White and Riecken (1955) on Iowa Soils. Related studies also include those of A1-Barrak and Lewis (1978) on Eastern Nebraska soils. Previous climosequence studies include that by Buntley and Westin (1965) on some soils of Iowa and North Dakota. RabbenHorst and Wilding (1986) also studied the properties of the soils of Texas in a climosequence. It is interesting to note that even less information is available on bio-climosequence studies of soils than can be obtained for separate biosequence and climosequence studies outside Nigeria.

Climatic and vegetation zones in Nigeria closely correspond with each other (Higgins, 1965), thus providing a

basis for bio-climosequence studies of the soils. However, earlier works on Nigerian soils have commonly emphasized characterization for soil and Landuse mapping; only little work has been done to assess the properties of Nigerian soils in a bio-climosequence as is attempted in the present study. Such works include the study by Higgins (1965). He examined the joint influence of Climate and vegetation on northern Nigerian soils developed form various parent materials. Klinkenberg and Higgins (1970) have also studied the soils of northern Nigeria developed from different parent materials under various climatic conditions. In Southern Nigeria, the very few related studies include that of Ogunwale (1973). This study involved the examination of the genesis and classification of Soils derived from sandstones of various lithological origin in the major ecological zones of Nigeria.

The present study which looks at the influence of climate and vegetation under "uniform" parent-material (older granite), time (Pre-Cambrian era), and topography (unpland soils on middle-slope positions), is expected to provide some information on the bio-climatic sequence of soils in Nigeria.

It is therefore the objective of this study to:

(i) assess the status of soils developed on older granites under different climatic and vegetational (bio-climatic) conditions in Nigeria.

(ii) classify the soils according to the USDA Soil Taxonomy (Soil survey staff, 1975) and the

FAO/UNESCO soil map of the world (FAO/UNESCO, 1974).

(iii) assess the extent to which results of studies carried out on soil developed on similar parent material can be transferred across climatic and vegetation zones in Nigeria.

These objectives are to be achieved through the description, measurement and evaluation of the morphological, physical and chemical characteritics of the soils.

2: REVIEW OF LITERATURE

2.1: Factors of soil formation.

The soils of any area are known to be a product of the interaction between five factors namely parent material, vegetation and related organism, climate, topography and time. Each of these factors has been widely discussed in soil studies as independent factors and in some cases, as they relate to soil formation (Jenny, 1941). Existing information on such studies are summarized below:

2.1.1: Climate and Soil Formation

The process of soil formation involves a number of climatic variables which include hydrological factors such as rainfall and the volume of through-leaching, the period each year during which the profile is wet, and the rise and fall of the water table; and temperature (Jones and Wild, 1975; Zonn, 1986). Only few of these climatic variables, have been studied in any detail in relation to soil formation; Ahn (1970) gave the clearest account of them so far. Ahn, in one of his studies showed that as one goes northwards across the Savanna, profiles become shallower, and depending on parent material, richer in weatherable minerals. This trend was attributed both to a declining weathering intensity as mean annual rainfall decreases and to a greater exposure to erosion as the vegetation becomes sparser. A result of the dominance of shallow profiles is that the deep rooted components of the Savanna vegetation

may often be in contact with weathering minerals. As a result of this contact, the soil - plant nutrient cycle is not as closed in the Savanna as it is on the deeply weathered profiles of the Forest.

Climate is also known to influence, to a large extent, the mineralogy of soils. It has been observed that during prolonged and intensive weathering under high rainfall and temperature, losses of silica in soils are proportionately greater than those of the sesquioxides (Ahn, 1970). However, kaolinite predominates in the Ferrallitic and Ferruginous soils of the Savannas while 2:1 lattice silicates are usually found in soils of the semi-arid regions (Ojanuga, 1979). In sub-humid areas with a longer dry season, valleys have also been found to contain 2.1 expanding clays (Greenland, 1981).

Few studies have also related the development of argillic B horizons to climate. Such studies include that of Sys (1967), in which he showed that textural B horizons develop more easily under dry sub-humid or semi-arid tropical climates; actual argillic horizons are not very common under humid tropical and equatorial climates. The greater development of the argillic horizon in the dry zones of the tropics than in the wet zones was attributed to an appreciable rise in pH and a temporary mobilization of clay that usually results from the sudden wetting of a dry soil (Kapalge, 1976).

Differences have been observed in textures of soils developed from similar parent material (Sandstones) under different climatic conditions in Nigeria. Ogunwale (1973) found that low clay contents are recorded for Nigerian soils under extremely wet or extremely dry climatic conditions as is found in Northern and Southern Nigeria respectively. On the other hand, in the medium rainfall area (1016-1524 mm), there was high clay accumulation at depth in the profiles. The above trend was attributed to the fact that rainfall in the northern states of Nigeria is too low for appreciable weathering of the sandstone into clay, while the extremely high rainfall in the southern parts, as observed in Benin and Agbaru, could be too high for the clay formed to remain in the profile depth sampled. Much of the clay formed in these high rainfall areas is removed from the porous upper few feet of the soils. The Silt: Clay ratio of soils have also been observed to decrease with increase in rainfall (Young, 1976). This decrease has been attributed to an increase in chemical weathering and consequent transformation of silt fractions into clay with increasing rainfall.

Colour is one of the important soil properties used in morphological characterization of soils. Most tropical soils are characterized by reddish or yellowish colours. Some investigators have explained that the intensity of coloration, and sometimes, the colour itself vary depending on climate. The red and yellow colours of iron-rich soils are commonly known to reflect the moisture conditions in a

soil profile. The yellow colours are caused by the presence of hydrated forms of iron oxide while typical red soils, probably characterized by hematite, reflect an oxidated state in the soil (Kapalge, 1976). Climate, through its influence on colour can therefore be regarded as helpful in classification of soils (Watson, 1976; Tomlinson, 1965).

Accounts of the influence of climatic factors on soil chemical properties also include the works of Jaiyeoba (1983; 1985). He observed in these studies that for about 100mm increase in mean annual rainfall, the soil CEC increased by an average of 0.43 meq/100g of soil and the pH and percent base saturation decreased in values at rates of 0.093 and 3.17% respectively in Northern Nigeria. For the exchangeable cations, he reported that there were initial low average values in the 100-900mm rainfall zone, followed by the highest average values at the 900 - 1200 mm zone for Ca, Mg, Na, and at the 1300 mm - 1500 mm rainfall zone for exchangeable K. Very low percent base saturation of the cation exchange complex was observed in the intensively leached soils of Gembu, an area in Nigeria characterized by high rainfall (Higgins, 1965). Total bases of soils in the Gembu area were found to be low while percent carbon and total phosphates were high. Soils of the Jos plateau, which also experience high rainfall, were found to have similar characteristic as those of Gembu, but of a little lower magnitude.

2.1.2: Vegetation and Soil Formation.

Pedologists have long been interested in the contrasts between soils formed in fairly close proximity under different vegetation types such as prairie/savanna and forest and under transitions between them (Jones and Beavers 1964; White and Riecken, 1955). These studies showed that soil properties under prairie ecosystems varied from those under forest on uniform parent materials in the north central region of the United States. As observed by Daniels, et. al (1962), soil pH values were higher for the surface soils under decidous forest than under prairie, each recording pH values of 6.5 and 5.1 respectively. However, base saturation of 90% was recorded under prairie and 80% under decidous forest contrasting the observation by Sys (1967) that base saturation values were higher in the humus layer under forest than under Savanna in the Congo. A similar trend which reveals a greater quantity of nutrients cycled through the vegetation in the forest zone than in the Southern Guinea savanna of some West African soils was also observed by Nye and Greenland (1960). A probable explanation for the above is that because tree roots penetrate more deeply than grass roots in less weathered materials, trees are able to return more bases to the soil.

The clay contents of soils have also been found to vary under different vegetation cover. A clay content of 28% was recorded under prairie while 21% was recorded under decidous forest in Iowa (Daniels, et. al., 1962).

For the effect of vegetation on the organic matter content of soils, Brady (1974) indicated that organic matter content of the grassland soils is generally much higher, especially in the surface horizons. This is explained in the terms of the interaction that develops among the natural vegetation, other soil organism, and the characteristics of soil. As a result of such interaction in soils developed under native grasslands, non-symbiotic nitrogen fixers (Azotobacter) tend to flourish, thus providing an opportunity for an increase in both the nitrogen and organic matter contents of the soil. The higher organic matter according to Brady (1974), gives the soil a darker colour and higher moisture and cation holding capacities as compared to the forest soil.

Vegetation cover reduces natural erosion rates, thereby slowing down the rate of mineral surface removal (Sys, 1967). It is obvious then that the nature and number of organisms growing in and on the soil will play a vital role in the kind of soil that develops.

2.1.3: Parent material and Soil Formation

Parent material has been described by Fitzpatrick (1980) as consisting of mineral material or organic matter or a mixture of both. Organic matter is usually composed predominantly of unconsolidated, dead and decaying plant remains. Mineral material, which is the most widespread type of parent material, comprises a large number of different rock forming minerals and can either be in a

consolidated or unconsolidated state.

The influence of parent material has often been obscured by prolonged pedogenesis such that in some cases, it may be very difficult to decide what the parent material of a soil actually was (Jones and Wild, 1975). Even so, it has been possible and very useful to relate the properties, classification as well as the agricultural potentials of West African soils to their apparent parent material. For example, Jenny (1965) delineated the soils of Upper Volta according to the geological formation upon which they were found: fertile brown soils, high in clay and mineral reserves were found on Pre-Cambrian Birrimian formations (amphibolites, shales, dolerites and diorites), while fertile, heavy, base-rich soils were found on alluvium. He found sandy soils of only medium to low fertility on granite and sandstones in the area.

A relationship between soil texture and parent material has been widely recognised in Nigeria (Jones 1973; Jones and Wild, 1975). Higgins (1965) found that even under different bio-climatic zones, soils developed from Basement Complex (acid igneous rocks) commonly recorded increase in clay content with depth. Their surface textures were commonly loamy sand to sand, merging through loam to clay loam or sandy clay loam; with a structure at least weakly developed apparent in the heavier textured horizons. This structure is commonly classified as moderate. Also, the chemical composition of rock appears to affect the type of clay formed. In Ghana, basic rocks were found to favour the

formation of 2:1 lattice silicates, including montmorillonites, whereas rocks high in quartz and feldspar generally gave rise to kaolinite (Stephen, 1953). This explains the tendency for the cation exchange capacity of soils to be higher over basic rocks. Other chemical properties of soils have also been found to be influenced by parent material. For example, in Nigeria, Wild (1971) observed that total K averaged 2.18% in Savanna soils on Basement complex but only 0.08% in soils formed on sandstone. Higgins (1965) also showed that total exchangeable bases are low to moderate, usually less than 5 meq/100g soil in Savanna soils developed from acid igneous rocks. Total phosphate figures of these soils are also moderate to low, seldom exceeding 150ppm. In northern Nigeria, Jaiyeoba (1983) has also observed that soils formed from and over basic rocks like basalt and shales are higher in cation exchange capacity, pH, exchangeable bases and percent base saturation than those formed over acidic rocks like granite, granite-gneiss and sandstone. The variation in average pH values of soils derived from different geological formations is further stressed by Leow and Smith (1981). According to them, while pH average values are highest (about 6.27) on granodiorites, lower values (6.15 and 6.14) are found on soil developed on feldspathic quartzites and biotite granite-gneiss; the lowest average value of 5.75 was recorded in soils from Schists.

2.1.4: Topography and soil formation

Topography, which refers to the outline of the earth's surface, is synonymous with relief.

The fact that significant differences occur in the chemical, physical and biological properties of tropical, and in particular African soils in relation to topography is recognised (Ahn, 1970; Young, 1976). In the Keffi plains of northern Nigeria, weighted average values of organic carbon were found to decrease from the summit down slope to the toeslope with only slight increase in values for the levee soils (Esu at al. 1987). Contrary to this observation, Whitefield and Furley (1971) observed that organic matter of the surface soil and Carbon: Nitrogen ratio increased from the summit downslope. They attributed this to the increasing wetness and decreasing mineralization of organic matter downslope respectively.

In northern Nigeria, Jaiyeoba (1983) observed a significant negative relationship in both pH and percent base saturation with altitude (1% and 5% levels of probability respectively). It was also found in a similar study in Northern Nigeria that the pH was lower in the basal slope position (Jaiyeoba, 1985). However, Esu et al. (1987) observed only little variation in the soil pH values for all the soils in the various landscape segments in the Keffi area of northern Nigeria. Jaiyeoba (1985) found that cation exchange capacity was relatively higher in the basal slope position in a related study in Northern Nigeria. On the contrary, lower values of cation exchange capacity were

recorded in lower slope positions than at the summit in the Keffi area with respective weighted averages of 3:7 and 8:8 meq/100g soil (Esu et. al, 1987).

Soil profile depths have also been found to be related to topography. Relatively young soils are found on crests and steep slopes whereas deep and usually more weathered soils are found at lower slope positions (Young, 1976). A related observation by Fitzpatrick (1980) is that the shallow and thin soils on steep mountain slopes usually contain many primary minerals while high percentage of clay and resistant minerals are found in soils of less steeply sloping old land surfaces. This is due to the fact that soils of less steeply sloping old land surfaces are more stable and undergo more weathering than those on steep mountain slopes which frequently undergo colluviation.

2.1.5: Time and Soil Formation

Soil development in relation to time can be considered as occurring in three stages: (i) the immature or young stage, (ii) the mature stage and (iii) the senile stage. The immature or young stage is that characterized for example, by organic matter accumulation in the surface soil and by little leaching or translocation of colloids. Only the A and C horizons are present and soil properties to a large extent, have been inherited from the parent material. The mature stage is marked by the development of the B horizon while the senile stage is reached by the mature soil becoming highly differentiated so that large

differences exist in the properties of the A and B horizons if sufficient time has elapsed (Foth, 1978).

Many studies relating time as a factor of soil formation to soil properties have been based on the use of chronosequences (Franzmeier and Whiteside, 1963; Stevens and Walker, 1970; Adams and Walker, 1975a and b). A chronosequence, as defined by Jenny (1941, 1961) is an array of related soils in a geographic area that differ primarily as a result of time as a soil forming factor. Adams and Walker (1975) in their study of some chronosequences observed a degradation in absolute amounts of total nitrogen, oxidizable carbon, cation exchange capacity, Ca, Mg, K, Al, Fe and P as well as profile clay with increasing soil development.

Working on time as a factor in the genesis of soils developed in recent alluvium in Pennsylvania, Bilzi and Ciolkosz (1977) discovered that three of the four soils studied which were of the same chronological age (200 - 500 years) had experienced minimal morphological development than the fourth which was approximately 1,500 years older. These young soils had weak to moderate subangular blocky structure which, it was said, may be due to the high silt and low clay content of the B horizon in one of the soils. However, greater morphological development was very evident in the B horizon of the fourth soil. The B horizon of this soil which also happened to be the oldest had chromas as high as 6 indicating significant oxidation while thin clay films present on prism faces and in pores indicate the

possibility of some clay translocations. Boundary conditions between the horizons of these soils were also found to be more evident in the older soils than in the younger soils.

The greater age of the fourth soil is also reflected in the development of fragipan-like features such as a firm and brittle moist consistence of the lower B horizon. However, comparing the thickness of clay films of the four soils, it was discovered that the thickness of clay films is not as good an estimate of pedologic age as the volume of clay in the soils. Bilzi and Ciolkosz (1977) also explained that the ratio of acid oxalate to citrate dithionite extractable Fe (the active Fe ratio) is expected to increase at the initial stages of weathering and soil development due to the fact that the release of Fe from primary minerals may exceed the rate of crystallization into secondary compounds. This ratio should however decrease with increasing soil age.

From their study of some soils, Dickson and Crocker (1954) and Alexander (1974) also discovered that colour values changed greatly from 7 to 3 with respect to both time and depth and the colour chroma developed with time from 1 to 3. The modification of colour value with time was suggested to be mainly related to organic matter while the change in chroma was attributed to free Fe oxide coatings on the soil particles.

2.2: Older Granites in Nigeria

Older granites form one of the two broad classes of rocks under the Basement Complex Formation. These comprise

rocks of wide range of composition and structure such as granite, granodiorites, adamellites, syenites, quartz-monzonites and various gneissic rocks of varying textures.

Adopting the classification of Hockey et al. (1963), Oyawoye (1965) classified older granites of Nigeria into two groups:

(a) The Porphyroblastic older granites

(b) The Granite-gneisses and gneissose-granites.

2.2.1: The Porphyroblastic Older Granites

These are rocks commonly described as porphyritic older granites. They vary in composition, texture and colour. A distinct characteristic of this group of rocks is the presence of conspicuous amounts of large microcline porphyroblasts in a fine to medium - grained matrix. The feldspar porphyroblasts may be pinkish, white, yellowish brown or dark grey.

The other minerals commonly present are plagioclase feldspars, quartz, hornblende and biotite. The plagioclase feldspar is always oligoclase, occurring in large to small plates. Biotite is always present while hornblende may or may not be present. There is a distinction between the hornblende - bearing porphyroblastic older granites and the mainly biotite-bearing ones. Hornblende occurs in association with biotite. However, in some forms, Magnetite occurs in place of the biotite and hornblende to form magnetite - granite (Oyawoye, 1970).

2.2.2: Granitic-gneisses and Gneissose-granites.

There is a fairly wide distinction of fine-grained gneissoses or gneissose rocks. These rocks vary in composition from granite to granodiorite. They vary widely in character and mineralogical composition. The foliation may be poor or strong. They are also often markedly varied in colour and texture. The colour variation may be due to differences in biotite and feldspar concentrations while the textural variation is often due to changing size and amounts of small feldspar porphyroblasts.

These rocks have been described as having a granoblastic texture under the microscope. They are also known to be composed of microcline, oligoclase, quartz and biotite (Freeth, 1969). Muscovite occurs with biotite in dominant to subordinate amounts in some areas. Quartz, feldspar, biotite and or hornblende appear to be common to the older granites.

3: ENVIRONMENT OF STUDY AREAS

3.1: L o c a t i o n

The areas studied fall within four bio-climatic zones namely the Sudan, Northern and Southern Guinea Savanna and Rainforest zones (Keay, 1952) in a north-south transect. In the northern-most zone, the Sudan Savanna zone, the two areas studied are located one in Rano and the other in Rurum within Kano State. Each of the two sites studied in the Northern Guinea Savanna zone is located in Ikara and Hunkuyi respectively. Within the Southern Guinea savanna, a profile each in Malette and Ejiba were studied, while within the Southern-most zone, the Rainforest zone, the two areas studied are located in Igbado, on either side of the Ondo-Ore road (Fig. 1).

3.2: C l i m a t e

The Climate of Nigeria is characterized by two well-defined seasons: the wet season with cloudy weather and winds from the South West, and the dry season with continual sunshine and winds from the north east. The precipitation in Nigerian is controlled by these two wind currents. These currents are separated by a boundary - the intertropical front - into the equatorial maritime air mass characterized by rain-bearing south-westerly winds and the tropical continental air mass of dry north-easterly winds known as the harmattan. This front moves northwards across the south of the country in February reaching the northern limits around July and August before retreating to the south again.

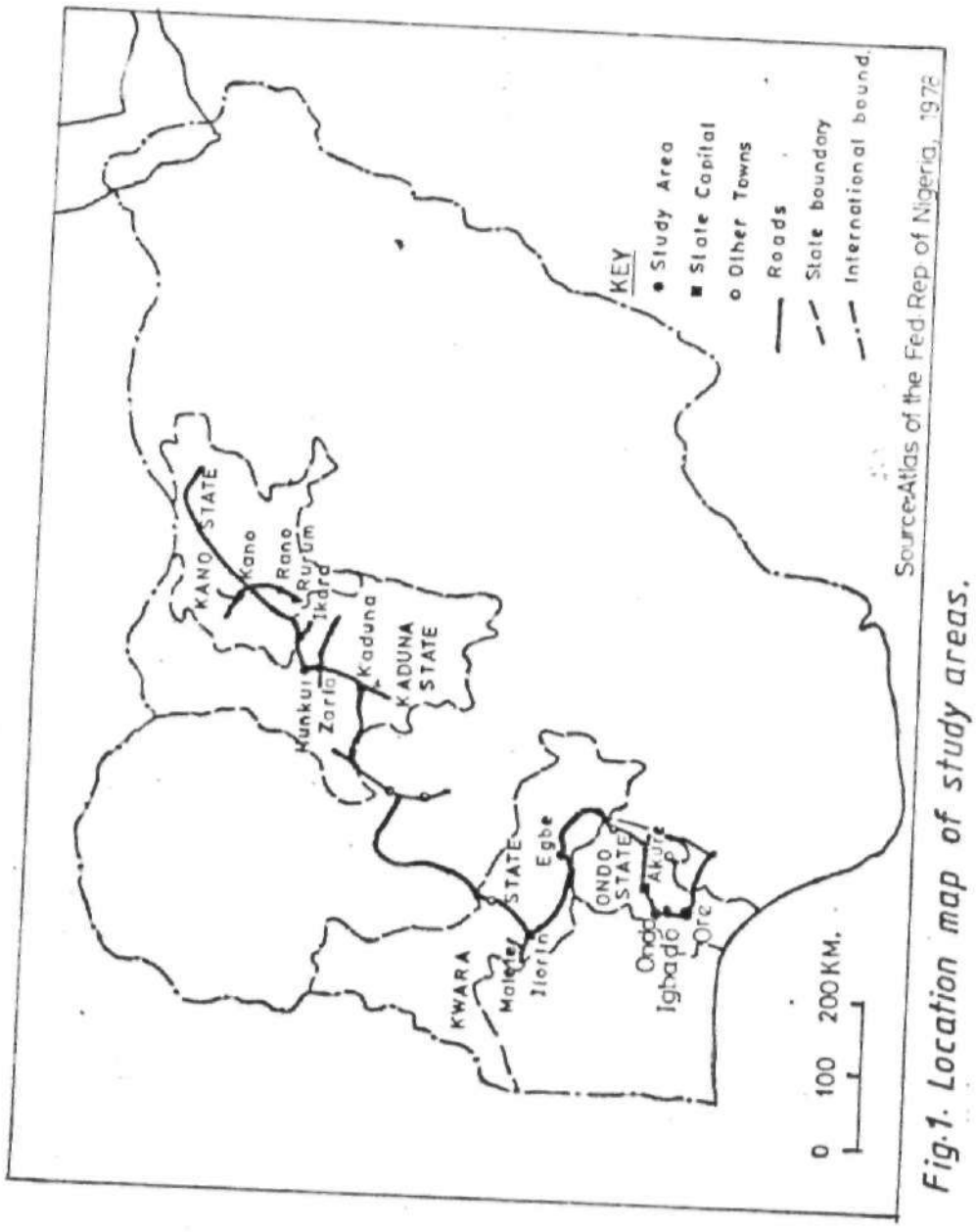


Fig.1. Location map of study areas.

The movement results in the occurrence of a single rainy season in the northern areas (500 - 1000mm) while in the south, the distribution is of twin peak type (1,150 - 1,750mm). A relation between rainfall, vegetation zone and duration of the dry season is therefore observed in the country making for a convenient delineation of the country into bio-climatic zones based on rainfall and vegetation (Keay, 1953; Higgins, 1965).

3.2.1: R a i n f a l l

A trend is observed which shows a north to south variation in rainfall characteristics such as amount, intensity and seasonality. The amount of rainfall increases from North to South (Fig. 2), with the northern-most zone of the study areas, the Sudan savanna zone, recording the lowest mean annual rainfall of about 884mm. South of this zone, the figures increase progressively through the other three zones with the Northern Guinea savanna zone recording an annual mean of about 1114mm, the Southern Guinea savanna zone, 1275mm and the Rainforest zone, about 1587mm as mean annual rainfall (Table 1).

The figures in Table 1 reflect an increase in rainfall intensity as well as increasingly frequent occurence southwards with the least intensity and frequency observed for the Sudan savanna zone. It is noteworthy that in these zones, especially in the more northern zones, variations in the amount of rainfall below the mean have been observed to be more frequent than variations above it (Barbour et. al.

