ANALYSIS OF TH3 RELATIONSHIP BETWEEN SOIL PROPERTIES AND SOIL FORMING-FACTORS IN THE NIGERIAN SAVANNA

by

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DECL.R.TION

I hereby declare that this thesis has been composed by myself and that it is a record of my own research work. It has not been accepted in any previous application for a Higher Degree. All quotations aredistinguished by quotation marks and the sources of information are specifically acknowledged by means of references.

- Idris Jaiyeoba,
September, 1986.

TO

MY FATHER

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ABSTRACT

An examination of the status and the relationships between key soil properties and the soil-forming factors of climate, parent material and relief, under savanna environment, form the primary objectives of this study.

The data used wore obtain mainly from the noral land resource survey covering; north central nigeria.The survey was carried out by the Land Resoure Division, British Ministry of Overseas Development, and covers an area of about 230,000km^2 .Selection of profiles from the survey data were based on their wide range of characteristics, representative of soils within particular geomcrphic units, and availability of information on some of the soil-forming factors considered, -»7hich arc missing from the land resource survey data. All together, 385 pro files were selected.

The method of analysis of the spatial variability of the soil properties cantered on the use of simple linear regression analysis, in respect of factors with interval data, and one-way analysis of variance for those at normal level and also interval level, following a preliminary conversion onto ordinal.

In nearly all the samples considered, tho particle-size distribution reveals the presence of a maximum of sand and minima of silt/clay. On the whole, however, the subsoils / and Sandy and more clayey than the topsoils. The soils

are generally low in organic matter, total nitrogen, and exchangeable base (K, Na, Mg & Oft) content except soils formed from basalt and shale and over somo tasal slope positions which have moro than average values, ..rcflecting presumably the low organic matter and clay contents, the CEC values are low and the soil reaction weakly to moderately acid.

The soil structural units are predominantly moderately dove loped but the soils themselves show little compaction and are characterized by relatively high effective depth.

Stop by stop examination of individual soil properties and the soil-forming factors reveals numerious .invariably disperate relationships often explicable only in terms of local conditions. However, by combining all the variables involved in an analysis of variance and covariance, the results seem to suggest that the variability of virtually all the soil properties considered, except the PH, | ' the fine sand subfraction which are mere strongly related to the rainfall factor, are better explained in terms of the material factor than in terns of the other factors.

Apart from being the major factor controlling the pH, %BS and the fine sand, the rainfall factor is also, important in the variability of most of the other properties, particularly the organic total nitrogen, bulk density and clay, and thus the CEC of the soils. The organic carbon, fine sand, %BS show stronger.

correlation with altitude than the other properties. Slope position is more important in the variability of the organic carbon, total nitrogen, sand, clay, CEC, %BS and bulk density than of the other properties-. By contrast, the temperature and slope gradient factors play relatively minor roles in the spatial variability of the soil properties considered, except the soil effective depth in respect of the second factor.

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CHAPTER I

BACKGROUND, AIMS AND OBJECTIVE OF THE STUDY

1.1 FACTORS OF SOIL FORMATION

As expressed by Buol et al. (1973), a factor of soil formation is an agent, force, condition or relationship, or combination of these, which influences, has influenced, or may influence the several reactions (both physical and chemical) involved in the formation of soil humus and mineral matter. The process of forming the soil mineral matter from a hard rock can be divided into two fairly distinct but sequential stages. These are the disintegration of the rock material on the one hand, and soil formation per se on the other. While the disintegration of the rock material involves the formation of the soil parent material from hard rock, predominantly by physical weathering processes, soil formation is mainly a biochemical weathering process (FitzPatrick, 1971; Faniran & Areola, 1978).

As might be expected, a detailed list of the many forces acting on, or which are capable of acting on the soil would be staggering. In view of this, a few major factors have been selected by soil geneticists, to serve as a framework for organizing pedological investigations and data collection. As firmly established by Dokuchaev (1886), soils develop as a result of the interplay of parent material, climate, organisms, topography and time. It is these factors that fundamentally determine the nature and character of the pedogenic processes involved in soil formation (young, 1976; FitzPatrick, 1971). The five factors were given in the major re-statements of the [illegible] theory of soil-forming factors by Jenny (1941).

Some of these factors are however being disaggregated by scientists at present, and the ensuing sub-units treated as independent variables in their own right. An example is the separation of the influence of man and hydrology from the organism and topography factors respectively (Young, 1976).

The effects of the soil-forming factors on pedogenic processes are not all of the same nature. Parent material supplies the mineral substances from which the soil profile is developed and its effect on the processes are indirect. Organisms both supply organic substances and affect processes, climate supply gases and water, and also affect processes, while relief only affect the processes. Unlike the other factros, time refers basically to the age of the soil and is a measure of how long the soil has been in the process of formation (Jenny, 1941, Buol et. al., 1973; Young, 1976). Furthermore, whereas the distribution of some of these factors on the earth's surface is rather random (e.g. human influence) others have a distribution which parallels the climatic patterns (e.g. natural vegetation covers).

In an attempt to make their discipline quantitative rather than merely qualitative, several pedologists have tried to formulate functional relations between soil-forming factors and soil properties. As expressed by Jenny (1941) and later modified by several others (e.g. Stephens, 1947; Crocker, 1952; Young, 1976), the relations can be defined as

$$s = f(c, p, o, r, t.....) \text{---- } (1.1)$$

$$S = f(c, p, o, r, t .....) \text{---- } (1.2)$$

where

s = any soil property

S = the totality of the soil

c = climate

p = parent material

o = organisms

r = relief

t = time

f = a function of

Equation (1.1) states that any single soil property is dependent on each of the five factors, and other factors operating (e.g. past climate). Equation (1.2) makes the same statement for the soil as an entity.

There are several problems associated with these equations. In the first place, the factors are never truly independent of one another. Secondly, there is the difficulty of assigning numerial values to some of these variables. Finally, the equations neglect the fact that most soils are polygenetic in origin, and have undergone successive phases of development (Bridges, 1970). In spite of these short-comings however, the functional relationship approach is potentially valuable. It is possible for example to take any one of the factors, and consider its variations against the background of the others, thus obtaining a better picture of the effect of that particular one on a soil property, a soil horizon, or the soil profile as a whole (Birch & Friend, 1956; Jones, 1973; Young, 1976; Leow & Smith, 1981).

Practically, the equation provides useful guide for the selection of most appropriate variable(s) that could be used in soil classification and in the predition of soil pattern.

1.2 PROBLEMS AND OBJECTIVES OF THE STUDY

The significance of the knowledge of the spatial variability of soil properties, in respect of key environmental factors, in the rationalization of the observed distribution pattern and hence in soil survey can hardly be overemphasized. In spite of this however, few attempts have been made to systematically assess these relationships for many areas in the tropics. As a result, serious misconceptions on the mode of environmental influence in the region still prevail in pedological literature. The significance of climate in particular has been overestimated while the importance of parent material and relief has been almost completely ignored.

This study does not attempt to be a comprehensive account of spatial variability of soil properties in respect of the soil-forming factors in the whole of savanna region but concentrates on certain aspects in area covering north central Nigeria. These aspects are:

(i) Soil-forming factors - rainfall, temperature, parent material, attitude, slope gradient and slope position.

(ii) Soil properties - orgnic carbon and nitrogen contents, texture, degree of structural development, bulk density, effective soil depth, exchangeable bases, CEC, pH and %BS.

The specific objectives of the study are to:

(i) present a clear picture of the absolute values and spatial variations of the selected soil properties

for the study area;

(ii) examine the statistical relationships between the individual soil properties and the soil-forming factors of parent material, climate and relief; and

(iii) examine quantitatively the relative importance of the soil-forming factors considered in determining the variability of the soil properties.

The data used were obtained mainly from the general land resource survey covering the study area. The survey was carried out by the Land Resources Division (LRD) of the British Ministry of Oversea Development, at the request of the Federal Government of Nigeria. It covered a period of about 6 years (1974-1979) and an area of about 230,000 km^2 of north centeral Nigeria. Except in respect of Kano and Kaduna plains, in which the Department of Geography Bayero University, Kano, still holds the original data sheets, at present, all the data acquired during the survey are held in microfilm at the Federal Department of Agriculture, Lagos.

The examination of the status and spatial variability of the soil parameters considered, in respect of the soil-forming factors, were for both the 0 - 15cm and 50 - 80cm depth which were referred to in the body of the work as topsoils and subsoils, respectively. The only exceptions are the organic matter and nitrogen. As these two elements commonly abound or concentrate on the surface horizons of the soil, the values for virtually all the profiles selected for the deeper horizons were uniformly zero. The variabilities of the two properties were therefore considered in respect of only the topsoils.

1.3 LITERATURE REVIEW

The following sections deal with a review of previous pedological works relevant to the present study, with particular reference to tropical areas. Reference are also made to work done elsewhere. The review covers four general areas, namely, the effects of parent material, climate, topography and the other soil-forming factors.

1.3.1 Parent material effect

The influence of parent material on soil characteristics has often been obscured by prolonged pedogenesis and indeed, in some cases, it may be very difficult to decide what the original parent material actually was (Young, 1976). Nevertheless, a number of workers have found quite significant correlations between several properties of soils and their apparent parent material, so much so that many of the earliest approaches to soil survey and classifications were based on the underlying geological materials. In their work in western Nigeria, for example, Smyth and Montgomery (1962) distinguished between six associations of soils which correspond to the following six parent rock classes:

1. Coarse-grained granite and gneiss
2. Medium-grained granite gneiss
3. Fine-grained biotite gneisses and schist
4. Amphibolites
5. Quartz gneisses and schist
6. Sericite schist

In Burkina Faso (formerly Upper Volta), both Lenouf (1954) and Jenny (1965) divided soils in the country into the following general groups:

1. Fertile-brown, clayrich soils on Pre-cambrian Birrimian Formations (amphibolites, slates and diorites)
2. Fertile, heavy, base-rich soils on alluvium
3. Sandy soils of medium to low fertility on granites and sandstones.

Following these pioneering works, extensive research on the effects of parent material on soil properties has been carried out. In a study in Malaya, under a rainforest climate, Swan (1970) observed that whereas soils developed on quartz-rich rocks such as granite and quartzite are generally low in silt and clay, those over volcanic rocks, which are generally low in quartz materials, contain substantial amounts of these fine textures.

Parent material has also been found to have a marked influence on the type of clay mineral present in the soil profiles. Ogunwale (1973) in Nigeria, Martin et al. (1966) in North Cameroon, Boulvert (1968) in the Central African Republic and Stephen (1953) in Ghana have at one time or the other made the observation that whereas the clay mineralogy of soils formed from such felsic rocks as granite, gneiss, sandstone and quartzite are mostly kaolinite, those of the soils formed from the basic rocks, like amphibolite, gabbro and basalt, are predominantly montmorillonite and illite.

Apart from its influence on the texture and clay mineralogy of soils, several workers have also shown a dependence of the soil organic matter on parent material.

In the Mokwa-Kontagora area of Nigeria, Vallete (1973) has observed that the organic carbon of soils over Basement Complex rocks are higher than those over sandstone. A soil survey report, covering the Biu Plateau and its environs in North Eastern Nigeria contains a similar result in which soils formed on basalt generally contain higher organic matter content than those formed on granitic rocks (Carroll & Hope, 1970).

A dependence of soil base status, CEC and pH on parent material has also been reported. For example, in Zambia (then Northern Rhodesia), Webster (1959 & 1965) observed that the CEC of soils derived from volcanic rocks and shales were generally higher than those from granitic rocks. In the savanna region of Nigeria, Wild (1971) found that whereas total exchangeable K of soils (18 samples) averaged 2.18 me/100g on Basement Complex rocks, it was only 0.08 me/100g (4 samples) in those on sandstones. In the Central African Republic, Boulvert (1968) observed that soils over para-amphibolite were much richer in total exchangeable bases than soils over migmatite.

In a study under a savanna climate in northern Nigeria, Leow and Smith (1981) observed that soils on granodiorite and feldspatic quartzite had lower pH values than those over biotite gneiss and semi-pelitic schist. The differences in the pH, between the various parent rocks, according to the authors, were statistically significant at the 0.001 probability level. Furthermore, although in general the clay contents were low, those on schist and gneiss (20.3 and 18.7 respectively) were higher than those on quartzite (9.8%) and granodiorite (11.3%).

In two related soil surveys in northern Nigeria, Vallete (1973) and Higgins (1963) noted that the soils formed on sandstones are generally very deep and sandy. They further observed that while soils developed on granite and quartzite have shallow solum and are gravelly in texture, those formed over schist are characterized by deep to very deep solum and are more clayey in texture.

Furthermore, in the West Lake Region of Tanzania, Moberg (1970) has observed that in soils developed over sandstone, a C horizon is rarely recognizable. By contrast, the soils derived from granite often have quite a deep C horizon below the soil solum.

1.3.2 Climate effect

Aspects of climate that are of major pedogenic significance that have been investigated include rainfall and temperature. In central United States of America, Jenny (1930, 1941) found that the effect of temperature obeyed the Vant Hoff's (1884) temperature rule. Thus, at constant moisture content, the average organic matter and nitrogen content of soils over the region increased two to three times for each fall of $10^{\circ}C$ in the mean annual temperature. Jenny also observed that at constant temperature, the organic matter and nitrogen content of soils in the region increased logarithmically with increase in precipitation.

Jenny et at. (1948 & 1960) studied the soils of Columbia, Latin America, Costa Rica and India and found considerable

agreement with results reported earlier on for soils of the United States except that, under similar temperature and moisture conditions, Columbia soils had much higher organic matter and nitrogen contents than those of central and equatorial America and India.

In Hawaii, Dean (1937) found that the carbon and nitrogen contents of soils increased with increasing rainfall. The C/N ratio of the soils also showed an increase with increase in rainfall. Two geographically limited surveys in West Africa demonstrated similar trends. Gavaud (1968) in Niger showed a decrease in organic matter north-ward, as the mean annual rainfall decreased from 790 to 280mm. Kadeba (1970) found a strong positive correlation between organic matter content of soils and rainfall in samples from some forest reserves in northern Nigeria. In his broad survey of the organic matter and nitrogen content of West African Savanna soils, Jones (1973) showed that the organic matter in the topsoils (0-15cm) increased significantly with increase in rainfall in the range of 350-1,905mm, at a rate of 0.17% for every 100mm increase in the mean annual rainfall. This was in general agreement with an earlier study of Birch and Friend (1956) in the Highlands of Kenya. Here, it was observed that each 254mm increase in rainfall was associated with an organic matter increase of about 1.3% in the soils.

In his work on soils derived from sandstones of Nigeria, Oguntale (1973) observed that in contrast to the soils from the heavy rainfall areas in the country, soils from the low rainfall areas contained weatherable primary minerals in their silt and clay fractions.

He also observed that as rainfall increased, the clay content of soils also increased, up to about the 1,524mm ishoyet beyond which it started to decline. In the same study, Ogunwale also reported a decrease in the base saturation and pH with increasing rainfall.

In Ghana, Ahn (1961) found that soils of the lower Tano River basin and environs formed over Basement Complex Formations, with about 1,650 to 1,770mm annual rainfall, were higher in organic matter content, pH, quartz and gravel contents, but lower in percentage base saturation, than those developed over the same parent materials, but in the less wet forest area of the north and east of the country.

In a catenary study over granodiorite under rainforest climate in Singapore, Leow (1979) found that presence of sandy topsoils and heavier subsoils to be the main features of the particle-size distribution. In a similar study in northern Nigeria, under a savanna climate and on granitic parent rock, Leow and Ologe (1982) have made quite comparable observation in which a sandy layer is overlying a moderately heavy subsoil.

In his studies of soils developed over sandstones in Nubia, Wild (1974) made the observation that in spite of the rather permeable nature of the parent the sub-humid area had rainfall been adeq viation and attendant profile differentiation ions of the Negev Desert on the other hand al than the physical disintegration of the sa cumulation of some fine materials in the su

1.3.3 Relief effect

Relief is an imprtant factor of soil formation and several soil properties have been reported to be relief-related.

In the study of soils formed over Basement Complex rocks under savanna climate in Nigeria referred to earlier on, Leow and Smith (1981) also observed a clear tendency for the top-soils to become coarser as slope angle increased. They also found a downslope increase in both the clay and silt, but a decrease in the gravel and sand, contents.

Comperable results have also been found by Jahn (1967) and Morgan (1973) both of whom note that slope-wash increases in amount with slope angle; as a result, coarse-textured soils are often found on steep slopes, whilst the amount of silt and clay are usually greater in gently sloping areas.

In a catenary study on granite in Western Ashanto, Ghana, Radwanski (1957) observed that both the upper and middle slope positions consisted of red to brown sandy soils, containing mostly kaolinitic clay mineral. On the lower slopes on the other hand, colluvial deposits had resulted in a yellow-brown sandy clay, grading into sand in the valley bottom. In Norway, the A_2 horizon has been reported to be thicker in podzols formed in depressions than those formed on uplands (Lag, 1951). The opposite effect was found however in Ultisols on the coastal plain of North Carolina (Daniels et at., 1967) where the A_2 horizon was found to be thicker on well-drained upland sites than in poorly-drained depressions.

With reference to slope angle and solum thickness, Norton and Smith (1930) found in Illinois, USA, that the depth of the solum varied from 28-25cm on slopes of 14% and 8% respectively to 64cm on 1% slopes.

The relationship between attitude and organic matter and nitrogen, has also been demostrated. In East Africa, for example, Birch and Friend (1956) observed that on average, each 3,048m rise in altitude in the region is associated with 0.8% and 0.04% increase in organic matter and total nitrogen respectively. Datacontained in a soil and ecological survey

report of west Cameroon also suggests a general increase in the soil organic matter and total nitrogen contents with elevation (Jones, 1973).

Apart from the dependence of several physical and biological properties of soils, mentioned above, on relief, significant correlations with some chemical characteristics of the soils have also been reported. Leow and Smith (1981) observed a notable pH increase with increase in slope angle in soils formed on Basement Complex rocks in northern Nigeria. A similar relationship between soil pH and slope angle has been reported in the temperate region, for example in the Oxford area of Britain by Furley (1968).

Furthermore, in a soil survey in Western Samoa, Wright (1963) found that at about 610m above sea level, the soil consists of loamy sand with an average depth of 10cm. At about 1,597m however, the soil , consists, of about 15cm of peaty sandy loam, overlaid by about 15-20cm of acid forest peat. Also in the basaltic lava and volvanic ash of Upolo, where although the high rainfall and temperature have resulted in highly weathered soils, Swindle (1965) noted a clear change from predominantly gibbsite-dominated soils in the lowland areas to kaoline-dominate soils in the uplands.

Another aspect of relief that has been investigated as causing differences in soils, particularly in temperate areas, is slope aspect. In a comparative study of north-and-south-facing slopes in Michigan for example, Cooper (1960) made the following observations:

a) the soils on the south-facing slopes have an A-horizon that is lighter in colour, and a B-horizon that is

more-reddish, than those on the north-facing slopes;

b) the soils on the south-facing slopes have better developed Bt-horizons than those on the north-facing slopes; and

c) the soils on the north-facing slopes have a thicker solum than those on the south-facing slopes.

Shulgin (1957) also made comparable observations in the Ukrainian region of the USSR .

1.3.4 Effects of other soil-forming factors

Vegetation has often been found to correlate with the type of soil (Areola, 1983; Bridges, 1970; Crocker, 1952). In traversing from the forest area to the savanna in Nigeria for example, Moss and Morgan (1970) have observed that the vegetation boundary coincided with a soil texture change, with the forest located on soils of heavier texture. And in comparing the soil formed on the Basement Complex rocks of western Nigeria across forest-savanna boundaries, Ojo-Atere and Murdoch (1971) observed that although the soil series formed under the savanna and forest have the same horizon sequence, they differ significantly in respect of several soil properties. According to the authors, the forest series have better developed Bt-horizon, higher pH, organic matter and total nitrogen contents, but lower C/N ratio than the savanna series.

Another aspect of the organic factor in soil formation is the soil fauna. In the rainforest region of south western Nigeria, Nye (1954 & 1955) observed significant differences in both the mechanical and chemical composition of mounds

produced by ants and termites and the surrounding soils. From the data obtained, Nye concluded that, at least, half a ton per acre of earth is deposited on the surface each year by termites. The activities of the earthworm Hippopers higerigre (Taylor) was also described. It was estimated that the worms deposited about 20 tons of soil per acre a year on the surface under the forest in the form of cylinderically shaped casts. The casts, according to Nye, are higher in organic matter, exchangeable Ca and Mg, pH, CEC and %BS than the top 15cm of soil. Similar colonies of mound-building ants have been described in East Africa by Hesse (1955) and in several temperate forests, such as the deciduous forests of North Eastern United States (Salem & Hole, 1968), the Harvard forest of northern England and the Great Plains (Thorp, 1949).

1.4 LOCATION AND EXTENT OF THE STUDY AREA

The western and eastern boundaries of the study area are marked by approximately Longitudes 7° and 10°E. The area extends from south of the Benue valley northwards to the border with the Niger Republic (Fig. 1.1). The area's most southerly boundary comes to within 220km of the Gulf of Gunea. The area covers approximately 230,000km^2 and includes the Jos Plateau, the Benue valley and the greater portion of the High plains of Hausaland (Buchannan & Pugh, 1955). The area is of particular interest, first because of the ready availability of relevant data. But it has been selected for this study because it encompases a considerable diversity of weathering environments. First, there is a marked change in climate, particularly rainfall, and vegetation cover from the southernto

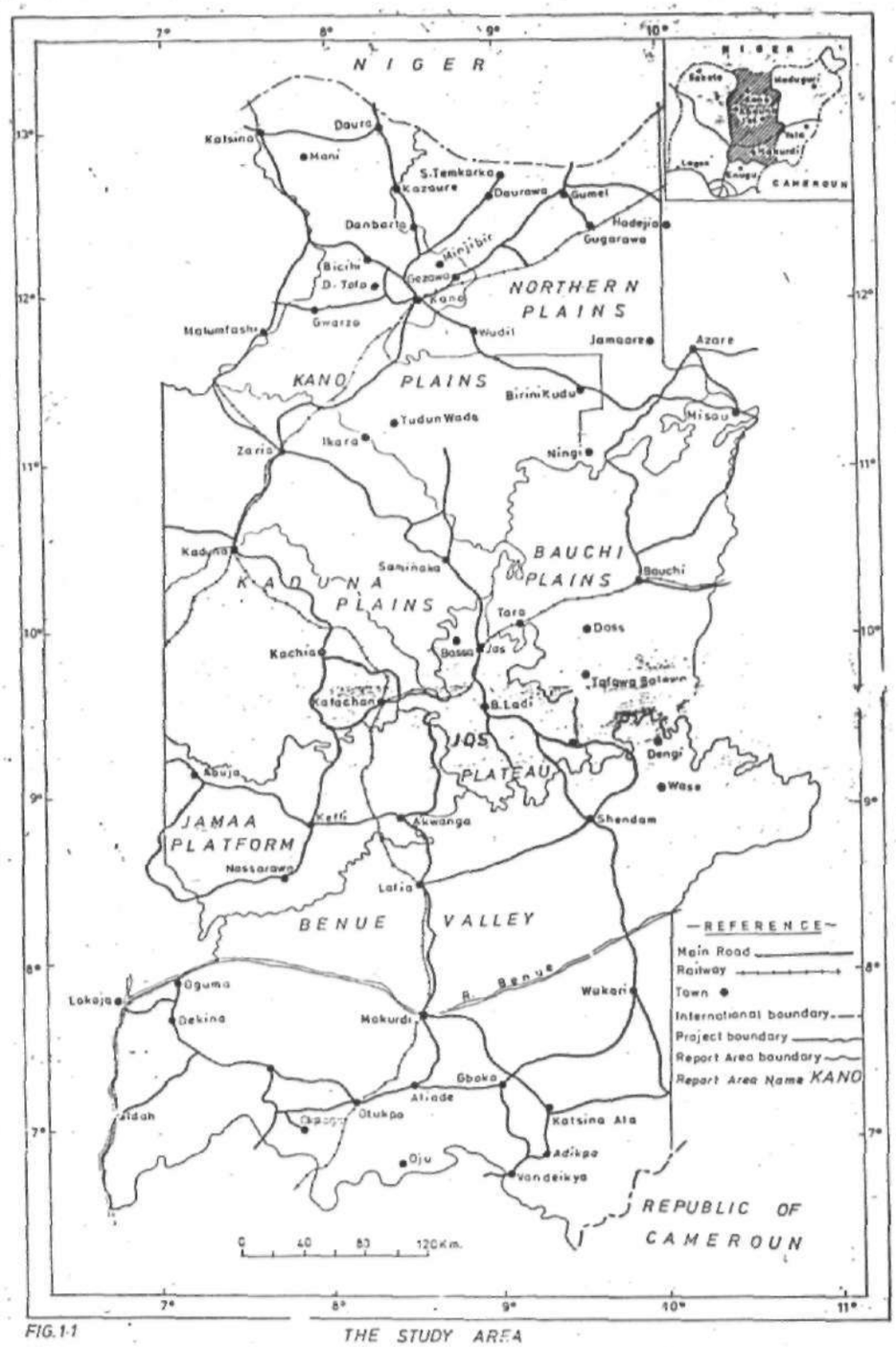


FIG.1-1 THE STUDY AREA

the northern parts of the area. In addition, altitude varies from the Benue valley (below 40m) to the Jos Plateau (over 1500m). Finally, there is a great range in the age, composition and structure of the underlying rocks and soil parent materials. These vary from Precambrian Basement Complex rocks to Tertiary lava flows, and include quite recent sedimentary formations. These conditions provide an excellent opportunity for determining the extent to which the relationships between soil properties and soil-forming factors over fairly large area in a tropical environment conform to those already found in other parts of the world.

Many soil properties are undoubtedly related to vegetation cover and drainage condition, but these factors depend very much on other factors particularly rainfall, slope position and human activities (Young, 1976). For this reason, rather than treating vegetation and drainage condition in this study as independent variables *per se*, they have been taken merely as as medium through which these other factors express themselves.

Time has been omitted in this study because it is difficult to define and quantify (Buol *et al.*, 1973). The influence of man, particularly through cultivation, is also undoubtedly a very potent factor of soil formation in the area. There are relatively few portions of the area where, to a greater or lesser extent, man's activities have not had some repercusions on the landscape. The inclusion of human factor *per se* in this study however, is hampered by lack of reliable information on specific landuse type and intensity of uses. It is the factors of parent material, climate (rainfall & tempterature) and relief

(altitude, gradient and slope position) that have been specifically considered in this project.

In addition to the soil properties listed on page 4, under the objectives, two additional textural related parameters were considered. The first of these is the silt/clay ratio. The inclusion of this parameter was prompted by the general observation that in the course of soil formation, the silt content of the soil tends to decrease while the clay content increases, due to an increasing transformation of the former to the latter. Although appearing to be relatively simple, the index has been applied by several workers (e.g. van Wambeke, 1962; Martin, 1970; Young, 1976) in characterizing the weathering status of soils and should work fairly effectively in this present study; at least for those soils derived from igneous rocks, with no secondary clay minerals.