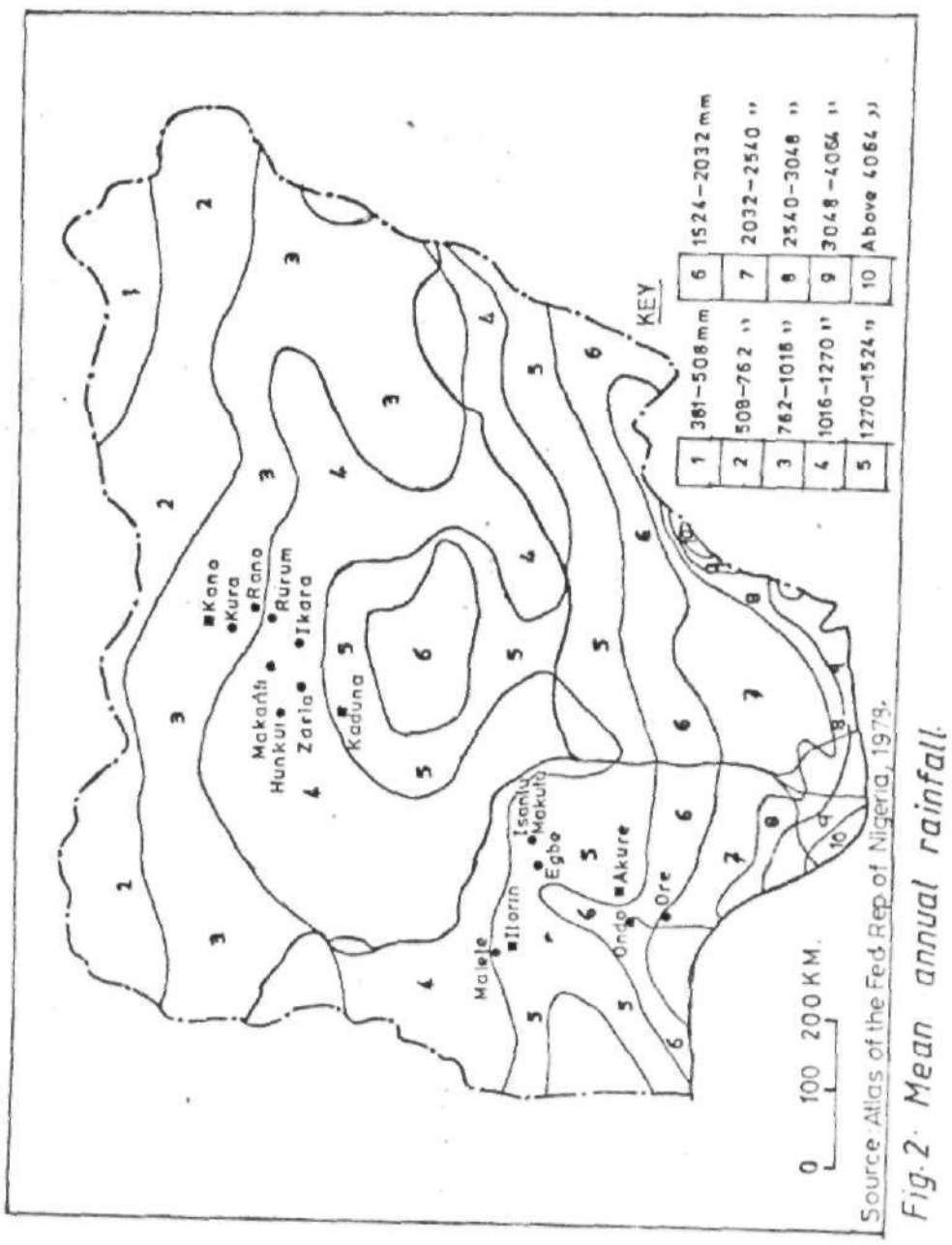


Fig. 2 Mean annual rainfall.

Table 1: Mean annual Rainfall and Potential Evapotranspiration rate of the study areas (mm)

	Sudan		Northern Guinea		Southern Guinea		Rainforest	
	Rainfall	P.E*	Rainfall	P.E*	Rainfall	P.E*	Rainfall	P.E*
	mm							
J	0.0	133.35	0.25	115.54	1.91	104.92	10.16	105
F	0.25	141.22	1.54	120.65	16.25	109.04	35.56	115
M	1.78	182.88	7.11	146.56	60.71	137.67	109.22	136
A	8.89	193.55	36.83	153.16	104.90	122.94	157.48	122
M	70.10	187.96	132.08	153.67	169.42	117.86	170.18	120
J	132.84	154.40	165.61	125.48	192.28	100.58	213.36	95
J	210.88	126.49	221.49	107.70	142.24	88.90	236.22	87
A	313.94	109.73	281.43	97.03	127.00	85.60	132.08	82
S	132.84	126.49	230.38	106.93	249.43	88.65	236.27	92
O	12.70	144.02	36.07	119.63	168.08	102.36	195.58	105
N	0.0	139.95	1.27	108.71	28.45	110.24	73.66	104
D	0.0	127.51	0.0	106.13	10.67	104.90	17.78	105
Annual Total	884.17	1769.62	1114.04	1461.52	1275.33	1282.95	1587.50	1268.0

P.E* : Potential Evapotranspiration.

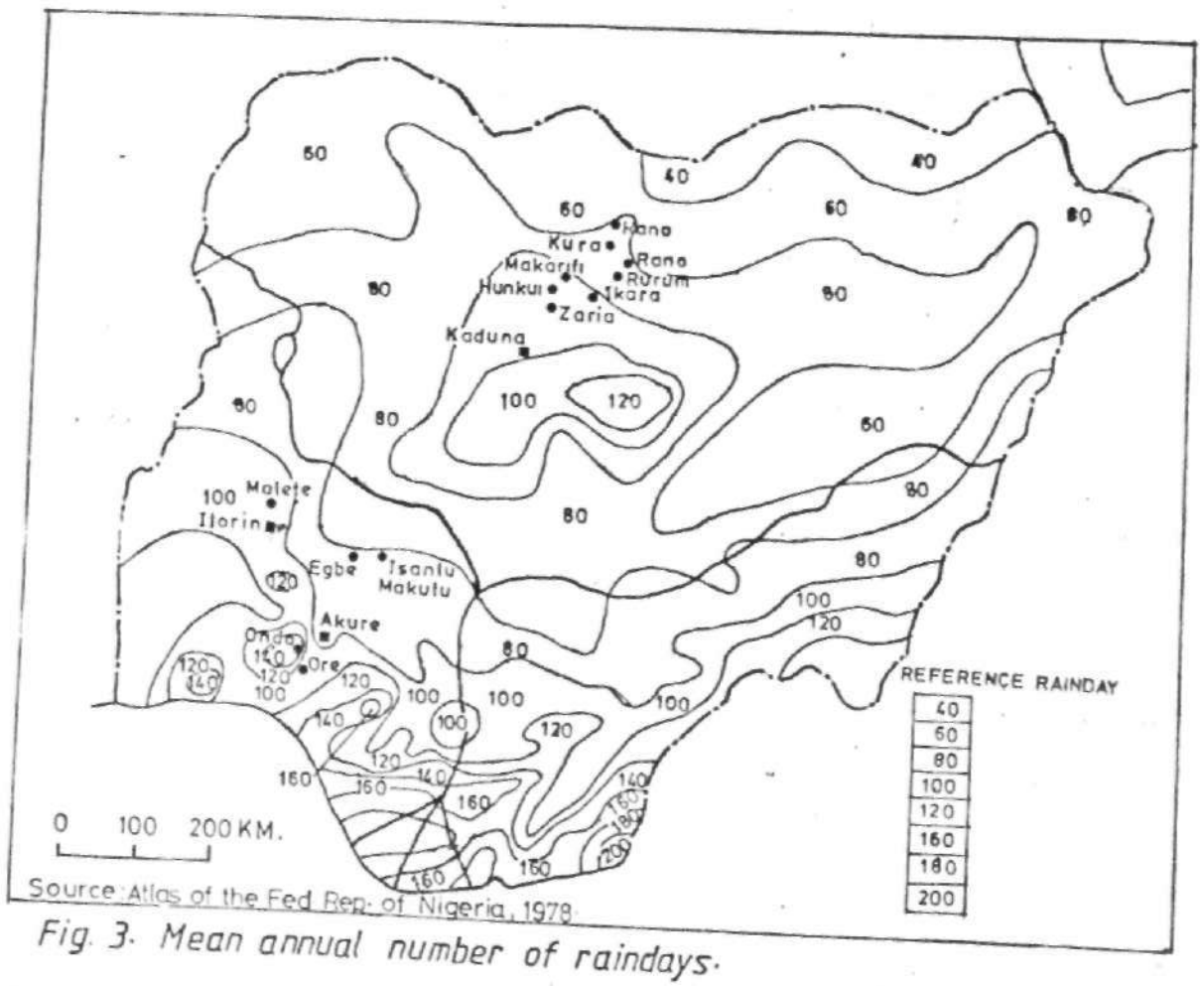
Sources: Atlas of the Federal Republic of Nigeria. 1978.
Sayth and Montgomery. 1962.
Oyediran Ojo, 1977.

1982).

Rainfall in Nigeria is highly seasonal in character with well-marked wet and dry seasons such as are characteristic of the monsoonal types of climate. Like the total amounts of rainfall, the length of the rainy season increases southwards. The onset of the rains also become progressively earlier southwards from the Sudan savanna zone which records the least number of raindays (80 days). Equal lengths of raindays (100 days) are observed in both the Northern Guinea savanna and Southern Guinea savanna zones. The Rainforest zone records the highest number of raindays of 140 days (Fig. 3).

It is commonly observed in all the zones that the energy content of the rainfall systems, of the water they hold and of the rates at which it is shed is quite large; this implies that there is a great erosive potential, which is characteristic of rainfall in Nigeria (Rackham and Innes, 1978; Rains et. al. 1977). The destructive storms accompanied by lightening which mark the beginning of the rainy seasons in Nigeria also contribute to the large erosive power of the rainfall.

The length of the dry season which is most prolonged in the Sudan savanna zone, decreases progressively through the Northern and Southern Guinea savanna zones to the Rainforest zone where the shortest length of dry season is observed. The dry season extends for seven to eight months in the Sudan savanna zone, four to five months in the Northern Guinea savanna zone, three to four months in the Southern



Source: Atlas of the Fed. Rep. of Nigeria, 1978

Fig. 3. Mean annual number of raindays.

Guinea savanna zone and two to three months in the Rainforest zone (Udo, 1978; Rackham and Innes, 1978; Atlas of the Federal Republic of Nigeria, 1978; Bennet et. al. 1977).

A year to year variation in the above rainfall characteristic is experienced in all the zones, sometimes caused by local variations in other climatic factors such as temperature.

3.2.2: Evapotranspiration.

In the Sudan savanna zone, an estimated mean annual potential evapotranspiration rate of 1769.6mm is recorded. A value of 1461.5mm is recorded for the Northern Guinea savanna zone while for the Southern Guinea savanna and the Rainforest zones, estimated mean annual evapotranspiration figures of 1283mm and 1268 mm are recorded respectively (Table 1).

Of the four zones, the Sudan and Northern Guinea savanna zones have three to six months in which rainfall exceeds evapotranspiration while six to nine months are recorded for the Southern Guinea and the Rainforest zones in which rainfall exceeds evapotranspiration (Davies, 1973).

In general, there is much lower evapotranspiration during the rainy season than during the dry season in all the zones.

3.2.3: Temperature, Net Radiation and Sunshine Hours

Temperatures vary widely from the north to the south of Nigeria. However, Udo (1978) expressed the view that

temperatures are fairly constant in the south (Fig. 4). Temperatures are high throughout the year in the Sudan savanna zone with the mean daily maximum temperatures ranging widely between 21.78 °C in December and 30.50 °C in April with an annual mean of 25.98 °C. In the northern Guinea savanna zone, mean daily temperatures of 22.00 °C in December and 28.33 oC in April are observed with an annual mean of about 24.41 °C. In the Southern Guinea savanna zone, mean daily temperatures vary between 24.83 °C and 28.83 °C in August and March respectively with an annual mean of 26.53 °C while in the Rainforest zone, mean daily temperatures, vary between 23.61 °C in August and 27.50 °C in March with an observed annual mean of 25.99 °C (Table 2).

In the North, temperatures are highest between April and May and lowest in December, corresponding to the beginning of the rainy season and middle of the harmattan period respectively. In the Southern zones, on the other hand, the highest temperatures are observed around March and the lowest around August (Atlas of the Federal Republic of Nigeria, 1978; Kowal and Knabe, 1972).

The Sudan and Northern Guinea savanna zones experience mean annual net radiation of 541.83 and 442.67 Cal/cm/day respectively while the Southern Guinea savanna zone experiences a mean annual net radiation of 631.67 Cal/cm day and the Rainforest zone, 428 Cal/cm/day (Table 2).

Mean annual sunshine hours of 25.62, 24.47, 19.20 and hours per month are recorded for the four zones the Sudan, Northern Southern Guinea savanna and Rainforest zones

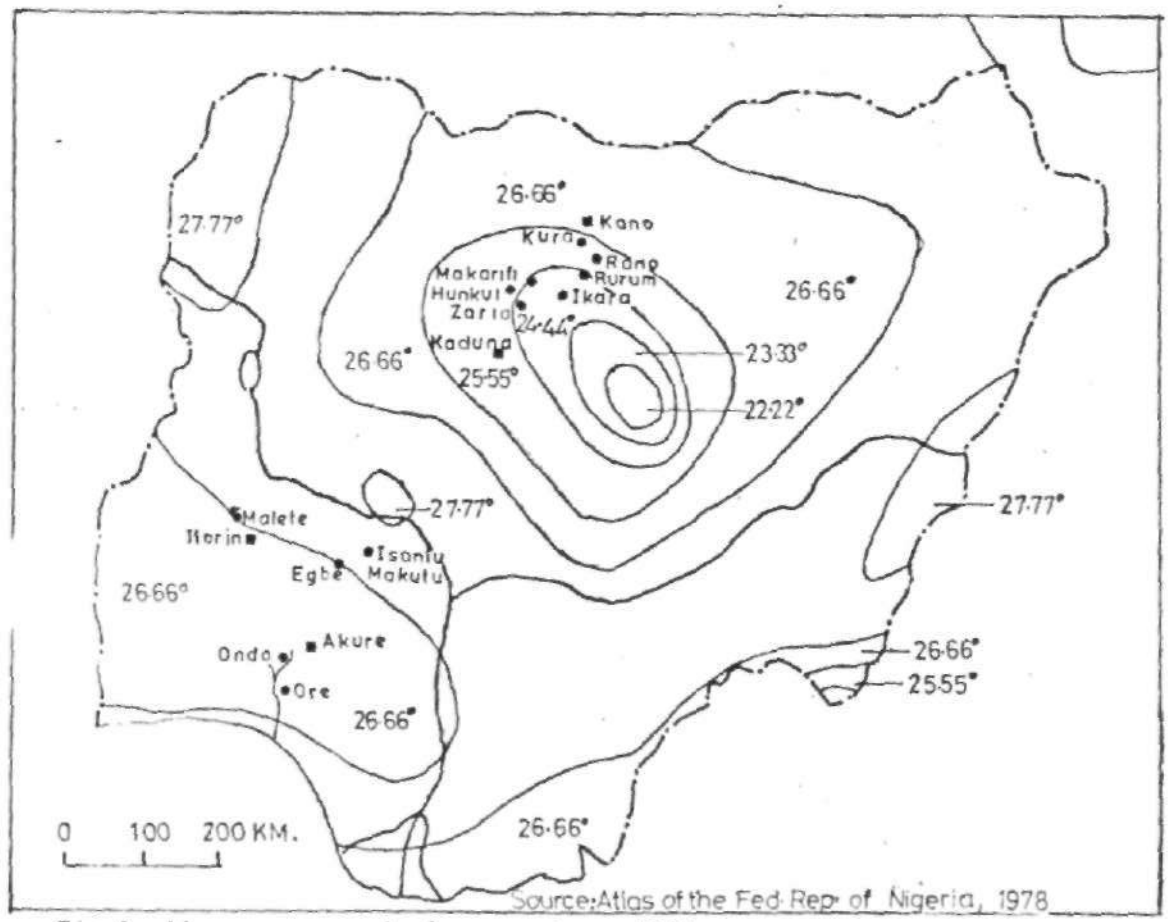


Fig. 4. Mean annual temperature (°C).

Table 2: Sunshine hours, Net radiation and Temperature of the study area

	Sudan Savanna Zone			Northern Guinea Savanna Zone			Southern Guinea Savanna Zone			Rainforest Zone		
	Sunshine (hr/month)	Net radiation (Cal cm^{-1} day^{-1})	Air Temp. (^{o}C)	Sunshine (hr/month)	Net radiation (Cal cm^{-1} day^{-1})	Air Temp. (^{o}C)	Sunshine (hr/month)	Net radiation (Cal cm^{-1} day^{-1})	Air Temp. (^{o}C)	Sunshine (hr/month)	Net radiation (Cal cm^{-1} day^{-1})	Air. Temp. (^{o}C)
J	26.94	252	21.22	26.02	156	21.78	21.12	530	25.89	21.67	336	26.39
F	27.16	342	23.78	28.73	166	23.44	23.32	659	28.44	21.12	384	27.50
M	25.92	414	27.78	26.64	352	26.89	21.91	709	28.83	19.90	480	27.50
A	25.25	574	30.50	24.13	580	28.33	20.07	731	28.00	18.39	528	26.67
M	26.34	726	30.44	25.75	636	27.28	21.20	733	27.11	19.04	480	25.11
J	26.09	747	28.17	23.56	647	24.83	1926	672	26.11	16.18	490	23.06
J	22.67	722	25.78	18.51	591	23.61	14.22	565	25.06	10.91	384	23.39
A	18.01	649	24.94	14.81	551	23.22	11.75	541	24.83	7.19	432	23.61
S	23.73	744	25.67	20.48	635	23.83	14.30	600	25.83	8.86	432	24.41
O	28.49	669	26.83	28.13	566	24.44	18.55	664	25.94	16.09	480	25.23
N	29.48	398	24.61	29.25	281	23.17	22.83	635	26.50	19.76	432	26.11
D	27.64	265	21.78	27.41	151	22.00	21.84	541	26.44	22.23	288	26.11
Annual Mean	25.62	541.83	25.98	24.47	442.67	24.41	19.20	631.67	26.53	20.13	428	25.94

Source: The National Atlas of Nigeria (1978).

respectively (Kowal and Knabe, 1972; Smyth and Montgomery, 1962).

3.3: Vegetation and Landuse.

The vegetation of Nigeria is determined primarily by climate, and particularly by the mean annual rainfall and the Severity of the dry season conveniently measured by the minimum relative humidity and length of the rainless period (Keay, 1952).

The vegetation of the Sudan savanna zone has been grouped under the Combretaceous Woodlands and wooded savanna characterized mainly by the Anogeissus leiocarpus species (Atlas of the Federal Republic of Nigeria, 1978). There are two distinct tree types in this vegetation zone - (i) larger trees (7.62 to 15.24m high) with wide-spreading crowns of which Anogeissus leiocarpa, Schlerocarpa birrea, Balanites aegyptiaca, Lannea microcarpa and Prosopis africana are common examples (ii) Smaller trees (4.6 to 6.1m high), typical examples of which are species such as Combretum glutinosum and Acacia senegal. Erect shrubs such as Randia nilotica and woody climbers such as Combretum micranthum and Capparis corymbosa are abundant. Though many of the trees in this zone have small leaves or leaflets (microphylls or smaller), there is a fair proportion of broad-leafed plants (mesophylls).

Grass in this zone of which the dominant species is the Andropogon gayanus, is shorter and more feathery than in the Guinea savanna zone south of it. Also the grass roots

in this area does not send up fresh shoots until just before the rains.

Vegetation of the Northern Guinea savanna zone is the mixed leguminous wooded Savanna type (Figs. 5a and b). A wooded savanna type of vegetation is defined as a mixed formation of trees, shrubs and grasses; the grasses are at least 1.22m tall, perennial, forming a continuous layer dominating a lower stratum usually burnt annually, with flat leaves, where woody plants are usually present in variable density (Atlas of the Federal Republic of Nigeria, 1978). The physiognomic types in this zone are the tree savanna in which trees and shrubs are scattered, and shrub savanna with shrubs only and trees absent. The dominant species in this zone are the Isoberlina species with characteristic woody species such as Isoberlina doka, Isoberlina tomentosa, and Daniella oliveri among others. The grass species in this zone consists mainly of Hyparrhenia and Andropogon species.

The vegetation of the Southern Guinea savanna zone has been classified by Barbour et. al. (1982) as Forest - savanna mosaic. This is an area of wooded savanna where Daniella oliveri is usually the most abundant species and a characteristic feature is the presence of Elaeis guinensis (oil palms). It is also an area of relict moist, semi-decidous forest on high level sites and well developed riparian forest in the valley very close to the northern edge of the zone. Afzelia africana and Khaya senegalensis are quite common. Associated species include Ficus capensis, Parkia clappertoniana, Terminalia laxiflora and so

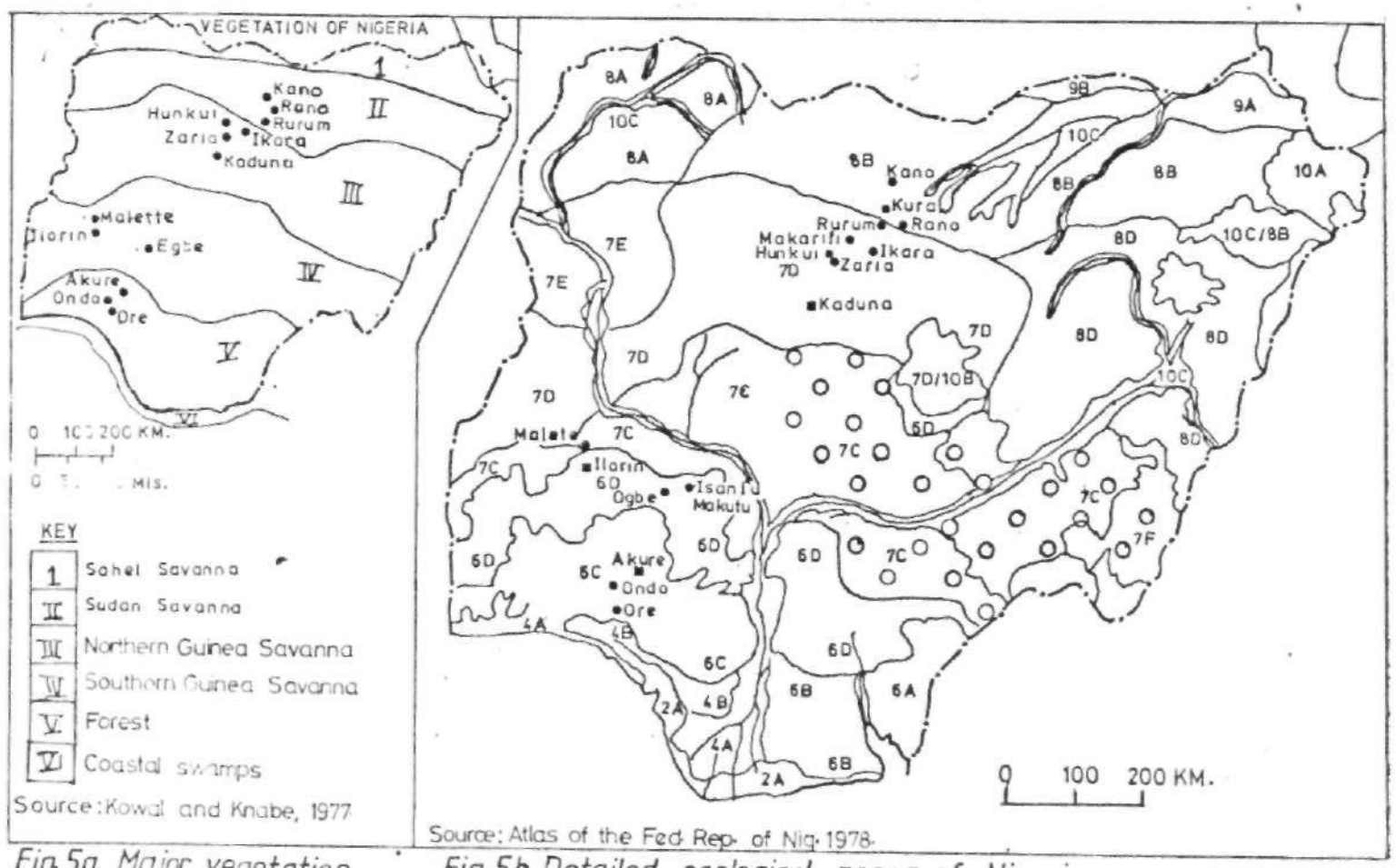


Fig 5a Major vegetation zones of Nigeria

Fig 5b Detailed ecological zones of Nigeria

on. Common grass species in the area include Imperata cylindrica which invades the land during the period under cultivation, and the tall leafy grass, Andropogon tectorum (Clayton, 1958, Atlas of the Federal Republic of Nigeria, 1978). The lower substratum in this zone is also subjected to frequent annual burning (plate 1).

The Rainforest zone falls within the moist woodland forest region. This vegetation belt is abundant in leguminosae (Gossweiller odendron) and Meliaceae (Khaya ivorensis). Some of the emergent trees in this zone are decidous in the dry season in areas of moist lowland forest while many are decidous forest areas (Atlas of the Federal Republic of Nigeria, 1978).