The second parameter is the index of textural differentiation within the soil profile. The index, which is a measure of the degree of development of a textural B horizon (Bt) is defined as

$$I_t = \frac{\text{clay \% in the surface layer}}{\text{clay \% in the layer with maximum clay}}$$

The FAO soil classification defines Bt horizon as that containing translocated silicate clay. Nevertheless, the definition has been found to be inadequate by several workers on the ground that clay cutans are not always present in textural B horizons nor do the layers always show the increase in bulk density that would be expected from clay illuviation (Oertel, 1968; Brewer, 1968).

The definition also neglects the possibility of differential weathering with higher clay production in the more or less permanently moist subsoil (Young, 1976). In this study, the term textural B horizon is taken to mean an horizon with appreciably more clay than some horizons above it, irrespective of the origin of this clay.

An I_t value of unity signifies absence of textural B horizon within the soil profile i.e. uniform profile, and the further away the ratio is from unity, the greater the degree of textural differentiation.

CHAPTER II

METHODOLOGY

2.1 DATA BASE: THE LRD CENTRAL NIGERIA PROJECT

The methods adepted by the Land Resources Division (LRD) of the British Directorate of Oversea Development in the survey of the land resources of central Nigeria have been described in detail by Bawden (1969) and McTainsh et. al (1980). Since the data for this study was derived mainly from the project however, it would be necessary to decribe briefly the principal survey and analytical procedures, of the relevant portions, adopted.

2.1.1 Survey procedure

The steps taken in the field survey were as follows:

(i) Division of the area into broad physiographic units such as hills and mountains, dissected areas and plains, using air photographs (1:40,000) and, ground reconnaissance

(ii) Sub-division of the area into units containing relatively uniform landforms termed Geomorphic Units, also using air photos (1:40,000).

(iii) Location within each Geomorphic unit of at least one soil sampling transect or toposequence, extending from an interfluve crest to a basal area.

(iv) Location of at least one point, where the soil profile was examined, on each slope facet (i.e. segment of slope with uniform slope angle) within a toposequence.

Because of the problem of accessibility in some areas however, it was not possible to cover all the Geomorphic Units identified in step (ii).

The morphological features of (the profile face within) each soil profile were described and the information recorded directly onto coded Soil Profile Data Sheets (Appendix 1). Soil samples were collected from each horizon and the characteristics of the site, such as altitude, slope angle, slope position and microrelief recorded on coded Site Data Sheets (Appendix 2). Representative soil profiles within each Geomorphic Unit covered were later selected for laboratory analysis and the results presented on Laboratory Analysis Sheets (Appendix 3).

2.1.2 Analytical procedures

Except for the particle-size analysis performed by the Kentings Earth Science Soil Laboratory, Jos (now moved to Kano), for a small fraction of the samples, all the samples during the land resource survey were analysed by the Tropical Soil Unit, LRD, London.

The pipette and sieving methods were used for particle size analysis, after pre-treatment of the samples with hydrogen peroxide and calgon solution.

The organic carbon was measured by the Walkey and Black Oxidation method while the total nitrogen by the Kjeldahl extraction method, using a selenium catalyst and a sodium sulphate to sulphuric acid ratio of 1:7.

The exchangeable Ca and Mg were estimated on the Perkin Elmer atomic adsorption spectrophotometer, using strontium to prevent interference from phosphorus by extraction with N ammonium acetate at pH 7.0, and the exchangeable Na and K on the Technicon auto-analyser by flame emmision spectroscopy, with an internal lithium standard.

The CEC was estimated on the auto-analyser, as indophenol blue, by removal of adsorbed ammonia from the determination of the exchangeable bases with N potassium chloride, at pH 2:5.

The bulk density determination was based on the mass of 10ml of air-dried soil and the pH by the use of pH meter in soil water ratio of 1: 5.

The %BS was derived as

$$\%BS = 100\ (Em)/CEC$$

where Em is the sum of milliequivalent per 100g of exchangeable cations Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}.

2.2 RESEARCH DESIGN

2.2.1 Soil-forming factors data

The Site Data Sheets contain information on the slope position, drainage condition (site drainage) and slope gradient. Some contain information on altitude and geology (geology of the soil and undelying geology), but none with respect to rainfall and temperature. To made up for the missing data on altitude, geology and climate of the selected soil profiles, published information have had to be sort for instead. By means of 1:50,000 topographic maps (published by Federal Survey

Department of Nigeria) and various geological reports of portions of the area, it was possible to determine fairly accurately the altitude and underlying geology respectively, of each profile where a profile was excavated and examined.

Information on climate was much more problematic. This is because, except for the role of water in the erosion or deposition of soil materials at the soil-air-interface, and that of temperature in evapotranspiration, the major functions of temperature and water are within the soil profile - weathering, leaching, translocation etc. (Buol et al., 1973; Young, 1976). This implies that the use of soil temperature and the average total rainfall less the amount that is likely to be lost by evapotranspiration (ie. effective precipitation) in an area, over a period of time, provides a much more realistic basis for the assessment of the pedogenetic significance of the climatic factor, as compared to the use of simple air temperature and gross rainfall data (Ologe, 1976). Although such information are of the greatest importance for a deeper understanding of the development of soils in the project area, data for the first parameter, and that for the computation of the latter are simply not available. Moreover, presumably because of the relatively few functional meteorological stations within the area, there are infact no columns provided for even the mean annual rainfall and air temperature (which have been used in this study).

The mean annual temperature and rainfall data, on which this study is based, were abstracted almost exclusively from Kowal and Knabe's (1972) Agroclimatological Atlas of Northern States of Nigeria.

A greater portion of the data in this atlas is itself based on extrapolations, but no other comparable work is available that might have been used in this study.

2.2.2 Selection of profiles for this study

The criteria for the selection of the profiles in this study were two: Firstly, the profile description must be found in the series of LRD reports titled "Soils and Landforms", published for the Central Nigeria Project. These manuals contain basically the descriptions of some profiles described as "typical profiles" of the various geomorphic units. Secondly, it should be possible to obtain acceptable information on at least two of the missing data on the environmental factors of parent material, climate and altitude.

On the whole, the analytical results and morphological descriptions of 385 profiles (covering the whole of north central Nigeria) were selected for this study from the survey data (fig. 2.1). This gives a sampling density of 1 in 597 km^2.

Table 2.1 gives the breakdown of the profiles according to the different soil-forming factors. In zoning the rainfall factor, the limiting values defining the vegetation communities of Forest/Savanna mosaic, Southern Guinea Savanna, Northern Guinea Savanna and Sudan Savanna, in the area, were used (Table 3.1). For altitude, the values are quite similar to those defining the planation surfaces of Jos Plateau, High Plains, Chad Formation and Jama's Platform, and Benue valley (3.3.4). Because of the very high skweness, and rather narrow ranges, of the temperature and slope gradient data for the region, the limiting values for the division of these two factors into zones were chosen rather arbitrarily.

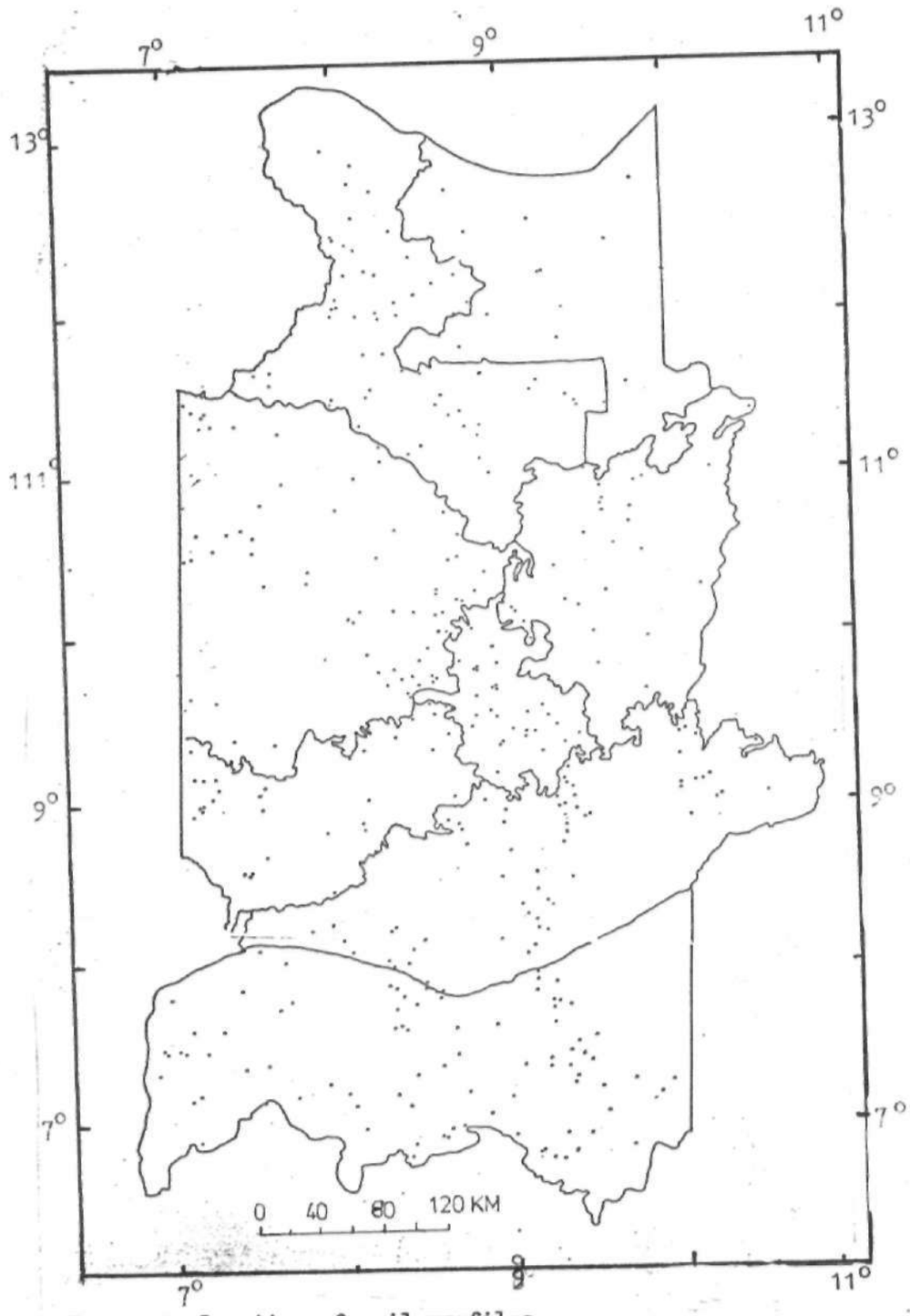


Fig. 2.1 Location of soil profiles

Table 2.1: Breakdown of the soil profiles selected into the different soil-forming factors

Parent material		
Granite	...	36
Gneiss	...	32
G/gneiss	...	38
Schist	...	34
Sandstone	...	36
Basalt	...	42
Shale	...	42
Alluvuim	...	30
Colluvuim	...	32
Aeolian	...	38
Ironpan	...	22
Rainfall zones		
600 - 900mm	...	71
900 - 1200mm	...	103
1200 - 1500mm	...	130
1500 - 1800mm	...	78
Temperature zones		
20 - 25°C	...	108
25 - 27°C	...	122
27 - 28°C	...	148
Altitudinal zones		
< 300m	...	110
300 - 600m	...	167
600 - 900m	...	71
> 900m	...	34
Slope angle classes		
< 5°	...	326
5 - 10°	...	48
> 10°	...	8
Slope positions		
Upper	...	119
Middle	...	147
Basal	...	116

In view of the enormous resources required to carry out the kind of survey that would yield the data used for this study, it would have been absolutely impossible for a single person to carry it out, especially at the level of detail achieved by the LRD, for a degree project such as this. In spite of some missing information in the Site Data Sheets (which were fairly easily rectified), the large number of samples involved and the wide area over which they were collected, coupled with the standardization of both the field and laboratory methods, make the data particularly suitable for a study involving several key soil properties, and their correlations with the environmental factors, over a relatively large area under sub-humid to semi-arid tropical conditions.

2.2.3 Data analysis

The relationship between the soil properties and the soil-forming factors was examined in one and/or two major ways. First, it was examined by the use of simple linear correlation and regression, relating each of the soil properties to the soil-forming factors. Secondly, it was examined by one-way analysis of variance. While the former test was applied to only those factors with interval data (rainfall, temperature, altitude and slope gradient), the latter was applied to both the factors that are norminal (parent material & slope position) and interval in nature (Ebdon, 1977). In addition, in some instances, the relationship between the particular soil property or properties and the soil-forming factor in question was examined against the background of the other factors. The objective of this step was to obtain greater indepth view of how a particular factor affects specific soil properties under fairly similar condition.

Other statistical techniques used were chi-square analysis, for the soil structure in which the data was ordinal in nature, analysis of variance (several ways) and covariance, for evaluating the relative importance of the soil-forming factors on the spatial variability of the soil properties considered.

As some of the effects of the soil-forming factors on some profile properties are often indirectly through effects on other soil properties, particularly the colloidal materials (Young, 1976), the clay and/or organic carbon contents were also taken as independent variables in some situations and treated as such along with the environmental or external soil-forming factors considered. In view of the relatively large number of variables involved altogether however, only the major scatter diagrams, generated in the analysis for the topsoils, have been included in the body of the results. Statistically significant relationships or differences, at the 0.05; 0.02; 0.01 and 0.001 probability levels were however indicated in both the scatter diagrams, and all the tables summarizing the results obtained, where applicable.

All statisticall analyses were carried out using the computer.

CHAPTER III

PHYSICAL ENVIRONMENT OF THE STUDY AREA

3.1 RELIEF AND DRAINAGE

The major features of relief and drainage of the study area are shown in Fig.3.1. The relief can be divided into three broad categories viz: the Lowlands, the High Plains and the Jos Plateau.

The Jos Plateau is the most striking morphological feature in the area. The plateau, which is pear-shaped and covers an area of about 8,600km^2 has a surface which descends gradually northwards, from 1,400m to 1,100m above sea level. It is essentially an erosion relic of the quite resistant Older and Younger Granites. Within the granitic hill masses of the plateau are vast tracts of flat to gently undulating terrain, developed mostly on deeply weathered Older Basalt.

To the North and East of the plateau lie the High Plains of Hausaland. The plains are separated from the plateau by steeped escarpments and dissected zones. The only exception is a small portion in the North, where the Plains grade right to the main plateau surface with only a minor morphological break. The Plains descend gradually from the foot of the Plateau to the edge of the project area, in the North from about 1,000m to less than 600m, in the East from 760m to 450m and in the West, from 900m to 600m. Much of the Plains comprise quite extensive tracts of almost level to gently undulating dissected lands, broken by rocky hills and inselbergs which frequently rise up to 40 or 50 metres above the surrounding plains.

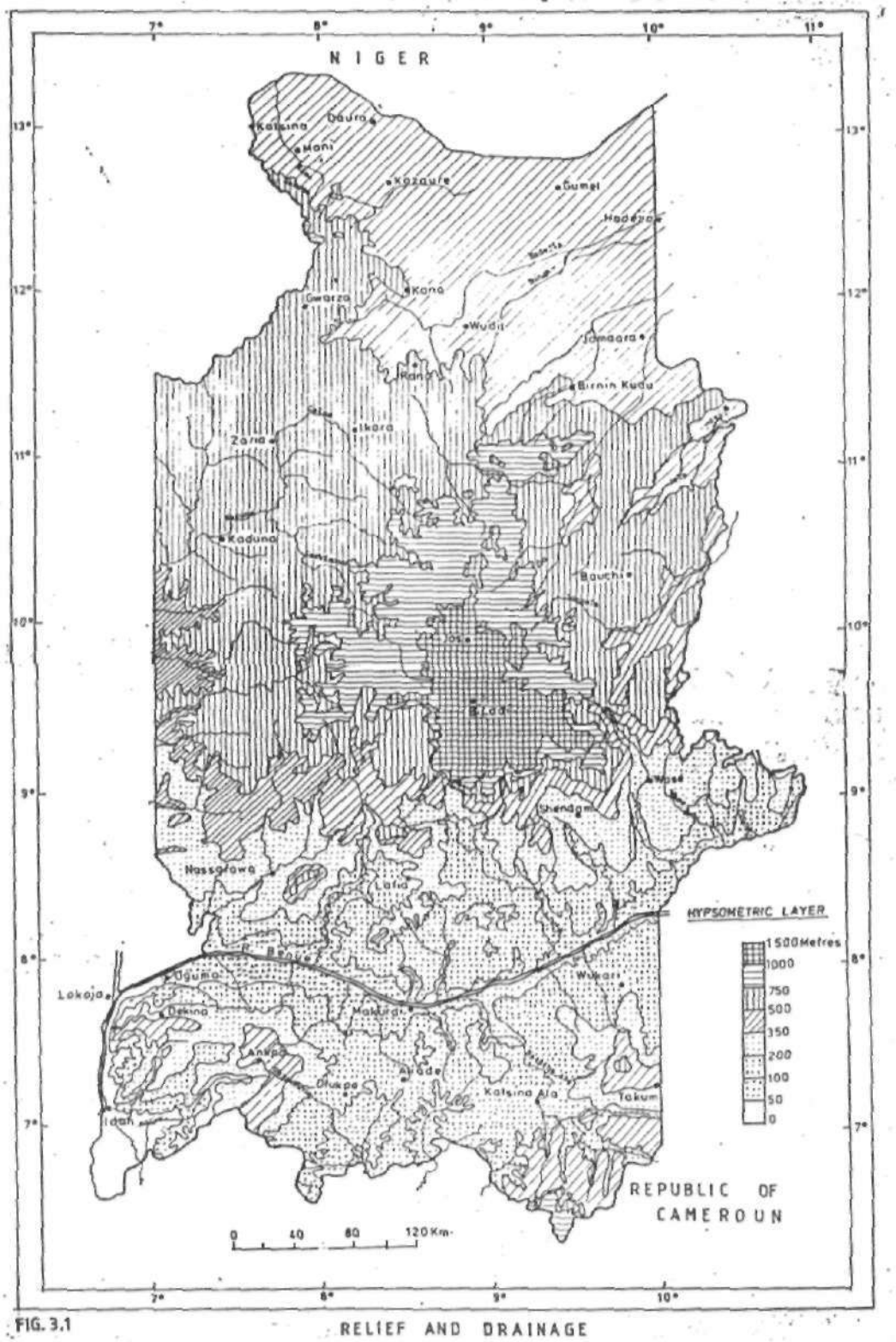


FIG. 3.1 RELIEF AND DRAINAGE

Bordering the High Plains and the Jos Plateau in the south-west is a group of plains often collectively described as the Jama'a Platform (Grove, 1956). The Platform is about 450m and 600m above-sea-level at its boundary with the High Plains and the Jos Plateau, respectively, but only about 180m in its south-western edge.

The High Plains and the Jama'a Platform, as well as the Jos Plateau are separated from the lowland to the south by a strongly dissected zone termed the Benue Escarpment Zone (Rackham, 1970). The Benue River forms the main axis of this low-lying area to the south and falls from about 90m in the East to about 45m at its confluence with the Niger. On either side of the river, extensive plains, broken by sandstone hill masses slope irregularly away from the river.

In the northern part of the study area, the Lowlands mainly form part of the Chad Basin and consist of vast almost featureless plains.

Most of the major rivers draining the study area take their source from the Jos Plateau and are predominantly tributaries of the Niger-Benue system. In the north-west for example are the Sokoto and Kaduna Rivers, and in the east, the Gongola, A small area south-west of the area, however, is drained by the Anambra River system which takes its source from north west of Otukpo while Konishiha and several others drain southward into the Cross River. Also in the north-east, the Hadejia River system drains into the Lake Chad.

The hydrology of the rivers in the area reflects the climatic environment, particularly the seasonal and torrential character of the rainfall. It also varies with the presence or absence of wide floodplains, (locally known as fadama) in the basins, and the direction of flow. For example streams associated with wide floodplains, presumably because of greater water retentive capacities of the alluvial materials, flow for longer period than those in basins without floodplains (Plate 1). Similarly, streams flowing northward experience less downstream increase in discharge than those flowing southward, due mainly to decreasing rainfall and increasing evaporation (Ololobou, 1982). Three main types of stream flow pattern are generally recognized in the area (Ologe, 1978) namely:

(i) Perennial flow - occuring in the large streams which are characterized by low dry season discharge and flash floods superimposed on high rainy season discharges;

(ii) Seasonal flow - zero dry season flow; flash floods superimposed on rainy season flow which may be high or low depending on catchment area and geographical location;

(iii) Flash flow only (i.e. stream flow occuring during and for a short while after run-off producing storms), characteristic of small streams generally, gullied environments and areas of rock outcrops.

The seasonal variation in the amount of grounwater is considerable, although not as pronounced as in river channels.

In general, groundwater levels are higher during the rainy season than in the dry season. They are also higher in the "fadamas" than in the upland areas. In a study of the hydrology of a small catchment basin near Zaria, for example, it was observed that the depth of the dry season water table varied from 0.2m in the valley bottom to 13.4m near the interfluve crest (Kowal et al., 1971).

The groundwater level also fluctuates seasonally, being generally more variable in the interfluve areas than in the basin areas (Olowu, 1967; Ososami, 1968; Gill, 1974).

3.2 GEOLOGY

The geology of the area varies considerably, from Precambrian to Lower Palaeozoic age Basement Complex of igneous and metamorphic rocks, through Cretaceous sedimentary rocks and Late Tertiary to Quaternary lavas, to recent sediments of alluvium, colluvium and wind-blown deposits (Fig. 3.2).

The Precambrian-Lower Palaeozoic Basement Complex rocks underlie the whole area and are composed mainly of gneisses, migmatites. Most of these rocks have, however, been extensively modified by metamorphism and now mainly occur as granites, granite-gneisses and migmatites. In some places, there are extensive outcrops of schists with phyllites and interbedded quartzites and marbles.

The Older Granites, consisting mainly of granites and granodiorites, and in some places, syenites and migmatites and quite resistant to weathering and have given rise to the

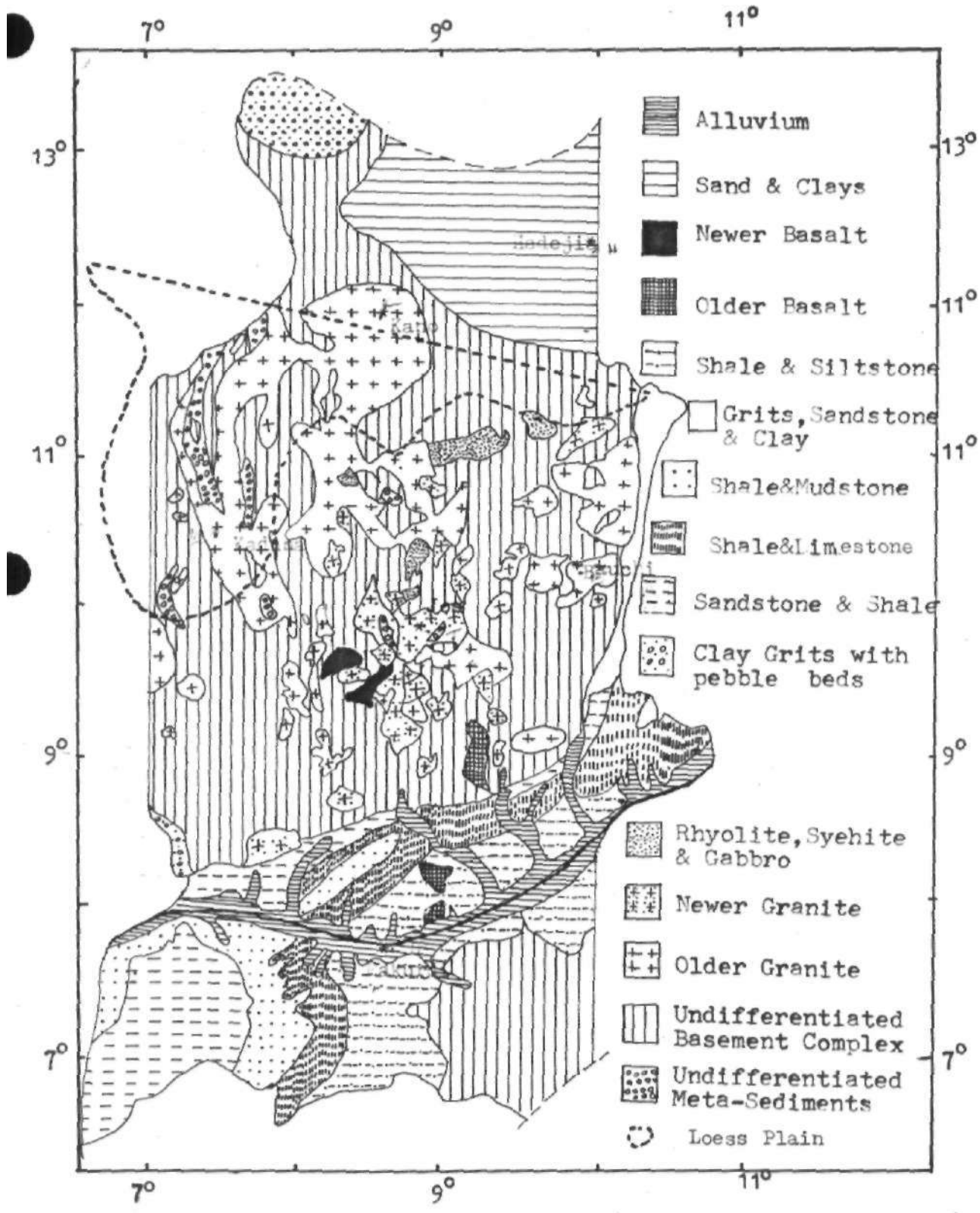


Fig. 3.2 Geology



PLATE I Alluvial flodplain --- along Kubani River, Zaria



PLATE II Volcanic vent, Jos Plateau

characteristic groups of dome-shaped inselbergs that diversify the monotonous High Plains (Buchanan & Pugh, 1955). The Younger Granites are also widespread, especially on and around the Jos Plateau. They had been discordantly intruded into the Basement Complex during the Jurassic. They commonly occur as ring complexes, reflecting several cycles of intrusion, and possessing clear topographical definition. This intricate pattern, combined with variations in thickness and composition of overlying sedimentary materials causes great variability over short distances in the soil cover over the Basement Complex rocks of the region.

The Jos Plateau provides the most extensive area of lava flows in the study area. Several others are also found in much of the High Plains, but most of these are small and do not have a discernible vent or focus (Bennett et al., 1977). The volcanic rocks, consist mainly of basalt, gabbro, pyroxenite and peridotite. While some of these rocks have been deeply weathered and carry a thin sheet of ironpan, the youngest ones have been much less affected by weathering and erosion and can usually be traced to fairly well preserved cones. (Plate II).

The most extensive area of sedimentary rocks lies in the Benue Valley. This is a trough-like feature, trending north-east from the Niger towards the Chad Basin. It is bounded to the North and South by the Basement Complex rocks and is filled with up to 6,000m of predominantly deltaic, marine and estuarine Cretaceous sediments, mainly sandstones and shales, with rare intercalated alkaline basic lavas (Kogbe, 1976). The deposition has been controlled by the evolution of the Benue Valley and several theories have been put forward to account for its

formation (King, 1950; Cratchley & Jones, 1965; Wright, 1968; Burke et.al., 1970).

Another area of fairly extensive Cretaceous sediments is in the extreme north-east, the Gumel-Hadejia area. The sediments consist mainly of feldspathic clayey snadstone and grits with basal pebble beds. They are reported by du Preez (1958) to have a maximum thickness of about 100m with a very low regional dip to the north-east.

The recent sediments of colluvium, alluvium and wind-blown deposits are examined under the section on geomorphology (3.3).

3.3 GEOMORPHOLOGY

The three broad physiographic regions of the study area have been described (Section 3.1). The common occurence of gently undulating plains, sometimes broken by hill ranges or inselbergs, was also pointed out. This section takes a closer look at these features. The nature of the surface materials and the evolution of the landscape are also discussed.

3.3.1 The Plains

Ologe (1978) has identified the most important geomorphological characteristics of the plains in the study area to be as follows:

- the predominantly low relative relief (i.e. the height range between interfluve crests and valley bottom or that between the lowest and the highest contours within a grid square; - the presence of narrow valley floors, except along some of the large rivers, which often have a low terrace or terraces in addition to the contemporary floodplain;

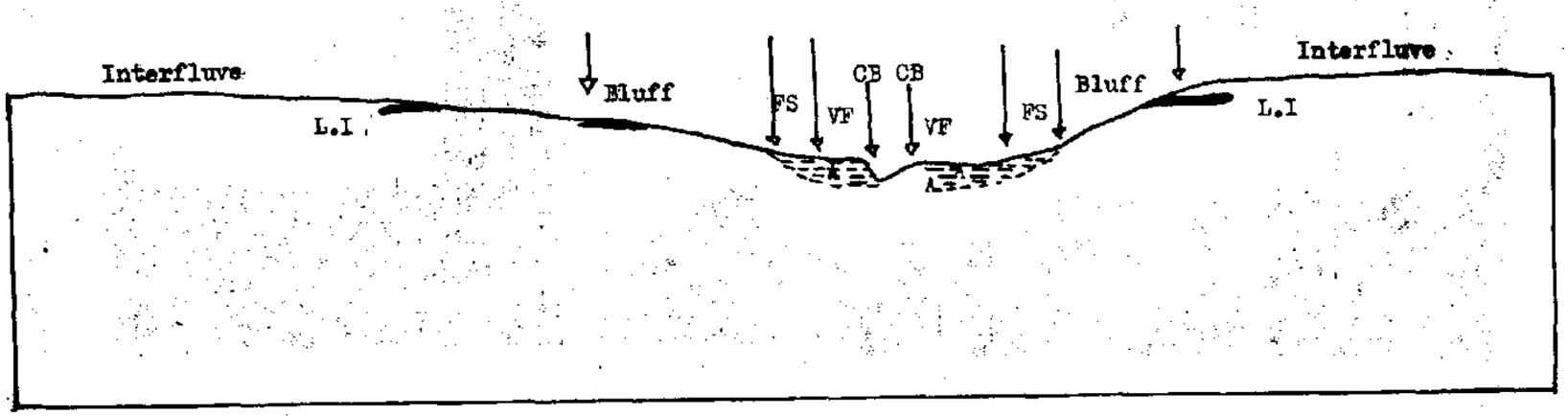


Fig.3.3 Model of valley form on plains over the study area showing slope elements: L.I=Laterite ironstone; A=Alluvium; FS=Foot slope;VF=Valley floor; CB=Chanel bank



PLATE III Incised stream channel with gullying, Kano



PLATE IV Vegetated gully, Bauchi

- the occurence consistently along valley sides of a belt of relatively steep slopes (i.e bluff lines) between broad gently sloping convex interfluves and short foot-slopes that are either planar or concave in form (Fig. 3.3);
- the relative infrequency and small size of rock outcrops;
- the common occurence of thin sheets and small scarps of lateritic ironstone;
- the generally good condition of drainage.

Another remarkable feature of the plains that has been described is the prevalence of rivers that have shallowly incized into the landscape and are thus characterized by steep to vertical banks (up to 6m high in places). However, only locally are they being actively eroded at the present time. Quite often, most of them have been stabilised or are overhung by a vegetation cover (Plates III & IV).

3.3.2 The Residual Hills

The residual hills dotting the landscape of the study area take different forms. Prominent among them are the inselbergs, found on granites and migmatites and sometimes on granite-gneisses. They occur mostly as impressive steep-sided domes, but also as elongated and assymetrical features. They may be relatively free of boulders, but more commonly, carry boulders of various sizes on their tops and on fairly gentle side slopes (Plates V & VI).

Broken rocky hills or tors are another variant (Plate VII). Others include, low narrow ridges on sandstone quartz and pegmatite veins, often rising less than 10m above the surrounding terrains,

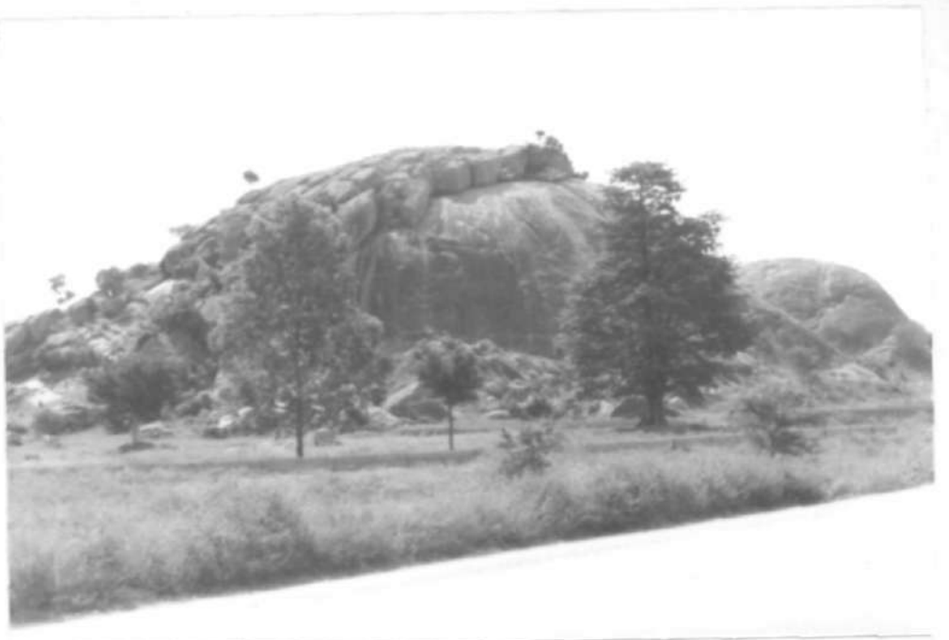


PLATE V Dome-shaped inselberg --- displaying weathering by exfoliation, Zaria



PLATE VI Asymetrical inselberg, Kufena Hill, Zaria

and low whalebacks on migmatites, granites and granite-gneisses (Plate VIII).

3.3.3 Superficial Materials

Based on the mode of origin, the superficial materials of the study area may be classified into four: weathered regolith or saprolite, colluvial deposits, alluvial deposits and aeolian deposits. These form the soil parent materials over the area. They also provide valuable insight into the past and contemporary geomorphic processes in the area.

The weathered saprolite overlies the solid bedrocks, except where the latter is exposed at the surface. Because of the differential weathering rates of the rocks, the depth of the saprolitic layer tends to be highly variable even over short distances. No systematic data on the depth of weathering over the area exist yet. However, the fragmentary evidence which exists indicate that the saprolitic substratum is much shallower in the hilly and strongly dissected areas, than on the undulating plains (Faniran, 1974). The texture of the material is also quite variable, from gravelly or sandy, to clay loam in its upper part, but becoming coarser, less clayey progressively toward the underlying rocks.

Colluvial deposits occur as thin sheets on valley side slopes, over an origiral erosional surface often exhibiting a marked microtopography. The materials are usually poorly stratified, poorly sorted and stony. Often associated with the materials are lateritic ironstones.



PLATE VII Broken tor, Zaria



a



b

PLATE VIII (a) Whaleback, Zaria (b) Laterite capped mesas



PLATE IX Lateritized soil profile--- there is a relatively sharp boundary betwwen the laterite layer and the underlying materil, sugesting secondary mode of formation

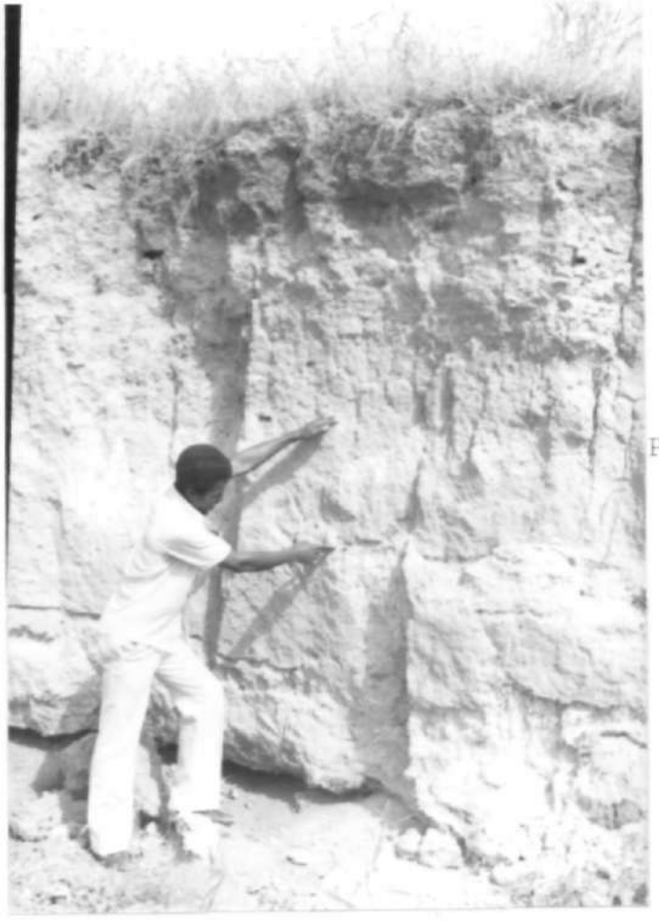


PLATE X Alluvial deposit---- showing strafication of materials, Usman River, Abuja

These occur as thin sheets also, usually less than a metre thick, on slope crests and valley sides, and as small scarps, sheets and boulders on the bluff line. There is often a sharp boundary between the ironstone layer and the subjacent mottled weathered rocks (Plate IX). This feature, together with an inclusion of discrete boulders of ironstone in the material is usually seen as a pointer to the secondary nature of the material, having been derived from an erosional destruction of an earlier equally extensive cover of higherlying primary laterite (Thomas, 1974; Faniran, 1970; Ologe, 1971 & 1978).

Alluvial deposits have been reported to be associated with all the drainage courses in the area (Hutcheon et. al., 1975). However, significant deposits, in terms of areal extent, are not common and are restricted to the floodplains of the dominant rivers and their tributaries. In addition, extensive deposits also occur below the major hill masses; wider near the hill front, and narrowing away from it, these deposits are found where a number of streams debouching from hill masses converge. The deposits, which are generally thick and usually have few stones in them, are however not being actively augmented today and often show varying degrees of stream dissection (Ologe, 1978).

In general, the alluvial deposits are sandy in texture, and are usually stratified (Plate X).

Three major types of aeolian materials may be discerned within the study area. These include the Dune deposits, the Sand-Sea deposits and the Loess-like drift deposits (Hutcheon,

et. al., 1975; Bennett et. al., 1978; Higgins, 1963; Lowes, 1962). The fixed linear dunes occur in the north-western portion of the area. They form part of what has been described as the Ancient Erg of Hausaland, a vast area running eastwards, as far as Maiduguri. The dunes are of varying thickness and are oriented mainly ENE to WSW (Falconer, 1911; Grove, 1958).

Unlike the fixed linear dunes, the sand-sea deposits lack any definite pattern and are occupying a vast country north of Kano. The sand mantle shows a marked variation in thickness as well but in general, shows an overall thinning south-westward (Grove et. al., 1963, 1968).

The loess-like drift deposits occur mainly in the north-western part (Kaduna-Zaria-Kano axis) of the area (Fig. 3.2). Although generally thin, particularly on interfluve areas (often less than 1.5m), thicker accummulations (sometimes up to 4.6m) are found in some valley bottoms. The exact origin of the loessal material has not been fully researched into. However, it is being hypothesized that the materials are products of wind deposition and have been brought into the area in a manner similar to the harmattan dust of the present day (McTainsh, 1984).

3.3.4 Geomorphic Evolution

Most workers in northern Nigeria seem to agree that the area, in geomorphological terms consists of a series of planation surfaces, separated by scarps and dissected zones. By planation surface is meant a geographically plain surface produced by

processes of erosion and mass wasting (Brown, 1968). In addition, small upstanding areas can be recognized which carry remnants of higher surfaces. The main planation surfaces have been recognized, and often mapped from Falconer (1911) onward, including Dixey (1947), Pugh and King (1952), Grove (1952 & 1956), King (1962), Rackham (1970) and Ologe, (1978). The formation of these surfaces, according to these scholars, were closely related to the geological evolution of the Niger-Benue Trough which they said has provided the regional base level for the area since it was formed apparently in mid-Cretaceous times. While there is no general agreement on the actual number and dates of initiation of major cycles of erosion over the study area, and over Nigeria as a whole, it is generally held that repeated downwrapping of the trough and/or upwarpping of its flanks has provided successively lower base levels of erosion from which successive cycles of landscape planation were initiated.

The highest extensive planation surface within the area is the Jos Plateau surface. Thorp (1967a) is of the opinion that the surface is of Cretaceous age. King (1962) has mapped the area as Post-Gondwana. This surface is also represented on numerous isolated massifs in the study area (Thorp, 1967a).

Below the Jos Plateau, and skirting it to the North, East and West are the High Plains, representing higher group of planation surfaces. The group corresponds to the surface mapped as the African Surface by King (1962) with the age being put at Late-Cretaceous to Mid-Tertiary.

The lowland in the north (part of the Chad formation that lies within the project area), and the group of plains lying southwest of the Jos Plateau, i.e. the Jama'a Platform, according to King belong to the Post-African cycle (Late-Cainozoic). As suggested by Creve (1956), they were out during the Tertiary period.

Finally, there is the Benue valley which according to King, belongs to the Congo cycle of Quartenary age.

Subsequent to their formation, the major planation surfaces have been considerably retouched and micro-sculptured, producing several more surfaces, some erosional and some aggradational. The details of these srufaces vary considerably, from one locality to another. Nevertheless, some appear to have a wide geographical distribution and these have already been described in Section 3.3.1.

According to de Swardt (1946), the development of such post-planation surfaces are the result of repeated changing circumstances of climate, vegetation and hydrology since the pleistocane time. Applying this principle to the landscape of Abuja area, Ologe (1978) has suggested the following sequence or subsequent events:

(i) Deep weathering and lateritization;

(ii) Incision of stream channels and the erosion of narrow, bluff-bounded valleys; aggradation of the valley floors (i.e deposition of the Older Alluvium;

(iii) Incision of stream channels into the Older Alluvium or closely followed by deposition of the Younger alluvium;

(iv) Incision of stream channels into the Younger Alluvium and contemporary deposition of sands and gravels in some of the channels.

A broadly similar sequence of events was earlier-on described by the Professor in the Zaria region, and by several others from other parts of Nigeria (e.g. Bond, 1949, Thorp, 1970).

3.4 CLIMATE

The area has a semi-arid (northern part) to sub-humid (southern part) tropical climate explicable in terms of the seasonal shifting of a transient discontinuous zone, the Inter Tropical Discontinuity (I.T.D.), where unlike air masses converge. To the north of the area, the continental Sahara area generates more or less permanent high pressure belt, resulting in north-easterly commonly dust laden winds (Harmattan)on the southern flank. These winds, at the surface, are cool and typically dry, contrasting strongly with the mositure-laden south-westerly winds that orginate from the high pressure cells over the South Atlantic.

The contrasting air masses progress seasonally north and south, in response to the sun's apparent annual movements, drawing with them the ITD. The position of this zone, although subject to considerable short period fluctuations, is generally situated at approximately 8°N in January and at nearly 20-22°N in July (Fig. 3.4.). Thus the ITD crosses the study area twice a year; one on its northward journing and again during the southward journing, and most of the climatic parameters (i.e the onset of rains, annual amount, time of retreat, length of rainy season and temperature) are broadly associated with this movement (Ogunteriba, 1983; Agboola, 1979).

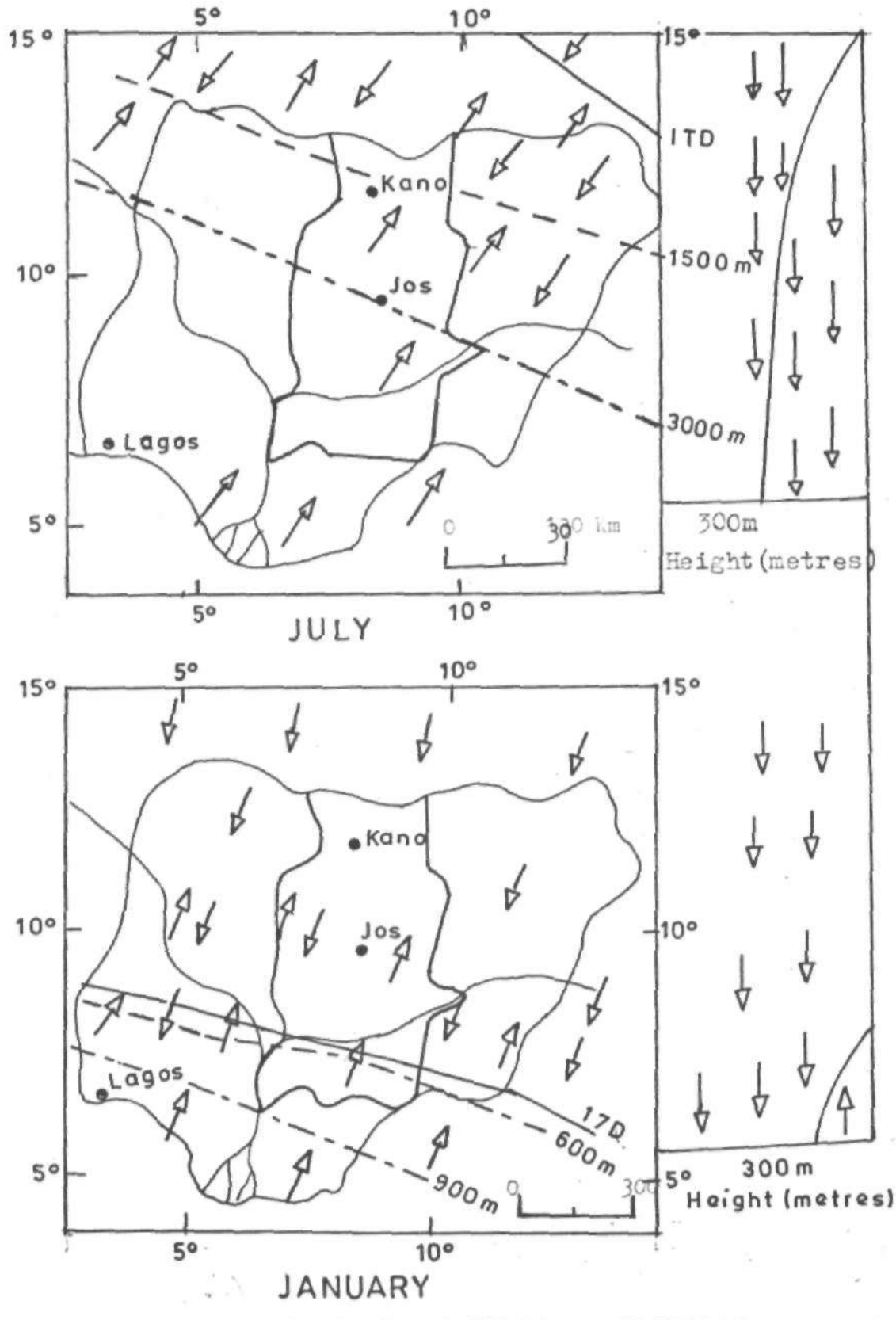


FIG.3·4 : SECTION OF I.T.D. ACROSS NIGERIA
(after Oguntoyinbo 1983)

3.4.1 Temperature

Temperatures over the study area are generally lowest during the months of December-January (but rarely fall below 20°C), as the amount of energy coming from the sun is lowest during that period and there is much back radiation at night. From February onwards, temperatures start to rise, due to increasing radiation from the sun. The highest temperature occurs at about the onset of the rains, i.e. April-May. During the rainy season itself however, maximum temperatures are depressed, due to cloudiness and the cooling effect of the rain. Minimum temperatures are relatively high and constant during the rainy season as cloudiness and humidity prevent back radiation. After the rains, maximum temperature increases again at first, declining later to the dry season level. Figure 3.5 shows the mean annual temperature distribution over the study area (Kowal & Knabe, 1972).

3.4.2 Rainfall

Figure 3.6 shows the mean annual rainfall distribution for the study area. There is a fairly regular south-north gradient of decreasing rainfall, from about 1,770 mm in the South to less than 650 mm in the extreme north, modified locally by the influence of high ground (Kowal & Knabe, 1972). The Jos Plateau for example induces an increase of rainfall on its South and West margins, with a corresponding decrease in the rain shadow areas to the North and East (Bauchi-Numan axis).

Rainfall in the area are characterized by high intensities and kinetic energy, and relatively big drop sizes (Lal, 1977). The distribution of a maximum 7.5 minute intensity recorded for Samaru in the Zaria region in 1976 for example showed that only 29% of the storms received had an intensity that was less than 25mm hr^{-1}.

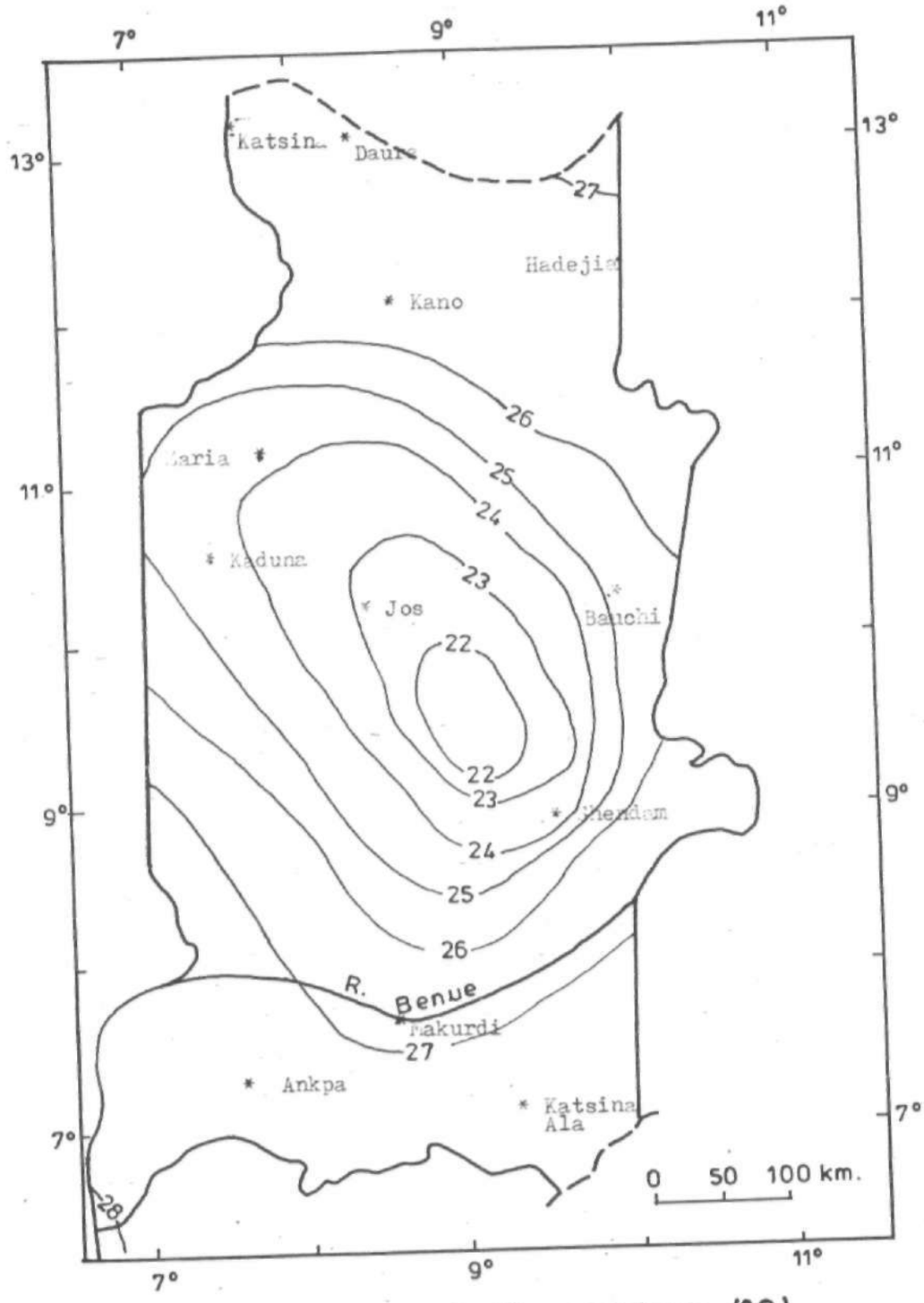


Fig. 3·5 Mean annual Temperature (°C)