Except in the forest reserves, most of the moist forest zone today consists of an intricate mosaic of farms, farm fallow, and young secondary forests (plate 2). The oil palm (Elaieis guinensis) is also characteristic of this zone with several species of shrubs, dicots and monocot species also common in the understorey of these moist forests (plates 3 and 4). The roots of many of the woody climbers remain in the soil such that these plants are often the first to cover abandoned farms. A few, usually broad-leafed grasses such as Olyra latifolia, Streptogyne gerontogeae and many others are also found in the undergrowth of these forests.

3.4: Geology and Geomorphology

The geological map of the study areas is shown in Figure 6, while plate 3 shows outcrops of older granite



Plate 1:

Bush burning in Malette area in the Southern Guinea Savanna Zone.



Plate 2:

Mosaic of farms, farm fallow and young Secondary forests in Igbado (Rainforest Zone).



Plate 3:

Oil palm (Elaeis guineensis) and shrubs, dicots and monocots commonly found in the understorey of the Rainforest zone (Arrow shows a granitic outcrop).



Plate 4:

Vegetation of the understorey and fallow land in the Rainforest Zone.

rocks (arrows) which were common occurrences in all the zones. The areas sampled are found on older granite geology.

Landform types in Nigeria are closely associated with the rocks from which they are derived. On the Basement Complex rocks, landforms can be grouped into three types: the river valleys, the pediments and the residual hills. The study areas are on pediments. These pediments have been described (Barbour et. al., 1982) as "extensive plains generally sloping at about 5^{o}." They are occasionally characterized by the exposure of solid rocks almost parallel to the ground. Outcrops of fresh rocks forming hills up to 100m high are also present and the rounded hills known as inselbergs on the pediments, eventually broken up by weathering along their joints to produce groups of hills known as castellated kopjes. Inselbergs were found in the surroundings of the study sites within the four bio-climatic zones (plate 3).

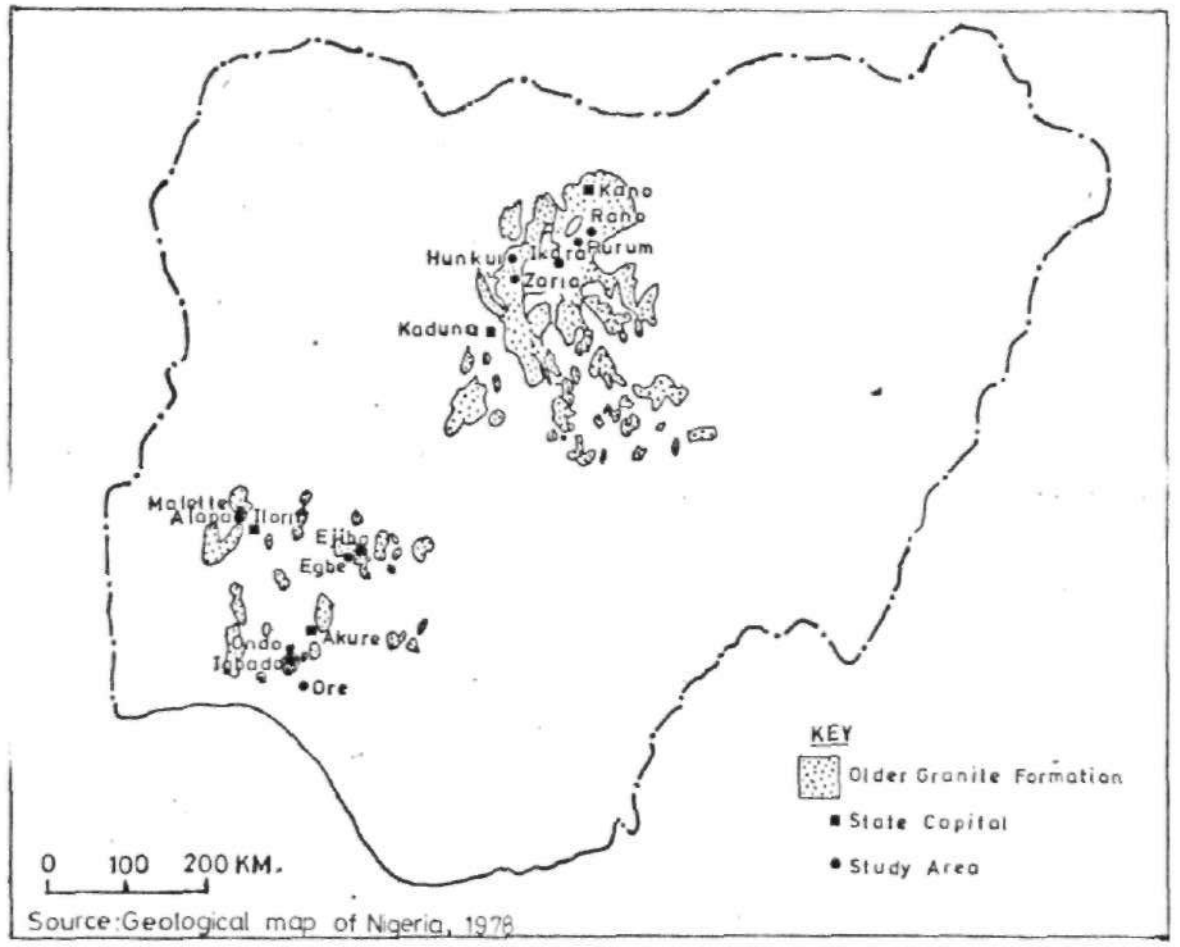


Fig. 6 Geology of study area

4: MATERIALS AND METHODS

4.1: Field Studies

Field studies were carried out in four sample areas each of which is located in the Sudan Savanna, the Northern Guinea Savanna, the Southern Guinea Savanna and the Rainforest bio-climatic zones respectively. Informations were obtained from the climatic and vegetation maps of Nigeria which when superimposed on the geological map of the country allowed for the delineation of these bioclimatic zones. This was done to ensure that the sample areas in each zone fell within the older granite - geologic zones as shown on the geological map of Nigeria (Geological Survey of Nigeria, 1974), and are characterized by uniform rainfall, temperature and vegetation conditions.

All profiles were sited on mid-slope positions within the above bio-climatic zones. In a north-south transect, the Sudan savanna zone is represented by a pedon along Kano - Rano road and the other in Rurum both in Kano State. South of these are the Ikara and Hunkuyi pedons representing the Northern Guinea Savanna zone within Kaduna State. The Southern Guinea Savanna zone is represented by two pedons, one each in Malette and Ejiba in Kwara State while the southernmost bio-climatic zone, the Rainforest zone, is represented by two pedons at different locations in Igbado (Ondo State) along the Ondo - Ore road.

A total of eight profile pits were then dug at the selected sites to characterize the soils. In each pit, the

morphological characteristics of the soils were described following the pattern given in the Soil Survey Manual (Soil Survey Staff, 1951; Soil Survey Staff, 1981). Following descriptions, samples were collected from each horizon for laboratory analyses.

4.2: Laboratory Studies

The samples collected from the eight pedons were air-dried for several days ground, and sieved through a 2mm sieve after gently breaking the peds in a porcelain mortar and the percent gravel (> 2mm fraction) was determined.

4.2.1: Particle Size Distribution

Particle size distribution was determined by the method described by Day (1965). The gravel content was 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, oven-dried and sieved into two size ranges, the coarse sand range (250 - 2000cm) and the fine sand range (50 - 250um).

4.2.2: S o i l pH

Soil pH was determined both in 1:1 soil:water and 1:1 soil: 0.01M $CaCl_2$ ratios.

4.2.3: Organic Carbon

Organic carbon was determined by the Walkley - Black method (Jackson, 1958; Allison, 1965). The soil organic

matter was digested with potassium dichromate ($K_2Cr_2O_7$) using concentrated sulphuric acid to increase temperature and hasten the reaction.

One gram each of the finely ground air-dried soil sample was weighed into 250 ml Erlenmeyer flasks and 10 mls of 1N $K_2Cr_2O_7$ added. Then 20 mls concentrated sulphuric acid (H_2SO_4) was added and the content of each flask was allowed to stand for thirty minutes after which the mixture in it was diluted to 250 mls with distilled water. Excess dichromate was back-titrated with ferrous ammonium sulphate using barium diphenylamine sulphate as indicator.

4.2.4: Total Nitrogen

Total nitrogen was determined by the regular Macro-kjeldahl method (Bremner and Mulvaney, 1982). One gram of soil was weighed into a digesting tube into which 20mls of concentrated sulphuric acid was added and digested for two hours. The content of the tube was then emptied into a 250ml volumetric flask and filled to mark. This was distilled, after which 10 mls of the distillate was titrated with 0.01N H_2SO_4 to the end point.

4.2.5: Available Phosphorus

Available phosphorous was determined by the Bray - 1 method (Bray and Kurtz, 1945). Phosphorus extracting solution (7mls) was added to 1gm of soil in a test-tube and shaken for about five minutes. The content of the test-tube was filtered into another test - tube. Then 1ml of a solution made of 5mls of distilled water, 2 mls of Ammonium

molybdate, concentrated stanuous chloride and 33 mls of water was added to the filtrate, shaken and allowed to develop colour. The colour intensity was read-off at 660 wavelength of absorbence and concentration of phosphorus determined from a standard curve.

4.2.6: Exchangeable Acidity

Exchangeable acidity was determined using 1N KCl (Peech, 1965).

Ten grams of soil was leached for two hours with 1N potassium chloride (KCl) into a 100ml volumetric flask. Three drops of phenolpthalein indicator was added to 50mls of the leachate which was then titrated with 0.1N NaOH to the pink end point and back titrated with a few drops of 0.1NHCl till the pink colour disappeared. Then 10mls of 1NNaF was added and titration continued using 0.1NHCl till a colourless end point which persisted for over 10 seconds was obtained. Exchangeable acidity was calculated from the milliequivalents of NaOH used.

4.2.7: Exchangeable Cations

Exchangeable cations (Ca, Mg, K and Na) was determined by the 1N NH_4OA_c (pH 7.0) method of Chapman (1965).

Ten grams of soil was leached for two hours with 1N NH_4OA_c at pH7.0 into a 100ml volumetric flask. The exchangeable Ca and Mg were read-off with the atomic absorption spectrophotometer (AAS) and the Na and K with the flame photometer.

4.2.8. Cation Exchange Capacity

Cation exchange capacity was determined using the ammonium acetate (pH 7.0) saturation followed by displacement of the adsorbed NH_4^+ by the acid - NaCl method described by Chapman (1965). Effective CEC was also determined by adding the value of exchangeable acidity obtained by the 1N KCl method (4.2.6) to total exchangeable bases. The cation exchange capacity of the mineral clay colloids was estimated from CEC (by NH_4OA_c) and the percentage of organic carbon (%C) as follows:

$$\text{CEC-Clay} = \frac{\text{CEC } (NH_4OA_c) - 3.5 \times \%\ C}{\%\ \text{Clay}} \times 100$$

This estimate assumes that 1% organic carbon account for an exchange capacity of 3.5 meq/100g of soil determined empirically for Savanna soils by Sombroek and Zonneveld (1971).

4.2.9: Base Saturation

Base saturation (effective and neutral) was calculated by dividing the total exchangeable bases (Ca, Mg, K and Na) by the effective CEC and the CEC obtained by the NH_4OA_c procedure respectively.

4.2.10: Micronutrients

Total micronutrients (Fe, Mn, Zn and Cu) were determined by fussion of sodium carbonate (Na_2CO_3) with 0.2g soil following the procedure of Syers et. al. (1968). The amount of these nutrients in the soils were read off with the atomic absorption spectrophotometer (AAS).

Extractable micronutrients (Fe, Mn, Zn and Cu) were determined by the DTPA method of Lindsay and Norvel (1978). Then concentrations of these nutrients were quantitatively determined using a Perkin-Elmer 603 atomic absorption spectrophotometer (AAS).

4.2.11: Extractable Iron Oxides

The organic bound, amorphous forms and total free forms of iron oxides in the soils were determined using the sodium pyrophosphate, the acid-ammonium oxalate and the citrate-bicarbonate-dithionite (CBD) methods respectively.

The method of McKeague (1967) was used for the determination of the organic bound form of iron oxide in the soils. About 2g of soil which had been passed through a 250 um sieve was transferred to a 500 cm^3 bottle to which 200ml 0.1M $Na_4P_2O_7$ - solution was added by means of pipette. This was closed and shaken overnight. Then 25ml of the suspension was transferred to each of two 50 cm^3 centrifuge tubes and centrifuged. The Fe content in the clear supernatant solution was determined by AAS after dilution.

The amorphous form was extracted using the method of Schwertmann (1964). Approximately 0.5g of soil was weighed into a 50 cm^3 centrifuge tube to which 25 cm^3 of acidified ammonium oxalate extraction solution was added. The tube was closed with a stopper and shaken in darkness for four hours. A portion of the extract was diluted and the Fe content determined by the AAS.

The total free iron oxides in the soils was determined by the method of Mehra and Jackson (1960). About 1g of the 0.2mm fraction of the soil sample was weighed into a 50cm^3 plastic centrifuge tube to which 40cm^3 of sodium citrate solution and 5cm^3 of sodium bicarbonate solution were added. The tube with its content was heated on a water bath to 70 - 80^{o}C. 1g of sodium dithionite salt was added to the content of the centrifuge tube, stirred continuously for 1 minute and occasionally for 15 minutes. The treatment with CBD was repeated till the reddish colour of the sample had disappeared. The suspension was then centrifuged and the extract decanted into a 200 cm^3 volumetric flask. The soil was washed twice with 40 cm^3 sodium citrate, centrifuged and the clear supernatant solution added to the extract in the 200cm^3 volumetric flask. A portion of this extract was diluted and Fe content determined the AAS.

4.3: Statistical Analysis

Two statistical methods of analysis were used namely simple regression analysis and analysis of variance. The regression analysis was employed to correlate the properties with one another while the analysis of variance was used to relate the properties with depth and bio-climatic zones.

5: RESULTS AND DISCUSSION

An evaluation of morphological, physical and chemical characteristics of the soils are discussed below. A summary of soil characteristics within each bio-climatic zone are also discussed.

5.1: Soil Morphology

The soils are formed in residual materials derived from older granite rocks which were found outcropping in most of the areas studied (plate 3). The residuum is overlain in some pedons by aeolian deposits as in the pedons studied in the Sudan Savanna zone at Rano, Rurum and the Northern Guinea Savanna pedon of Hunkuyi, or by colluvial materials as in the Northern Guinea Savanna pedon of Ikara and the two Rainforest pedons of Igbado near Ondo.

Most of the soils are deep to moderately deep; the deepest profile is about 144cm deep while the shallowest measures a depth of only about 70cm. The restriction in depth of the soils is either as a result of the presence of petroplinthite layer (lithoplinthite) or a result of contact with underlying weathering rocks of the Basement Complex.

It is noteworthy that the deepest profile is not any of the two profiles in the Rainforest zone where climatic conditions should favour the most intense weathering and hence the occurrence of very deep soils. A most probable reason for this deviation is the fact that the two forest zone pedons are located on the most steeply sloping



Plate 5:

Gravelly surface soils in the steephy sloping sites of the Rainforest zone.

positions of all the pedons studied. A corollary to this is the continuous truncation, through the process of soil erosion, of these Igbado pedons which are also characterized by the accumulation of colluvial coarse and gravelly materials as is observed on the surfaces around the profiles in plate 7.

The soils exhibit moderate to strong structural development in nearly all the subsoil horizons, a fact which explains the good drainage conditions of the soils. However, surface soil structure of some of the pedons especially in the savanna zone is weak. Clay lessivation, and to a lesser extent, iron oxide movement within the profile are evidenced by the presence of argillic B horizons as well as clay coated pores in all zones. Coatings of iron oxides on peds as well as the presence of iron nodules also support this eluviation - illuviation process in the soils. Two representative soil profiles described for each of the four bio-climatic zones are presented below.

The soils were described following the pattern described in the soil survey manual (Soil Survey Staff, 1951; 1981). Soil descriptions are for the moist state unless otherwise stated.

5.1.1: Soils of the Sudan Savanna Zone

These include deep to moderately deep, well drained, strong brown (7.5YR 5/6) to yellowish red (5YR 5/8) gravelly sandy clay loam soils with strong brown (7.5YR 4/6) to dark brown (7.5YR 3/3) sandy loam surface horizons. The soils,

which occupy mid-slope positions of 1 to 2% slopes, vary in depth. A typical profile in this zone shows a lithic contact at about 85cm with the soil parent material consisting of residuum derived from older granite rocks mantled by aeolian deposits.

Dark red, fine to medium iron nodules and iron - manganese concretions are common in the subsoils, while very few medium sub-angular quartz and feldspar grains are found in the surface soils.

There is evidence of clay and iron lessivation as indicated by clay and iron oxide cutans in pores and on ped faces. The clay skins and the increased clay content of the B horizons suggest the development of argillic horizons.

The pedons studied, all of which are on mid-slope positions, exhibit weak tc moderate and strong structural development of the surface soils and subsoils respectively.

Two soil profiles (pedons 1 and 2) typifying soils of the Sudan Savanna zones are described as follows:

P E D O N 1

General Site Information

Location:	Tudun-Wada Dankadai, Rano; about 400m east of the Kano - Rano road.
Taxonomic Classification:	Plinthustalf (USDA). Plinthic Luvisol (FAO).
Soil Parent Material:	Aeolian over residual materials derived from older granite rock.
Geomorphology/Physiography:	Very gently rolling inselberg landscape.
Topography:	Middle slope position, 2% slope.

Vegetation/Landuse:	Crop residues on fallow land; shrubs and herbaceous plants in uncultivated spots with very few scattered trees.
Soil erosion hazard:	Slight to moderate sheet erosion; Aeolian deposition.
Drainage:	Well drained.
Depth to water table:	Not encountered.
Depth to impenetrable layer:	Petroplinthite layer at 122cm.

Horizon Descriptions

Horizon	Depth(cm)	Description
Ap	0-31	Strong brown (7.5YR 4/6) sandy loam; moderate fine to medium subangular blocky structure; soft (dry) very friable (moist) slightly sticky (wet); few fine to medium continuous pores. Common fine to medium roots; common ant holes; clear smooth boundary.
E	31-62	Strong brown (7.5YR 5/8) sandy loam; moderate fine to medium subangular blocky structure; slightly hard (dry) friable (moist) slightly sticky (wet); few fine to medium continuous pores; few fine medium roots; some ant and termite holes; clear smooth boundary.
2Btv1	62-94	Yellowish red (5YR 5/8) sandy clay loam; moderate medium subangular blocky structure; very hard (dry) friable (moist) sticky (wet); common thin clay skins in pores; common medium rounded hard iron nodules; some ant and termite holes; gradual wavy boundary.
2Btv2	94-122	Strong brown (7.5YR 5/6) gravelly sandy clay loam; strong fine to medium subangular blocky structure; very hard (dry) friable (moist) sticky (wet); common moderately thick clay and iron oxide coatings on ped faces and in pores; common fine to medium continuous pores; few fine to medium roots; many iron nodules and iron-manganese concretions; common feldspar grains; some ant and termite holes.

P E D O N 2

General Site Information

Location:	Rurum village
Taxonomic Classification:	Plinthustalf (USDA) Plinthic Luvisol (FAO)
Soil Parent Material:	Aeolian over residual materials derived from older granite rocks.
Geomorphology/Physiography:	Gently rolling inselberg landscape.
Topography:	Middle slope position, 2% slope.
Vegetation/Landuse:	Intercropping of bulrust millet, sorghum and cowpeas.
Soil erosion hazard:	Slight to moderate sheet erosion; Aeolian deposition.
Drainage:	Well drained.
Depth to water table:	Not encountered.
Depth to impenetrable layer:	Paralithic to lithic contact at about 85 cm depth.

Horizon Descriptions

Horizon	Depth(cm)	Description
Ap	0-15	Dark brown (7.5YR 3/3) gravelly sandy loam; weak medium crumbly and weak medium subangular blocky structure; very friable (moist), many very fine and fine continuous pores; many very fine and fine roots; some termite holes; common medium very hard iron nodules; gradual wavy boundary.
AB	15-35	Dark reddish brown (5YR 3/4) sandy loam; weak fine to medium subangular blocky structure; very friable (moist); common very fine and fine roots and few coarse roots; common termite holes; gradual wavy boundary.
2Btv1	35-70	Dark reddish brown (5YR 3/4) dominant over red (2.5YR 4/6) sandy clay loam; strong porous massive structures; friable (moist); many very fine and fine to medium roots, common fine

		quartz gravels in the lower part of the horizons; many termite holes and several cavities 10 - 20cm in diameter; clear smooth boundary.
2Btv2	70-85	Paralithic contact grading into lithic contact over a few cm.

5.1.2: Soils of the Northern Guinea Savanna Zone

Soils of the Northern Guinea Savanna zone are well drained with gravelly or concretionary, sandy clay loam surface soils over sandy loam subsoils. The colour of the surface horizons is dark yellowish brown (10YR 4/4) tending to brownish yellow (10YR 6/6) and strong brown (7.5YR 4/6). The subsoil horizons have yellowish brown (10YR 5/8) matrix colours.

These soils with moderate structural development, are commonly gravelly. Pedon 3 is clayey right from the surface horizon, suggesting the exposure of the subsoil at the surface due to truncation of the surface; and has many medium quartz gravels, iron - manganese concretions and stones scattered on the soil surface.

One of the two profiles (Pedon 3) is located on a strongly sloping site of about 7% gradient and experiences severe sheet erosion. A result of this is the truncation of the surface soils to expose the weathering bedrock structure at a very shallow depth.

Clay lessivation and development of argillic horizons are evidenced in the soils by the presence of clay cutans on ped faces and in pores as well as by increased sticky consistence (when wet).

The representative pedons (Pedons 3 and 4) are described below:

P E D O N 3

General Site Information

Location:	Ikara; about 1km out of town, and a few meters off the Ikara - Anchau road.
Taxonomic Classification:	Oxic Haplustalf (USDA) Dystric Nitosol (FAO).
Soil Parent Material:	Colluvial over residual materials derived from older granite rocks.
Geomorphology/Physiography:	Strongly rolling inselberg landscape.
Topography:	Middle slope position, 7% slope.
Vegetation/Landuse:	Herbaceous plants and few scattered trees in uncultivated spots, farm fallow.
Soil erosion hazard:	Severe sheet and slight gully erosion.
Drainage:	Well drained.
Depth to water table:	Not encountered.
Depth to impenetrable layer:	Paralithic to lithic contact at about 144 cm.

Horizon Descriptions

Horizon	Depth (cm)	Description
Apc	0-6	Dark yellowish brown (10YR 4/4) gravelly sandy clay loam; moderate fine to medium subangular blocky structure; slightly hard (dry) friable (moist) slightly sticky (wet); few thin clay cutans in pores and bridges; common medium continuous pores; common fine roots; many medium iron nodules and Fe-Mn concretions;

		common ant and termite holes; abundant quartz gravels and stones plus Fe-Mn concretions scattered on the soil surface; clear wavy boundary.
Btc	6-34	Brownish yellow (10YR 6/6) gravelly sandy clay loam; moderate medium subangular blocky and platy structure; hard (dry) friable (moist) sticky (wet); common moderately thick clay cutans in pores; common fine to medium continuous pores; few fine roots; common iron nodules and many Fe-Mn concretions; abundant feldspar grains; common ant and termite activity; rock structure still evident; gradual wavy boundary.
2BCtc1	34-72	Yellowish brown (10YR 5/6) gravelly sandy clay loam; strong fine to medium subangular blocky structure; hard (dry) friable (moist) sticky (wet); common fine clay skins on ped faces; common fine continuous pores; few fine roots; common iron and manganese concretions angular in shape and mixed with medium angular blocks of weathering feldspar; some ant and termite holes; clear, wavy boundary.
2BCtc2	72-119	Yellowish brown (10YR 5/8) gravelly sandy loam; moderate fine to medium subangular blocky structure; hard (dry) friable (moist) slightly sticky (wet); common moderately thick clay cutans in pores; few fine continuous pores; few fine roots; many coarse Fe-Mn concretions;. common angular feldspar grains; some ant and termite holes; feldspar-rich rock structure evident; gradual smooth boundary.
2Cc	119-144	Yellowish brown (10YR 5/8) gravelly sandy loam; structureless (massive); slightly hard (dry) friable (moist) slightly sticky (wet); common Fe-Mn concretions; rock structure much more evident here with abundant weathering feldspar grains.

P E D O N 4

General Site Information

Location:	Hunkuyi, about 100m West of the old Kano road.
Taxonomic Classification:	Oxic Haplustalf (USDA) Dystric Nitosol (FAO)
Soil Parent Material:	Aeolian over residual material derived from older granite rock.
Geomorphology/Physiography:	Gently rolling inselberg landscape.
Topography:	Middle slope position, 2% slope.
Vegetation/Landuse:	Crop residues (sorghum, water melon) on fallow land while the uncultivated spots are dominated by grass.
Soil erosion hazard:	Slight sheet erosion; Aeolian deposition.
Drainage:	Well drained.
Depth to water table:	Not encountered.
Depth to impenetrable layer:	Not encountered.