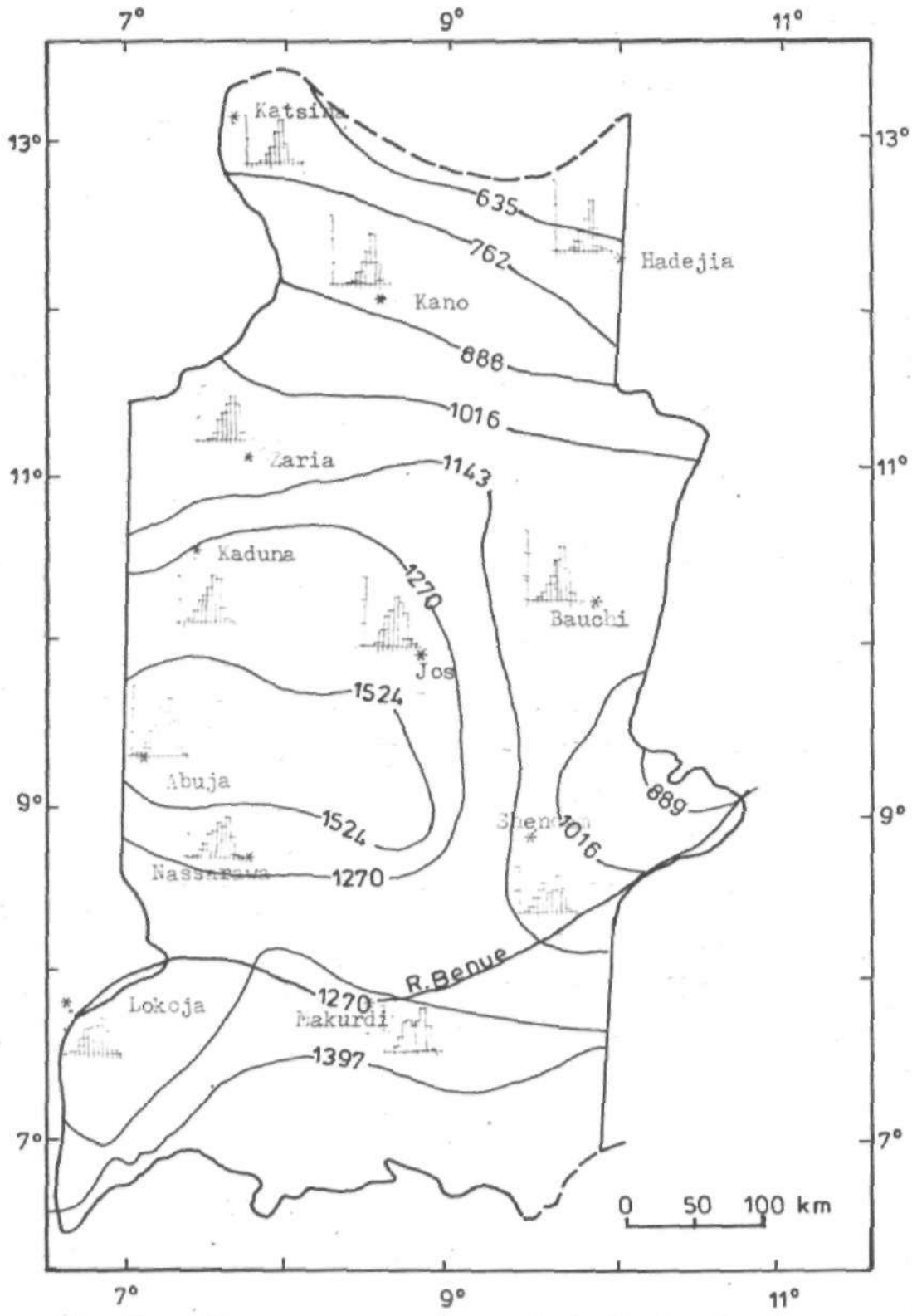


Fig. 3·6 Mean annual rainfall (mm)

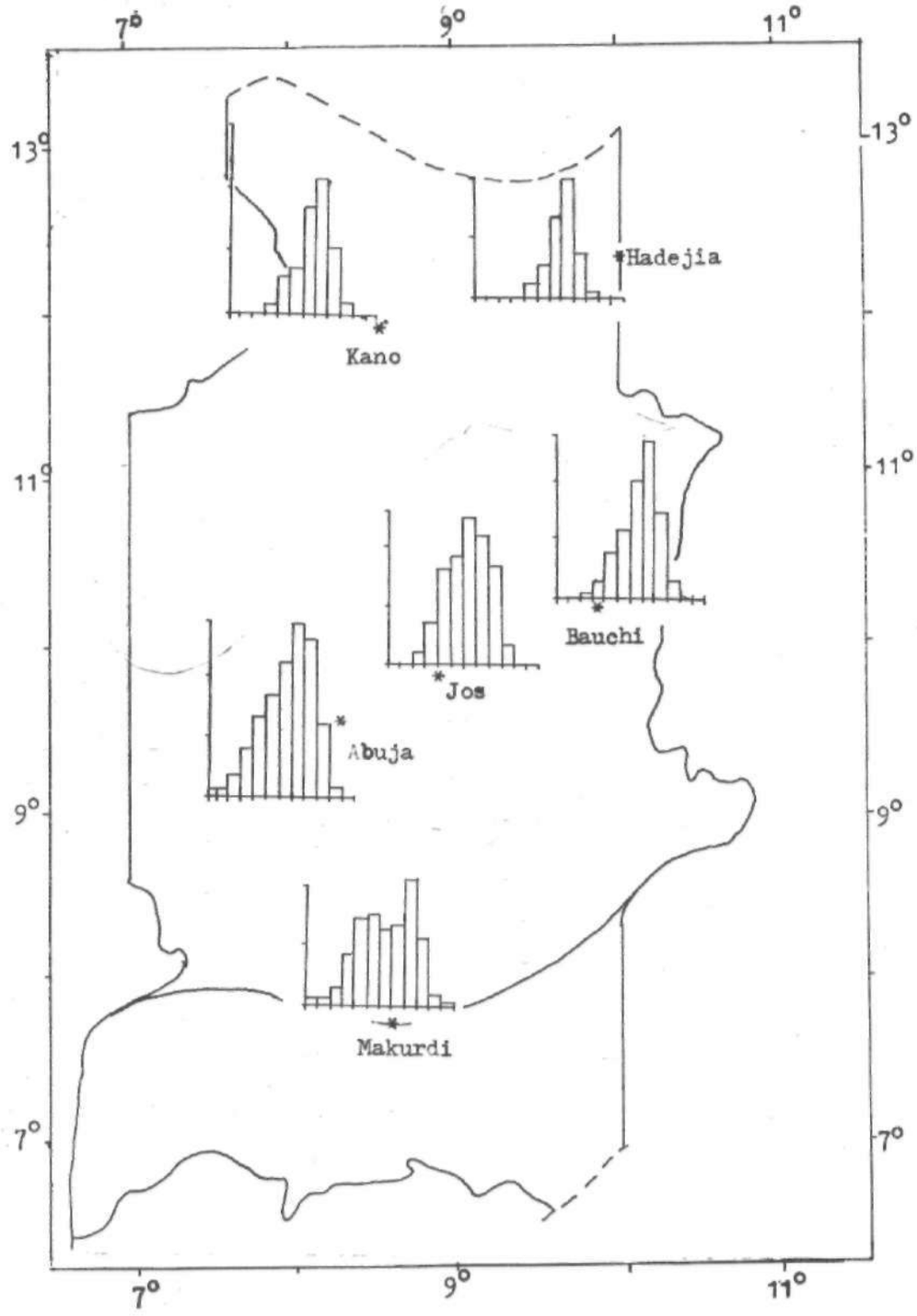


Fig. 3.7 Montly rainfall distribution of selected stations

As much as 61% of the storms fell at intensity between 25 and 74mm hr^{-1}. In all, 35% of the rains fell at intensity exceeding 50mm hr^{-1}. (Kowal & Kassam, 1976). Also at Samaru, a 20mm rainstorm with a peak intensity of 111mm. hr^{-1} has been found to possess a total energy load of 31.6 to 38.4 Joules $m^{-2}mm^{-1}$ of rain (Kowal & Kassam, 1977).

In the extreme north of the area, the mean monthly rainfall distribution shows a single peak, occuring at about August, and a raidless period of over 9 months. Further south, there is a bi-modal rainfall pattern with peaks in June/July and September/October, and a 3 to 4 month dry season (Fig.3.7). Even much more meaningful to pedogenesis is the effective rainy period, Kowal and Knabe (1972) defined this period as the number of decades (10-day period) between the effective start of rains (when rainfall is greater than 25.4mm and with two subsequent decades of precipitation greater than half evapotranspiration) and the end of rains (the last decade in the rainy season with at least 12.7mm rainfall and evapotranspiration in the previous decade not less than precipitation). Based on the author's extrapolations for the whole of northern Nigeria, the value of rainy period should vary from about 230 days in the extreme south-east to less than 90 days in the extreme north, over the study area (Fig. 3.8).

Although the length of time moisture is available in the soil is more important to the pedogenic processes than the total amount of water which is received in an area, over the present study area, the spatial variabilities of both the mean annual rainfall amount and the length of rainy period are sufficently close to justify the use of the former in this project (Figs.

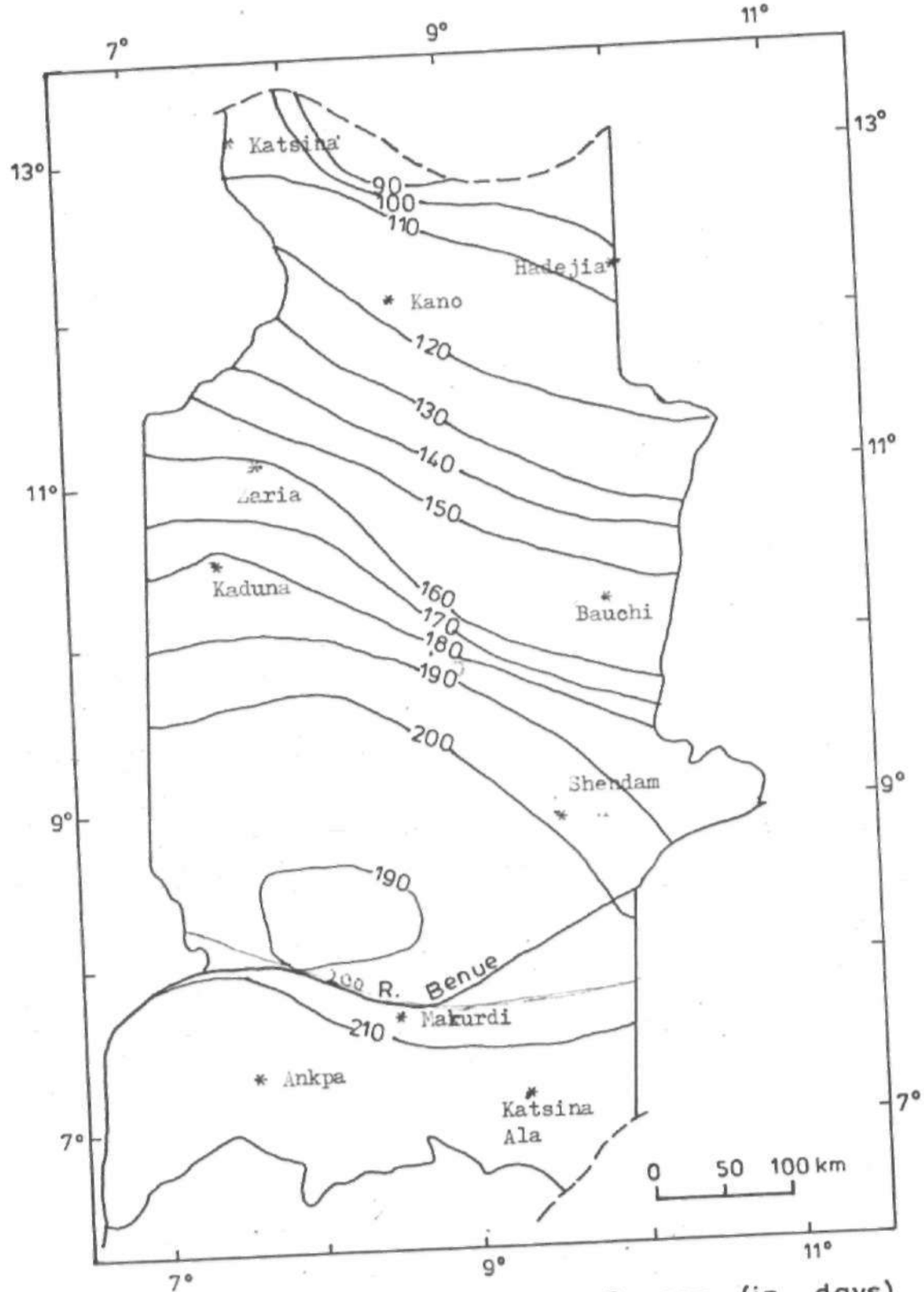


Fig. 3·8 Length of the Rainy Season (in days)

5. NET PRIMARY PRODUCTIVITY AND VEGETATION COVER

The net primary productivity of vegetation of an ecosystem refers to that productivity which in theory can be utilized by other organisms. It equals the rate of photosynthesis (dry-matter production or gross primary production) minus the rate of plant respiration (Billings, 1976). The pedogenic significance of this part of plant produce rests on the fact that the bulk of the organic matter component of the soil comes from this source.

In tropical environments where mean temperatures are high, much of the gross primary production is lost in respiration (Whittaker, 1970; Kormondy, 1976). For Nigeria, with mean annual temperatures ranging from about 20°C to 30°C (Oguntoyinbo, 1983) for example, as much as 35% to 68% of the gross primary production is consumed by respiration (Ologe, 1979).

Data on actual net primary productivity in the tropics are very scanty. This is more so for the savanna region. Several attempts have been made by ecologists to assess the average annual rate of net primary production in the world major ecosystems. According to Reichle's (1970) estimate, average net value in the present study area showed a decrease from about 5,520 Kcal m^{-2} yr^{-1} in the wetter south to less than 920 kcal m^{-2} yr^{-1} in the drier extreme north.

Based on the energy conversion efficiency, and the amount of total incoming radiation during the growing period, Kowal and Kassam (1976) have suggested the net primary production rates for the major bio-climiatic regions of the West African Savanna to be as follows:

Northern Sahel = 1,082 kg/ha yr^{-1}

Southern Sahel = 1,742 kg/ha yr^{-1}

Sudan = 2,324 kg/ha yr^{-1}

Northern Guinea = 3,097 kg/ha yr^{-1}

Southern Guinea = 3,889 kg/ha yr^{-1}

The suggested south to north decrease is supported in a study by de Leeuw, (1976) of fodder resources in Nigeria east of Longitude 10°E and north of the River Benue. The dry matter yield of the rangeland types in the area was measured at the end of the growing season and found to vary from about 4000kg/ha in the south to about 200kg/ha in the North.

There are several problems associated with the above sets of data which make their comparability rather difficult. Firstly, those derived from field experimentation do not relate to the whole of the plant component of the ecosystem. Secondly, those based on estimation were derived by different methods and thirdly, there are differences in the units of measurement. Nevertheless, they are consistent in indicating that there is a clear south-north decrease in net primary productivity in the study area and that the value is considerably higher in the southern part than in the northern part.

The importance of vegetation in soil formation lies not only in the provision of the bulk of the organic component of the soil solid phase, but also in the protection it offers, through the canopy and litter fall, against direct insolation and raindrops. The root system, particularly adventitious roots, are also known to play an important role in the physical constitution of the soil materials (Daji, 1970).

Four principal latitudinal vegetation zones, which may be correlated with the climate sequence from south-north, may be discerned in the area, namely, Forest/Savanna mosaic, Southern Guinea Savanna, Northern Guinea Savanna and Sudan Savanna (Table 3.1). In addition to these four, there is the Plateau Grassland (Fig.3.9).

Table 3.1: Climatic/Vegetation Zones of Pedogenetic Significance in the Study Area

Vegetation belt	Mean annual rainfall (mm)	Dry season: Approx. no. of months with 60mm rainfall	Approx. Koppen equivalent
Forest/Savanna mosaic	1200–1800	2–6	A_m p.p.
Southern Guinea Savanna	900–1200	3–5	A_w"
Northern Guinea Savanna	900–1200	5–7	A_w pp.
Sudan Savanna	600–900	6–8	C_{wa} p.p.
Plateau Grassland	900	0–6	C_{fa}

The true climax vegetation in the Forest/Savanna mosaic zone is semi-deciduous high forest (Plate XI). The relatively undisturbed forest has emergent species like Celtis spp. Triplochiton scleroxylon and Chloropbora excelsa and forest scrubs, climbers, forbs and grasses. Cultivation and fire, deliberately started by man, have however reduced much of the forest to high woodland savanna in which trees grow together with tall grasses, almost indistinguishable from the Southern Guinea savanna to the north.

The Southern Guinea savanna zone lies to the north of the Forest/Savanna mosaic.

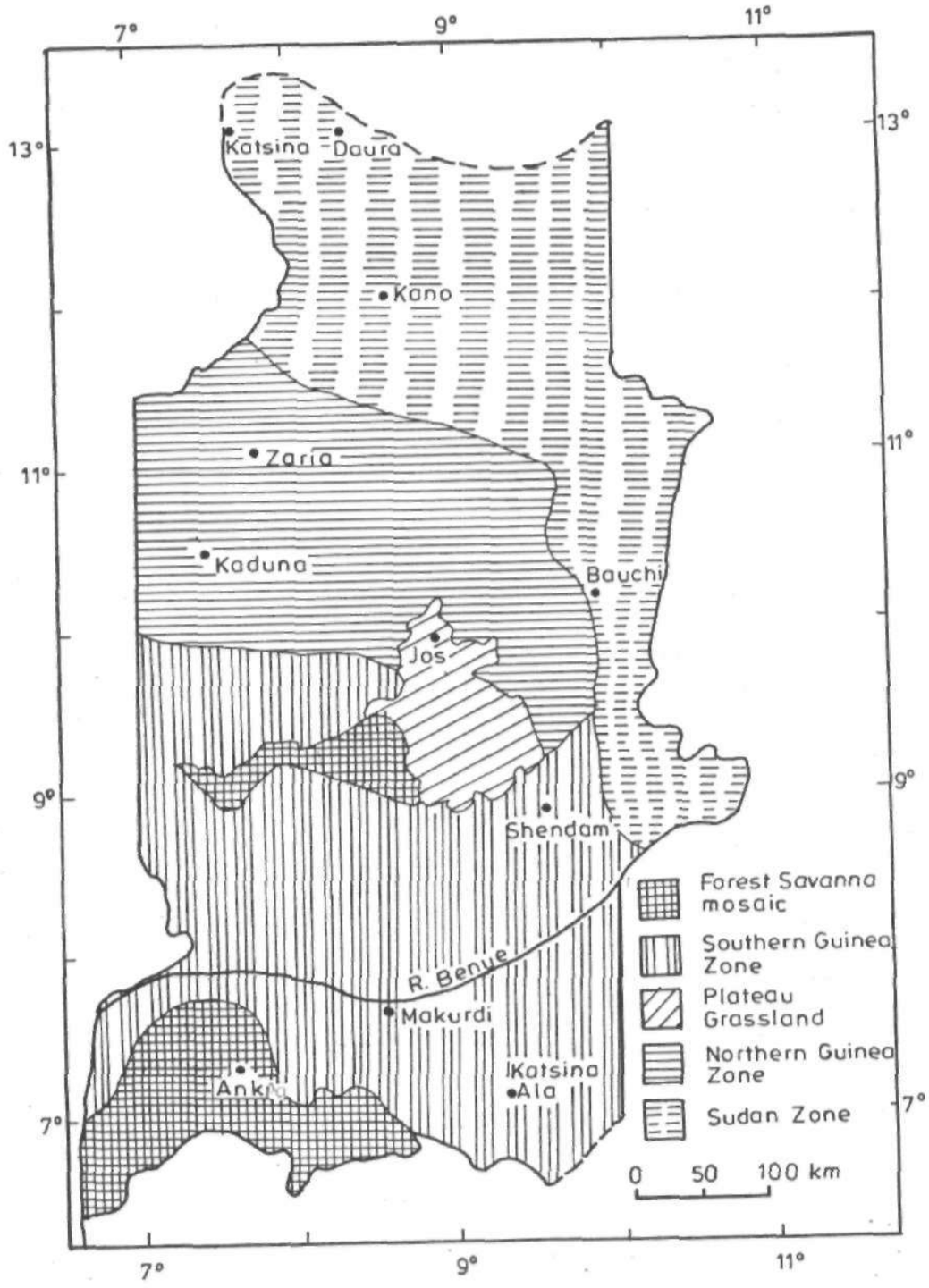


Fig. 3·9 Vegetation Zones



PLATE XI Secondary rain forest, Otukpo --- incidence of fire at the interior of the forest

In densely farmed/settled areas, only economic and shade providing tree species, such as Parkia clappertoniana, Ceiba pentandra, Vitex doniana, Afzelia africana, Daniellia oliveri and Tamarindus indica, are allowed to remain. In the remote relatively uninhabited areas, the tree stratum, which is more dense, is dominated by species such as Isoberlinia doka, Monotes kerstingii and Uapaca togoensis . Grasses in this zone are mostly perennial, growing only in the rainy season and usually in clumps.

The character and life-form of the tree species and grasses in the Northern Guinea zone are quite similar to those in the Southern zone except that they are shorter and the grasses tend to grow mainly in tussocks, with bare ground between them. Similar to the southern Guinea zone, only economic and shade providing trees are allowed to remain on farmlands and in areas close to settlements.

Vegetation in the Sudan zone is composed of grasses with trees or shrubs in very variable proportions. At one extreme may be areas of grass with hardly any woody plant, particularly in areas near settlements, at the other extreme may be trees standing closely in thickets whose foliage merges to form a canopy. The light rainfall and short rainy season cause trees and shrubs to be xerophilous.

The Plateau Grassland occurs largely on the Jos Plateau. The plateau, at an elevation of about 1,220m, has an annual rainfall at Jos of about 1,400mm and a greater probability of of occasional rain showers during the dry season (Oguntoyinbo, 1983).



PLATE XII Re-aforestration programme ——— Eucalyptus Plantation, Jos Plateau

Temperatures are generally lower than in the Northern Guinea zone. Eucalyptus and Pines, planted in plantations, are the dominant tree species on the plateau (Plate XII).

3.6 SOILS

Based on the FAO genetic classification system, four major groups of soils can be distinguish in the area. They are: (i) alluvial soils (ii) regosols (iii) ferralsols and (iv) ferruginous tropical soils (Areola, 1983) (Fig. 3.10).

Extensive allivial soils are found along the major river valleys such as those of the Niger, Benue, Kaduna and Gongola, while smaller deposits (Fadama) are to be found along the small rivers.

The regosols occupy the north eastern portion of the area. They are brown to grey brown, coarse sandy soils developed on sand drift and continental sedimentary deposits. They are often characterized by iron concretions in the weathering profile.

The ferralsols are reddish yellow in colour and cover the southern part of the area. They are associated with areas of sedimentary rocks, although they are not completely confined to these. They are intensively leached and contain very limited reserves of weatherable minerals. The soil are characterized by deep porous sandy loam or loamy sands, with the clay content increasing gradually with depth and, the soil reaction strongly acid.

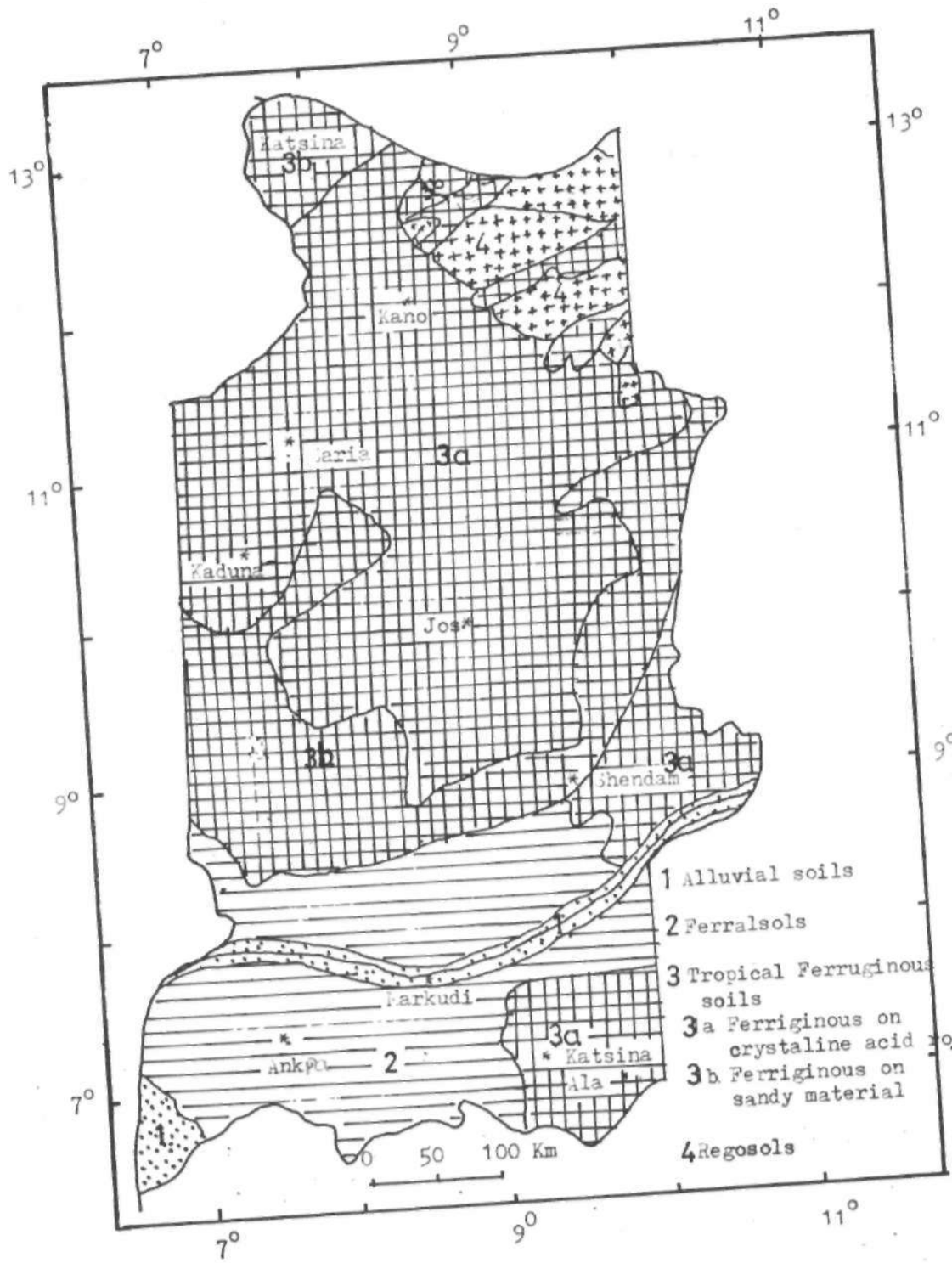


Fig. 3.10 Soils

The ferruginous tropical soils cover the greater portion of the area. The soils are derived mainly from the Basement Complex and old sedimentary rocks, although in the Bauchi area they are developedon drift material covering both these types of rocks. In the more humid Forest/Savanna mozaic zone, the soils are generally deeper, more moist and less prone to develop massive ironstone layers until deforestation has exposed the land to direct insolation.

The soils have low to medium organic matter content, moderate to good water holding.capacity and a friable consistence. But as with most tropical soils, they are intensively leached and therefore are of low natural fertility.

Often associated with the ferruginous soils are the lithosols. They are at their most extensive extent on and around the Jos Plateau, where the topography is steep and irregular.

3.7 LANDUSE

Present day landuse in the area takes different forms, the most widespread of them being arable farming (Fig.3.11), both the intensive and extensive types. The intensive type is widely practiced in the Fadama (particularly during the dry season) and in areas close to settlements (Plate XIII). The extensive type on the other is characteristic of the plains further away from the fadamas and settlements. Under this category, an area is cropped for a number of years, followed by a similar period of bush fallow, i.e. a period during which land is not cropped and in which grass and woody scrubs are allowed to regenerate. Much work has been done on the traditional agricultural systems in Nigeria (Buchana & Pugh, 1955; Morgan, 1959; Mortimore & Wilson, 1964; Udo, 1970; Abumere, 1983).