Horizon Descriptions

Horizon	Depth(cm)	Descriptions
Ap	0-15	Dark yellowish brown (10YR 4/4) loam; moderate fine to medium subangular blocky structure; soft (dry) very friable (moist) slightly sticky (wet); many fine to medium continuous pores; common fine and medium roots; few fine rounded iron nodules; some ant and termite holes; aeolian deposit apparent; clear smooth boundary.
Bt	15-34	Strong brown (7.5YR 4/6) clay loam; strong medium subangular blocky structure; very hard (dry) friable (moist) sticky (wet); common thin clay skins on ped faces and in pores;

		many fine to medium pores; few fine and medium roots; some ant and termite holes; gradual smooth boundary.
2Bt1	34-67	Yellowish red (5YR 6/8) clay loam; moderate medium subangular blocky structure; hard (dry) friable (moist) sticky (wet); common moderately thick clay cutans on ped faces, in pores and bridges; many fine common medium continuous and very few coarse discontinuous pores; common fine to medium roots; common iron nodules and Fe-Mn concretions; some ant and termite holes; gradual smooth boundary.
2Bt2	67-106	Strong brown (7.5YR 5/6) clay loam; moderate medium subangular blocky structure; slightly hard (dry) very friable (moist) sticky (wet); common moderately thick clay cutans on ped faces and in pores, many fine to medium continuous pores and very few coarse discontinuous pores; few fine to medium roots; few soft iron nodules; common fine hard Fe-Mn concretions; some ant and termite holes; clear smooth boundary.
2Bt3	106-132	Yellowish brown (10YR 5/8) gravelly clay loam; moderate fine to medium subangular blocky structure; slightly hard (dry) very friable (moist) sticky (wet); few thin clay skins on ped faces and in pores; common fine to medium continuous pores; very few fine roots; few Fe-Mn concretions; common weathering feldspar; many medium soft iron nodules.

5.1.3: Soils of the Southern Guinea Savanna Zone

Pedons in the Southern Guinea Savanna zone include well drained reddish brown (5YR 4/4) to strong brown (7.5YR 5/6) sandy clay loam and clay soils with dark brown (7.5YR 4/2) sandy loam surface horizons. The soil parent material is residual material derived from older granite.

Slight to moderate sheet erosion is evident on the soil surfaces. The soils are rather shallow, with depth restricted by petroplinthite layers encountered at an average depth of about 80 cm.

The structural development of the surface soil is weak while the subsoils are strongly structured. Illuviation argillans are observed in the subsoils. Iron oxy-hydroxide cutans and a few medium iron nodules were also observed. Common, fine fissures extending from top to the bottom of the Btv horizon were observed too, indicating a high clay content of the horizon.

Two pedons (5 and 6) which are representative of this zone are described below:

P E D O N 5

General Site Information

Location:	Malette, behind the ADP staff quarters, South West of the town.
Taxonomic Classification:	Plinthustult (USDA) Plinthic Acrisol (FAO)
Soil Parent Material:	Residual material derived from older granite rocks.
Geomorphology/Physiography:	Gently rolling, planar granitic Inselberg landscape.
Topography:	Middle slope position, 3% slope.
Vegetation/Landuse:	Hyparrhennia, Combretum species; cropping of cultivated spots to cowpeas.
Soil erosion hazard:	Slight to moderate sheet erosion.
Drainage:	Well drained.

Depth to water table: Not encountered.

Depth to impenetrable layer: Petroplinthite layer at 85cm depth.

Horizon Descriptions

Horizon	Depth(cm)	Description
Ap	0-20	Dark brown (7.5YR 4/2) sandy loam; weak moderate platy and weak fine subangular blocky structure; soft (dry) very friable (moist) non-sticky (wet); many medium continuous pores; common fine to medium roots; some ant holes; gradual wavy boundary.
E	20-45	Reddish brown (5YR 4/4) sandy clay loam; weak medium subangular blocky structure; slightly hard (dry) very friable (moist) slightly sticky (wet) common fine to medium continuous pores; common fine to medium roots; some ant and termite holes; clear smooth boundary.
Btv	45-85	Strong brown (7.5YR 5/6) clay; strong coarse subangular blocky structure; very hard (dry) friable (moist) sticky (wet); common moderately thick clay cutans and iron-oxyhydroxide coatings in pores and bridges; many fine to medium continuous pores; common fine roots; common medium iron nodules; some termite holes; common fine fissures extending from top of horizon downwards; abrupt boundary to underlying petroplinthite layer.

P E D O N 6

General Site Information

Location: Egbe - Ejiba road, about 6km from Egbe on the right hand side.

Taxonomic Classification: Plinthustult (USDA)
Plinthic Acrisol (FAO)

Soil Parent Material: Residual material derived from older granite.

Geomorphology/Physiography: Strongly rolling Inselberg landscape.

Topography: Middle slope position, 5% slope.

Vegetation/Landuse: Imperata cylindrica, Hyparrhenia species, cassava farm.

Soil erosion hazard: Slight to moderate sheet erosion.

Drainage: Well drained.

Depth to water table: Not encountered.

Depth to impenetrable layer: Petroplinthite layer at 70cm.

Horizon Descriptions

Horizon	Depth(cm)	Description
Apc	0-16	Dark brown (7.5YR 4/2) gravelly sandy loam; weak fine to medium subangular blocky structure; soft (dry) very friable (moist) slightly sticky (wet); many fine to medium continuous pores; many fine to medium roots; common ant and termite activity; gradual wavy boundary.
BAc	16-36	Reddish brown (5YR 4/4) sandy clay loam; moderate medium subangular blocky structure; slightly hard (dry) friable (moist) slightly sticky (wet); few thin clay cutans in pores and bridges; common fine to medium continuous pores; many fine and very few coarse roots; many medium quartz grains; common ant and termite holes; diffuse smooth boundary.
Btv	36-70	Reddish brown (5YR 4/4) gravelly sandy clay loam; moderate medium subangular blocky structure; hard (dry) friable (moist) sticky (wet); many moderately thick clay cutans in pores and bridges; many fine to medium continuous pores; common fine to medium and few coarse roots; many medium quartz grains; common ant and termite activity; abrupt, irregular boundary to underlying petroplinthite (ironpan) layer.

5.1.4: Soils of the Rainforest Zone

These include well-drained, gravelly sandy clay loam soils with clay subsoils. Soil parent material consists of colluvial deposits over residual material derived from older granite rocks high in mica. The surfaces of the soils are characterized by common pegmatic and granitic rock outcrops scattered over the area. Weathered rock material is encountered at an average depth of about 100cm.

Slight to moderate sheet erosion is observed at the profile sites while areas of cleared vegetations are subjected to severe sheet and gully erosion. This is explained by the fact that the profile sites are steeply sloping, recording slopes of about 14% on middle slope positions.

The surface horizons are very dark grey (10YR 3/1) and dark brown (7.5YR 4/4). The colours change in hue to 5YR in the subsoil horizons where the characteristic colour is yellowish red (5YR 4/6). The colours in the B and C horizons are rather mixed.

Common medium iron nodules and common quartz gravels are present in the soils. Also common are weathering feldspar grains and mica flakes in subsoil horizons. Development of argillic horizons are evidenced by the presence of moderately thick clay cutans. Weak and moderate structural developments are observed in the surface and subsoils respectively. The descriptions of pedons 7 and 8 representing soils of the Rainforest Zone are presented

P E D O N 7

General Site Information

Location:	Igbado village (12 km from Ondo junction), on the left hand side of the Ondo - Ore road.
Taxonomic Classification:	Orthoxic Tropudult (USDA) Orthic Acrisol (FAO)
Soil Parent Material:	Colluvial deposits over residual material derived from older granite rocks.
Geomorphology/Physiography:	Very strongly rolling Inselberg landscape.
Topography:	Middle slope position, 14% slope.
Vegetation/Landuse:	Cultivated to cocoyam plantain, bananas, cocoa; climbers, shrubs, bamboo, Iroko and palm trees in uncultivated spots.
Soil erosion hazard:	Slight to moderate sheet erosion.
Drainage:	Well drained.
Depth to water table:	Not encountered.
Depth to impenetrable layer:	Weathering rock material at about 87cm.

Horizon Descriptions

Horizon	Depth(cm)	Description
Apc	0-16	Very dark grey (10YR 3/1) gravelly sandy clay loam; weak fine to medium crumb structure, soft (dry) very friable (moist) slightly sticky (wet); many fine to medium continuous pores; many fine to medium roots; many medium iron nodules; common ant and termite holes; abrupt smooth boundary.

Ec	16-44	Dark brown (7.5Y YR 4/4) Cobbly sandy clay loam; moderate medium subangular blocky structure; hard (dry) very friable (moist) slightly sticky (wet); many medium continuous pores; many medium roots; abundant medium and coarse iron nodules and abundant quartz gravels and stones; common ant and termite holes; clear wavy boundary.
2Btc	44-68	Yellowish red (5YR 5/6) gravelly clay; moderate medium subangular blocky structure; very hard (dry) very friable (moist) sticky (wet); many thick clay and iron - oxyhydroxide coatings on ped faces; common medium continuous pores; common medium roots and few coarse roots; common medium iron nodules and many medium quartz grains; common ant and termite holes; gradual smooth boundary.
2Btsc	68-87	Yellowish red (5YR 5/8) gravelly clay; moderate medium subangular blocky structure; very hard (dry) friable (moist) sticky (wet); common moderately thick clay and iron - oxyhydroxide coatings on ped faces; common medium continuous pores; common medium roots; few medium iron nodules; common quartz grains; common ant and termite holes; diffuse smooth boundary.
2BCrt	87-121	Red (10R 4/8), Red (2.5YR 4/8) and strong brown (7.5YR 5/8) for the rock structure, the hematitic and goethitic illuvial clay respectively; clay loam; structureless (massive); very hard (dry) friable dominant rock structure (moist) sticky (wet), common moderately thick clay and iron - oxyhydroxide coatings in between rock fragments and pores; common medium continuous pores; few fine roots; weathering pegmatic rock structure dominant with weathered feldspar and few mica flakes.

P E D O N 8

General Site Information

Location:	Igbado village (12 km from Ondo junction), on the right hand side of the Ondo - Ore road.
Taxonomic Classification:	Orthoxic Tropudult (USDA) Orthic Acrisol (FAO)
Soil Parent Material:	Colluvial over residual materials derived from older granite rock.
Geomorphology/Physiography:	Very strongly rolling Inselberg landscape.
Topography:	Middle slope position, 15% slope.
Vegetation/Landuse:	Cultivated to bananas, plantain, palm trees and cocoa, with shrubs, climbers and Iroko trees in uncultivated spots.
Soil erosion hazard:	Slight to moderate sheet erosion, severe sheet and gully erosion in areas of cleared vegetation.
Drainage:	Well drained.
Depth to water table:	Not encountered.
Depth to impenetrable layer:	Weathered rock material at about 100 cm.

Horizon Descriptions

Horizon	Depth(cm)	Description
Apc	0-14	Dark reddish brown (5YR 3/2) gravelly sandy clay loam; weak medium subangular blocky and weak fine crumb structure; soft (dry) very friable (moist) slightly sticky (wet); many fine to medium continuous pores; common fine to medium few coarse roots; common medium iron nodules and many coarse quartz gravels; many fine mica flakes; abundant ant and

		termites holes; clear smooth boundary.
Ec	14-47	Reddish brown (5YR 4/4) gravelly sandy clay loam; weak medium subangular blocky structure; soft (dry) very friable (moist) slightly sticky (wet); many fine to medium continuous pores; common fine to medium roots; common iron nodules; many medium quartz gravel; many fine mica flakes; granitic rock fragments; common ant and termite holes; abrupt smooth boundary.
2Btc	47-63	Yellowish red (5YR 4/6) gravelly sandy clay; moderate medium subangular blocky structure; hard (dry) very friable (moist) sticky (wet); common moderately thick clay and iron - oxyhydroxide coatings on ped faces and in pores; many medium continuous pores; common fine to medium roots; common medium iron nodules and many quartz grains and evidence of weathered rock structure; abundant mica flakes; common ant and termite holes; gradual smooth boundary.
2BCrt	63-102	Red (10R 4/8), yellowish red (5YR 4/6) and strong brown (7.5YR 5/8) for the rock structure, hematitic and goethitic illuvial clay; clay; structureless (massive) breaking into strong medium subangular blocks; very hard (dry) friable (moist) sticky (wet); common moderately thick clay and iron - oxyhydroxide coatings in pores and within weathered rock structure; abundant mica flakes and weathering feldspar; common ant and termite activity; abrupt wavy boundary.
2Cr	102-130	Massive micaceous granitic weathering rock layer mixed with some illuvial clay.

5.2: Physical and Chemical Characteristics

5.2.1: Particle Size Distribution

Particle size distribution data for the soils are presented in Table 3. Except for the subsoils of pedons 5, 7 and 8 which are clayey, the largely sandy and loamy texture of the soils reveal the sandy nature of the parent material of the soils in general, and the silty nature of the parent material of some of the surface soils.

Textures largely vary from sandy loam to sandy clay loam in the Sudan and Northern Guinea Savanna zones. It is also noteworthy that pedon 3 within the Northern Guinea Savanna zone records a sandy clay loam surface texture, overlying a less clayey subsoil. This support the earlier assertion that the profile has been truncated by the process of soil erosion resulting in an almost complete removal of the original surface soil here. Pedons 5 and 6 of the Southern Guinea Savanna zone have sandy loam surface textures. This overlies a sandy clay loam subsoil in pedon 6 and a clay subsoil in pedon 5. The higher clay content in the Rainforest zone is revealed in the dominantly clay subsoils which are overlaid by gravelly sandy clay loam surface soils in pedons 7 and 8.

The content of coarse fragments in the soils include common to many manganiferrous concretions and very hard iron nodules in addition to coarse quartz fragments in the Sudan and Northern Guinea Savanna zones. The distribution of the coarse fragments in pedon 3 is nearly even throughout the

Table 3: Particle size distribution data of the soils.

Horizon	Depth	Gravel	Sand			Silt	Clay	Textural Class
			Coarse sand 250-2000um	Fine sand 50-250um	Total sand <2000um	50-2um	<2um	(USDA)
	cm	% of total soil	% of < 2000 um fraction					
Sudan Savanna Zone								
Pedon 1: Plinthustalf (USDA)/Plinthic Luvisol (FAO)								
Ap	0-31	4	8	92	72	14	14	Sandy loam
E	31-62	1	7	94	66	14	20	Sandy loam
2Btv1	62-94	4	6	94	58	14	29	Sandy clay loam
2Btv2	94-122	59	25	75	56	16	29	Gravelly sandy clay loa
Pedon 2: Plinthustalf (USDA)/Plinthic Luvisol (FAO)								
Ap	0-15	1	19	42	61	22	17	Gravelly Sandy loam
AB	15-35	2	8	38	46	33	21	Sandy loam
2Btv1	35-70	11	7	49	56	16	19	Sandy clay loam
2Btv2	70-85	12	21	27	48	27	26	Sandy clay loam
Northern Guinea Savanna Zone								
Pedons 3: (Oxic Haphustalf USDA)/Dystric Nitosol (FAO)								
Apc	0-6	47	61	39	62	16	22	Gravelly Sandy Clay loa
Btc	6-34	22	72	28	58	12	30	Gravelly Sandy Clay loa
2BCtc1	34-72	30	75	25	60	16	24	Gravelly Sandy Clay loa
2BCtc2	72-119	29	64	36	60	20	20	Gravelly Sandy loam
2Cc	119-144	25	66	34	60	22	18	Gravelly Sandy loam

Table 3 contd.: Particle size distribution data of the soils.

Horizon	Depth	Gravel	Sand			Silt	Clay	Textural Class
			Coarse sand 250-2000um	Fine sand 50-250um	total sand <2000um	2-50um	<2um	(USDA)
	cm	% of total soil	% of < 2000 um fraction					
Pendon 4: (Oxic Haplustalf (USDA)/Dystic Nitosol (FAO)								
Ap	0-15	2	30	70	50	36	14	Loam
Bt	15-34	2	30	71	40	30	30	Clay loam
2Bt1	34-62	9	23	77	32	32	36	Clay loam
2Bt2	67-106	1	25	76	34	34	32	Clay loam
2Bt3	106-132	11	39	61	38	30	32	Gravely Clay loam

Southern Guinea Savanna Zone

Pedon 5: Plinthustult (USDA)/Plinthic Acrisol (FAO)								
Ap	0-20	tr	68	33	74	10	16	Sandy loam
E	20-45	1	74	26	64	12	24	Sandy clay loam
Btv	45-85	2	75	25	42	10	48	Clay
Pedon 6: Plinthustulf (USDA)/Plinthic Acrisol (FAO)								
Apc	0-16	17	71	29	72	14	18	Gravely Sandy loam
BAc	16-36	17	69	31	64	16	20	Gravelly Sandy cla.
Btv	36-70	27	76	24	66	16	24	Gravelly Sandy cla.

Table 3 contd.: Particle size distribution data of the soils.

Horizon	Depth	Gravel	Sand			Silt	Clay	Textural Class
			Coarse sand 250-2000um	Fine sand 50-250um	total sand <2000um	50-2um	<2um	(USDA)
	cm	% of total soil	% of < 2000 um fraction					
Forest Zone								
Pedon 7: Orthoxic Tropudult (USDA)/Orthic Acrisol (FAO)								
Apc	0-16	39	68	32	64	12	24	Gravelly Sandy Clay Loam
Ec	16-44	53	70	30	64	14	22	Cobbly Sandy clay loam
2Btc	44-68	37	73	27	36	10	54	Gravelly clay
2Btsc	68-87	30	60	40	32	10	50	Gravelly clay
2BCt	87-121	20	67	33	32	14	54	Clay
Pedon 8: (Orthoxic Tropudult (USDA)/Orthic Acrisol (FAO)								
Apc	0-14	29	64	36	66	12	22	Gravelly Sandy clay loam
Ec	14-47	52	67	33	66	14	20	Gravelly Sandy clay loam
2Btc	47-63	43	69	31	60	14	26	Gravelly sandy clay loam
2BCrt	63-102	17	79	27	40	14	46	Clay
2BCr	102-130	13	71	30	46	12	42	Clay

profile. A large amount of stones are scattered on the surface of this pedon, revealing the colluvio - residual nature of the parent material, which is also associated with pedons 7 and 8 of the Rainforest zone. Pedons 4, 7 and 8 contain lower amounts of coarse fragments, especially in their surface horizons, than in pedons 1, 2 and 3.

5.2.1.1: Gravel Content

Results of analysis of variance show that there is no significant difference in gravel content both between the surface and subsoil horizons as well as between zones. In other words, though the Rainforest zone recorded the highest percentage of gravel content, and the Southern Guinea Savanna zone the lowest, neither such zonal variations nor the variation in surface soil and subsoil distribution of gravel is statistically significant at 5% level of probability.

5.2.1.2: Sand Fraction

Total sand content ranged between 32% to 74% with a mean of 58.87% of the fine earth or the less than 2000um fraction (Table 3). The high total sand content of the soils reflect the granitic origin of the parent material. In all the zones total sand content of the surface soils was significantly higher than the subsoil content at 5% level of probability. When separated into coarse sand (250 - 2000um) and fine sand (50 - 250um) the values ranged between 6 and 79% with a mean of 50.06% for the coarse sand subfraction and between 24% and 94% with a mean of 44.31% for the fine

sand subfraction for all the soils. The difference in total sand content of the soils between the zones is not statistically significant.

Coarse sand content of the soils vary significantly between the zones at 1% level of probability. The Southern Guinea Savanna zone and the Rainforest zone recorded significantly higher mean values of coarse sand (72.50% and and 69.00% respectively) than the Northern Guinea Savanna zone (47.00%) which in turn recorded a significantly higher mean value of 11.75% than the Sudan Savanna Zone. No significant difference was found in the fine sand distribution between zones.

5.2.1.3: Silt Fraction

Silt content ranged between 10% and 36% with a mean of 17.50% of the less than 2000um fraction (Table 3). Even though the surface soils are generally higher in silt than the subsoils in all the zones, the difference is not statistically significant.

Silt content differed significantly between the zones at 5% level of probability. Similar mean values were recorded for the Sudan Savanna and Northern Guinea Savanna zones; however, the Northern Guinea Savanna zone recorded a significantly higher mean value of silt than the Southern Guinea Savanna and the Rainforest zones at 5% levels of probability. Respective means of 25.50%, 19.00%, 12.75% and 12.75% were recorded for the Northern Guinea Savanna, the Sudan Savanna, the Southern Guinea Savanna and the

Rainforest Zones.

The high silt content of the Savanna soils distinguish the soils from those of the Rainforest zones; the Rainforest zone recorded the lowest values of silt thus reflecting the decreased influence of aeolian deposition in the zone compared to the influence in the Savanna zones north of it.

5.2.1.4: Clay Fraction

Clay content in the soils ranged from 14 to 54% with a mean of 26.56% (Table 3). Values increased from the A horizons to the B horizons and then decreased in the underlying BC and C horizons (Figure 7). Clay maxima values in the Bt horizons ranged from 24 to 54%. The high clay content in the B horizons relative to the A or C horizons confirm the presence of argillic horizons in all the zones.

From the on going, it is evident that clay content of the soils vary significantly between surface soils and subsoils. A significantly higher clay content is recorded for the subsoils than the surface soils at 1% level of probability in all the zones. The lower clay content of the surface soils is a characteristic that has been observed for most soils on Basement Complex in Nigeria (Ojanuga, 1969; Leow and Ologe, 1982; Esu et. al. 1987). This characteristic has been attributed to biological (termite) sorting of soil materials, downward eluviation of clay and erosion, all of which activities are common occurrences in all the zones. The lower clay content of the topsoils relative to the subsoils could also mean a more intensive chemical

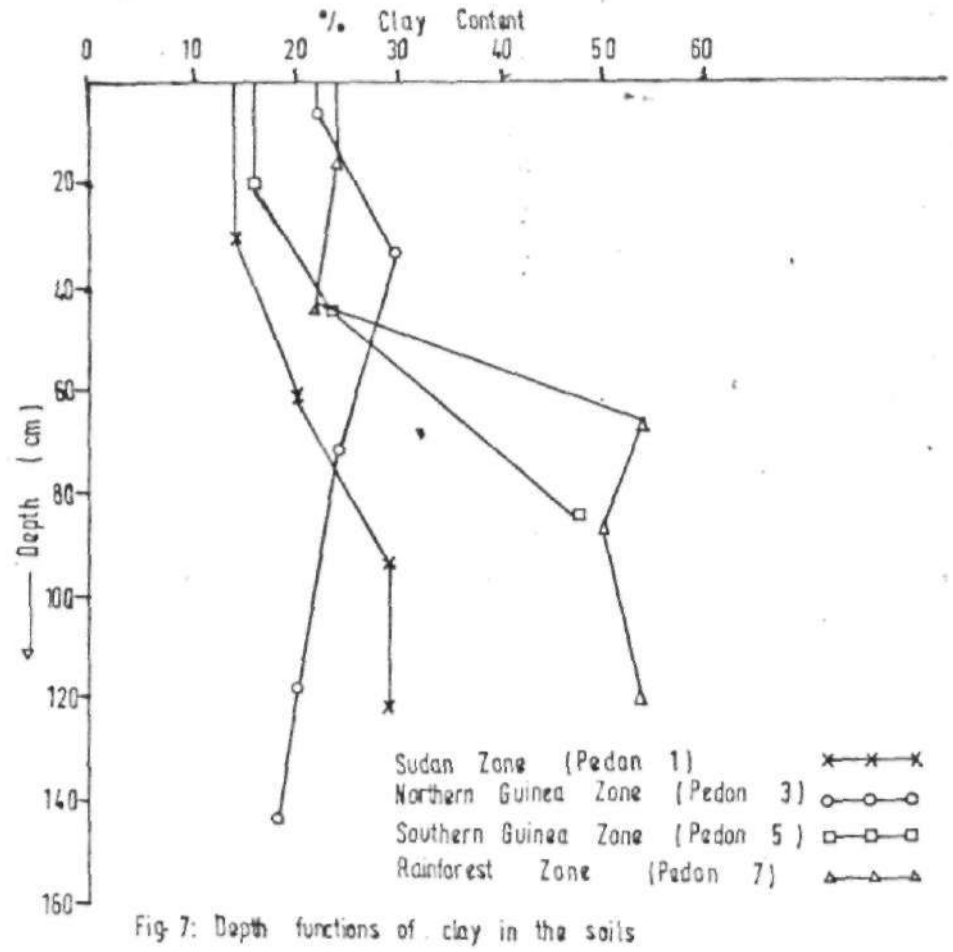


Fig 7: Depth functions of clay in the soils

weathering at the subsoils relative to the topsoils.