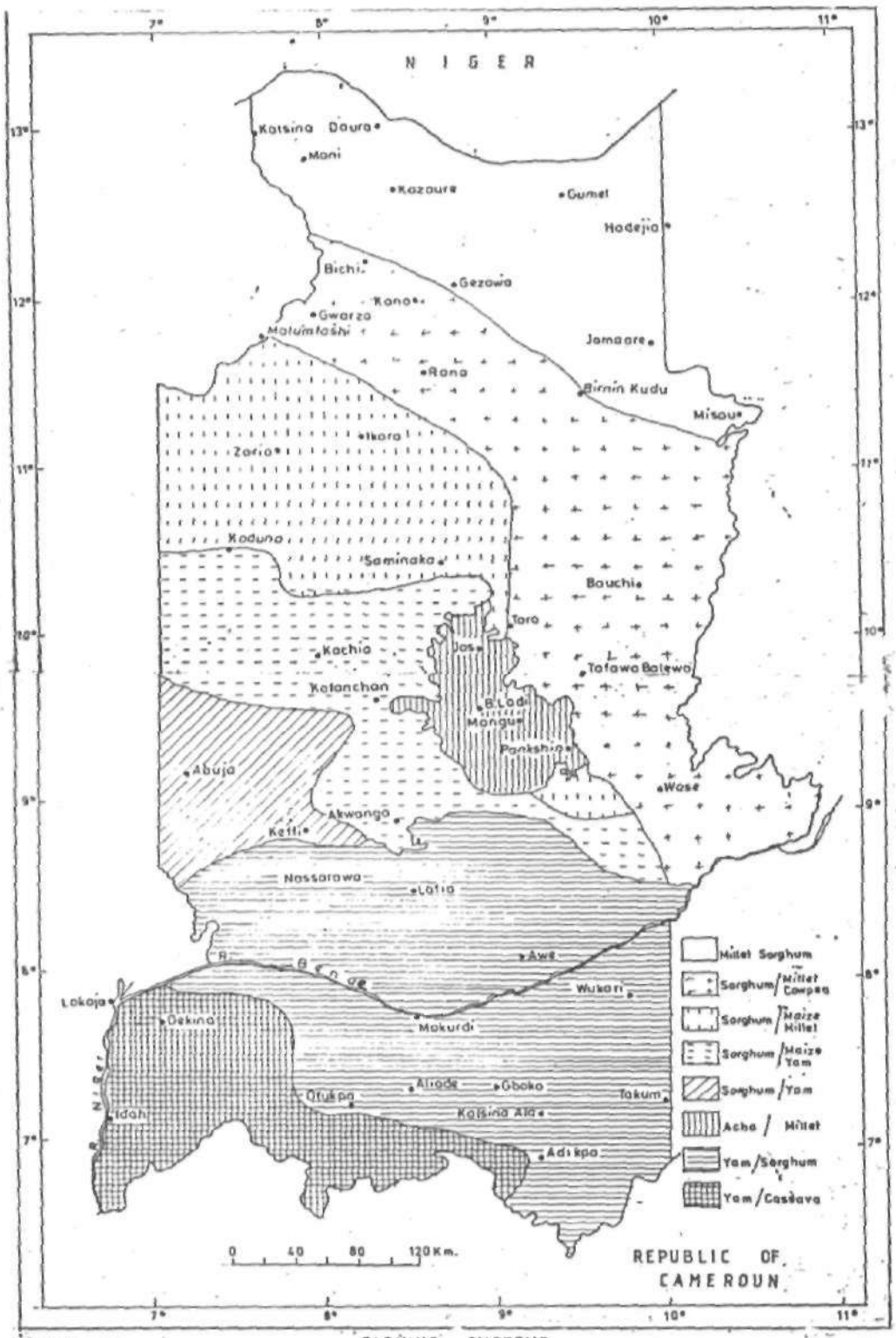


FIG. 3-11 FARMING SYSTEMS



PLATE XIII Dry Season Farming on the fadama, Kano

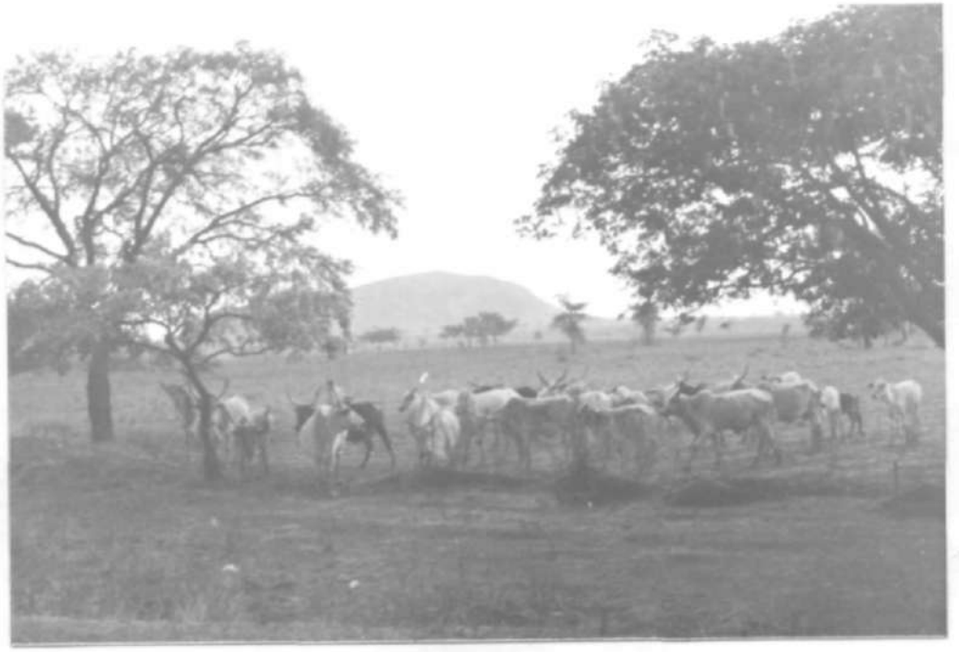


PLATE XIV Animal grazing, Abuja



a



b

PLATE XV (a) Quarrying, Ikara (b) Tin mining activities and landscape, Jos Plateau

They are basically one of small-scale subsistence farming in which cash crops play a small but significant part. The crops are largely rainfed and are cultivated by hand-hoe, assisted in some places by draught animals. Tractors are however beginning to be used in some areas.

Animal husbandary is another major form of landuse in the area. A common sight in the area is the migrant Cattle-Fulani, who wander from place to place, over the plains, in search of pasture, especially on their seasonal trek north (during the rainy season) and south (during the dry season (Plate XIV). On their way, they set fire on perennial grasslands to remove old straw-like materials thereby stimulating new growth for stock to graze. This practice (i.e bush brning), over the years, has had several unfavourable repercussions on the floristic composition of plant cover over the study area, such as the disappearance of several useful perennial species (Hopkins, 1979).

The third major landuse category involves the establishment of settlements, mining and construction of roads, railways, bridges, dams and several other infrastructures (Plate XV). While some old settlements have been abandoned, leaving behind only vestiges, new ones are springing up, particularly along roads and railways.

With the exception of the establishment of forest reserves and plantations, the net effects of the various forms of landuse practice in the study area, over the years, have been to degrade not only the vetegal cover, but also the land surface, as increasingly wider areas are being exposed to agents of weathering and denudation.

3.8 SOIL EROSION

Except in the extreme north, where wind erosion predominates, soil erosion by water is the most widespread in the study area. It occurs during the wet season as the short duration but high intensity rainstorms generate excess runoff. Although less severe than in certain areas in southern Nigeria, where annual rainfall is much greater (Ofomata, 1965; Jeje, 1978) erosion by water in the study area is already posing not only agricultural and engineering problems, but also socio-economic problems as well, in many places. It occurs quite extensively on exposed road cuttings, embankments, faces of borrow-pits, river banks and hill slopes with very little vegetation cover (Plate XVI). The process has been accentuated in many places by man's mis-use of the land, such as indiscriminate cutting of trees, overgrazing, bush burning and continous cultivation of some lands, often without regard to soil capability. For example, the traditional length of fallow period which used to be longer than 10 years has dropped as low as 3 to 4 years in many places. This is too short a period to adequately rebuild soil fertility and in fact, in some of the densely peopled areas, continuous cultivation is now common place not by choice, but by necessrity.

PLATE XVI Soil erosion:

(a) on fallow land, Mani



(b) along roadside, Zaria



(c) along stream-side, Saminaka



CHAPTER IV

RESULTS I: THE TEXTURE OF THE SOILS

4.0 INTRODUCTION

The focus of this chapter is on the particle size-distribution of the soils, both the topsoils (0-15cm) and the subsoils (50-80cm), and the Index of textural differentiation within the soil profile (I_t). It examines the results obtained from the analysis of the relationship between the particle sizes of the soils and the soil-forming factors considered.

4.1 TOPSOILS

4.1.1 The particle size distribution

The frequency distribution of the particle sizes of the topsoils was essentially one with a maximum of sand and minima of silt and clay (Fig.4.1.). Possible explanations for this phenomenon are strong eluviation and colluviation. Eluviation removes the fine particles in a vertical direction and deposits them in the subsoil as illuviated cutans whilst colluviation and lateral eluviation remove the fine particles in a lateral direction (Kowal, 1968a; Leow & Ologe, 1982). It also probably reflects the generally coarse textured nature of the Basement Complex and sedimentary rocks from which the soils were largely derived.

The proportions of the coarse sand (200-2000 microns) and fine sand (50-200 microns) were highly variable but the mean of the latter was generally higher than that of the former.

The silt fraction (2-50 microns) too was highly variable.

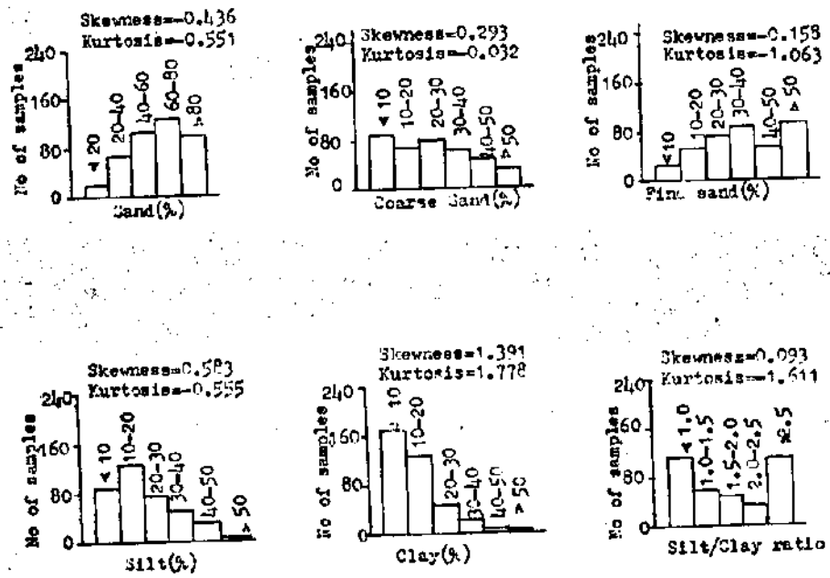


Fig.4.1 The particle-size distribution of the topsoils

Nevertheless, although generally low in the absolute sense, the mean (21.5%) was higher than that reported by Ojanuga (1969 & 1975) and Leow (1975 & 1979) for the soils of the humid tropical lowland of southwestern Nigeria and Singapore, respectively. Consequently, the mean of the silt/clay ratio (2.13) was relatively high. This feature (i.e of relatively high silt/clay ratio) reflects perhaps the influence of aeolian deposition of fine materials over parts of the study area.

4.1.2 Relationships between the soil texture and the soil-forming factors

4.1.2.1 Parent material

Table 4.1 gives the summary of the spatial variation of the particle size of the topsoils over the various parent materials. The sand fraction ranged between a mean value of 78.3% over sandstone to only 40.6% over basalt. It was not suprising to see therefore that analysis of variance revealed highly significant differences in the fraction between the parent materials. When split into coarse sand (200-2000 microns) and fine sand (50-200 microns) subfractions, the fine sand sub-fraction predominated except on granite gneiss where there was a little more coarse sand than fine sand. This may be because of the more efficient breakdown of the less resistant minerals (feldspar in particular) to fine sand (Ollier, 1970), and/or aeolian addition of fine sand. For the transported materials, the aeolian material contained the highest mean fine sand (51.0%) and alluvium the least (40.0%).

Table 4.1: The texture of the topsoils and parent material

Parent Material		SEDIMENTARY							TRANSPORTED				
		Granite	Gneiss	C/Gneiss	Schist	Sandstone	Basalt	Shale	Alluvium	Colluvium	Aeolian	Ironpan	
No of samples		36	32	38	34	36	42	42	30	32	38	22	
Sand(%)	$\bar{x}$	66.9	64.3	67.3	62.5	78.3	40.6	56.6	65.3	69.1	69.5	72.4	****
	S.D	18.2	15.1	13.8	18.9	15.7	17.9	16.6	20.1	20.5	18.5	15.2	
	CV%	27.2	23.5	20.5	30.2	20.1	44.1	29.3	30.8	29.7	26.6	21.0	
Coarse sand(%)	$\bar{x}$	31.1	29.4	35.3	28.5	36.9	19.4	20.4	25.3	23.7	18.5	26.0	****
	S.D	20.9	11.9	14.3	17.6	23.3	12.4	16.9	17.4	10.7	15.2	16.8	
	CV%	67.2	40.5	40.5	61.8	63.1	63.9	82.8	68.8	45.1	82.2	64.6	
Fine sand(%)	$\bar{x}$	35.8	34.9	32.0	34.0	41.4	21.1	36.2	40.0	45.4	51.0	46.4	****
	S.D	16.1	12.5	16.8	14.1	18.5	12.5	14.9	20.1	20.0	25.0	13.8	
	CV%	45.0	35.8	52.5	41.5	44.7	59.2	41.2	50.3	44.1	49.0	29.7	
Silt(%)	$\bar{x}$	52.6	20.2	21.7	22.6	14.7	28.0	26.8	20.3	18.3	19.9	16.5	***
	S.D	14.5	12.5	11.1	14.4	12.3	10.7	13.9	12.2	13.9	11.5	11.2	
	CV%	27.5	61.9	51.2	63.7	83.7	38.2	52.9	60.1	76.0	57.8	67.9	
Clay(%)	$\bar{x}$	10.5	15.5	11.0	14.9	7.0	31.4	16.6	14.4	12.6	10.6	11.0	****
	S.D	6.8	8.1	5.3	7.8	5.4	13.4	9.3	11.6	9.8	9.2	5.4	
	CV%	64.8	52.3	48.2	52.3	77.1	42.7	56.0	80.6	77.7	86.8	49.1	
Silt/clay ratio	$\bar{x}$	2.7	1.6	2.4	1.7	3.1	1.1	2.3	2.1	2.0	2.4	2.2	***
	S.D	1.7	1.4	1.5	1.2	3.0	0.7	1.8	1.8	1.5	1.0	2.0	
	CV%	63.0	87.5	62.5	70.6	96.8	63.6	78.3	85.7	75.0	41.7	90.9	

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05
S.D = Standard deviation; CV% = coefficient of variability percent.

For the silt fraction, differences in the variances of the parent materials were significant at the 0.01 probability level and the mean values ranged between 28.0% over basalt and 14.7% over sandstone in the case of the sedentary materials, and between 20.3% over alluvium and 16.5% over ironpan deposit for the transported materials.

Like the other particle sizes, the clay fraction varies considerably, from a mean of 31.1% over basalt to only 7.0% over sandstone, in the case of the sedentary materials, and from 14.1% over alluvium to 10.6% over aeolian deposits for the transported materials. The differences in the fraction, between the various parent materials, were statistically significant at the 0.001 probability level.

When the total samples considered were broken down according to the four rainfall zones adopted in this study, except for the fine sand subfraction over the first two lowest rainfall zones, and the silt fraction over the third zone, all the particle sizes showed significant differences between the parent materials at all the rainfall levels (Appendix 4). Moreover, for the sednetary parent materials, although there were slight deviations in the relative position of the proportions of some of the fractions for some zones, in all the rainfall zones, soils over basalt and shale were consistently less coarse than those over the other materials, most especially granite and sandstone.

The marked differences in the particle size distribution of the soils selected in this study, over the different parent materials,

could be explained in terms of the differences in the texture and the relative ease of weathering of the mineral grains making up the parent materials (Jackson, 1968; Ollier, 1970; Buol et. al., 1973). The comparatively higher percentage of the clay and silt fractions over basalt and shale is a reflection perhaps of both the fine textured nature of the rocks and/or greater proportion of the less resistant materials, such as pyroxene and amphiboles in the rocks. These contrast with the acid rocks, such as sandstone and granite, which are usually not only coarse in texture but also contain a high proportion of the quite resistant minerals, particularly quartz and muscovite (Buol et. al., 1973).

. 4.2.2.2 Climate

The sand fraction showed highly significant and positive relationship with the mean annual rainfall (Fig.4.2). The regression equation is

Sand % = 98.25014-0.02817 Rm ..... (4.1)

where Rm is the mean annual rainfall (mm)

As suggested by equation (4.1), for every 100mm increase in the mean annual rainfall over the area, the sand content of the topsoils decreases by a mean value of 2.8%. Analysis of variance also revealed significant differences in the sand fraction between the rainfall zones. The fraction varies from a mean of 81.5% in the driest rainfall zone through 61.9% and 61.5% in the second and third zones to 55.5% in the wettest zone (Table 4.2).

Each of the sand subfractions also showed a significant relationship with the mean annual rainfall but while the relationship for the coarse sand was positive, that for the fine sand was negative. The regression lines are expressed by equations (4.2) and (4.3) and indicate that on

$$\text{Coarse sand \%} = 11.8412 + 0.01218Rm \quad \ldots\ldots (4.2)$$

$$\text{Fine sand \%} = 86.40888 - 0.04035Rm \quad \ldots\ldots (4.3)$$

the average, each 100mm increase in mean annual rainfall in the study area results in a 1.2% increase and a 4.0% decrease in the coarse sand and the fine sand contents of the topsoils respectively.

Again, by the analysis of variance, it was established that differences in both the coarse sand and the fine sand sunfractions between the rainfall zones, were highly significant and the impression on the whole was one of an increase in the former fraction and decrease in the latter, with increase in rainfall.

The regression of the silt and clay fractions on rainfall was positive. While the relationship was significant at the 0.01 probability level for silt, however, it was at the 0.001 level for clay. As suggested by equations (4.4) and (4.5), on average,

$$\text{Silt \%} = 10,43586 + 0.00909\ Rm \quad \ldots\ldots\ldots\ldots (4.4)$$

$$\text{Clay \%} = 9,00806 + 0.01932\ Rm \quad \ldots\ldots\ldots\ldots (4.5)$$

each 100mm rise in the mean annual rainfall over the study area results in about 0.91% and 1.9% increase in the silt and clay contents of the topsoils respectively. By analysis of variance, both fractions also showed statistically significant

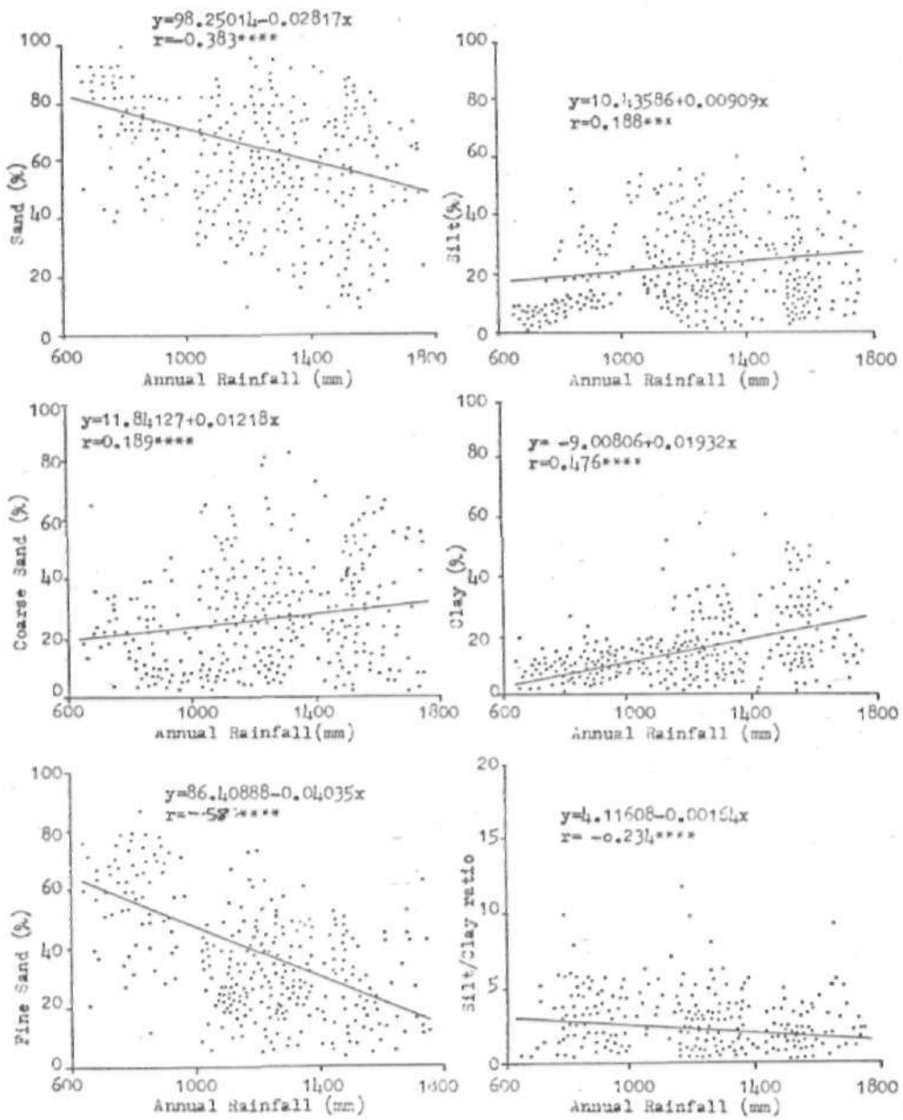


Fig.4.2 The texture of the topsoils and climate

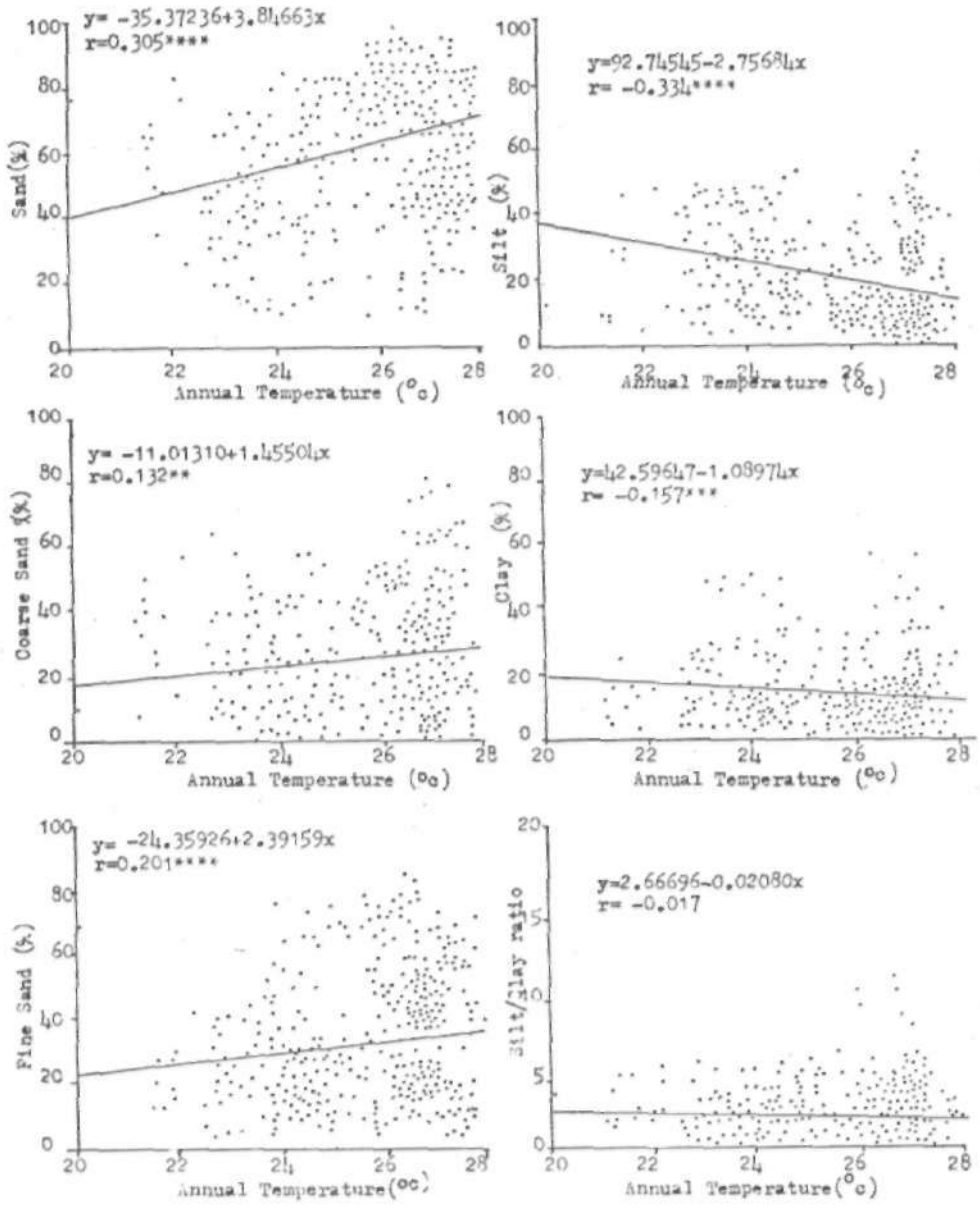


Fig.4.2(cont.) The texture of the topsoils and climate

Table 4.2: The texture of the topsoils and climate

Climatic factor		Rainfall (mm) 600-900	900-1200	1200-1500	1500-1800	Temperature (°C 20-25	25.27	27-28
No of samples		71	103	130	78	108	122	148
Sand(%)	$\bar{x}$	81.5	61.9	61.5	55.5****	52.8	71.3	66.4****
	S.D	11.4	45.5	19.7	23.1	16.8	18.0	20.0
	CV%	14.0	73.5	32.0	41.6	31.8	25.2	30.1
Course sand(%)	$\bar{x}$	18.6	26.6	30.0	28.1****	22.5	26.6	29.6**
	S.D	11.8	17.5	18.0	18.6	15.0	14.4	20.4
	CV%	63.4	65.8	60.0	66.2	66.7	54.1	68.9
Fine sand(%)	$\bar{x}$	62.9	35.3	31.5	27.4****	30.3	44.7	36.8****
	S.D	12.6	13.9	15.7	13.2	16.5	22.3	14.8
	CV%	20.0	39.4	49.8	48.2	54.5	49.9	40.2
Silt(%)	$\bar{x}$	12.5	25.8	22.3	22.5***	29.3	16.7	19.7****
	S.D	8.5	12.2	13.6	13.2	11.8	11.4	13.4
	CV%	68.0	47.3	61.0	58.7	40.3	68.3	68.0
Clay(%)	$\bar{x}$	6.0	12.3	16.2	22.0****	17.9	12.0	13.9*
	S.D	4.0	7.1	10.8	13.5	11.2	10.2	10.8
	CV%	66.7	57.7	66.7	61.4	62.6	85.0	77.7
Silt/clay ratio	$\bar{x}$	2.5	2.7	1.9	1.4****	2.2	2.0	2.2
	S.D	1.6	2.3	1.8	1.3	1.4	1.4	2.0
	CV%	64.0	85.2	94.7	92.9	63.6	70.0	90.9

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** 0.02; * = 0.05

differences between the rainfall zones. For clay, the mean values vary from 6.0% in the lowest rainfall zone, through 12.3% and 16.2% in the second and third zones, respectively, to 22.0% in the wettest zone. Such trend in the fraction with rainfall may be attributed to an increase in chemical weathering and clay formation, with increase in rainfall. The trend of the means of the silt fraction with the rainfall zones on the other hand, although also positive on the whole, was less systematic, as the highest value occured in the second rainfall zone. Like the clay fraction, the positive correlation of the silt and rainfall may be as a result of an increase in chemical weathering with increase in rainfall. The quite similar values of the fraction within the third and fourth rainfall zones however suggest, perhaps, an increasing transformation of the fraction into clay as rainfall increase.