According to Jones and Wild (1975) increase in clay content with depth is thought to be related to climate such that the most pronounced textural B horizons are found in "leached ferrallitic soils" of the humid savannas of West Africa. As illustrated by the depth functions of clay in the soils in Figure 7, however, soils of the Southern Guinea Savanna zone and Rainforest zone have more pronounced textural B horizons than soils in the more arid Sudan and Northern Guinea Savanna zones.

The clay content increases from the Sudan Savanna Zone to the Rainforest zone with ranges of 14 - 29%, 14 - 36%, 16 - 48% and 20 - 54% and corresponding means of 21.50%, 23.00%, 27.25% and 34.50% recorded for the Sudan, Northern and Southern Guinea Savanna, and the Rainforest Zones respectively. The difference in clay content between the zones is however not statistically significant.

5.2.2: Soil pH

The pH values of the soil horizons (Table 4) ranged between 4.5 and 8.2 with a mean of 5.9 in water and between 3.9 and 7.4 with a mean of 5.1 in 0.01M $CaCl_2$, indicating very strongly acid to moderately alkaline soil reaction (Soil Survey Staff, 1951). About 59% of the samples have pH values less than 6.0 and only about 9% above 7.5. The major factors responsible for this low pH include perhaps the acidic nature of the parent rocks; the rocks are low in bases and as such when they weather, the end products are

Table 4: Organic carbon, pH, total nitrogen and extractable phosphorous contents of the soils.

Horizon	Depth	pH		Organic	Total	Extractable
		H_2O	$CaCl_2$	C	N	P
	cm			%		mg/kg
		Sudan Savanna Zone				
Pedon 1:	Plinthustalf (USDA)/Plinthic Luvisol (FAO)					
Ap	0-31	7.8	6.5	0.38	0.04	20.80
E	31-62	7.4	6.6	0.28	0.02	1.40
2Btv1	62-94	7.4	6.5	0.22	0.04	1.40
2Btv2	94-122	7.6	6.9	0.22	0.04	1.05
Pedon 2:	(Plinthustalf (USDA)/Plinthic Luvisol (FAO)					
Ap	0-15	6.8	5.5	0.61	0.03	2.10
AB	15-35	6.4	5.2	0.37	0.02	1.30
2Btv1	35-70	7.3	6.0	0.39	0.01	1.80
2Btv2	70-85	8.2	7.4	0.34	0.01	1.40
		Nothern Guinea Savanna Zone				
Pedons 3:	(Oxic Haplustalf (USDA)/Dystic Nitosol (FAO)					
Apc	0-6	5.9	4.8	0.64	0.05	2.45
Btc	6-36	5.3	4.6	0.42	0.04	0.70
2Bctc1	36-72	5.9	5.3	0.23	0.02	tr
2Bctc2	72-119	6.2	5.6	0.06	0.02	2.45
2Cc	119-144	6.4	5.9	0.10	0.04	4.90
Pedon 4:	(Oxic Haplustalf (USDA)/Dystric Nitosol (FAO)					
Ap	0-15	5.0	4.2	0.50	0.04	17.50
Bc	15-34	5.4	4.9	0.46	0.04	0.70
2Btc1	34-67	5.3	5.0	0.50	0.04	0.35
2Bt2	67-106	5.0	4.8	0.18	0.01	tr
2Bt3	106-152	7.4	6.7	0.18	0.01	tr

Table 4 contd.: Organic carbon, pH, total nitrogen and extractable phosphorous of the soils.

Horizon	Depth	pH H_2O	pH $CaCl_2$	Organic C	Total N	Extractable P
	cm			-------%--------		mg/kg
Pedon 5: (Plinthustulf (USDA)/Plinthic Acrisol (FAO)						
Ap	0-20	6.4	5.7	0.50	0.04	3.50
E	20-45	5.0	4.1	0.24	0.05	3.50
Btv	45-85	4.6	4.0	0.50	0.05	2.45
Pedon 6: (Plinthustulaf (USDA)/Plinthic Acrisol (FAO)						
Apc	0-16	5.5	4.9	0.38	0.03	2.45
BAc	16-36	5.3	4.5	0.54	0.04	1.75
Btv	36-70	5.6	4.6	0.23	0.03	1.40
Forest Zone						
Pedons 7: (Orthoxic Tropudult (USDA)/Orthic Acrisol (FAO)						
Apc	0-16	6.4	6.0	1.74	0.16	4.20
Ec	16-44	6.3	5.8	0.23	0.04	2.45
2Btc	44-68	4.9.	4.2	0.64	0.04	1.75
2Btsc	68-87	4.5	4.1	0.38	0.04	tr
2BCrt	87-121	4.6	3.9	0.50	0.04	tr
Pedon 8: (Orthoxic Tropudult (USDA)/Orthic Acrisol (FAO)						
Apc	0-14	6.0	5.5	1.70	0.15	0.70
Ec	14-47	5.6	4.6	0.23	0.03	3.85
2Btc	47-63	5.0	4.4	0.22	2.02	2.45
2BCrt	63-102	4.9	4.4	0.22	0.03	0.70
2Cr	102-130	4.8	4.2	0.18	0.02	1.40

low in bases too. The sandy texture, coupled with low levels of organic matter content are known to encourage quite an effective leaching of cations into the subsoils from the topsoils.

pH values of surface soils are expected to be lower in the Southern Guinea Savanna and especially in the Rainforest Zone due to increased leaching of bases from the surface into the subsoils within this zones in that order. Rather, the surface soils in the Southern Guinea Savanna and Rainforest zones record higher pH values than the subsoils. This can be attributed to the low levels of exchangeable H (table 5) in the surface soils within the two zones. The higher pH in the surface soils of the Southern Guinea Savanna and Rainforest zones might also be due to greater root and litter decomposition as well as the biogenetic cycling of other bases, thus emphasizing the suggestion that vegetation overrides climate in influencing the depth variation of pH values in these zones (Jones and Wild, 1975). Mean pH values of 7.1, 5.5, 5.6 and 6.0 were recorded for the surface soils in the Sudan, Northern and Southern Guinea Savannas and Rainforest zones respectively.

Soil pH values varied highly between the zones. The Sudan Savanna zone recorded a mean value of 7.4 which is significantly higher than the mean values recorded for the other zones at 5% level of probability. Mean pH values of 5.6, 5.3 and 5.2 were recorded for the Northern and Southern Guinea Savanna and the Rainforest zones respectively; corresponding pH ranges of 6.4 - 8.2, 5.0 - 6.4, 4.6 - 6.4

Table 5: Exchangeable cations, total exchangeable bases (TEB), Cation exchangeable capacity (CEC) and base saturation (BS) of the soils.

Horizon	Depth	Exchangeable Cations						Total Exch.	Cation Exchange Capacity			Base Saturation	
		Ca	Mg	K	Na	Al	H	Bases	NH_4OH_2	ECEC	CEC-Clay	NH_4OH_2	ECEC
	Cm	----------			meq/100g of soil		----------				meq/100g of clay	--- % ---	
Sudan Savanna Zone													
Pedon 1: Plinthustalf (USDA)/Plinthic Luvisol (FAO)													
Ap	0-31	14.00	1.36	0.57	0.06	0.02	0.06	16.08	21.20	16.16	141.93	76	100
E	31-62	3.20	0.52	0.17	0.01	0.01	tr_4	4.01	8.60	4.02	38.10	47	100
2Btv1	62-94	4.95	0.77	0.17	0.04	0.01	tr	3.93	9.80	5.94	31.14	61	100
2Btv2	94-122	5.60	0.99	0.12	0.03	0.01	tr	6.81	1.60	6.82	37.59	59	100
Pedon 2: Plinthustalf (USDA)/Plinthic Luvisol (FAO)													
Ap	0-15	4.24	1.20	0.55	tr	tr	tr	5.99	6.29	5.99	24.78	95	100
AB	15-35	4.74	0.73	0.34	tr	tr	tr	5.81	6.29	5.81	23.45	93	100
2BCtc1	35-70	7.30	1.0	0.23	0.01	tr	tr	8.59	8.24	8.59	23.71	100+	100
2Btv2	70-85	3.52	0.75	0.27	0.01	tr	tr	4.55	7.56	14.55	25.50	100+	100
Northern Guinea Savanna Zones													
Pedon 3: (Oxic Haplustalf (USDA)/Dystic Nitosol (FAO)													
Apc	0-6	2.25	0.75	0.12	0.05	0.02	0.02	3.17	7.40	3.19	23.45	43	99
Btc	6-34	3.00	0.69	0.15	0.06	0.01	0.01	3.90	8.20	3.93	22.43	48	99
2Bctc1	34-72	4.40	1.24	0.24	0.10	0.01	tr	5.97	10.20	5.99	39.15	59	100
2BCtc2	72-119	6.00	1.80	0.18	0.15	0.01	tr	8.13	12.20	8.14	59.95	67	100
2Cc	114-144	7.30	1.77	0.14	0.17	0.01	tr	9.08	15.40	9.09	83.61	59	100

Table 5 contd.: Exchangeable cations, total exchangeable bases (TEB), Cation exchangeable capacity (CEC) and base saturation (BS) of the soils.

Horizon	Depth	Exchangeable Cations						Total Exch. Bases	Cation Exchange Capacity			Base Saturation	
		Ca	Mg	K	Na	Al	H		NH_4OA_c	ECEC	CEC-Clay	NH_4OA_c	ECEC
	Cm	meq/100g of soil									meq/100g of clay	%	
Pendon 4: (Oxic Haplustalf (USDA)/Dystic Nitosol (FAO)													
Ap	0-15	1.05	0.28	0.09	0.41	0.01	0.02	1.83	5.40	1.86	26.07	34	98
BE	15-34	2.79	0.93	0.10	0.02	0.01	tr	3.85	8.20	3.88	21.97	47	100
2Bt1	34-67	3.90	0.59	0.15	0.04	0.02	tr	5.68	8.80	5.70	19.58	65	100
2Bt2	67-106	3.00	1.44	0.14	0.03	0.01	0.02	4.61	9.20	4.64	26.78	50	100
2Bt3	106-132	2.30	1.31	0.14	0.30	0.02	tr	3.77	7.40	3.79	21.16	51	100
Southern Guinea Savanna Zone													
Pedon 5: Plinthustult (USDA)/Plinthic Acrisol (FAO)													
Ap	0-20	0.70	0.26	0.06	0.01	tr	tr	1.03	4.20	1.03	15.31	25	100
E	20-45	0.50	0.23	0.05	0.01	0.02	0.04	0.79	4.00	0.85	13.17	20	93
Btv	45-85	0.95	0.59	0.06	0.02	0.04	0.01	1.62	4.60	1.76	5.94	35	92
Pedon 6: Plinthustult (USDA)/Plinthic Acrisol (FAO)													
Apc	0-16	1.05	0.45	0.07	0.01	tr	tr	1.58	5.20	1.58	21.50	30	100
BAc	16-36	0.70	0.28	0.08	0.01	0.02	0.02	1.07	4.40	1.11	9.45	24	96
Btv	36-70	0.93	0.46	0.07	0.01	0.03	0.03	1.47	4.60	1.53	11.29	32	96

Table 5 contd.: Exchangeable cations, total exchangeable bases (TEB), Cation exchangeable capacity (CEC) and base saturation (BS) of the soils.

Horizon	Depth	Exchangeable Cations						Total Exch.	Cation Exchange Capacity			Base Saturation	
		Ca	Mg	K	Na	Al	H	Bases	NH_4OAc	ECEC	CEC-Clay	NH_4OAc	ECEC
		Ca			meq/100g of soil						meq/100g of clay	%	
Rainforest Zone													
Pedon 7: Orthoxic Tropudult (USDA)/Orthic Acrisol (FAO)													
Apc	0-16	5.09	0.16	0.17	0.04	tr	tr	5.46	11.60	5.46	23.54	47	100
Ec	16-44	1.50	0.31	0.45	0.01	tr	tr	2.27	4.20	2.27	15.43	54	100
2Btc	44-68	1.15	0.34	0.18	0.02	0.02	0.02	1.70	4.60	1.78	4.37	37	98
2Btsc	68-87	0.54	0.39	0.12	0.02	0.03	0.07	1.08	3.60	1.18	3.91	30	92
2BCrt	87-121	3.75	1.74	0.14	0.02	0.05	0.13	5.66	9.40	5.84	14.17	60	97
Pedon 8: Orthoxic Tropudult (USDA)/Orthic Acrisol (FAO)													
Apc	0-14	0.65	0.23	0.08	0.01	0.01	tr	0.97	3.80	0.98	9.77	26	99
Ec	14-47	1.15	0.34	0.18	0.03	0.02	0.02	1.70	4.80	1.74	19.98	36	98
2Btc	47-63	0.75	0.29	0.11	0.01	0.01	tr	1.16	3.60	1.17	10.88	32	99
2BCrt	63-102	1.35	0.75	0.15	0.02	0.01	tr	2.27	5.00	2.28	9.20	45	100
2Cr	102-130	1.05	0.56	0.08	0.01	0.02	0.02	1.70	4.80	1.74	9.93	35	98

tr - trace

and 4.8 - 6.4 were recorded for these zones.

The soil pH values in water were highly correlated with values of pH in 0.01M $CaCl_2$ (r=0.9880).

5.2.3: Organic Carbon

The soils are generally low in organic carbon content (Table 4). The range in all the soils is 0.06 to 1.72%. This may be attributed to the rapid microbial mineralization of added litter in all the soils due to the generally high temperatures recorded all the year round in all the zones. The generally low organic carbon content of tropical soils have also been attributed to low polymerization of humic compounds with stable components that commonly accumulate as complexes with soil clays. These humic compounds are therefore easily leached out of the soil system, thus accounting for their low organic carbon content (Ojanuga, 1971).

The organic carbon content of the soils vary more with depth than with zones. Ranges of 0.22 to 0.61%, 0.06 to 0.64%, 0.24 to 0.54% and 0.18 to 1.74% were recorded for the Sudan Savanna, the Northern Guinea Savanna, the Southern Guinea Savanna and the Rainforest zones respectively, with corresponding means of 0.35%, 0.41%, 0.040% and 0.54%. The surface soils differ very significantly from the subsoils in organic carbon content at 5% level of probability. With the exception of the Southern Guinea Savanna zone, the soils contain significantly higher amounts of organic carbon in the surface soils than in the subsoils (Figure 8). Mean

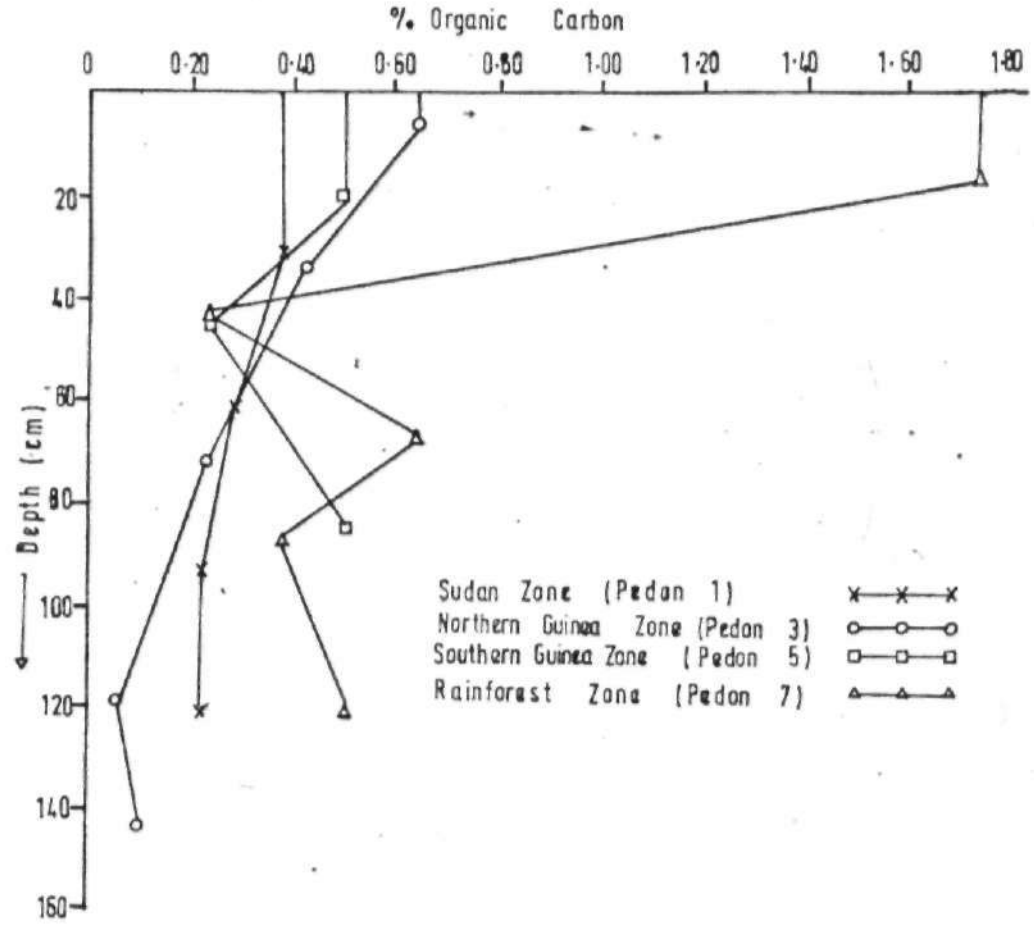


Fig. 8: Depth functions of organic carbon in the soils

organic carbon values of 0.73%, 0.57% and 0.40% were recorded for the surface soils in the Rainforest zone, the Northern Guinea Savanna and the Sudan Savanna zones respectively. The Southern Guinea Savanna zone recorded the lowest mean value of 0.37% for the surface soil.

The lower value of organic carbon recorded for the surface soil of the Southern Guinea Savanna zone than the subsoil is primarily due, perhaps, to anthropogenic interference and to the gravelly nature of the surface soils which possibly promotes rapid leaching of organo - metallic complexes from the surface to the subsoil. Soils of the Rainforest zone which have the highest mean annual rainfall and longest rainy season contain relatively much higher organic carbon than soils of the drier Savanna zones (the Sudan, Northern and Southern Guinea Savanna zones respectively). This agrees with the relationship observed by Nye and Greenland (1960), Kadeba (1970) and Jones and Wild (1975). They observed significantly high positive correlations between organic carbon and mean annual rainfall which most likely reflects longer growing season and consequently more return of vegetative matter to the soil in the Rainforest zone.

Bush-burning (Plate 1) encouraged by the greater severity of the dry season is common in the Savanna zones and especially in the Sudan Savanna and Northern Guinea Savanna zones. The bush - burning diminishes plant species and by reduction or total elimination of the grass and leaf litter in an area, it also serves as a drain mechanism on

the soils' major source of organic matter. In fact, Ahn (1970) estimated that the total weight of vegetation of the Savanna may be only 1 - 5 tons dry weight per acre while about 150 tons dry weight per acre is recorded for Rainforest vegetation; this further explains the lower values of organic matter recorded for the Savanna zones than for soils of the Rainforest zone. However, the differences in organic carbon content of the soils between the zones are not statistically significant indicating that irrespective of vegetation zone, the organic matter content of soils developed on older granites are generally low.

5.2.4: Total Nitrogen

Total nitrogen values varied from very low to moderately low with a range of 0.01 to 0.16% in the soils (Table 4). Significant differences in total nitrogen were observed both between zones and between surface soils and subsoils in each zone.

The depth distribution of total nitrogen revealed highly significant difference in values between the surface soils and subsoils at 1% level of probability. As can be observed in Table 4, the total nitrogen content of the surface soils ranged between 0.02% and 0.16% with a mean of 0.05%. The surface soils in the Rainforest zone recorded higher values of total nitrogen than surface soils of the three savanna zones, reflecting a close relationship between nitrogen and organic matter contents in the soils. The lower levels of total nitrogen in the surface soils of the

savanna zones reflect the lower leaf litter in these zones than in the Rainforest zones.

Total nitrogen values decreased from the Rainforest zone to the Sudan Savanna zone. Soils of the Rainforest zone with a range of 0.02 to 0.16% and a mean of 0.05% recorded significantly higher total nitrogen values than those of the three Savanna zones. The Southern Guinea Savanna and Northern Guinea Savanna zones recorded similar values of total nitrogen which are in turn significantly higher than the value for the Sudan Savanna zone. Ranges of 0.03 to 0.05%, 0.01 to 0.05% and 0.01 to 0.04% were recorded for the Southern Guinea, Savanna, the Northern Guinea Savanna and the Sudan Savanna zones with respective means of 0.04%, 0.035% and 0.025%, reflecting the trend of organic matter content in the soils. Jones (1973) in his study of soils in the Savanna found very significant positive correlations between nitrogen and soil carbon, and nitrogen and mean annual rainfall at 0.001% and 0.01% levels of probabilities respectively. The lower values of nitrogen in the Savannas than in the Rainforest soils therefore can be linked with the higher rainfall and hence organic matter content in the Rainforest than in the Savanna zones. The similarity in pattern of total nitrogen and organic carbon distribution in addition to the influence of organic matter distribution on the zonal variation of total nitrogen suggests the importance of vegetation in influencing the distribution of total nitrogen in the soils. However, the dependence of vegetation on other factors, particularly on

rainfall makes it very difficult to separate it as an independent factor (Jones, 1973). Therefore it may be said that climate and vegetation act together in influencing the distribution of total nitrogen in the soils.

5.2.5: Extractable Phosphorous

Data related to extractable phosphorus are presented in Table 4. In general, the soils contain low levels of extractable phosphorus apart from pedons 1 and 4 in the Sudan Savanna zone and the Northern Guinea Savanna zone respectively. The other pedons have values which range between trace amounts and 4.90 mg/kg of extractable phosphorous. Pedons 1 and 4 have ranges of 1.05 to 20.80 mg/kg and between trace amount and 17.50 mg/kg. These high values have been attributed to some anthropogenic influences such as addition of P-fertilizers to crops previously grown on the soils where the pedons were located.

Higher values of extractable phosphorus are recorded for the surface soils, often followed by a sharp decrease in the subsoils. Though not statistically significant at 5% level of probability, the relatively higher amount of extractable phosphorus of the surface soils could be linked with the higher content of organic matter in the soils.

The application of humified organic matter to different soil types (ferruginous, hydromorphic and ferrallitic soils) from Senegal, the Malagasy Republic and the Central African Republic is known to have increased phosphate concentration in the soil solution (Bhat and Bouyer, 1968; Bhat, 1970;

Oliver, 1972 and Pichot et. al., 1973). However, similar to the observation made by Esu (1982) in his study of some soils in the Kaduna area, organic carbon content did not vary directly with the amount of extractable phosphorous in these soils. For instance, Pedon 8 has a mean organic carbon content of 0.67% in the surface soil and a corresponding mean extractable phosphorus content of 2.88 mg/kg while pedons 2 and 5, have organic carbon contents of 0.47% and 0.36% and corresponding extractable phosphorous values of 1.64 and 3.50 mg/kg in their surface soils respectively.

However, the inconsistence in accumulation of phosphate at the surface, a pronounced occurrence in the savanna, has been attributed to the decrease in the return of phosphorous to the soil surface as the vegetation becomes sparser (Enwezor and Moore, 1966; Ipinmidun, 1972).

Generally, no significant differences in extractable phosphorous values between zones were observed at 5% level of probability.

5.2.6: Exchange Acidity

Exchange acidity values determined by 1M KCl are given in Table 5. Exchange acidity in the soils is very low varying between trace amounts to 0.18 mg/100g of soil. The low exchange acidity is a reflection of the low amounts of exchangeable Al and H in the soils.

There is no significant difference between the surface and subsoil in exchangeable Al and H contents at 5% level of

probability. The Southern Guinea Savanna zone records the highest values of both exchangeable Al and H. However, the differences in exchange acidity both between zones and between surface and subsoil within each zone are not significant at 5% level of probability.

Similar to the observations of Balasubramanian et. al. (1984) for some Savanna soils, the problem of reserve acidity is evidently not severe in these soils.

5.2.7: Exchangeable Cations

The data on exchangeable cations and total exchangeable bases (TEB) are presented in Table 5. The principal saturating cation in the soils is Ca.

The amount and distribution of total exchangeable bases showed marked randomness with depth though high values were commonly obtained for the B horizons. It is interesting to note however, that the upper B horizons of most of the soils have relatively lower amounts of exchangeable bases. This according to Esu (1982), may be due to leaching losses of the bases or the eluviation of bases into the underlying lower B and C horizons. Awujoola (1979) linked such a distribution to the clay content.

The content of exchangeable cations in the soils vary significantly between zones. The range of total exchangeable bases in the soils is between 0.79 and 16.08 meq/100g of soil with a mean of 3.78 meq/100g soil. The values in soils of the Sudan Savanna zone ranged between 3.93 and 16.08 meq/100g of soil with a mean of 7.15 meq/100g

soil. This is significantly higher than the total exchangeable bases values for the Northern Guinea Savanna and Rainforest zones, the contents of which do not differ significantly from one another. However, the values of total exchangeable bases in the Northern Guinea Savanna zone are significantly higher than values for the soils of the Southern Guinea Savanna zone. Ranges of 1.83 to 9.08 meq/100g soil, 0.97 to 5.66 meq/100g and 0.79 to 1.62 meq/100g soil were recorded for the Northern Guinea Savanna zone, the Rainforest zone and the Southern Guinea Savanna zone respectively with corresponding means of 4.12, 2.52 and 1.36 meq/100g soil.