In a way similar to the particle sizes of the soils, the regression of the silt/clay ratio on the mean annual rainfall was highly significant (0.001 level), and the trend negative, Differences in the means of the ratio between the rainfall zones were also quite significant statistically.

When the effect of rainfall on the particle sizes of the soils were examined over similar parent materials, the result obtained showed considerable variability. As can be seen in Appendix 5, while some of the mineral fractions showed a certain degree of significant correlation with rainfall over the igneous and metamorphic rocks of gneiss, granite-gneiss and schist, as well as on the transported parent materials,

for example, there was virtually no statistically significant relationship between any of the fractions and rainfall over sandstone. Furthermore, only the fine sand fraction showed a significant relationship with rainfall over shale, and clay over basalt. These relationships are not fully understood but could be as a result of the much stronger influence of the mineralogical composition and textures of these lithologies, on the texture of the resultant soils.

The correlation coefficient values for the silt/clay ratio vary over the different parent materials. It was interesting however that all the values were negative; implying, perhaps, a universally increasing weathering rate with increasing rainfall over all the parent materials.

When examined against the background of the slope position, except for the silt fraction, the regression of the particle sizes on rainfall showed quite high and statistically significant correlation coefficient values (0.001 probability level each) at both the interfluve crest and the middle slope positions. At the lower slope position however, the correlation coefficient values were quite low and as such non-significant statistically, except for fine sand and clay (each at the 0.05 level).

Except in the basal area, where the correlation coefficient for the coarse sand fraction was negative, and that for the silt positive, the overall picture was still that of increasing coarse sand and clay, and decreasing fine sand and silt, with increasing mean annual rainfall, over all the slope positions.

The strength of the correlation coefficient values of the silt/clay ratio and rainfall followed similar downslope trend. That is, the relationship between the ratio and rainfall was significant at both the crest and middle slope positions but not signicifant in the basal area.

The regression of the sand fraction, and those of the coarse sand and fine sand subfractions, on the mean annual temperature was positive and, except for the coarse sand, statistically significant (Fig.4.2). By analysis of variance , differences in each of the fractions between the temperature zones were also quite significant (Table 4.2).

The regression of the silt and clay fractions on the mean annual temperature, although also significant, was negative. By analysis of variance, differences in the means of each of the fractions between the temperature zones were also significant, at the 0.001 level for silt and 0.05 level for clay.

The observed positive trend in the sand fraction and the negative trend in the silt and clay with temperature for the topsoils over the study area were contrary to Jenny's (1941) observation in the Central United States, where differences in temperature is more marked, of increased finer fractions and decrease in coarse fractions with increased temperature, which he attributed to an increase in chemical weathering and clay formation with increase in temperature.

When the relationship between each of the particle sizes and the mean annual temperature was examined under similar parent materials and slope positions, the results obtained showed that, just as with rainfall, the effect of temperature on the particle sizes varies considerably (Appendix 5). There were however no such marked differences in the strength of correlation of the particle sizes with the factor between the upper slope positions and the basal positions, as was observed with rainfall.

4.1.2.3 Relief

As the scatter diagrams in Figure 4.3 indicate, the regression of the various particle sizes on altitude was quite significant (at the 0.05 level for coarse sand and 0.001 level each for the other particles). The general trend was that of decreasing sand fraction and increasing silt and clay with altitude. The simple regression lines are expressed by equations (4.5), (4.6) and 4.7) and indicate that on average, every 100m rise in altitude in the study area is associated with about 7.5% decrease in the sand fraction of the topsoil and 3.7% and 3.9% increase in the silt and clay, respectively.

$$\text{Sand \%} = 76.39742 - 0.00754\ \text{Al} \quad \ldots\ldots(4.5)$$

$$\text{Silt \%} = 15.39142 + 0.00372\ \text{Al} \quad \ldots\ldots (4.6)$$

$$\text{Clay \%} = 8.10005 + 0.00387\ \text{Al} \quad \ldots\ldots (4.7)$$

where Al is altitude in metres

Analysis of variance also showed quite significant differences, except for coarse sand, in the fractions, between the altitudinal zones and the overall picture was again that of decreasing

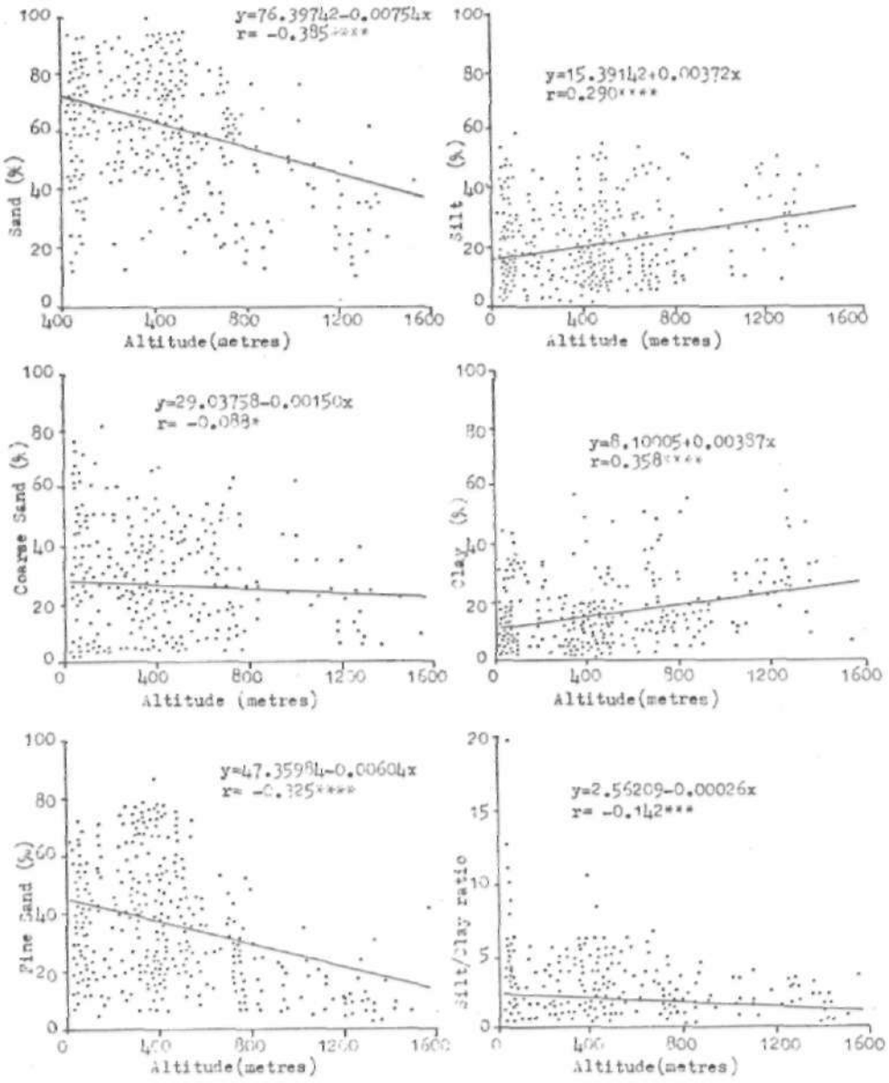


Fig.4.3 The texture of the topsoils and relief

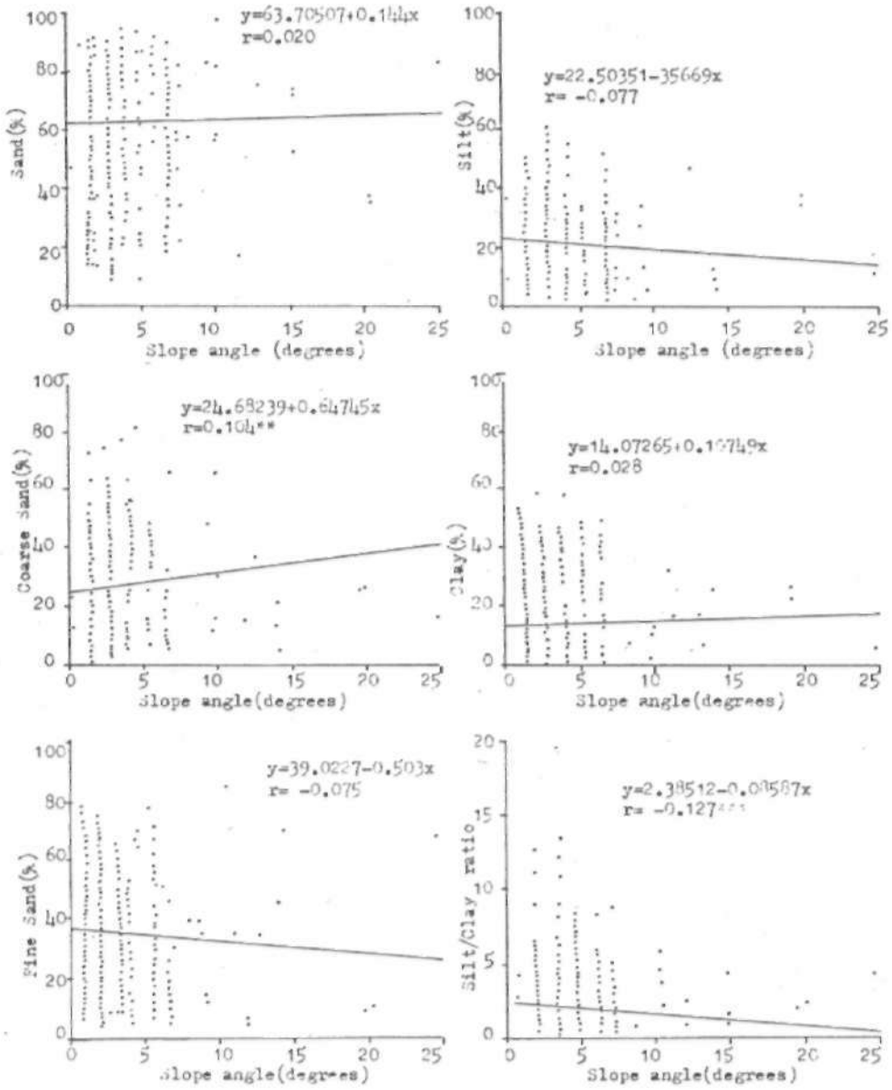


Fig.4.3(cont.) The texture of the topsoils and relief

coarser fraction and increasing finer fractions, following an initial increase for the former and decrease for the latter from the first to the second altitudinal zone (Table 4.3). Such distinctive trend in the particle size distribution of the soils with altitude in the region could be due to more rainfall, greater deposition of aeolian materials and older age of landscape, at higher altitude. It could also be a reflection, partly, of the predominance of transported parent materials at lower levels as compared to sedentary at upper levels.

When the relationships between the particle sizes and altitude were examined under the different parent materials and slope positions, the result obtained showed marked deviation from the overall picture described above, both in the trend and in the strength of the correlations of the fractions with altitude. As is observable in Appendix 5, none of the particle sizes showed significant correlation with altitude over sandstone and shale. This may be because these rock types, having been deposited in downwrapped sedimentary basins, are found at heights generally below 600m in the project area. Such distinctive topographic occurrence of the various parent rocks and parent materials was also responsible, possibly, for the differences in the trend of the silt/clay ratio's correlation with altitude over the different parent materials. While the relationships over sandstone, shale and on the transported parent materials were negative and only significant over colluvium, those over granite, granite-gneiss, schist and basalt were positive but non-significant statistically.

Table 4.3: The texture of the topsoils and relief

Relief factor		Altitude (metres)				Slope gradient			Slope position		
		<300	300-600	600-900	>900	<5°	5-10°	>10°	Crest	Middle	Basal
No of samples		110	167	71	34	325	48	8	119	147	116
Sand (%)	$\bar{x}$	67.2	70.3	55.9	40.9****	63.8	66.8	57.8	71.5	64.6	56.0****
	S.D	19.7	17.3	16.8	15.8	20.0	19.0	21.9	16.3	18.2	22.3
	CV%	29.3	24.6	30.1	38.6	31.3	28.4	37.9	22.8	28.1	39.8
Coarse sand(%)	$\bar{x}$	30.4	24.5	24.8	27.3*	26.1	30.6	21.2	29.3	26.0	24.0**
	S.D	21.3	15.8	15.6	11.3	18.1	12.6	10.8	19.0	17.2	15.5
	CV%	70.3	64.5	62.9	41.3	69.3	41.1	50.9	64.8	66.1	64.6
Fine sand(%)	$\bar{x}$	36.8	45.8	31.1	13.6****	37.7	36.2	36.4	41.6	38.6	32.0***
	S.D	14.4	19.9	12.1	9.2	18.7	18.8	25.4	19.1	17.9	15.8
	CV%	39.3	43.4	38.9	67.6	49.6	51.9	69.8	45.9	46.3	49.5
Silt (%)	$\bar{x}$	19.7	18.3	26.2	32.9****	21.8	19.0	23.6	18.3	22.1	23.8***
	S.D	13.8	11.4	12.2	11.0	13.0	13.3	14.9	11.7	13.1	13.8
	CV%	70.1	62.3	46.6	33.4	59.6	70.1	63.4	63.9	59.2	57.9
Clay (%)	$\bar{x}$	13.0	11.4	17.9	20.2****	14.4	14.1	18.2	10.2	13.3	20.2***
	S.D	10.0	9.4	11.0	11.8	11.4	8.3	9.4	7.8	9.3	13.1
	CV%	76.9	56.1	61.5	45.0	79.1	58.9	50.0	76.4	69.9	64.9
Silt/cay ratio	$\bar{x}$	2.4	2.1	2.0	1.5	2.2	1.6	1.7	2.5	2.3	1.6***
	S.D	2.0	1.4	1.5	0.9	2.0	1.3	1.4	2.4	1.8	1.2
	CV%	83.3	66.7	75.0	60.0	90.9	81.3	82.4	96.0	78.3	75.0

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05

In the case of slope position, although highly variable too, there were no distinctive contrasts in the degree of correlation of the particle sizes with altitude between the upper slope position and basal area as was observed for rainfall. Nevertheless, the relationship between the various particle sizes and altitude over each of the slope positions was that of decreasing coarser fractions and increasing finer fractions with altitude. The only exception was the coarse sand subfraction over the basal slope positions that showed a positive, though statistically insignificant, correlation coefficient.

Although non-significant over the interfluve crest, the silt/clay ratio showed some degree of negative and significant relationship with altitude over the middle and basal slope positions, suggesting an increasing weathering rate downslope.

As is observable in Figure 4.3, while the regression of the sand fraction, coarse sand subfraction and clay fraction on slope gradient was positive, those for the fine sand and silt was negative. The relationship was however significant only with respect to coarse sand. This was partially supported by the results obtained in the analysis of variance, in which none of the fractions revealed statistically significant differences between the three slope gradient classes adopted in this study (Table 4.3). Such lack of significant relationship between the various particle sizes, except coarse sand, of the topsoils and slope gradient may be a reflection, essentially, of the generally relatively gentle sloping terrains prevailing over much of the area (3.3.1).

The silt/clay ratio showed negative but non-significant relationship with slope gradient.

Differences in the means of the sand fraction between the slope positions, were statistically significant at the 0.001 probability level and vary from 71.5% at the interfluve crest through 64.6% at the middle position to 56.0% at the basal area. When split into coarse sand and fine sand, the pictures obtained were still very much the same, except that the variances of both the subfractions, for the slope positions, were less significant statistically (0.05 level for coarse sand and 0.01 for fine sand).

Differences in the silt and clay fractions between the slope positions were also quite significant. Unlike the sand fraction and subfractions however, they were both marked by a downslope increase, from 18.3% at the crest through 22.1% at the middle position to 23.8% at the basal position for silt, and from 10.2% through 13.3% to 20.2% for clay (Table 4.3).

In contrast to the overall picture with slope position, when the samples were split into the four rainfall zones adopted in this study, only some of the fractions revealed statistically significant differences between the slope positions over each of the rainfall zones (Appendix 6). In spite of that however, with the exception of the driest rainfall zone where the mean of the fine sand was higher, and those of the coarse sand and silt lower over the middle slope position, than the others, the general picture, was that of a downslope decrease in the sand fraction subfractions,

and an increase in the silt and clay fractions.

4.1.3 The relative importance of the soil-forming factors in determining the spatial variability of the soil texture.

In Table 4.4 is shown the variances of the particle sizes of the soils explicable in terms of the factors considered, and the proportion yet to be explained; using analysis of variance and covariance. With the exception of fine sand and silt, the parent material of the soils accounted for the greatest percentage variance of the different fractions. The proportion of the variance of the fractions explained by the factor ranged between 36.3% for clay and 8.7% for silt.

The percentage variance of the particle sizes explained by the climate factor ranked the highest for the fine sand and silt (24.9% and 10.5% respectively), and the second position for the sand fraction (10.3%) and coarse sand subfraction (8.1%), and the last postion for the clay fraction (7.3%). A breakdown of the figures however revealed that the proportions of the variances of the particle size explained by the rainfall parameter, except for silt, were several times greater than those for temperature.

The percentage variance of the particle sizes explained by the relief factor ranged between 8.3% for clay fraction and 0.9% for the coarse sand subfraction. There were however considerable variations in the relative contributions of the relief parameters. With the exception of the slope gradient however, each of the parameters accounted for over 2% of at least two of the fractions.

Table 4.4: The topsoils **texture: Percentage variance explained by the soil-forming factors considered**

Particle Size		Sand		Coarse sand		Fine sand		Silt		Clay	
Parent Material		25.1		12.7		19.0		8.7		36.3	
Climate	Rainfall	3.2	10.3	7.4	8.1	20.4	24.5	0.6	10.5	6.0	7.3
	Temperature	7.1		0.7		4.1		9.9		1.3	
Relief	Altitude	2.4		0.3		4.4		0.4		4.5	
	Slope gradient	0.2	5.5	0.1	0.9	0.0	5.9	0.5	2.2	0.0	8.3
	Slope position	2.9		0.5		1.5		1.3		3.8	
Total		40.9		21.7		49.4		21.4		51.9	
Residual		59.1		78.3		50.6		78.6		48.1	

4.2 SUBSOILS

4.2.1 The particle size distribution

Except for the silt fractions, the frequency distribution of each of the particle sizes differs appreciably from that in the topsoils. Fine sand subfraction still dominates the sand fraction but in general, the percentages of both the coarse sand and the fine sand subfractions, and thus the total sand fraction, showed a marked reduction, as compared to the topsoils. In contrast to the sand fraction, the clay fraction gave considerably higher values, as compared to the topsoils. Unlike in the topsoils, where over 70% of the total samples considered in this study had clay less than 20%, only about 24% of the samples had less than 20% clay and as high as 97% of the samples had over 30% clay (Fig. 4.4).

The index of textural differentiation ranged between 1.5 and 0.0 and averaged 0.40. Moreover, as much as 21% of the samples had values below 0.21, implying the presence of a textural B horizon, i.e. an horizon with appreciably more clay than some horizon above it (Young, 1976), in virtually all the selected profiles.

The presence of a textural B horizon (B_t), and the marked increase in the clay and decrease in the sand fraction with depth of virtually all the profiles selected for this study, possibly indicate loss of clay from the topsoils by eluviation and accumulation in the subsoils. It may also be due to a decrease in aeolian addition of coarse silt and very fine sand with depth and/or differential weathering, accompanied with greater clay production in the subsoils.

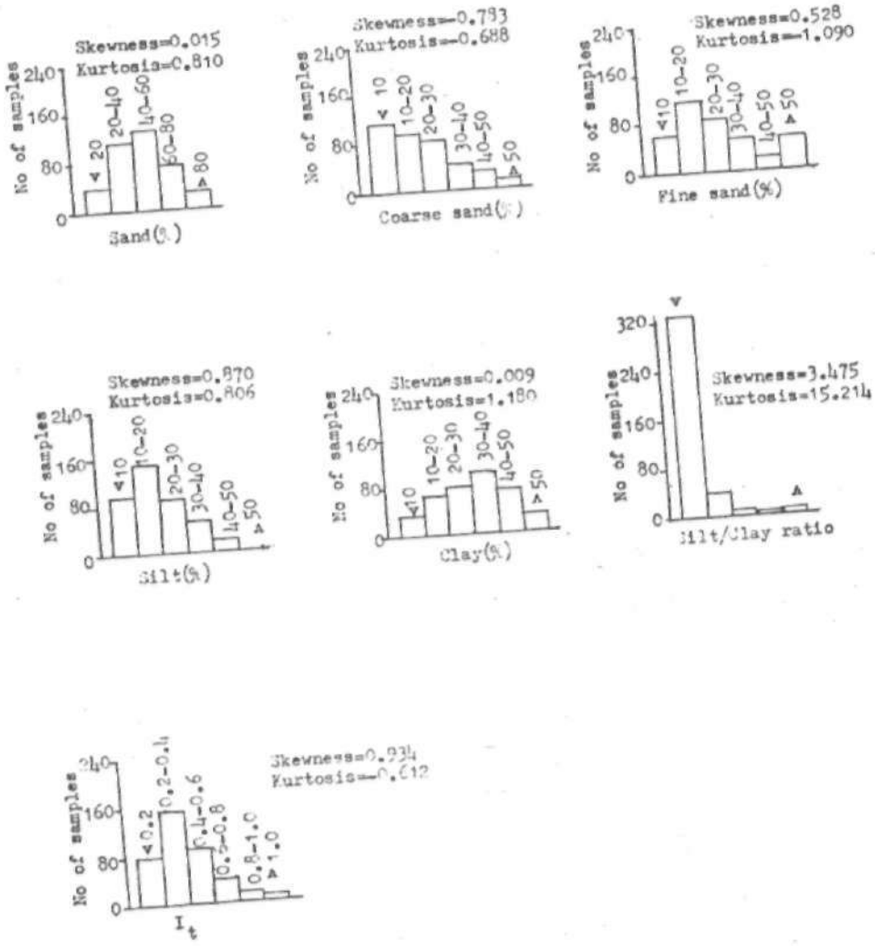


Fig.4.4 The particle-size distribution of the subsoils

Because of the relatively high values of the clay fraction, and the fairly constant values for silt, the silt/clay ratio of the soils showed comparatively lower values, relative to the topsoils. It ranged between 7.67 and 0.04 and averaged only about 0.70.

4.2.2 Relationships between the soil texture and the soil-forming factors

4.2.2.1 Parent material

The differences in the means of each of the fractions, between the parent materials, as in the topsoils, were highly significant. The pattern of the fractions over the transported parent materials and generally for the silt fraction, were quite differents from those for the topsoils. Unlike in the topsoils, soils over aeolian deposit and ironpan were more sandy, less silty and less clayey than those over alluvuim and colluvium. Here in the subsoils, the reverse was the case (Table 4.5). Possible explanation for such discrepancy is that relative to materials of sedementary origin, transported parent materials, particularly alluvium, colluvium and ironpan, are more often than not simply heterogeneous mixtures of materials - ranging in composition from very fine to very coarse, and from less resistent to quite resistant mineral grains. Such mixtures, moreover, tend to occur in distinct layers, each representing a specific episode of distant and/or nearby cycles of erosion and deposition (Ologe, 1978).

For the silt fractions, unlike in the topsoils, there were no marked differences in the mean value between basalt and shale on the one hand, and the granitic rocks on the other and infact, the value was highest over granite (23.5%).

Table 4.5: The texture of the subsoils and parent material

Parent Material		SEDIMENTARY							TRANSPORTED				
		Granite	Gneiss	G/Gneiss	Schist	Sandstone	Basalt	Shale	Alluvium	Colluvium	Aeolian	Ironpan	
No of samples		36	32	38	34	36	42	42	30	32	38	22	
Sand(%)	$\bar{x}$	49.9	47.8	48.7	42.8	61.6	28.9	38.9	61.1	55.9	53.5	51.3	****
	S.D	18.3	15.4	17.5	15.4	20.0	16.5	16.5	18.3	23.0	19.8	26.6	
	CV%	36.7	32.2	35.9	36.0	32.5	57.1	42.4	30.0	41.1	37.0	51.9	
Coarse sand(%)	$\bar{x}$	24.1	22.3	28.4	20.9	30.3	13.9	15.8	28.3	23.0	13.4	18.5	****
	S.D	18.2	13.4	15.5	12.7	18.9	12.5	13.4	15.6	12.8	10.5	12.3	
	CV%	75.5	60.0	54.6	60.8	62.4	89.9	84.8	55.1	55.7	78.4	66.4	
Fine sand(%)	$\bar{x}$	25.8	25.5	20.3	21.9	30.8	15.0	23.2	32.8	32.9	40.1	32.8	****
	S.D	15.6	11.6	14.2	10.1	17.0	11.5	12.3	16.9	20.6	21.9	22.7	
	CV%	60.4	45.4	69.9	46.1	55.2	76.7	53.0	51.5	62.6	54.6	69.2	
Silt(%)	$\bar{x}$	23.5	18.6	20.6	19.1	11.9	22.8	20.7	14.6	15.8	18.5	19.3	***
	S.D.	12.8	9.1	8.7	10.5	9.3	7.5	9.7	8.9	10.5	8.5	12.5	
	CV%	54.5	48.9	42.2	54.9	78.2	32.9	46.9	60.9	66.5	45.9	64.8	
Clay(%)	$\bar{x}$	26.9	33.6	30.7	38.1	26.5	48.3	40.3	23.3	28.3	28.0	29.4	*****
	S.D	10.8	10.8	12.7	12.8	14.7	14.3	13.5	10.8	15.5	13.4	15.9	
	CV%	40.1	32.1	41.4	33.5	55.4	29.6	33.5	46.3	54.8	47.9	54.1	
Silt/ clay ratio	$\bar{x}$	1.08	0.60	0.65	0.63	0.65	0.50	0.59	0.70	0.61	0.72	0.78	**
	S.D	1.06	0.35	0.80	0.60	0.45	0.41	0.37	0.49	0.32	0.27	0.52	
	CV%	98.1	58.3	94.1	95.2	69.2	82.0	62.7	0.7	52.5	37.5	66.7	
I_t	$\bar{x}$	0.35	0.45	0.36	0.36	0.32	0.57	0.42	0.33	0.38	0.34	0.45	****
	S.D.	0.11	0.16	0.18	0.22	0.21	0.22	0.22	0.20	0.18	0.16	0.22	
	CV%	31.4	35.5	50.0	61.1	65.6	52.3	52.4	50.6	47.4	47.0	48.9	

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05

The silt/clay ratio ranged between a mean of 1.08 over granite and 0.50 over basalt for the sedentary parent materials, and between 0.78 over ironpan and 0.61 over colluvium in the case of the transported materials. On the whole, differences between the various parent materials were significant at the 0.02 probability level.