The cations occurred in the order: Ca > Mg > K > Na in all zones. Similar trends in the occurrence of exchangeable bases have been reported for soils of the Jos plateau (Ojanuga and Awujoola, 1979), Zaria area (Awujoola, 1979; Malgwi, 1979) and for soils of the Kaduna area (Esu, 1982). The exchangeable Ca content of the soils ranged between 0.50 and 14.00 meq/100g soil while exchangeable Mg ranged between 0.16 and 1.77 meq/100g soil. Exchangeable K ranged between 0.05 and 0.67 meq/100g soil, and exchangeable Na ranged between trace amounts and 0.41 meq/100g soil.

The presence in soils of exchange sites which show specific affinity for Ca may be responsible for the predominance of Ca over the other cations in the soils (Becket, 1965). Another probable reason is the fact that of all the exchangeable cations, Ca is the least easily lost from the soil environment (Brady, 1974). The higher values

of exchangeable Mg obtained for the Sudan Savanna and Northern Guinea Savanna zones than the wetter Southern Guinea Savanna and the Rainforest Zone in particular agree with the findings of Sys (1967) who observed that when the climate becomes drier in the subwet regions of the tropics, Mg becomes relatively more important.

The Southern Guinea Savanna zone and the Rainforest zone appear to contain similar levels of exchangeable Ca, Mg. In addition, they record lower amounts of these cations than the Sudan Savanna zone. This may be explained by the fact that with increasing rainfall, leaching becomes dominant and leaching losses of these cations increase in the Southern Guinea Savanna and Rainforest zones, both of which record higher rainfall than in the Sudan Savanna zone. A similar observation was made by Scott (1962) for some East African soils.

5.2.8: Cation Exchange Capacity (CEC)

Two CEC values were obtained for all the soils: one is effective CEC by summation of exchangeable cations and exchangeable acidity (ECEC) and the other is neutral CEC determined by the 1N NH_4OA_c method. The magnitude of the CEC depends on the methods used and follows a trend closely related to that observed by Juo et. al. (1976) for some West African soils. Neutral CEC values were higher than the effective CEC values (Table 5). This trend has been attributed to the well known phenomenon that the CEC of tropical soils is highly pH dependent, i.e. it increased

with pH (Uehara and Keng, 1975; Balasubramanian et. al., 1984). As such, neutral CEC determined at a particular pH which might be quite different from the actual soil pH is always higher than the effective CEC determined at the soil pH.

The range for neutral CEC was from 3.60-21.20 meq/100g of soil while the range for effective CEC was from 0.85 - 16.16 meq/100g of soil (Table 5). Respective means of 6.87 and 4.07 were recorded for the neutral and effective CEC of all the soils.

Apart from the Northern Guinea Savanna zone, the neutral CEC values are higher in the surface soils than in the subsoils. On the other hand, the surface soils in all the zones have lower values of effective CEC than the subsoils. Since the present trend is to use the effective CEC rather than neutral CEC for fertility evaluation in tropical areas (Coleman, et al., 1959; Balasubramanian, et al., 1984), it could be said that the CEC of the surface soils is lower than that of the subsoils. However, the differences between the values of both the neutral CEC and effective CEC for the surface soils and subsoils are not significant at 5% level of probability.

The value of neutral CEC varied significantly between zones at 5% level of probability; effective CEC values also varied significantly between zones at 1% level of probability. The mean ECEC value for the Sudan Savanna zone was significantly higher than the mean values obtained for the soils of the other three zones which in turn did not

differ significantly from one another. Mean values of ECEC for the Sudan, Northern and Southern Guinea Savanna and the Rainforest zones are 8.18, 4.14 1.41 and 2.56 meq/100g soil respectively. Corresponding mean values of neutral CEC of 9.95, 8.19, 4.61 and 4.74 meq/100g of soil were recorded for the zones.

The significantly higher CEC recorded for soils of the Sudan Savanna zone than the Rainforest zone may be due to the higher content of lower activity clay down south than in the drier Sudan Savanna zone. The value of CEC-clay do not differ significantly between the zones, probably reflecting the non-significant differences in clay content between the zones. However, CEC-clay values increased southwards. The fact that kaolinite has a CEC of between 3 and 15 mg/100g clay (Grim, 1968), confirms the assertion that soils of the Southern Guinea Savanna zone and the Rainforest Zone, with means of 13.04 and 11.77 meq/100g clay respectively are dominated by the low activity kaolinitic clays.

5.2.9: Base Saturation

Base saturation as calculated by two methods is variable depending on the method used (Table 5). As would be expected, the base saturation by ECEC gave the highest values (a range of 92 - 100%) with most values falling between 96-100%, thus reflecting the very low corresponding ECEC values. The NH_4OA_c method gave lower values which ranged between 30 and 67%.

Differences observed in base saturation (both neutral and effective between the surface soils and subsoils are not statistically significant. However, the higher base saturation (by ECEC) in the surface soils than in the subsoils in the Southern Guinea Savanna zone and Rainforest zone may be attributed to the return of cations from the subsoil to the surface soil through the pumping effect of vegetation as earlier suggested.

Similar to the pattern of total exchangeable bases, CEC by NH_4OA_c and ECEC, base saturation varied significantly between zones. The Sudan Savanna zone recorded the highest values of base saturation (NH_4OA_c) with a range of 47 - 100% and a mean of 79%. The Northern and Southern Guinea Savanna and Rainforest zones recorded lower values which in turn did not differ significantly from one another. Ranges of 34 to 67%, 20 to 35% and 26 to 60% were recorded for these zones with respective means of 47.75%, 29.00% and 42.00%.

The zonal pattern of effective base saturation differs slightly. The Sudan Savanna zone, the Northern Guinea Savanna zone and Rainforest zone have values which are not significantly different from one another. The values for the Sudan Savanna and Northern Guinea Savanna zones were however significantly higher than those obtained for the Southern Guinea Savanna zone, while no significant difference in values of neutral base saturation was found between the Southern Guinea Savanna and Rainforest zones.

5.2.10: Micronutrient Elements (Fe, Mn, Zn and Cu)

Values of the content of all the total micronutrient elements (Fe, Mn, Zn and Cu) in the soils are presented in Table 6. Of the four total micronutrient elements studied, total Fe content was highest in the soils. Values of this element, ranged between 0.88 to 5.63% in whole profiles. Total Mn ranked next in the soils with values ranging between 125 to 775 mg/kg. Values of total Zn in the soils ranged between 25 to 325 mg/kg while total Cu, which was found to be present in the lowest amount in the soils of the four elements ranged between 30 to 100 mg/kg. These nutrients were found to occur in the order: extractable Fe > Mn > Zn > Cu in the soils.

5.2.10.1: I r o n

Total Fe contents in all the surface soils ranged between 1.06 - 4.60%. The surface soils in the Rainforest zone contained the highest amount of total Fe than in the three Savanna zones. Of the three Savanna zones, the surface soil in the Northern Guinea Savanna zone contained the highest amount while the least amount was recorded for the surface soil in the Sudan Savanna zone (Figure 9). The trend of distribution of total Fe in the subsoils is shown in Table 6. Similar to the distribution in the surface soils, the highest value for the subsoil content of total Fe was recorded in the Rainforest zone while the Northern Guinea Savanna zone ranked next; the lowest value of total Fe in the subsoil was recorded in the Sudan Savanna zone.

Table 6: Total and extractable micronutrient elements in selected pedons of the four zones

Horizon	Depth	Extractable Micronutrients (DTPA Extraction)				Total Micronutrients (Na_2CO_3 fussion)			
		Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
	Cm	---------- mg/kg ----------				- % -	--- mg/kg ---		
Sudan Savanna Zone									
Pedon 1: Plinthustalf (USDA)/Plinthic Luvisol (FAO)									
Ap	0-31	7.00	4.80	1.70	0.50	0.88	175	63	50
E	31-62	6.20	3.12	1.50	0.30	1.25	175	63	50
2Btv1	62-94	3.80	1.77	1.30	0.22	1.75	150	63	50
2Btv2	94-122	4.50	2.00	1.45	0.38	2.87	250	63	70
Northern Guinea Savanna Zone									
Pedon 3: Oxic Haplustalf (USDA)/Dystric Nitosol (FAO)									
Apc	0-6	23.50	10.80	2.00	0.50	2.08	200	63	30
Btc	6-34	10.00	2.00	1.12	0.34	3.13	160	125	50
2BCtc1	34-72	9.00	13.28	1.30	0.22	2.13	450	88	30
2BCtc2	72-119	10.70	12.40	1.21	0.22	5.25	550	175	100
2Cc	119-144	9.90	8.00	2.00	0.22	5.63	660	279	75
Southern Guinea Savanna Zone									
Pedon 5: Plinthustult (USDA)/Plinthic Acrisol (FAO)									
Ap	0-20	14.00	16.00	1.25	0.30	0.88	145	25	50
E	20-45	6.50	14.00	2.30	0.32	1.38	125	25	60
Btv	45-85	13.50	3.00	1.65	0.28	2.50	125	38	60

Table 6 contd.: Total and extractable micronutrient elements in selected pedons of the four zones

Horizon	Depth	Extractable Micronutrients (DTPA Extraction)				Total Micronutrients (Na_2CO_3 fussion)			
		Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
	cm	mg/kg				- % -	--- mg/kg ---		
				Rainforest Zone					
Pedon 7: Orthoxic Tropudult (USDA)/Orthic Acrisol (FAO)									
Apc	0-16	20.50	40.00	4.70	0.68	3.25	775	325	55
Ec	16-44	8.50	4.00	1.55	0.58	3.00	350	63	50
2Btc	44-68	15.50	1.60	1.10	0.24	4.25	250	113	50
2Btsc	68-87	10.00	1.40	1.08	0.16	5.00	200	113	50
2BCrt	87-121	6.50	0.40	2.09	0.06	4.36	200	125	50

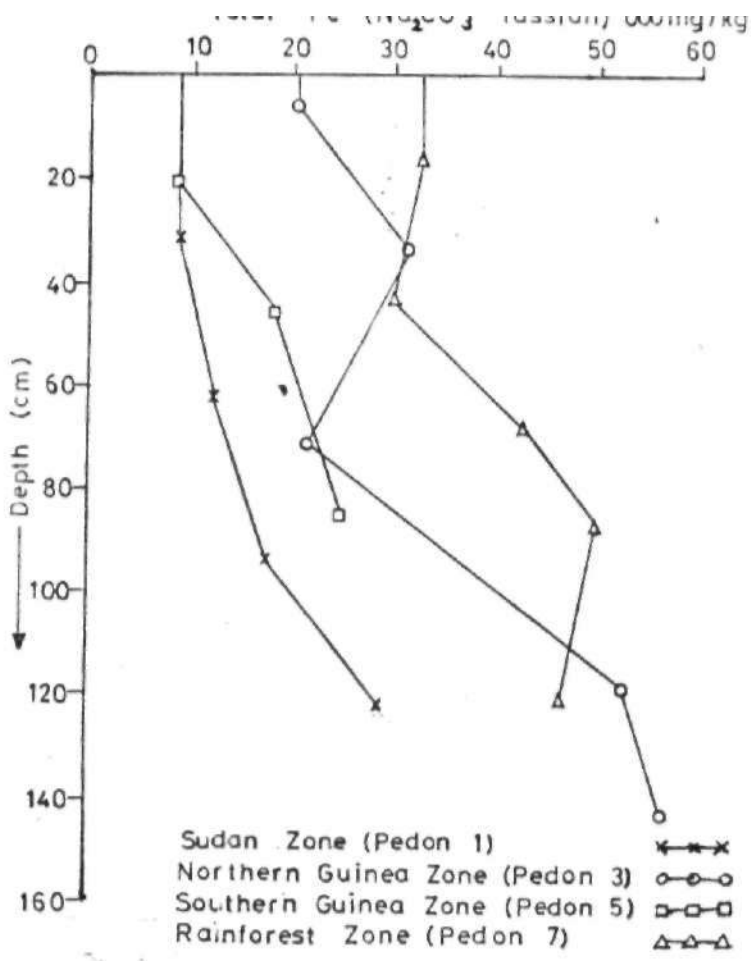


Fig. 9: Depth functions of total Fe - (Na_2CO_3 fussion)
in the soils

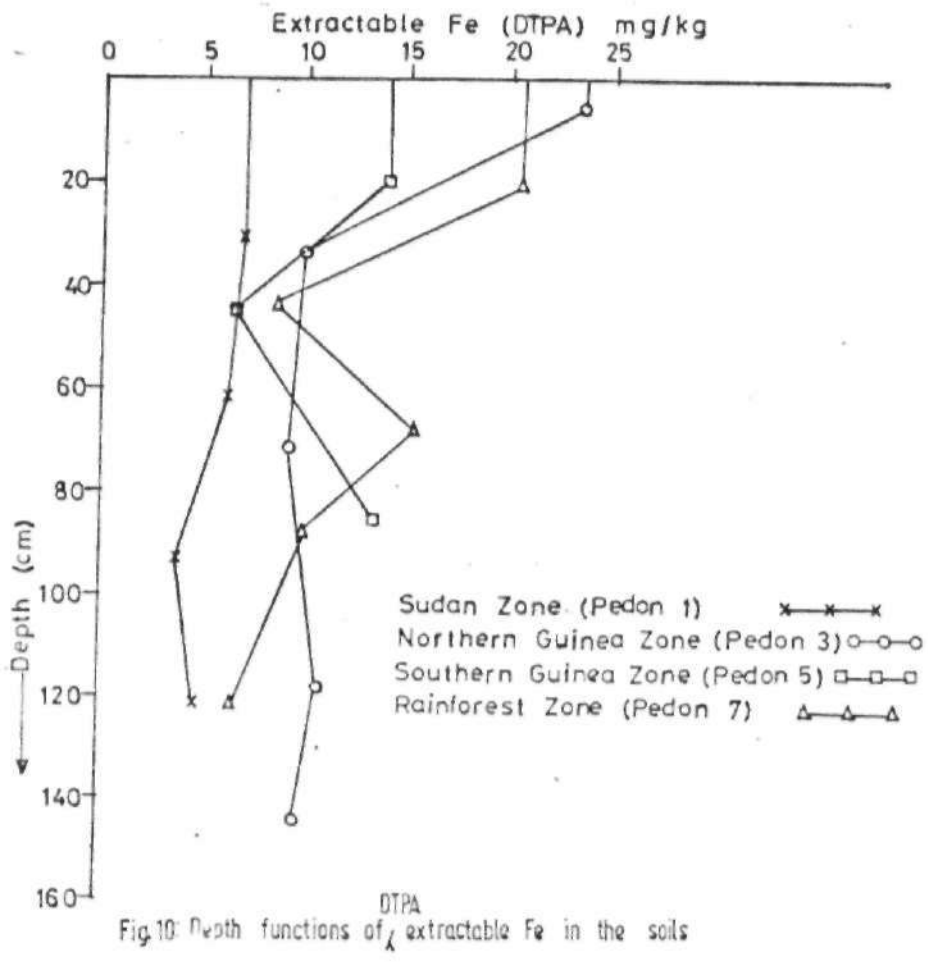


Fig. 10: Depth functions of extractable Fe in the soils

In general, the surface and subsoil distribution of total Fe in the soils seem to reflect the status of this nutrient element on zonal basis. The Rainforest zone contained the highest amount of total Fe with a mean value of 3.05% while the Southern Guinea Savanna and the Sudan Savanna zones recorded values of 1.97% and 1.67% respectively. This probably reflects the increasing intensity of weathering from North to South.

Extractable Fe content of the surface soils was higher than the subsoil content except in the Southern Guinea Savanna zone where a lower value was observed for the surface soil than for the subsoil. Extractable Fe values of 6.60 mg/kg, 23.50mg/kg, 9.93 mg/kg and 12.86mg/kg were recorded for the surface soils in the Sudan, Northern and Southern Guinea Savannas and Rainforest zones respectively. Subsoil values ranged between 4.3 to 13.50 mg/kg with the Southern Guinea Savanna zone recording the highest value and the Sudan Savanna zone the lowest value (Figure 10).

5.2.10.2: M a n g a n e s e

For the distribution of total Mn in the soils, the Rainforest zone recorded the highest value of 360.5 mg/kg. The Northern Guinea Savanna zone recorded a value of 331.5 mg/kg which is higher than values of 186.0 mg/kg and 129.0 mg/kg recorded for the Sudan and Southern Guinea Savanna zones respectively. Following the zonal trend of total Mn distribution, the surface soil in the Rainforest zone recorded the highest value of total Mn (505 mg/kg). The

Northern Guinea Savanna zone ranked next with a value of 200 mg/kg. The Southern Guinea Savanna zone which recorded the lowest value of total Mn for the whole soil also recorded the lowest surface and subsoil values of total Mn (Figure 11). However, the highest subsoil content of this element was recorded in the Northern Guinea Savanna zone rather than in the Rainforest zone which recorded the highest value for the whole soil. It is also noteworthy that unlike the trend observed for the depth distribution of total Fe, whereby all surface soils contained lower amounts than the subsoils, the Southern Guinea Savanna and the Rainforest Zones had higher amounts of total Mn in their surface soils than their subsoils. Lower values were recorded for the surface soils in the Sudan and Northern Guinea Savanna zones than in the subsoils. This trend probably reflects the effect of vegetation in the profile distribution of total Mn. The Southern Guinea Savanna and Rainforest zones with denser vegetation than the Sudan and Northern Guinea Savanna zones probably experience higher net rates of vegetal absorption of total Mn from the soils. The Mn thus absorbed is returned to the soils through litter decomposition, thus encouraging greater accumulation of Mn in the surface soils over time relative to the subsoils in these zones, than in the Sudan and Northern Guinea Savanna zones.

In all the zones, extractable Mn was higher in the surface soil than in the subsoil (Figure 12). Values of this element recorded for the surface soil in the Sudan, Northern and Southern Guinea Savanna and Rainforest zones

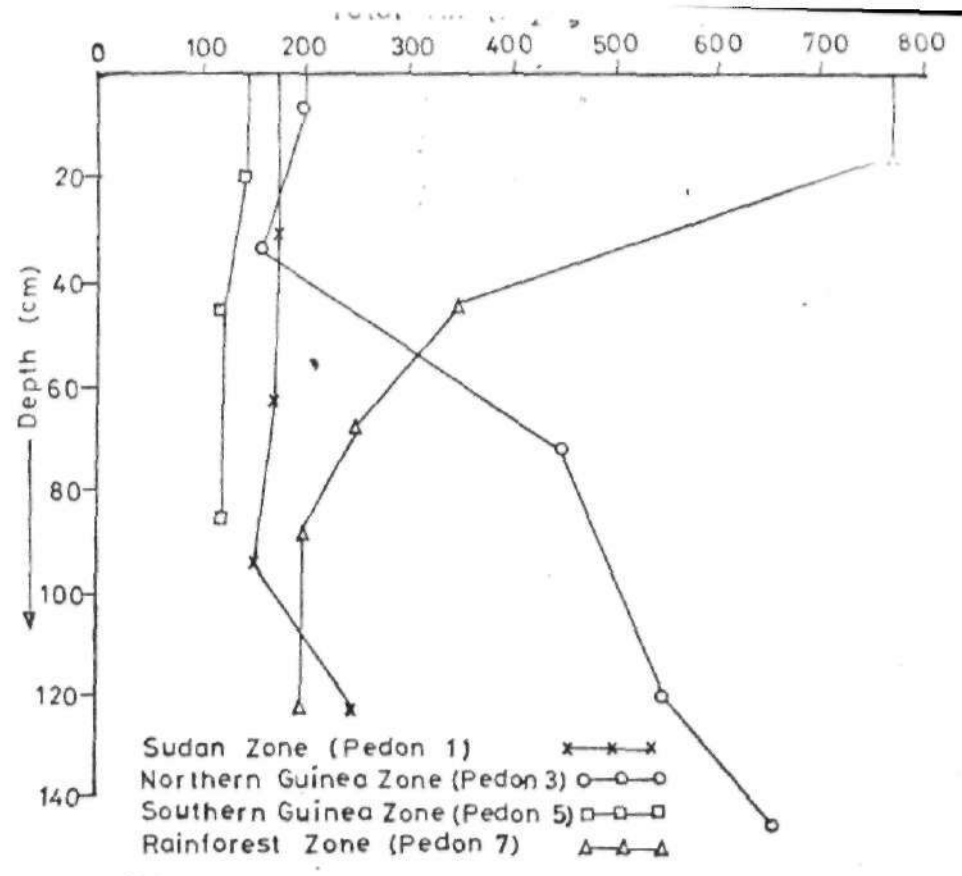


Fig 11: Depth functions of total Mn - (Na_2CO_3 fussion) in the soils

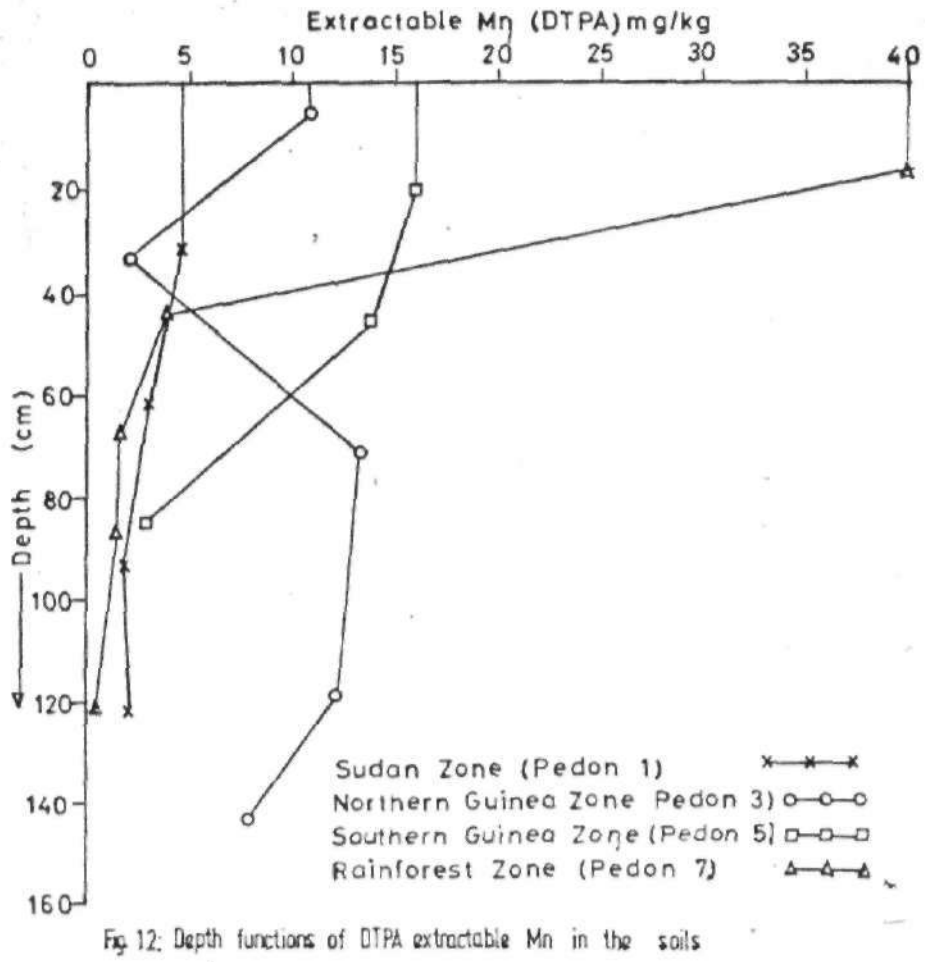


Fig. 12: Depth functions of DTPA extractable Mn in the soils

are 3.96 mg/kg, 10.80 mg/kg, 14.89 mg/kg and 17.09 mg/kg respectively.

5.2.10.3: Z i n c

The total Zn content of surface soils was lower than in the subsoils in the Sudan, Northern and Southern Guinea Savanna zones; in the Rainforest zone, a higher value was recorded for the surface soils than for the subsoils (Figure 13). However, similar to the zonal trend of distribution of total Mn in the soils, the Rainforest zone recorded the highest mean value of 138.0 mg/kg for total Zn content. The Northern Guinea Savanna zone recorded the next ranking value of 111.0mg/kg while the Sudan and Southern Guinea Savanna zones recorded 63.00 mg/kg and 31.50 mg/kg respectively as values of total Zn content.