In an apparent similarity to the spatial variability of clay content of the topsoils over the sedentary parent materials, the I_t showed comparatively higher mean values over basalt, shale and gneiss (0.57, 0.42 and 0.45 respectively). Values for the transported materials, however, followed a different pattern. Although clay percent was greatest over alluvium in the topsoils, the I_t mean value was greatest over ironpan (0.45) and approximately the same over the other materials (0.38-0.33).

4.2.2.2 climate

Similar to the topsoils, while the fine sand subfraction and the silt/clay ratio showed a decrease values with increase in rainfall, the coarse sand, clays and silt, showed an increase. Moreover, with the exception of coarse sand, the relationships were all statistically significant (Tables 4.6 & 4.7).

Table 4.6: Simple correlation coefficients between the texture of the subsoils and climate and relief

	Rainfall	Temperature	Altitude	Gradient
Sand	-0.442^{****}	0.234^{****}	-0.278^{****}	0.077
Coarse sand	0.042	0.191^{***}	-0.135^{***}	0.148^{***}
Fine sand	-0.567^{****}	0.113^{**}	-0.215^{***}	-0.038
Silt	0.188^{****}	-0.326^{****}	0.225^{****}	-0.086
Clay	0.481^{****}	-0.087^{*}	0.215^{****}	-0.050
Silt/clay	-0.146^{***}	-0.118^{**}	0.033	-0.066
I_t	0.152^{***}	-0.071	0.122^{**}	0.034

Levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

For the I_t, the relationship with rainfall was positive, suggesting either an increase in chemical weathering rate and clay formation in both the top-and sub-soils, or less illuviation of materials from the surface horizons and accumulation in lower horizons, or both.

Similar to the rainfall factor, all the particle sizes showed significant correlation with temperature and the relationship positive for the coarse fractions and negative for the finer fractions and the silt/clay ratio, as in the topsoils. Analysis of variance also revealed significant differences in the means of each of the fractions, between the temperature zones, although the value for the middle zone is either the least, or the highest, of the three zones.

Table 4.7: The texture of the subsoils and climate

Climatic factor		Rainfall (mm) 600-900	900-1200	1200-1500	1500-1800	Temperature (^{o}C) 20-25	25-27	27-28
No of samples		71	103	130	78	108	122	148
Sand (%)	$\bar{x}$	69.5	45.6	43.3	39.9****	38.6	56.0	48.4***
	S.D	16.0	15.7	20.5	19.1	14.8	21.7	19.7
	CV%	23.0	34.4	47.3	47.9	38.3	38.8	40.7
Coarse sand(%)	$\bar{x}$	19.9	21.7	22.4	20.9	16.4	22.8	23.6***
	S.D	11.5	16.5	16.3	15.1	12.1	13.3	17.9
	CV%	57.8	76.0	71.4	72.5	73.8	58.3	75.8
Fine sand(%)	$\bar{x}$	49.6	23.9	20.9	19.0****	22.2	33.3	24.8**
	S.D	16.1	18.8	12.9	12.4	13.7	22.4	13.4
	CV%	32.5	78.7	61.7	65.2	61.7	67.3	54.0
Silt (%)	$\bar{x}$	11.7	22.7	19.7	19.6***	25.0	15.8	17.1***
	S.D.	7.6	10.2	10.1	10.0	8.9	8.9	10.5
	CV%	64.9	44.9	51.2	51.0	35.6	56.3	61.4
Clay (%)	$\bar{x}$	18.8	31.7	37.0	40.5***	36.4	28.1	34.5****
	S.D	10.7	11.1	15.1	14.4	12.8	16.2	14.8
	CV%	56.9	35.0	40.8	35.6	35.2	57.7	42.9
Silt/clay ratio	$\bar{x}$	0.77	0.84	0.63	0.56	0.81	0.74	0.58**
	S.D	0.69	0.59	0.57	0.52	0.59	0.65	0.44
	CV%	89.6	70.2	90.5	92.9	72.8	87.8	75.9
I_t	$\bar{x}$	0.32	0.37	0.41	0.47****	0.43	0.39	0.38
	S.D	0.16	0.18	0.22	0.24	0.19	0.20	0.22
	CV%	50.0	48.6	53.7	51.1	44.2	51.3	57.9

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * 0.05

Table 4.8: The texture of the subsoils and relief

Relief factor		Altitude (metres) <300	300-600	600-900	>900	Slope gradient <5°	5-10°	>10°	Slope position Crest	Middle	Basal
No of samples		110	167	71	34	326	48	8	119	147	116
Sand (%)	$\bar{x}$	48.1	55.4	40.5	28.5****	47.4	51.9	50.5	54.4	47.9	41.8****
	S.D	19.9	20.8	16.1	13.8	21.2	19.7	18.6	18.9	20.6	21.6
	CV%	41.3	37.5	39.8	48.4	44.7	37.9	36.8	34.7	43.0	51.7
Coarse sand(%)	$\bar{x}$	23.4	22.0	17.8	17.9*	20.4	26.9	18.8*	24.5	21.5	17.4***
	S.D	18.1	14.8	13.4	9.2	15.3	15.0	13.5	16.1	15.9	12.7
	CV%	77.4	67.3	75.3	51.4	75.0	55.8	71.8	65.7	73.9	72.9
Fine sand (%)	$\bar{x}$	24.7	33.4	22.7	10.6****	27.0	25.0	31.8	29.9	26.4	24.5
	S.D	12.4	20.3	11.5	10.0	18.5	16.8	21.4	17.5	17.4	17.2
	CV%	50.2	60.8	50.7	94.3	68.5	67.2	67.3	58.5	65.9	70.2
Silt (%)	$\bar{x}$	17.7	16.8	23.1	24.9****	19.3	17.1	17.6	16.5	19.8	20.9**
	S.D	10.8	9.9	9.7	6.4	10.4	9.9	5.2	10.3	10.1	10.2
	CV%	61.0	58.9	41.9	25.7	53.9	57.9	29.5	62.4	51.1	48.8
Clay (%)	$\bar{x}$	34.2	27.8	36.3	46.5****	33.3	31.0	31.8	29.1	32.3	37.2****
	S.D	14.1	14.7	13.3	12.6	15.3	13.5	15.1	13.5	15.0	15.7
	CV%	41.2	52.9	36.6	27.1	45.9	43.5	47.5	46.4	46.4	42.2
Silt/clay ratio	$\bar{x}$	0.61	0.74	0.79	0.58	0.71	0.59	0.64	0.71	0.72	0.66
	S.D	0.47	0.70	0.70	0.24	0.68	0.39	0.25	0.70	0.61	0.52
	CV%	77.0	94.6	88.6	41.4	95.8	66.1	39.1	98.6	84.7	78.8
I_t	$\bar{x}$	0.36	0.39	0.44	0.47**	0.39	0.41	0.51	0.34	0.36	0.49****
	S.D	0.22	0.19	0.20	0.22	0.21	0.21	0.19	0.19	0.20	0.20
	CV%	61.1	48.7	45.5	46.8	53.8	51.2	37.3	55.9	55.6	40.8

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05

By both the regression analysis and analysis of variance, the relationship between the I_t and temperature was negative. Neither of the statistical tests however found this trend to be statistically significant (Tables 4.6 & 4.7).

4.2.2.3 Relief

In a way similar to the observed trend in the topsoils, there was a tendency for the texture of the subsoils to become less coarse with increase in altitude and downslope. By contrasts, the silt/clay ratio revealed no apparent or consistent trend with either of the factors. The I_t on the other hand showed a significant increase in value with increased altitude and downslope position (Table 4.8).

With respect to slope gradient, as was observed in the topsoils, while both the sand fraction and coarse sand subfraction showed increased values with increase in slope gradient, the fine sand subfraction showed a decrease. The relationships between the fractions and slope gradient was however significant only for the coarse sand. The silt fraction, like in the topsoils, also showed negative but non-significant correlation with slope gradient. Unlike the positive trend in the topsoils, the clay fraction too showed negative trend with the factor. The relationship however, was not significant, statistically.

Neither the silt/clay ratio, nor the I_t values showed statistically significant relationships with the slope gradient factor (Table 4.6 & 4.8).

4.2.3 The relative importance of the soil-forming factors in determing the spatial variability of the soil texture.

Table 4.9: The subsoils texture: Percentage variance explained by the soil-forming factors considered

Particle size		Sand		Coarse sand		Fine sand		Silt		Clay	
Parent material		20.2		14.3		16.6		10.2		23.8	
Climate	Rainfall	7.6	11.5	2.2	4.1	21.3	22.6	1.0	7.5	9.5	10.1
	Temperature	3.9		1.9		1.3		6.5		0.6	
Relief	Altitude	0.9	3.6	0.1	1.9	1.9	2.8	0.1	2.0	1.5	4.4
	Slope gradient	1.0		0.8		0.2		0.4		0.8	
	Slope position	1.7		1.0		0.7		1.5		2.1	
Total		35.3		20.3		42.0		19.7		35.3	
Residual		64.7		79.7		58.0		80.3		64.7	

As was observed for the topsoils, the percentage variance of the particle sizes of the subsoils explicable in terms of the parent material factor was by far the greatest. The only exception was the fine sand subfraction. The subfraction, like in the topsoils, had its largest percentage variance accounted for by the rainfall factor (about 21%). In addition to that, rainfall also played quite a significant role in the variability of the clay fraction and the total sand fraction. About 10% and 8% of the variances of these fractions, respectively, were explained by the factor. Unlike in the topsoils however, the factor accounted for only about 2% of the variances of the coarse sand subfraction (Table 4.9).

The percentage variance of each of the particle sizes explicable in terms of the temperature factor was comparatively lower than for the topsoils, except for the fine sand which showed a value that was almost three times greater.

The percentage variance of the particle sizes accounted for by altitude also showed a marked reduction. Unlike in the topsoils, where the coarse sand and silt were the only two fractions whose percentage variance explicable in terms of the factor was less than 2%, none of the fractions had more than 2% of its variance accounted for by the factor. Similarly, the percentage variance of the fraction explained by the slope position factor only ranged between 1.7% for sand and 0.7% for fine sand.

Except for silt fraction, the percentage variance of the particle sizes of the soils explicable in terms of the slope gradient factor was comparatively higher than in the topsoils.

Nevertheless, the values were also generally low, in comparison to the other factors. The highest was only 1% and that was the sand fraction.

4.3 DISCUSSION

Parent material acts on the particle size distribution of soils mainly through the predominant grain-sizes, and degree of resistance to chemical decomposition. These relate particularly to the relative proportion of sand-size quartz (S_iO_2) grains which are quite resistant to chemical weathering and the ferromagnesian minerals, such as pyroxenes (Ca (Mg, Fe) Si_2O_6) and amphiboles ($Ca_2Mg_5(OH,/Si_4O_{11})$), that weather relatively easily, yielding clay-size materials (Jenny, 1941). Thus a rock type or soil parent material consisting mainly of sterile sand-size quartz grains will give a sandy soil and relatively high silt/clay ratio even under intense weathering. On the other hand, all things being equal, a fine-textured parent rock or material, with more weatherable, less resistant minerals, will give rise to fine-textured soils and comparatively lower silt/clay ratio (Buol et. al., 1973; Young, 1976).

Thus over the present study area, the averages of both the silt and clay fractions, for both the topsoils and subsoils, were relatively higher over basalt and shales which are not only fine in texture but also often quite rich in iron and magnesium-bearing minerals which weather relatively easily. On the other hand, the fractions were relatively lower over granite and sandstone which by definition are made up predominantly of highly resistant and coarse quartz minerals. It could also explain why schist and gneiss, which are usually fine to medium in texture,

contain less quartz, but a higher proportion of ferromagnesian minerals, as compared to the granitic rocks, gave comparatively higher silt and clay percentages, relative to the other basement complex rocks.

In the case of the transported materials, the observed slightly higher silt and clay contents over alluvium and colluvium, relative to the other two, may have been as a result of the richness of the transported regolith in these fractions. Similarly, the generally very high fine sand content over the aeolian parent material reflects presumably the action of the wind involved in the formation of the material, since particle sizes in this range (1.0-0.002mm) are generally believed to be most susceptible to wind transport. According to Cooke & Warren (1973), the fluid threshold velocity (i.e. the critical velocity at which particle movement begins) is at a minimum at about 0.01mm diameter. Below that value, the velocity rises, due to increase in interparticle cohesion and decrease in surface roughness, whereas above it the velocity increases due to increase in particle size.

The significance of rainfall on soil texture hinges around its role as the principal factor affecting the chemistry of the weathering environment. It controls not only the supply of moisture needed for the chemical reactions that are involved in the weathering of minerals, but also determines the removal rate of soluble end-products of weathering (FitzPatrick, 1971; Thomas, 1974). The effect of rainfall on weathering and translocation of materials may also be exercised indirectly via the biophere, particularly the humic substances.

Organic decomposition products, primarily organic acids not only speed up chemical weathering processes and clay mineral production, but also, by forming complexes with the inorganic substances, mainly Fe and Al released by chemical weathering, increase their solubility and mobility (Ollier, 1970).

The observed positive trend in the coarse sand subfraction with the mean annual rainfall may be due to mechanical eluviation of the finer materials down the profile, and therefore, an increasing accumulation of the coarser materials. The negative trend for the fine sand subfraction and the positive for silt, and clay on the other hand could be as a result of the more rapid transformation of the subfraction into finer particles, as rainfall increases. The negative trend for fine sand is also no doubt a reflection of the greater aeolian addition of fine sand (and coarse silt) to the soils in the northern low rainfall areas, as compared to the southern parts with greater rainfall.

In view of the relatively low range of temperature values over the present study area, one possible explanation for increased sand fraction and decreased silt and clay fractions, observed, is the concentration of aeolian deposits in area with the highest temperature. Another explanation might lie in the rainfall pattern, which shows negative relationship with the temperature factor over the region.

This study reveals that altitude is also an important factor governing the spatial variation of the soil texture, its effects being exercised, presumably, indirectly mainly through the rainfall and, perhaps, temperature factors, coupled with erosion and deposition factor.

The increase in the finer materials, particularly clay, downslope, observed in this study, is in conflict with the results obtained by several other workers (e.g. Beckett, 1968; Nye, 1954; Milne, 1936; Swan, 1970 and Morgan, 1973) in which the finer materials were found to decrease downslope and were in most cases attributed to colluviation and lateral eluviation. This may be the case during a period of runoff when all entrained materials are being removed from the foot slope. Field observations in the present study area however rarely reflect such conditions. Rather, slope deposits are usually an admixture of materials, some of which were never entrained, some of which were deposited during runoff period, in most cases due to a change in slope gradient, and the rest of which were deposited presumably as runoff velocities decrease downslope. It is quite probable that this latter factor was responsible for the increased silt and clay fractions of the slope basal area.

The decrease in sand percent downslope may however be in part an apparent one, caused by pedogenesis in place, since over the study area, more water is usually available downslope due to an accumulation of runoff water derived from the surrounding higherlying areas and/or the influence of high water tables (3.1). The result is usually an increase in chemical weathering and clay formation (Young, 1976; Leow & Ologe. 1982). Furthermore, authorities in soil genesis have confirmed that as clay formation begins, the soil usually has a higher water-holding capacity that often results in accelerated clay formation and thus higher clay percent in the downslope areas (FitzPatrick, 1971).

The absence of systematic variations in the particle sizes downslope, particularly for the topsoils in which either the middle and basal positions, or the crestal and middle positions, recorded nearly equal values for some of the fractions may be due to the general rarity of sharp slope facets over the region (Areola, 1982). In some cases it could be due in part to the presence of micro-relief features over the dominant slopes. An example of such features might be a low angle over the dominant one. When this situation arises for example, runoff is usually decelerated over the low angle benches. Where the decrease in velocity of flow is significant enough, there may be deposition of entrained materials. Another micro-relief feature which might disturb a consistent pattern of sorting of materials downslope is the presence of large stone and/or tussocky vegetation which often cause a considerable re-organization of surface run-off into anastomosing hills (Smith et. al., 1978; Leow & Smith, 1981).

Other factors that are capable of disrupting consistent pattern of size sorting include "pedogenesis in place" resulting from differences in moisture; leaching and vegetation cover; the mineralogical composition, the frequency, openness and dispositions of fractures such as faults, joints and microfissures, of the underlying rocks, over the rolling landscape. The ready supply of one or a variety of particle sizes over the whole slope from a rapidly weathering regolith and the in situ breakdown of large stones on the slope could give an approximately uniform particle size distribution.

It is possible that some if not all of these factors may have contributed partially to the observed lack of consistent or significant relationship between the particle sizes, particularly the finer fraction, and slope in the study area.

CHAPTER V

RESULTS: II THE ORGANIC CARBON AND NITROGEN CONTENTS OF THE TOPSOILS

5.0 INTRODUCTION

In this chapter, the status of the organic carbon (an index of the organic matter content of soils) and associated properties of total nitrogen and carbon/nitrogen ratio of the topsoils, 0 - 15cm, are examined. The results obtained from the analyses of the relationship between the properties and the soil-forming factors considered (parent material, climate and relief), together with clay percent, are also presented and discussed.

5.01 The organic matter and nitrogen contents of the soils

Both the organic carbon and total nitrogen contents of the topsoils (0-15cm) are highly variable. While the organic carbon content ranges between 0.02% and 5.98% with a mean of only 0.88%, corresponding to about 1.5% organic matter (assuming that 1% organic carbon equals 1.72 organic matter; Young, 1976), the total nitrogen content varies from 0.01% to 0.64% with a mean value of about 0.08%. Because of variation in the techniques used by different workers for organic matter determination, an extensive comparison of these values with data from other areas is rather difficult. In comparison with the few cases known, where the methods of determination of the properties are similar to those adopted for the samples used in this study (e.g. in the forest region around Ibadan and the Kenya Highlands mentioned in Chapter I)

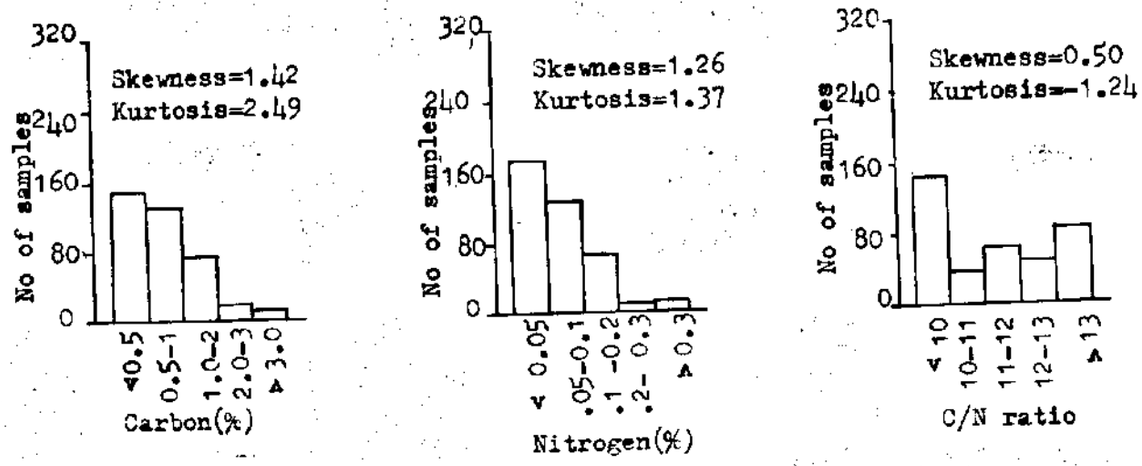


Fig. 5.1 The organic carbon and nitrogen contents of the topsoils

however, the values clearly indicate that the organic matter and nitrogen contents of soils, over the area are generally low. As can be observed in Figure 4.1, the organic carbon content of over 90% of the sites selected is well below 1%. These results are consistent with those obtained by Jones (1973), Awujoola (1979), Leow & Jaiyeoba (1982) for some savanna soils of West Africa and can be attributed to a variety of factors. Perhaps the most important of these are:

(i) the low rate of net primary production in the savanna biome;

(ii) the seasonal outbreak of bush fires which not only destroy much of the potential humus materials present in the form of leaf and grass litter, but also inactivate and sometimes totally exterminate non-fire resistant plant species;

(iii) over-grazing by animals.

The organic matter of soils and associated properties, over the region are therefore mainly derived from plant roots. And in soils with little or no vegetation cover, direct insolation is bound to cause more rapid oxidation of the humus material and volatilization of most of the essential soil ions (Thompson & Troeh, 1978). Subsequent erosion of the topsoil may result in even further losses of organic matter and nitrogenous compounds.

The carbon/nitrogen ratio of the soils ranges between 2.0 and 35.0, the average being about 11.7.

5.0.2 Relationships between the soil organic carbon and nitrogen and the soil-forming factors.

5.0.2.1 Parent material

Table 5.1 gives the summary of the relationship found between the organic carbon, total nitrogen and carbon/nirtogen ratio contents of the surface soils and parent materials. For the sedentary parent materials, the mean organic carbon contents were considerably higher over basalt and shale than over the other materials. The value over basalt for example (1.95%) clearly doubled the value for each of the others. Similarly, the amount in soils over alluvium were considerably higher than in soils over the rest of the transported materials. The differences in the organic carbon content between the various parent materials were thus quite significant statistically (0.001 level).

For total nitrogen, differences between the various parent materials were also quite significant. The variation in the mean of the property over the materials moreover parallels that of the organic carbon content. This is understandable since the element (i.e. nitrogen) occurs largely in organic form in soils (Bartholomew, 1972; Bartholomew & Clark, 1965; Thompson & Troeh, 1978).

The carbon/nitrogen ratio on the other hand showed very similar values over the parent materials, varying between a mean of 10.8 over gneiss and 14.2 over basalt in

Table 5.1: The organic carbon and nitrogen of the topsoils and parent material

	Parent material	No of samples	C % $\bar{x}$	S.D	CV%	N % $\bar{x}$	S.D	CV%	C/N ratio $\bar{x}$	S.D	CV%
SEDIMENTARY	Granite	39	0.54	0.30	55.6	0.05	0.02	40.0	11.0	3.5	31.8
	Gneiss	32	0.85	0.47	55.3	0.10	0.08	80.0	10.8	3.6	33.3
	₱/Gneiss	38	0.51	0.26	50.9	0.05	0.02	40.0	11.1	3.7	33.3
	Schist	35	0.85	0.44	51.8	0.07	0.03	42.9	11.5	3.0	26.1
	Sandstone	30	0.52	0.37	71.2	0.05	0.03	60.0	12.8	12.5	97.7
	Basalt	40	1.95	1.10	56.4	0.15	0.08	53.3	14.2	13.6	95.8
	Shale	42	1.25	0.83	66.4	0.11	0.07	63.6	11.7	4.5	38.5
TRANSPORTED	Alluvium	30	1.03	0.92	89.3	0.11	0.09	81.8	10.9	3.3	30.3
	Colluvium	32	0.63	0.60	95.2	0.05	0.04	80.0	13.2	9.2	69.7
	Aeolian	38	0.61	0.56	91.8	0.08	0.07	87.5	10.2	4.4	43.1
	Ironpan	22	0.61	0.49	80.3	0.06	0.04	66.7	11.2	4.0	35.7
			****			****					

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05

S.D = Standard deviation

the case of the sedentary parent materials, and between 10.2 over aeolian material and 13.2 over colluvium for the transported materials. Analysis of variance revealed no statistically significant differences in the C/N ratios between the various materials.

When the relationship between the properties and parent materail was examined over each of the four rainfall zones adopted in this study, although detailed variations were apparent, the general pattern of the spatial variability of the means of both the organic carbon and nitrogen contents over the different parent materilas were quite similar to the overall picture described above (Appendix 7). Except over the first rainfall zone, where there were no samples representing basalt, the mean values for both the organic carbon and total nitrogen over basalt and shale were considerably greater than over the other sedentary materials, in all the rainfall zones.

5.0.2.2 Climate

Both the organic carbon and nitrogen content of the soils showed positve and highly significant correlations with the mean annual rainfall (Fig. 5.2), reflecting presumably an increase in vegetal growth and biological activities in general as rainfall increases. As suggested by equations (5.1) and 5.2), on average, for every 100mm increase in the mean annual rainfall over the

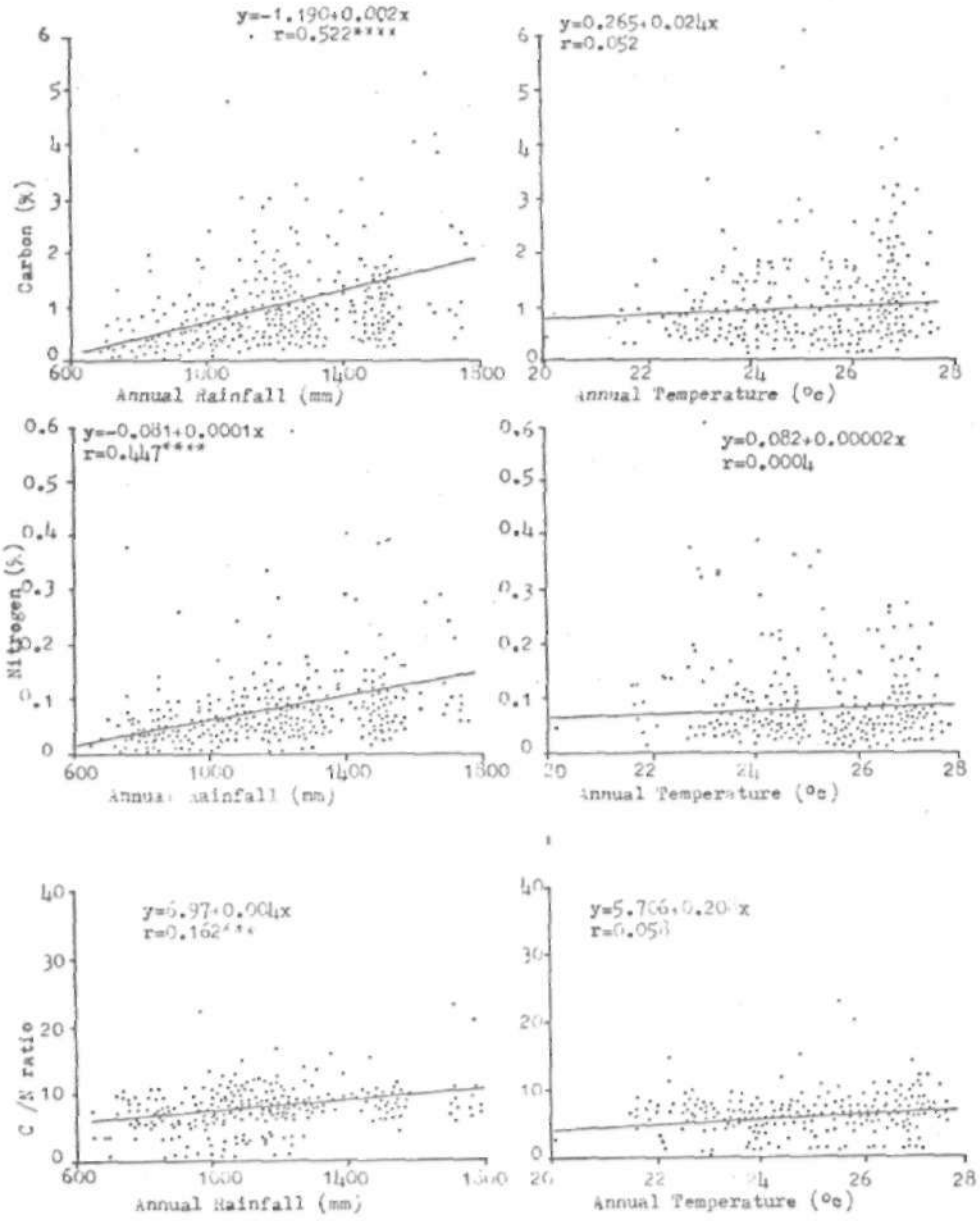


Fig.5.2 The organic carbon and nitrogen contents of the topsoils and climate

$$\%C = -1.1903 + 0.00169Rm \quad \ldots\ldots\ldots\ldots \quad (5.1)$$

$$\%N = -0.08149 + 0.00013Rm \quad \ldots\ldots\ldots\ldots \quad (5.2)$$

where Rm is the mean annual rainfall

study area, the organic matter content of the topsoil increases by 0.29% (assuming that 1% of carbon is equivalent to 1.72% of organic matter), and the nitrogen by 0.01%. By analysis of variance, differences in both properties between the rainfall zones were also highly significant (each at the 0.001 probability level). For the organic carbon, the mean values vary from 0.36% in the driest rainfall zone (600-900mm) to 1.57% in the wettest zone (1500-1800mm) and from 0.04% to 0.13% for nitrogen (Table 5.2).