Values of extractable Zn were also found to be higher in the surface than in the subsoils in all the zones (Figure 14). The highest surface value of 2.70 mg/kg was recorded in the Rainforest zone, a fact, which also is probably a reflection of the effect of vegetation. This is followed by a value of 2.00 mg/kg recorded for the Northern Guinea Savanna zone. The Sudan Savanna zone recorded the lowest surface value of 1.60 mg/kg. Subsoil values ranged between 1.36 - 1.65 mg/kg.

5.2.10.4: C o p p e r

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Total Cu values were lower for the surface than the subsoils in the Sudan, the Northern and Southern Guinea Savanna zones (Figure 15). Respective values of 50 mg/kg,

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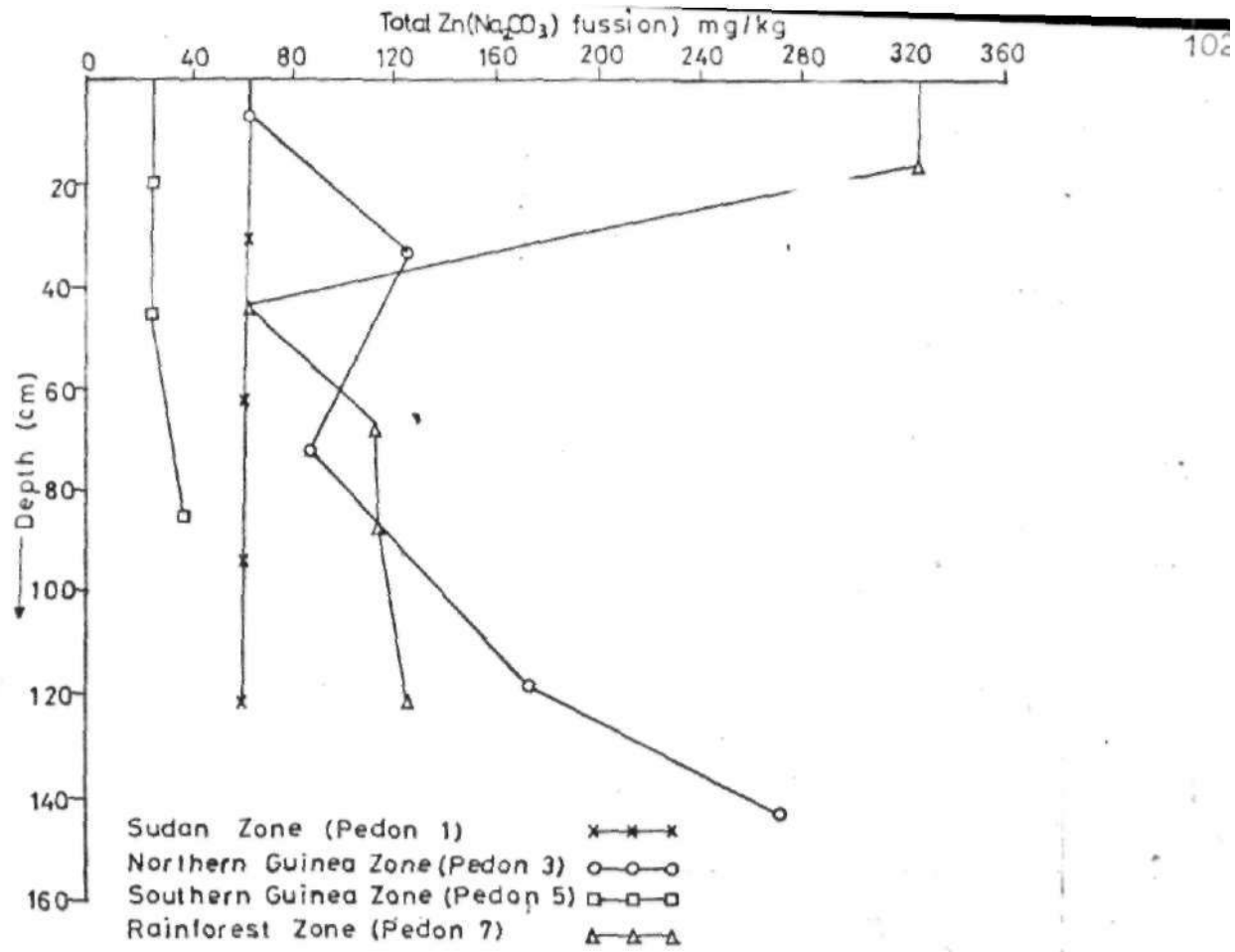


Fig 13: Depth functions of total Zn - (Na_2CO_3 fussion) in the soils

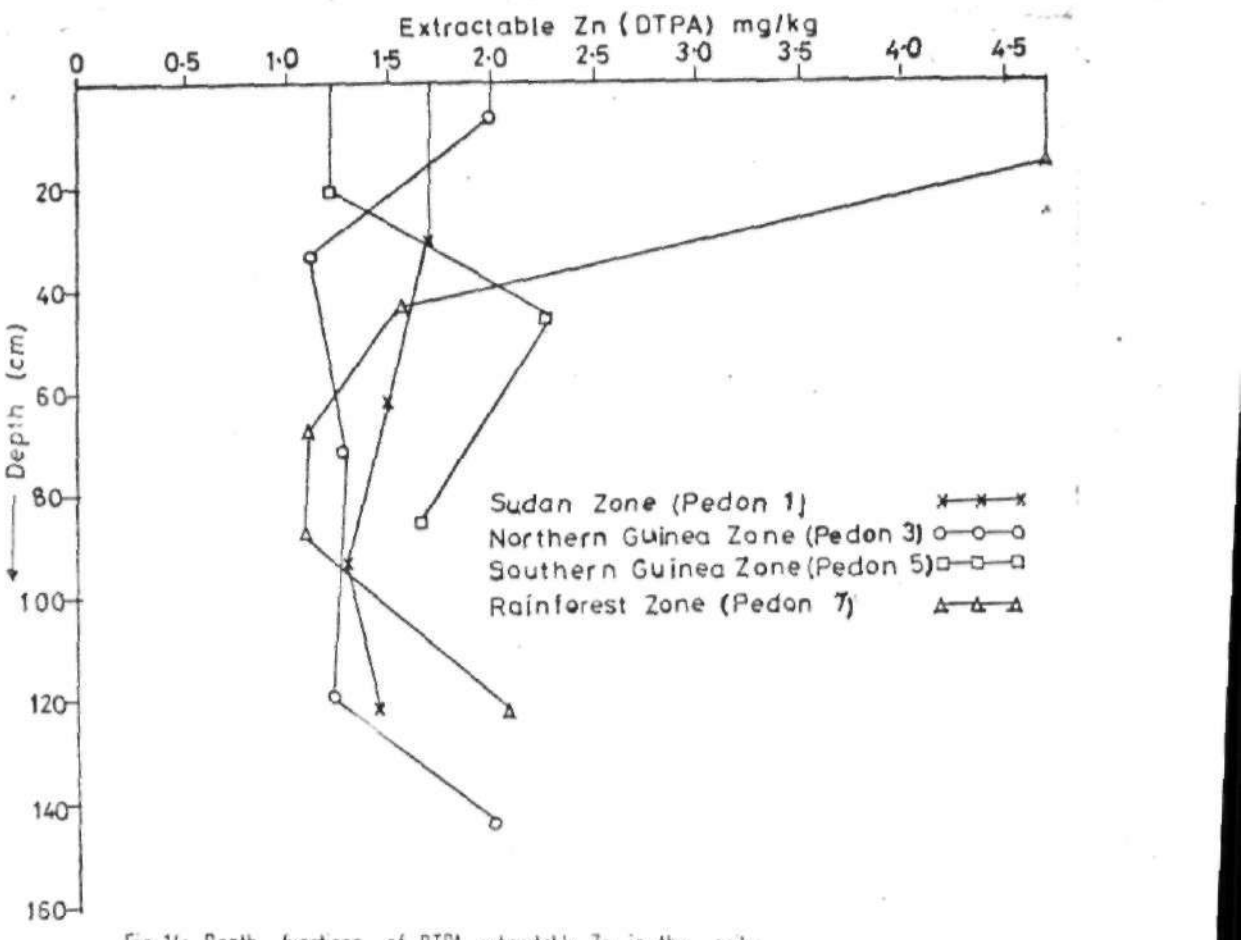


Fig 14: Depth functions of DTPA extractable Zn in the soils

30 mg/kg and 56 mg/kg were obtained for the surface soils in the above three zones. Values of 62 mg/kg, 66 mg/kg and 60 mg/kg were also recorded for the subsoils in these zones. In the Rainforest zone, a higher value of 52 mg/kg was recorded for the surface soil than the value of 50 mg/kg recorded for the subsoil in the zone.

The surface soil in the Southern Guinea Savanna zone recorded a lower value of extractable Cu than the subsoils, while in the other zones, surface soil values were higher than subsoil values (Figure 16). The highest values of extractable Cu (0.62 mg/kg) was recorded in the Rainforest zone. The Sudan, Northern and Southern Guinea Savanna zones recorded respective surface values of 0.040 mg/kg, 0.50 mg/kg and 0.31 mg/kg.

A significant positive correlation was found between extractable Mn and Fe ($r = 0.5507$). This relationship may be attributed to the fact that Mn and Fe usually form a manganiferrous complex in soils. Correlation and regression analyses also indicate that of all the physicochemical properties tested (Tables 3,4 and 5), only organic matter showed highly significant correlations with extractable Fe, Mn, Zn and Cu in the soils. The relationships, which are best described by quadratic models, are shown in Figures 17a,b,c and d. It was observed that 50.3%, 74.3%, 80.7% and 32.7% of the variation in extractable Fe, Mn, Zn and Cu can be accounted for by the contents of organic matter respectively. This result suggests that much of these extractable micronutrients present in the soils, especially

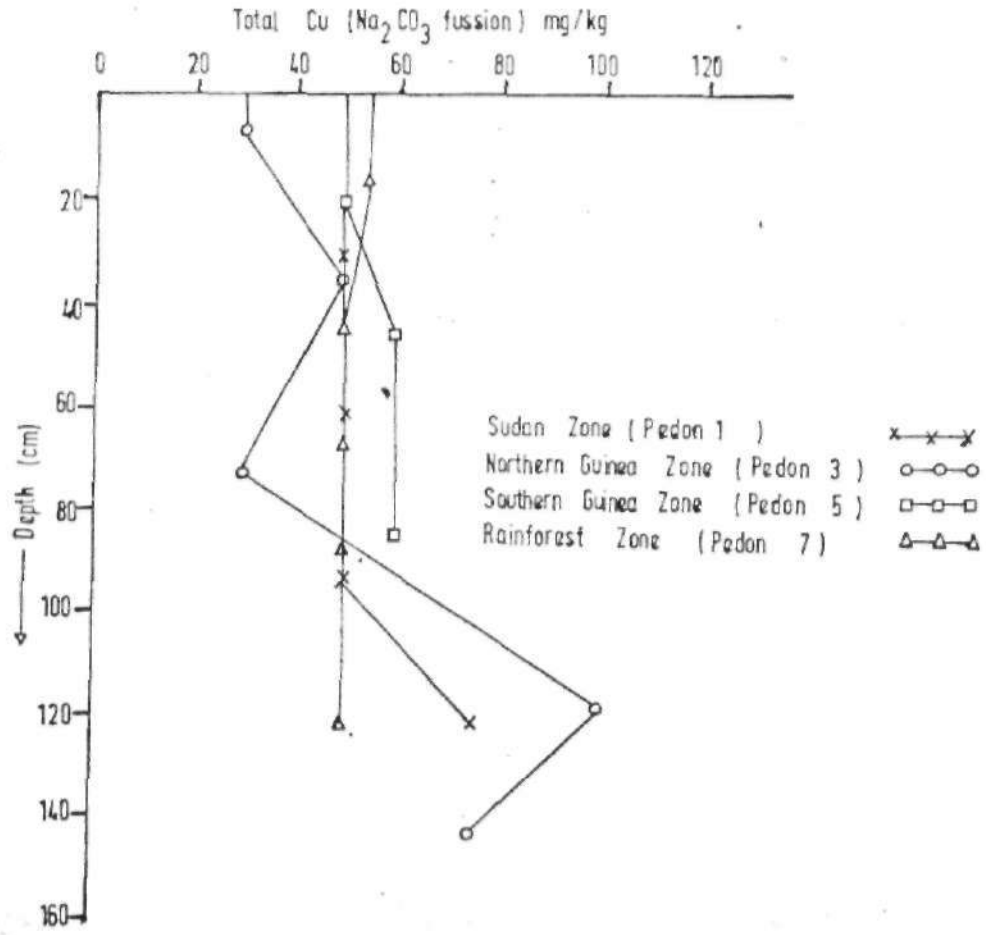


Fig 15: Depth functions of total Cu-(Na_2CO_3 fussion) in the soils

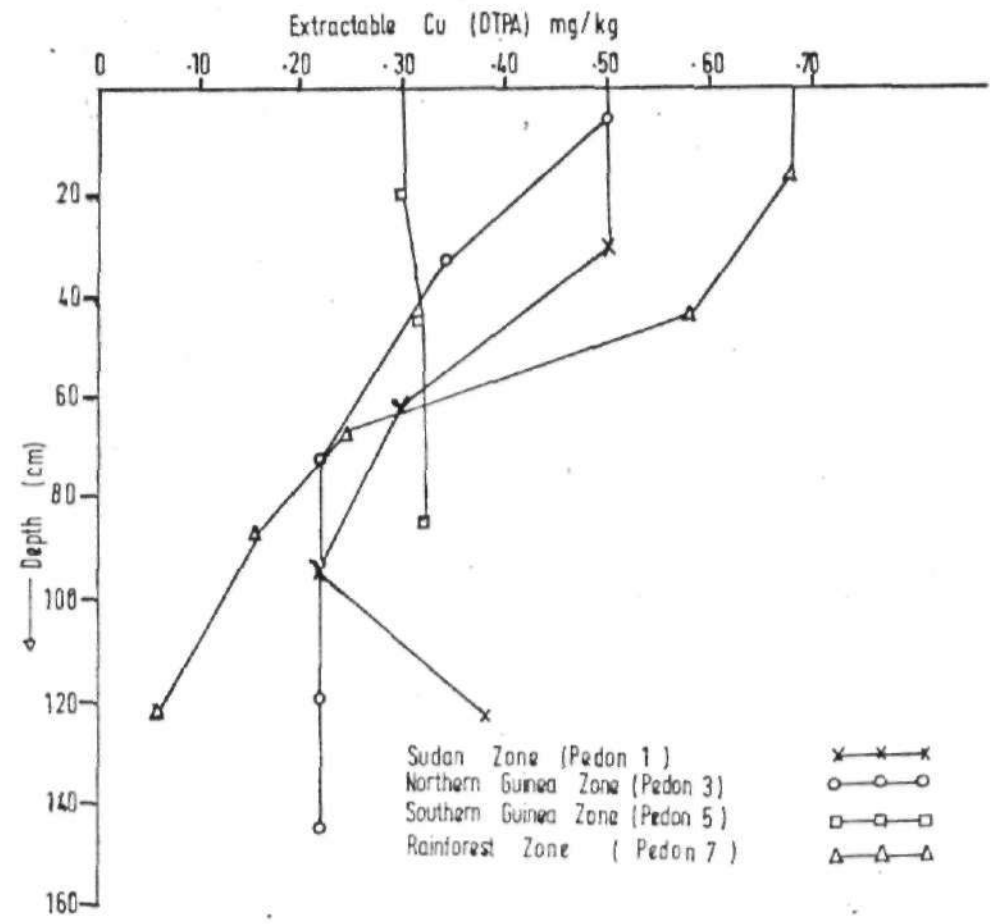


Fig 16: Depth functions of DTPA extractable Cu in the soils

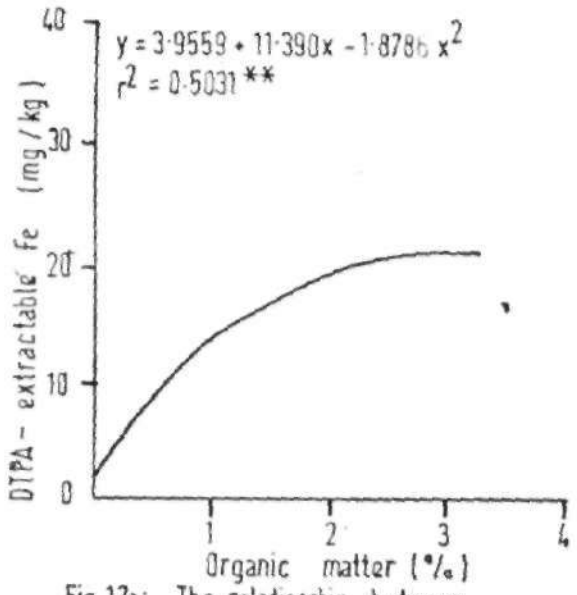


Fig 17a: The relationship between DTPA - extractable Fe and Organic matter in the soils.

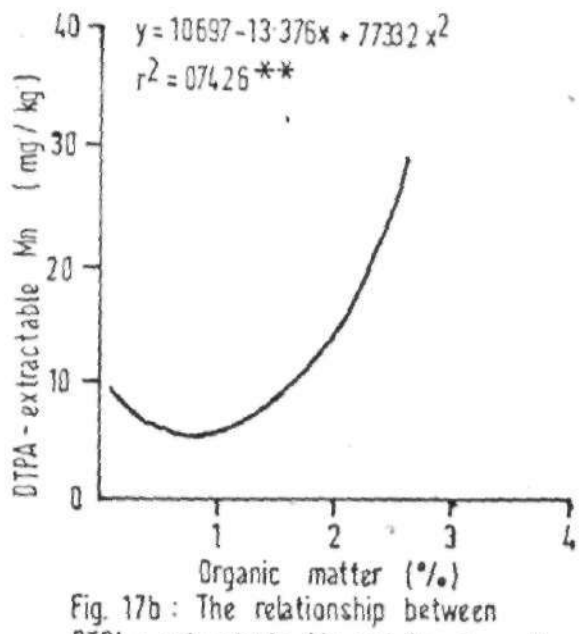


Fig. 17b : The relationship between DTPA - extractable Mn and Organic matter in the Soils.

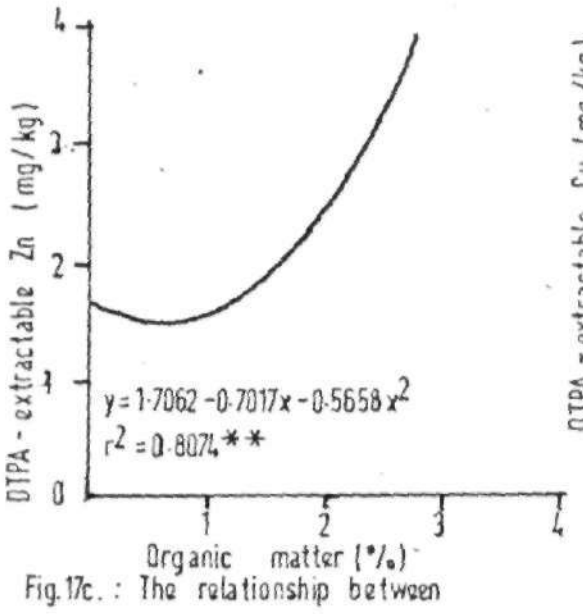


Fig. 17c. : The relationship between DTPA – extractable Zn and Organic matter in the Soils.

**: 1% level of significance,

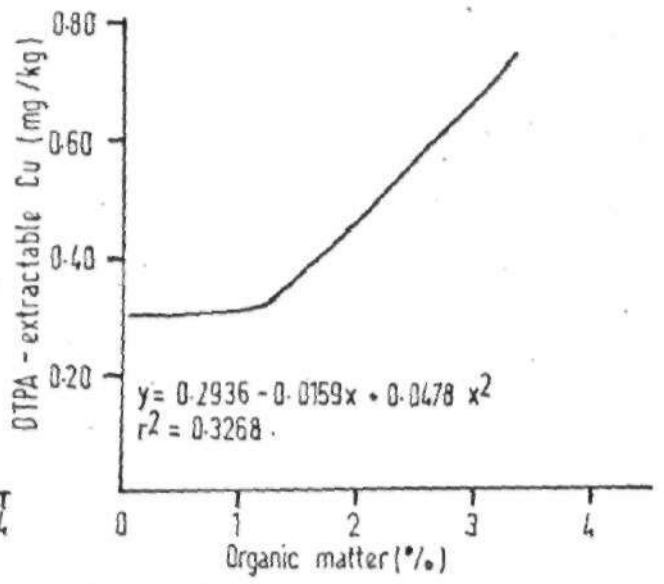


Fig. 17d: The relationship between DTPA – extractable Cu and Organic matter in the Soils.

*: 5 % level of significance

Mn and Zn are complexed with organic matter, thus highlighting the earlier assertions that vegetation has an appreciable influence on the zonal distribution of the micronutrient.

Given the tentative critical levels of DTPA - extractable Fe, Mn, Zn and Cu set at 4.5 mg/kg 1.0 mg/kg, 0.8 mg/kg and 0.2 mg/kg (Lindsay and Norvell, 1978), the results suggest that adequate amounts of plant available forms of these micronutrients are present in the soil.

5.2.11: Extractable Iron Oxides (Fe_2O_3)

Table 7 shows data related to the extractable iron oxides as well as the values of active Fe and Fe_d/Clay ratios in selected pedons. The profile distribution of the pyrophosphate extractable iron (Fe_p), the oxalate extractable iron (Fe_{ox}) and dithionite extractable iron (Fe_d) in the soils are shown in Figures 18, 19, 20 and 21.

The organic bound pyrophosphate extractable iron (Fe_p) in the soils range between 0.14 to 0.69%. This indicates the fact that Fe_p constitutes a negligible proportion of total free iron oxides in the soils in all zones. The low values of Fe_p may also be a reflection of the low organic matter contents of the soils.

The Fe_p content of the soils varied both between zones and between surface soil and subsoils. With the exception of the Sudan Savanna zone, Fe_p content of the soils were higher in the surface soils than in the subsoils (Figures 18, 19, 20 and 21). The lowest Fe_p value for surface soil

Table 7: Pyrophosphate (Fe_p), Oxalate (Fe_{ox}) and Dithionite (Fe_d) extractable iron oxides, active Fe and dithionite extractable Fe/Clay ratios in selected pedons of the soils.

Horizon	Depth	Fe_p	Fe_{ox}	Fe_d	$\frac{Fe_{ox}}{Fe_d}$	$\frac{Fe_d}{Clay}$
	Cm	------	%	------		
		Sudan Savanna Zone				
Pedon 1:	Plinthustalf (USDA)/Plinthic Luvisol (FAO)					
Ap	0-31	0.14	0.03	0.70	0.05	0.20
E	31-62	0.18	0.09	1.30	0.07	0.14
2Btv1	62-94	0.18	0.08	1.92	0.07	0.09
2Btv2	94-122	0.18	0.12	2.95	0.11	0.06
		Northern Guinea Savanna Zone				
Pedon 3:	Udic Haplustalf (USDA)/Dystric Nitosol (FAO)					
Apc	0-6	0.28	0.23	2.17	0.10	0.13
Btc	6-34	0.23	0.18	1.95	0.07	0.12
2BCtc1	34-72	0.24	0.08	3.17	0.13	0.08
2BCtc2	72-119	0.28	0.07	3.35	0.17	0.08
2Cc	119-144	0.15	0.07	1.89	0 11	0.08
		Southern Guinea Savanna Zone				
Pedon 5:	Plinthustult (USDA)/Plinthic Acrisol (FAO)					
Ap	0-20	0.15	0.08	0.50	0.03	0.50
E	20-45	0.14	0.24	1.40	0.06	0.10
Btv	45-85	0.21	0.13	2.70	0.06	0.08

Table 7contd.: Pyrophosphate (Fe_p), Oxalate (Fe_{ox}) and Dithionite (Fe_d) extractable iron oxides, active Fe and dithionite extractable Fe/Clay ratios in selected pedons of the soils.

Horizon	Depth	Fe_p	Fe_{ox}	Fe_d	$\frac{Fe_{ox}}{Fe_d}$	$\frac{Fe_d}{Clay}$
	Cm	------	%	-------		
			Rainforest Zone			
Pedon 7:	Orthoxic Tropudult (USDA)/Orthic Acrisol (FAO)					
Apc	0-16	0.36	0.19	1.20	0.05	0.30
Ec	16-44	0.39	0.25	2.60	0.12	0.15
2Btc	44-68	0.59	0.36	3.50	0.06	0.17
2Btsc	68-87	0.54	0.09	8.00	0.14	0.07
2BCrt	87-121	0.69	0.04	6.70	0.12	0.10

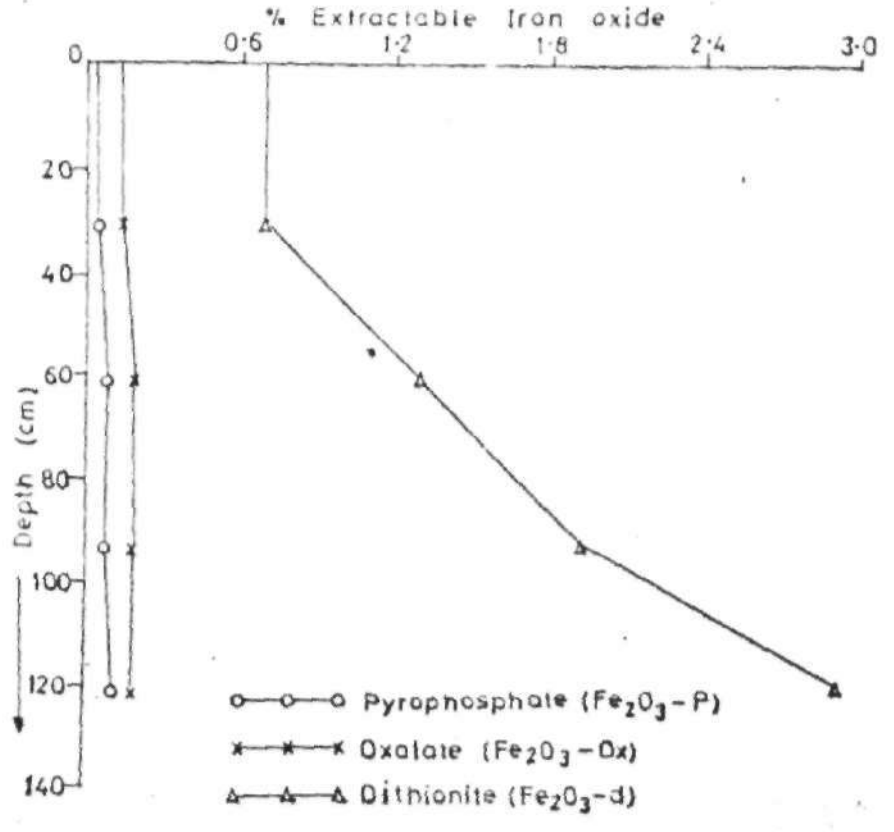


Fig 18: Depth functions of extractable iron oxide in the Sudan zone pedon

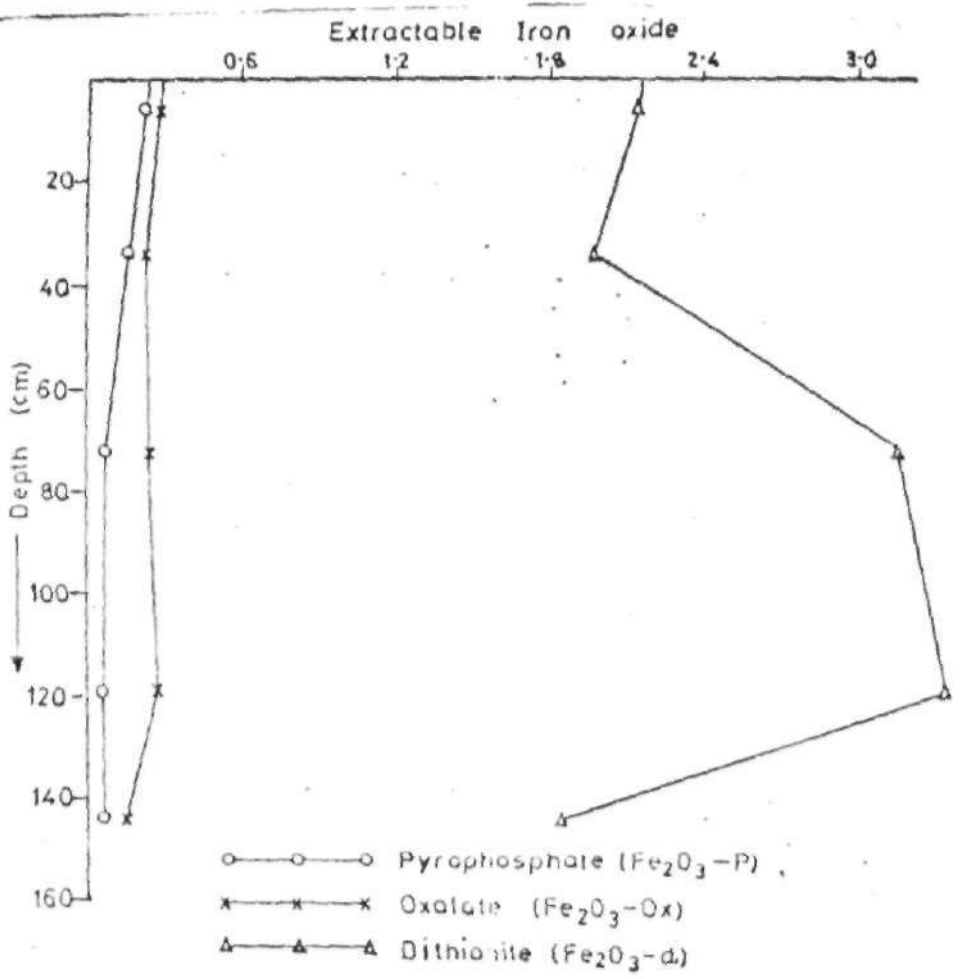


Fig 19: Depth functions of extractable iron oxide in the Northern Guinea zone pedon

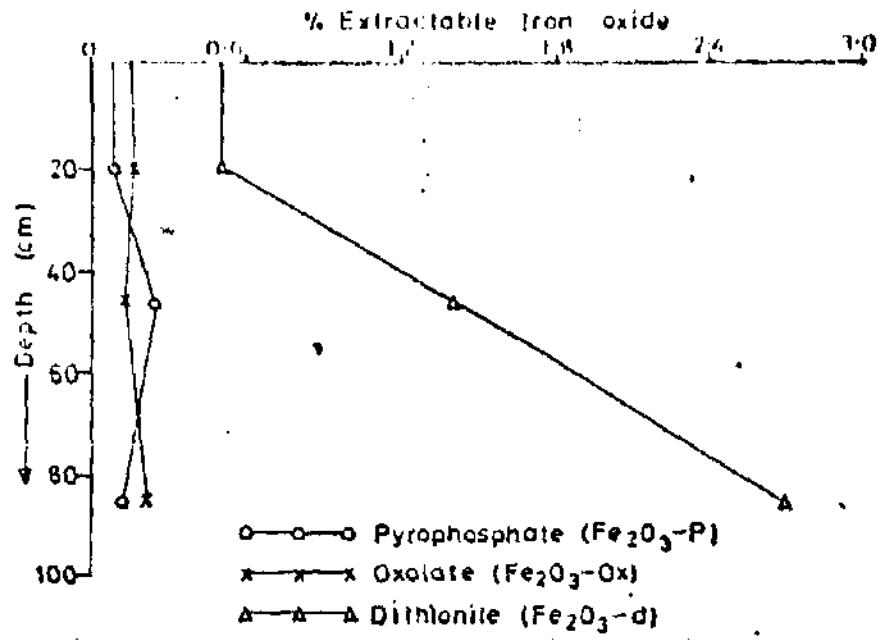


Fig 20: Depth functions of extractable iron oxide in the Southern Guinea zone pedon

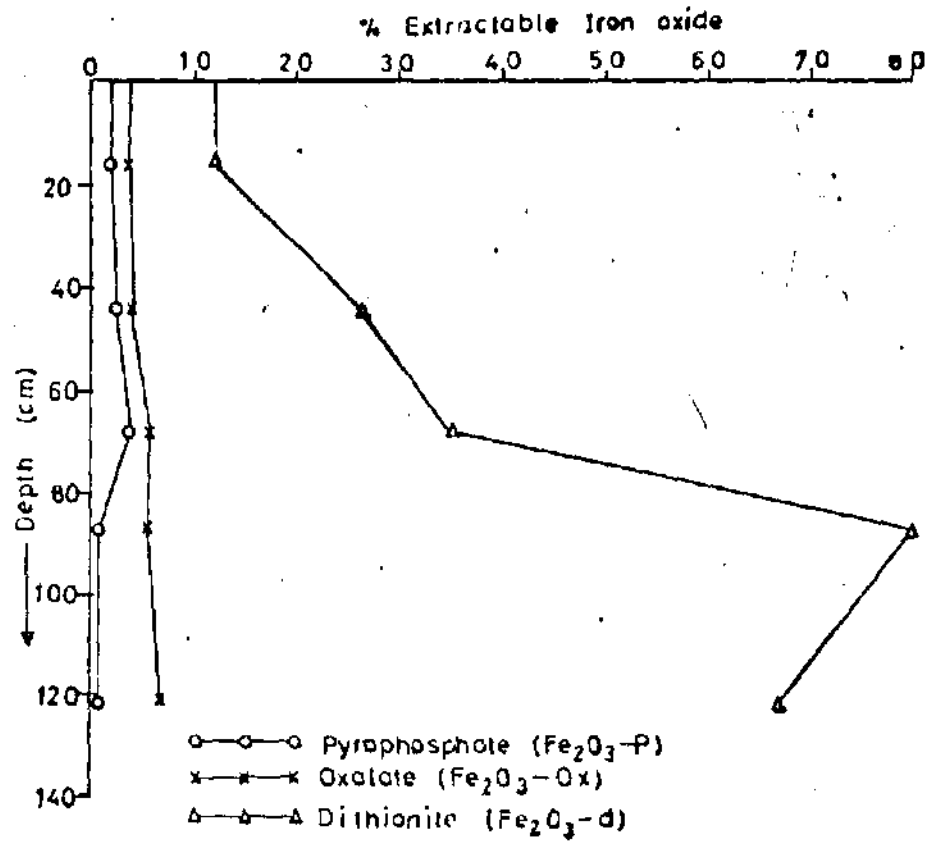


Fig 21: Depth functions of extractable iron oxide in the Rainforest zone pedon

was recorded in the Sudan Savanna zone which also happens to be the zone with the lowest organic matter content in the surface soil (Figure 8). The Northern Guinea Savanna and Rainforest zones recorded similar values of Fe_p in the surface soils. The two zones, coincidentally, also have close values of organic matter and clay contents in their surface horizons. This confirms for these two soils, the relationship commonly observed between organic matter and Fe_p content of soils (Juo et. al 1976; Kparmwang, 1987; Esu et. al., 1988). The surface soils in the Sudan Savanna zone in addition to having the lowest organic matter and clay contents of all the zones also have very coarse textured surface horizons. The relatively lower Fe_p in the surface soil within the zone may, therefore, also be due to the migration of the relatively low levels of iron oxide bound as organic complexes from the coarse textured surface soil to the subsoil.

Except in the Northern Guinea Savanna zone, the content of amorphous or oxalate extractable iron oxides (Fe_{ox}) was lower in the surface soils than in the subsoils (Figures 18, 19, 20 and 21). Values of Fe_{ox} in the surface soils ranged between 0.4 and 0.39% while values for the subsoils ranged between 0.18% and 0.69%.

Total free iron oxides or dithionite extractable iron oxides (Fe_d) generally increased with depth in the argillic horizons (Figures 18, 19, 20 and 21). The distribution followed the same general pattern of clay distribution in the soils all of which have fine - textured subsoils with

higher Fe_d content. This is a clear indication of movement of both iron oxides and clay into the subsoil through the eluviation - illuviation process. It is noteworthy however, that there is some variability in the Fe_d/clay ratio in the subsoils. The ratio of Fe_{ox} to Fe_d has been expressed as active Fe ratio (Lekwa and Whiteside, 1986). This ratio for these soils increased with depth in all the zones (Table 7), thus indicating that crystallized forms are lower in the lower horizons of these soils.

In order of decreasing total iron oxide content of the soils, the Rainforest zone recorded the highest values of Fe_p, Fe_{ox} and Fe_d with values of 0.19%, 0.50% and 4.06% respectively. The Sudan Savanna zone ranked next with values of 0.17%, 0.26% and 2.46% for Fe_p, Fe_{ox} and Fe_d respectively. The Southern and Northern Guinea Savanna zones recorded lower values in the order of 0.15, 0.18 and 1.85%; and 0.08%, 0.17% and 1.70% for Fe_p, Fe_{ox} and Fe_d respectively.

6: SOIL CLASSIFICATION

The soils have been classified according to both the Soil Taxonomy (soil Survey Staff, 1975) and the FAO/UNESCO soil map of the world (FAO/UNESCO, 1974). The differentiating characteristics that were employed for the classification include some morphological, physical and chemical properties of the soils that are considered important in both systems of classification.

6.1: Classification According to Soil Taxonomy

In classifying the soils according to Soil Taxonomy, some of the soils fitted into the great group category while others fitted into a lower category, the subgroup.

The Savanna zones with a rainy season of 3 months or more and soil moisture control section which is dry in some parts for 90 or more cumulative days have been inferred to have an ustic soil moisture regime. On the other hand, the Rainforest zone with a soil moisture control section that is not dry in any part for as long as 90 cumulative days has an udic soil moisture regime. The soil temperature regime is isohyperthermic in all the zones (Table 2).

Ochric epipedons and argillic horizons are present in pedons 1, 2, 3 and 4. These pedons also have base saturation higher than 50% (by NH_4OA_c method). These soils, therefore, fit into the Alfisol Order and the Suborder Ustalf.

Each of pedons 1 and 2 has plinthite that forms a continuous phase within 125 cm of the surface. They both,

therefore, fit into the great group Plinthustalfs. Pedons 3 and 4 are reddish to brownish Ustalfs with argillic horizons which have no colour hue redder than 5YR. These pedons therefore fit into the great group Haplustalfs (Table 8).

At the subgroup level, pedons 3 and 4 have a finer texture than loamy fine sand in subhorizons within 50cm of the surface. The argillic horizons in pedons 3 and 4 have base saturation (by NH_4OA_c) 50%. The pedons therefore, fit into the Oxic Haplustalf subgroup. Pedons 1 and 2 cannot be classified further at the sub group level since no subgroups have been developed for the great group Plinthustalf (Soil Survey Staff, 1975).

Pedons 5 and 6 have base saturation by NH_4OA_c of < 50% and organic carbon of < 0.9% in the upper 15cm of the argillic horizon exclusive of the Ap. They therefore, fit into the Ultisol Order and the Suborder Ustult.

Each of these pedons has plinthite that forms a continuous phase in a subhorizon within 125 cm of the soil surface. They, therefore, fit into the great group Plinthustult. These also cannot be classified further at the subgroup level as no subgroups have yet been defined for the Plinthustult great group (Soil Survey Staff, 1975).

Pedons 7 and 8 with their characteristic udic soil moisture regime have ochric epipedons and argillic horizons. They both have base saturation by NH_4OA_c < 50% and as such fit closely into the Ultisols Order and the Suborder Udults.

These two pedons have mean Rainy season (June, July and August) and mean Harmattan season (December, January and

Table 8: Summary of Soil Classification According to Soil Taxonomy and the FAO/UNESCO soil legend.

Pedons	Soil Taxonomy	FAO/UNESCO
1	Plinthustalf	Plinthic Luvisol
2	Plinthustalf	Plinthic Luvisol
3	Oxic Haplustalf	Dystric Nitosol
4	Oxic Haplustalf	Dystric Nitosol
5	Plinthustult	Plinthic Acrisol
6	Plinthustult	Plinthic Acrisol
7	Orthoxic Tropudult	Orthic Acrisol
8	Orthoxic Tropudult	Orthic Acrisol

February) soil temperatures that differ by less than 5°C (Table 2). For this reason, they have been fitted into the great group

Tropudults.

At the subgroup level, pedons 7 and 8 have texture finer than loamy fine sand within a depth of 50 cm from the surface. They have base saturation by NH_4OA_c > 35%, but < 50% at a depth of 125cm below the top of the argillic horizon a CEC of < 24 meq/100g of clay (NH_4OA_c) in the major part of the argillic horizon. They can therefore be classified as Orthoxic Tropudults.

6.2: Classification According to the FAO/UNESCO Soil Legend

Each of pedons 1 and 2 has an argillic horizon which has a base saturation of > 50% (NH_4OA_c). They can therefore, be classified as Luvisols. The pedons have plinthite within 125cm of the surface for which reason they have been classified as Plinthic Luvisols.

Pedons 3 and 4 have argillic B horizons with clay distribution in which the percentage clay does not decrease from its maximum amount by as much as 20% within 150cm of the surface. For this reason, pedons 3 and 4 have been classified as Nitosols. These pedons have base saturation less than 50% (NH_4OA_c) in the upper parts of their argillic B horizons thus classifying as Dystric Nitosols.

Pedons 5, 6, 7 and 8 have argillic horizons, they also have base saturation < 50% (NH_4OA_c) in at least some parts of their argillic B horizons within 125cm of the surface

thus classifying as Acrisols.

Pedons 5 and 6 have plinthite within 125 cm of the surface, and therefore classify as Plinthic Acrisols. Pedons 7 and 8 are basically Orthic Acrisols (Table 8).

SUMMARY AND CONCLUSION

This study was carried out with the main objective of assessing the status of the soils developed on older granites under different climatic and vegetal conditions in Nigeria; assessing the extent to which results of studies carried out on soils developed on similar parent materials can be transferred across bio-climatic zones in Nigeria, and to classify the soils. In pursuance of these objectives the following investigations were conducted as listed below:

(i). A general appraisal of the physical setting of the study area.

(ii). A study of the morphological, physical and chemical characteristics of the soils.

(iii). A taxonomic classification of the soils according to the Soil Taxonomy (Soil Survey Staff, 1975) and the FAO/UNESCO soil legend (1974).

The bio-climatic zones in a north to south transect are the Sudan Savanna, Northern and Southern Guinea Savannas and the Rainforest zones. Two pedons located at different sites were sampled within each of the zones.

Results of the study show that all the soils are well-drained, with most of the horizons exhibiting moderate structural development. The surface soils are light textured with surface textural class varying from sandy loam to sandy clay loam except in pedon 3 of the Northern Guinea

Savanna zone where a gravelly clay loam surface soil was observed largely because of the erosion of the original surface soil. The clay content of the subsoils increased from a mean of 18% in the Sudan Savanna to 22% in the Rainforest zone. In general, the largely sandy nature of the soils reveals the granitic origin of the soil parent material.

Among the physical parameters of the soils studied, only the coarse sand and the silt content of the soils varied significantly between the zones at 1% and 5% levels of probability respectively. The Sudan, Northern and Southern Guinea Savanna and Rainforest zones recorded mean coarse sand contents of 11.75%, 47.00%, 72.50%, and 69.00% respectively and corresponding mean silt contents of 19.00%, 25.50%, 12.75% and 12.75%. The higher silt content of the soils in the Sudan and Northern Guinea Savanna zones distinguish them from those of the southern Guinea and Rainforest which recorded lower mean values of silt, thus reflecting the reduced influence of aeolian deposition in the latter zones.

Among the chemical properties of the soils studied, soil pH, total nitrogen, exchangeable Ca, Mg and K, total exchangeable bases, CEC and base saturation (neutral and effective) vary significantly between the zones. Mean pH values of 7.3, 5.6, 5.3 and 5.2 were recorded for the Sudan, Northern and Southern Guinea Savanna and Rainforest zones respectively. The significantly higher pH (1% level of probability) recorded for the Sudan Savanna zone than the

other zones may be attributed to the dominant influence of the deposition of calcareous materials in the form of dust by the harmattan wind within the zone.

Total nitrogen values in the soils decreased from the forest zone to the Sudan Savanna zone, reflecting the zonal distribution pattern of organic matter in the soils although the absolute values of nitrogen and organic matter are low in all the soils.

Exchangeable bases in the soils occurred in the order: Ca > Mg > K > Na. The trend of zonal distribution of Ca was such that the Sudan Savanna zone recorded significantly higher amounts than the other three zones at 1% level of probability. The Sudan and Northern Guinea Savanna zones recorded significantly higher values of exchangeable Mg than the Rainforest and Southern Guinea Savanna zones at 5% level of probability. Exchangeable K in the soils was significantly higher in the Sudan Savanna zone than any other zone at 1% level of probability. The Rainforest and Southern Guinea Savanna zones recorded similar mean values of exchangeable K; but the difference in mean exchangeable K between the Southern and Northern Guinea Savanna was not statistically significant . Mean values of total exchangeable bases vary significantly between the zones at 1% level of probability. Mean total exchangeable base values of 7.15%, 4.12, 2.52 and 1.36 meq/100g of soil were recorded for the Sudan, Northern Guinea, Southern Guinea ar Rainforest zones respectively.

Mean effective CEC value of the Sudan Savanna zone soils is significantly higher than that recorded for the Northern Guinea Savanna, Rainforest and Southern Guinea Savanna zones (1% level of probability). The difference in mean CEC (by NH_4OA_c) values between the zones is significant at 5% level of probability; the Sudan and Northern Guinea Savanna zones recorded almost similar mean values (9.95 and 8.19 meq/100g soil respectively). However, no significant difference was observed in the mean values of neutral CEC for the Northern Guinea Savanna, Rainforest and Southern Guinea Savanna zones.

Base saturation varied significantly between the zones at 5% land of probability; the Sudan Savanna zone recorded significantly higher values of neutral base saturation than the Northern Guinea Savanna, Rainforest and Southern Guinea Savanna zones. The Sudan, Northern Guinea Savanna and Rainforest zones recorded similar values of effective base saturation which were higher than mean values recorded for the Southern Guinea Savanna zone. However, the mean value for the Southern Guinea Savanna zone did not differ significantly from the mean value of effective base saturation for the Rainforest zone.

No significant difference in the status of such soil chemical properties as organic carbon, extractable phosphorus, exchangeable Na, exchangeable Al and H and CEC - clay were observed between the zones.

Significant positive correlations were observed between organic matter and the extractable micronutrients in the

soils. This relationship probably explains in part, the trend of extractable micronutrients distribution between the zones; the Rainforest zones which recorded the highest mean values of organic matter also recorded the highest levels of extractable Mn, Zn and Cu, while the Sudan Savanna zone with the lowest values of organic matter recorded the lowest values of extractable Fe, Mn and Zn, although the soils are generally well supplied with the micronutrient elements studied.

The organic bound iron oxide (Fe_p) constitutes a negligible proportion of the total free iron oxides in the soils, perhaps because of low organic matter status of the soils. The zonal distribution of amorphous iron oxide (Fe_{ox}) as well as total free iron oxides (Fe_d) in the soils were in the order: Forest zone > Northern Guinea Savanna zone > Southern Guinea Savanna zone > Sudan Savanna zone. The same trend was observed for the active iron ratio and suggests a much higher intensity of weathering in the Rainforest zone than in the Sudan Savanna zone.

A significant level of interaction was observed between the zones and between the surface and subsoil in the distribution of total nitrogen only (1% level of probability). The total nitrogen content of the surface soil in the Rainforest zone is significantly higher than values recorded for the other zones. This probably reflect the higher content of organic matter in the Rainforest zone than the other zones.

The taxonomic classification of the pedons studied, both by the criteria of the USDA Soil Taxonomy and the FAO/UNESCO systems of soil classification, differed only between and not within zones. But while the soils in the Sudan Savanna and Northern Guinea Savanna zones fitted into the Alfisol Order, the soils in the Southern Guinea and Rainforest zones have developed into Ultisols. Following the USDA Soil Taxonomy, the Sudan Savanna pedons were classified at the great group level as Plinthustalfs while the Northern Guinea Savanna pedons were classified at the subgroup level as Oxic Haplustalfs. The Southern Guinea Savanna and Rainforest zone pedons were classified as Plinthustults (great group level) and Orthoxic Tropudults (subgroup level) respectively. Employing the FAO/UNESCO system, the Sudan zone pedons were classified as Plinthic Luvisols while the Northern Guinea Savanna pedons were classified as Dystric Nitosols. The soil pedons in the Southern Guinea Savanna zone were classified as Plinthic Acrisols, while the Rainforest pedons were classified as Orthic Acrisols (Table 8).

From this study it is observed that many of the properties varied significantly under the different bio-climatic conditions. It is also observed that the zonal means of some of the properties seem to differ widely, however, this differences are not significant due to the high standard errors recorded for such properties. In other words, the wide variations in the levels of such properties between the zones may be due to other reasons other than

differences in zonal characteristics. The interdependence of vegetation and climate is well known. This dependence seem to influence the zonal status of some of the properties studied, for example, bio-genetic cycling of nutrients within the soils system is expected to be higher under forest than under the less humid Savanna zones, given the higher net return of litter to the soil surface as well as higher levels of activity of microbial organisms under the humid Rainforest condition. However, TEB values for the Rainforest zone is not the highest, suggesting the influence of the process of leaching in the Rainforest zone. Barring experimental errors which were found to be non significant in most cases, it is clear, even from the classification of the soils, that the Sudan and Northern Guinea Savanna zones can be merged together while the Southern Guinea Savanna and Rainforest zones can equally be merged together in terms of many properties. It is therefore possible to transfer results of research on soils developed on older granites within the Sudan and Northern Guinea Savanna zones on one hand, and within the Southern Guinea Savanna and Rainforest zones on the other.

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