Table 5.2: The organic carbon and nitrogen contents of the topsoils and climate

Climatic factor	No of samples	C(%) $\bar{x}$	S.D	CV%	N(%) $\bar{x}$	S.D.	CV%	C/N $\bar{x}$	S.D.	CV%
Rainfall (mm)										
600 - 900	74	0.36	0.26	72.2	.04	.03	75.0	9.8	6.9	70.4
900 -1200	103	0.63	0.35	55.6	.06	.03	50.0	11.3	3.3	29.2
1200 -1500	130	0.95	0.75	78.9	.09	.10	88.9	12.3	7.6	61.8
1500 -1800	78	1.57 ****	1.00	63.7	.13 ***	.09	69.2	7.6 *	11.4	84.2
Temperature (°C)										
20-25	108	0.87	0.62	71.2	.09	.08	88.9	11.8	9.5	80.5
25-27	125	0.77	0.68	88.3	.07	.06	88.7	10.9	5.3	48.6
27-28	148	0.97	0.75	77.3	.08	.06	75.0	12.3	7.8	63.4

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 02; * = 0.05.

Similar to the variation in organic carbon and nitrogen, the carbon/nitrogen ratio shows a positive and significant correlation with the mean annual rainfall, a pattern that could be explained

on the basis that conditions that encourage the accumulation of organic matter in soils usually result in the widening of the ratio (Brady, 1974).

Appendix 8 summaries the result obtained when the relationship between each of the properties and rainfall was exained over each of the parent materials, the altitudinal zones adopted in this study, and slope positions, using regression analysis. With respect to parent materials, the correlation coefficients (r) between organic carbon and rainfall raged between relatively high values of 0.54, 0.55 and 0.66 on aeolian material, gneiss and colluvium respectively, and comparatively low values of 0.11 and 0.12 over granite-gneiss and alluvium respectively. Except for the latter two however (i.e. 0.11 & 0.12), all the correlation coefficients were statistically significant. The values for nitrogen over the parent materials, were similar to those for organic carbon, Except over basalt, however, those for the carbon/nitrogen ratio were in general statistically non-signficant.

The relationships between the organic carbon and nitrogen contents and the mean annual rainfall over each of the altitudinal zones were also all significant statistically (although as for the parent materials with varying degrees of levels of significance) and the trends postive. The sane thing was true for the slope positions, except organic carbon in respect of the basal slope position where the relationship was insignificant statistically.

Similar to the result obtained from the breakdown of the properties according to the different materials and altitudinal zones, and unlike the organic carbon and total nitrogen contents, the correlation coefficient values for the carbon/nitrogen ratio were significant only over the two middle altitudinal zones and over the basal slope position, all of which were positive.

Although the relationships were positive, none of the three properties revealed a statistically significant correlation with the mean annual temperature (Fig. 5.2). Analysis of variance too revelaed no significant differences in the means of the properties between the three temperature zones (Table 5.2). The results obtained when the samples were broken down according to the different parent materials, similar rainfall and altitudinal zones, were not materially different from this overall picture. The relationship between the factor and the properties was only significant over granite, schist and shale, and over the third altitudinal zone (600-900m) with respect to both the organic carbon and nitrogen, and over aeolian material for nitrogen only (Appendix 8).

The observed lack of significant relationship between the organic carbon and associated properties and temperature in the present study agrees with the results of Jones (1973) for West Cameroon, Birch and Friend (1956) for the Highlands of East Africa, and Prescott (1931) for Australia. Possible explanation for such non-significant

correlation between temperature and the properties over the above mentioned tropical regions, as well as over the present study area, lies in the generally high annual temperature prevailing in the areas. For in Central United State, with wider annual temperature ranges, Jenny, et. al. (1930 & 1941) did observe quite significant positive correlations between the properties and annual temperature (1.3.2).

5.0.2.3 Relief

The relationships between the organic carbon and nitrogen contents of the soils and altitude were pstive and statistically significant at the 0.01 and 0.05 levels respectively (Fig. 5.3). As suggested by the regression equations (5.3 & 5.4), derived from the analysis, each 1000m rise in

$$\%C = 0.730 + 0.00012\ Al \quad \ldots\ldots\ldots\ldots \quad (5.3)$$

$$\%N = 0.06456 + 0.00004\ Al \quad \ldots\ldots\ldots\ldots \quad (5.4)$$

altitude (Al) in the study area is associated with a 0.21% increase in the organic matter (assuming that 1% organic carbon equals 1.72% organic matter), and a 0.04% increase in the nitrogen contents of the topsoils, reflecting presumably an increase in rainfall with altitude over the area. The existence of positive relationship between the organic carbon and nitrogen contents, and altitude, was partially supported by results obtained from analysis of variance in which there was an initial decrease in the average of each of the properties with height, from the first

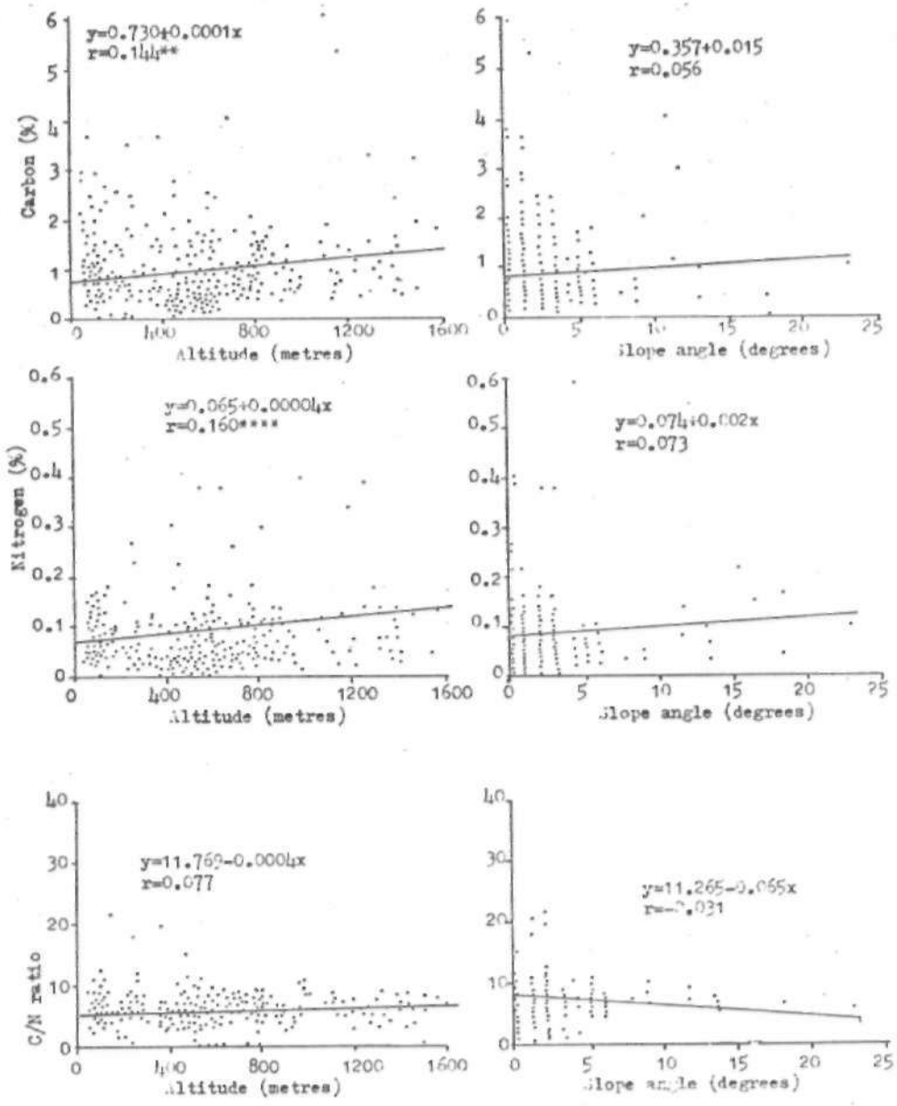


Fig.5.3 The organic carbon and nitrogen contents of the to soils and relief

to the second altitudinal zone, and thereafter an increase with increase in altitude (Table 5.3). The comparatively high mean value over the lowest altitudinal zone (less than 300), a zone falling almost entirely within the Benue Valley, was a reflection perhaps of the effect of higher rainfall and, the low value over the second zone (300-600m), the result of both the low rainfall, and mainly sandstone parent material, prevailing in the north-eastern corner of the area (Chapter III).

Table 5.3: The organic carbon and nitrogen contents of the topsoils and relief

Relief factor	No of samples	C(%) $\bar{x}$	S.D.	CV%	N(%) $\bar{x}$	S.D.	CV%	C/N $\bar{x}$	S.D	CV%
Altitude (metre)										
300	110	0.90	0.66	73.3	.08	.05	62.5	12.3	8.3	67.5
300-600	167	0.72	0.74	88.9	.07	.06	85.7	11.0	5.4	49.0
600-900	71	0.94	0.72	76.6	.09	.07	77.8	11.1	3.4	30.6
> 900	34	1.38 ****	1.33	96.4	.14 ****	.13	92.9	14.6	16.3	91.1
Gradient										
< 5°	326	0.99	0.84	84.8	.08	.06	87.5	11.5	6.0	52.2
5-10°	48	0.73	0.47	64.4	.08	.13	87.5	11.1	6.8	61.3
>10°	8	1.34	0.92	68.7	.09	.05	55.6	22.5	32.7	92.0
Slope position										
Crest	119	0.52	0.43	82.7	.05	.04	80.0	10.3	4.6	44.7
Middle	149	0.80	0.60	75.0	.08	.09	87.5	11.9	7.3	61.3
Basal	116	1.34 ****	1.06	79.1	.11 ***	.09	81.8	12.9 *	10.2	79.1

Analysis of variance levels of significant: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

Unlike the organic carbon and total nitrogen contents of the soils, neither the regression analysis, nor the analysis of variance

employed, revealed a statistically significant relationship between the carbon/nitrogen ratio and altitude.

When the samples were broken down according to the different parent materials, the relationship between the organic carbon and nitrogen contents and altitude were only significant over granite, schist, colluvium and aeolian material for both properties, and over shale and gneiss for nitrogen (Appendix 8). Such an observed pattern seems to contrast with Jones' (1973) observation of greater correlation between soil organic carbon content and altitude over basic rocks than over acidic rocks in West Cameroon, cited in the literature review (1.3.3). The absence of significant relationship between the properties and altitude over most of the parent materials however may be related to the fact that except for the transported parent materials of alluvium, colluvium and ironpan, which have wider coverage, most of the other materials are restricted to specific topographical positions over the study area. While basalt is to be found mainly in the upwarpped areas for example, sandstone and shales occur largely in the depressions or downwarpped areas (3.2).

None of the correlation coefficients for the carbon/nitrogen ratio over the different parent materials was significant statistically.

When the samples were broken down according to the four rainfall zones, only organic carbon showed statistically significant correlation with altitude and this was at the

wettest rainfall zone (1500-1800mm). Similarly, only organic carbon showed significant relationship with altitude when the samples were examined against the background of the different slope positions and this was over the middle psotion.

On the whole, the regression analysis (Fig. 5.3) and the analysis of variance (Table 5.3) revealed no apparent or significant relationship between slope gradient and the organic carbon, total nitrogen and carbon/nitrogen ratio of the soils. A slightly different picture was revealed however when the samples were broken down according to the different parent materials, into the four altitudinal zones adopted in this study, as well as into the different slope positions (Appendix 8). Although the relationship (i.e. between the properties and slope gradient) were still largely insignificant over most of the parent materials, they were significant over both the colluvial and ironpan materials for the organic carbon and nitrogen. The relationships were also significant for the two properties over the highest altitudinal zone (900m +), and over the crestal slope position. The trend of relationship between the properties and slope gradient under the above conditions moreover was negative, implying decreasing values of the properties with rise in slope gradient. Such departure from the overall picture was unexpected for, over the study area, both the colluvial and ironpan deposits are more often then not associated with the more undulating terrains below the hill masses or ranges. Similarly, in

the region, slope gradient is more varied and generally steeper over the more rugged higher altitudinal areas, and the interfluve positions, than over the pediment slopes.

As is shown in table 5.3, each of the properties revealed distinct differences between the slope positions. The mean organic carbon content varies from 0.52% over the upper slope position through 0.80% at the middle position to 1.34% in the basal area. In a similar fashion, total nitrogen and carbon/nitrogen increased downslope, from a mean value of 0.05% over the upper position through 0.08% at the middle position to 0.11% at the basal area for nitrogen, and 10.3 through 11.9 to 12.9 for carbon/nitrogen ratio.

When the relationships between the properties and slope position were examined against the background of rainfall, although non-significant over some of the zones, both the organic carbon and nitrogen contents were marked by comparatively higher mean values over the basal slope positions, at all the rainfall levels. Except over the direst rainfall zone however, the values for the carbon/ nitrogen ratio for each of the rainfall zones, showed less variability (Appendix 9).

5.0.3 Relationship between the soil organic carbon and nitrogen and the clay fraction

Both the organic carbon and nitrogen contents of the soils revealed highly signfficant and direct relationship with the soil clay content. The coefficient of determination (r^2) showed that about 26.9% and 10.7% variances of the

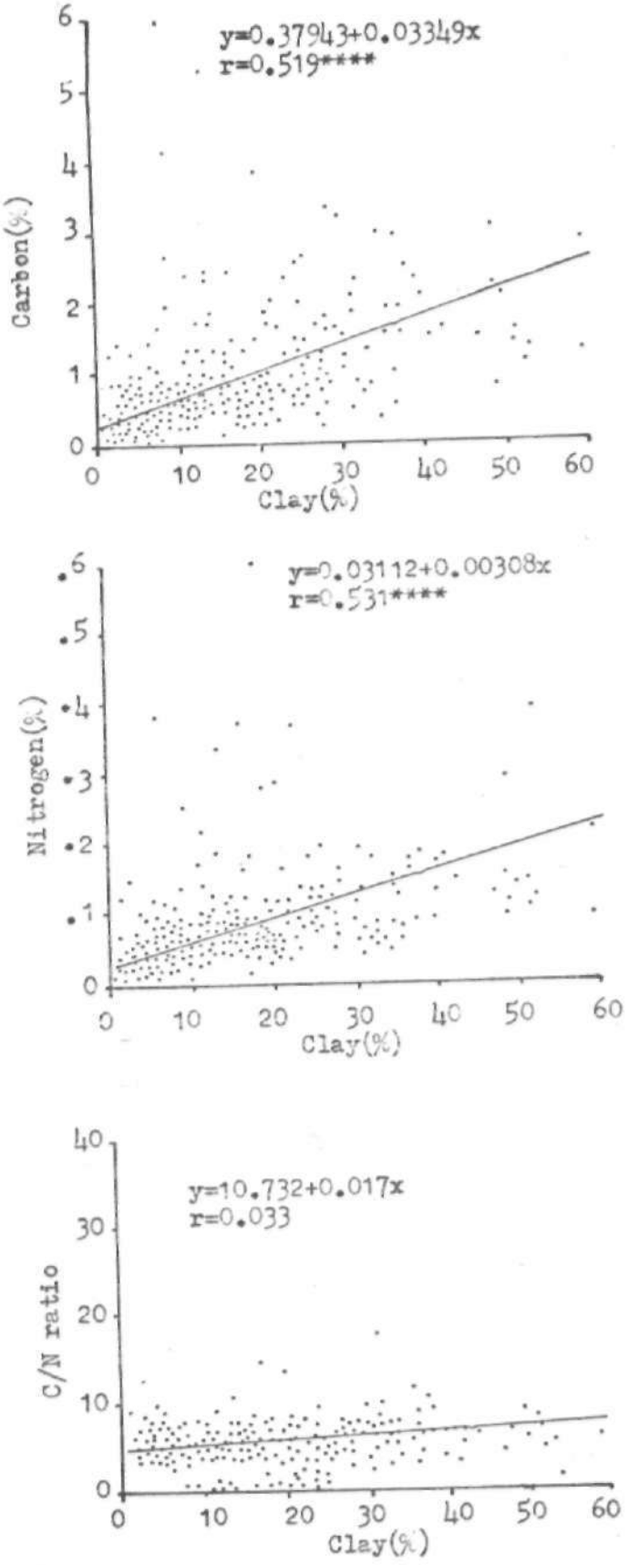


Fig.5.4 The organic carbon and nitrogen contents of the topsoils and clay

organic carbon and nitrogen, respectively, were due to this factor. As suggested by the regression equations (5.5) and (5.6) for every 10%

$$\%C = 0.37943 + 0.03349 \text{ clay} \quad \ldots\ldots\ldots\ldots \quad (5.5)$$

$$\%N = 0.03112 + 0.00308 \text{ clay} \quad \ldots\ldots\ldots\ldots \quad (5.6)$$

increase in the percentage clay content of the soils, the organic matter content increases by about 0.58% (assuming that 1% of carbon equals 1.72% of organic matter) and the total nitrogen by 0.03%. The positive and significant correlation between the soils organic carbon and nitrogen, and clay content, were supported by the result obtained from the analysis of variance in which differences in the means of the properties between the clay content classes were both statistically significant at the 0.001 probability level (Table 5.4).

Table 5.4: The organic carbon and nitrogen contents of the topsoils and clay

Clay %		<10	10-20	20-30	>30
No of samples		171	127	48	36
C%	$\bar{x}$	0.54	0.91	1.35	1.74****
	S.D	0.51	0.77	0.83	0.76
	CV%	94.4	84.6	61.5	43.7
N%	$\bar{x}$	0.05	0.08	0.13	0.14****
	S.D	0.04	0.08	0.13	0.07
	CV%	80.0	100.0	100.0	50.0
C/N ratio	$\bar{x}$	11.1	11.7	11.4	12.7
	S.D	6.9	5.7	4.7	4.5
	CV%	62.2	48.7	41.2	35.4

Analysis of variance levels of significance:
**** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

In contrast to the carbon and nitrogen contents of the soils, neither the regression analysis, nor the analysis of variance, revealed statistically significant relationship between the carbon/nitrogen ratio and the clay content.

When the relationships between the properties and clay were exained over the different parent materials, although with varying levels of significance, both the organic carbon and nitrogen showed quite significant and positive relationships with clay over all the materials, except over alluvium. The properties also revealed significant correlations with clay over each of the rainfall and altitudinal zones, and over each of the slope positions (Appendix 8).

In contrast to the organic carbon and nitrogen contents of the soils, the carbon/nitrogen ratio did not reveal any statistically significance correlation with clay over the different parent material, rainfall and altitudinal zones, and slope positions. The only exceptions are over the lowest rainfall zone, the second altitudinal zone and the basal slope position.

5.0.4 The relative importance of the soil-forming factors in determining the spatial variability of the soil organic carbon and nitrogen

The summary of the percentage variance of the soil organic carbon content and associated properties of nitrogen and C/N ratio explicable in terms of the soil-forming factors considered, using analysis of variance

and covariance, is shown in Table 5.5. The parent material factor alone accounted for about 29% of the percentage variance of the soil organic carbon content. This was followed by rainfall (about 9%) and slope position (about 7%). The relief parameter of altitude accounted

Table 5.5: The topsoils' organic carbon and nitrogen: percentage variance explained by the soil-forming factors considered.

Soil-forming factor	C %	N %	C/N ratio
Parent material	28.6	9.5	5.2
Rainfall	9.3 (9.3)	3.4 (3.4)	2.1 (2.6)
Temperature	0.0	0.0	0.5
Altitude	3.6	1.5	0.1
Slope gradient	0.0 (11.5)	0.1 (4.7)	0.0 (2.9)
Slope position	6.9	3.1	2.8
Explained	48.4	17.6	10.7
Residual	51.6	82.4	89.3

for a much smaller value (3.6%), while the percentage variances explained by the climatic parameter of temperature and the relief parameter of slope gradient were both practically zero. Consequently, only about one half of the variances of the property were explained by all the soil-forming factors considered.

In keeping with the trend for the organic carbon, the variability of the nitrogen content was also accounted for largely by the parent material, rainfall and slope position, and to a lesser extent, the altitude factor. The percentage variance of the property explicable in terms of each of the

factors was however markedly low, as compared to that for the organic carbon content. The result was an even much greater residual variance of the property (82.4%) unaccounted for by the factors considered.

Like nitrogen, only a very small proportion of the variances of the carbon/nitrogen ratio are explained by the factors considered; hence there is a very high percentage residual variance (89.3%) unexplained.

5.1 DISCUSSION

According to Jenny (1930), the order of importance of soil-forming factors as they affect the organic carbon and total nitrogen contents of soils in the central region of the United States of America were climate > vegetation > topography = parent material > age. Jenny et. al. (1948 , 1960, 1961) found a similar picture in Columbia, South America, Costa Rica and in India in which climate was the principal factor controlling the soil carbon and nitrogen contents. Under rather different tropical conditions in the East African Highlands, Birch and Friend (1956) also identified rainfall as having far greater influence on the organic matter and nitrogen contents of the soils, as compared to either temperature or altitude.

As is suggested by the figures in table 5.5 however, under conditions of semi-arid to sub-humid conditions prevailing in the present project area, although climate, especially rainfall, is still of great importance, the

parent material of the soils accounts for the greatest proportion of the percentage variances of both the organic carbon and nitrogen contents of the topsoils. This could be partly accounted for by lithological influence on soil texture, particularly the amount and type of clay minerals found in the soils. The very close relationship between clay and the elements is born out in section 5.0.3. Under rather similar climatic conditions of low to moderate rainfall, soils high in clay content contain higher organic carbon and nitrogen contents than those which are low in the material. The same thing is true of all slope positions.

Another possible explanation for the profound differences in soil organic carbon and nitrogen contents over the different parent materials observed in this study, lies in the nature of vegetal cover. Under natural conditions, sandy soils resulting from coarse-grained parent materials are inherently likely to be less fertile, since they store less water and nutrients, than soils with more clay resulting from the weathering of fine-grained and/or basic parent materials (Buol et. al., 1973). Moreover, since sandy soils are usually warmer and better aerated for the greater part of the year, than fine-textured soils, they usually permit more rapid oxidative decomposition of the organic matter sources (Brady, 1974; Baver et. al. 1972).

The comparatively higher organic carbon and nitrogen contents in soils formed over basalt and shale reflect, presumably, the higher soil pH and basic cations, and greater clay contents. It could also be as a result, partly, of greater montmorillonitic clay mineral type in the soils. In the case of the transported materials, the comparatively higher values over alluvium reflect, in addition to higher clay content, the importation of either the elements themselves, or their source materials from higher-lying areas, and perhaps their preservation by the slighly less well aerated conditions characteristic of floodplains.

Jenny and his co-workers (1930, 1934, 1948, 1950, 1960) made extensive research on the effect of the components of climate (temperature and rainfall) on organic matter and nitrogen levels in soils. The effect of rainfall on organic matter and nitrogen levels of soils is presumably that in which an increasing rainfall tends to favour an increasing vegetative growth and consequently, the production of large quantities of raw materials for synthesis into humic substances. High rainfall also exercises its influence through the activities of micro-organisms, and also the chemical properties of the soil. On the other hand, conditions of severe moisture defficency often result in seriously limited micro-biological activity in the long dry

period (Birch, 1958).

According to Jenny, et. al. (1941, 1960), the effect of temperature on soil organic matter and nitrogen contents of soils is also that in which an increasing mean annual temperature tends to favour the rate of both vegetative production and decomposition of organic matter. Results obtained from this study, however, did not fully support this. Although positive, the relationships between both properties and temperature were not statistically significant. It is quite probably that, over the study area, where there are marked wet and dry seasons, the effect of high temperature on both the photosynthetic activity of higher plants, and micro-biological activity, is practically nullified during the greater part of the year by the adverse effect of dry conditions.

Relief affects soil properties, including organic carbon and nitrogen contents, mainly through its influence on climate, runoff, evaporation and sediment transportation (Jenny, 1941; Kononova, 1966; Buol et. al., 1973; Young, 1976). As this study seems to suggest, over the study area, because of the relatively gently sloping nature of the landscape, the significance of slope gradient, as a factor

of soil-formation, is confined mostly t the interfluve areas and higher altitudes with steeper slope angles. Under these latter conditions, the relationship between organic carbon and total nitrogen and slope gradient was negative, reflecting presumably an increasing loss of the properties or source materials, through runoff, with increase in slope angle.

The effect of altitude on the soil organic carbon and nitrogen is mainly exercised through rainfall and/or temperature. According to Jenny (1941), an increasing rainfall tends to favour greater plant growth without having much effect on the rate of decomposition. A decreasing temperature on the other hand tends to slow down the decomposition processes more rapidly than the growth of plants. In the present study area, even though temperature has been found to exhibit little or no apparent significant relationship with the biological properties of the soils considered, altitude is associated with an increasing rainfall and decreasing temperature.

As for slope position, the higher organic carbon and nitrogen in the basal areas, as compared to the upper positions, may be due to transport of organic material and

nitrogenous conpounds downslope, which would not only enrich downslope areas, but also deplete these soils near the crest. But it could also be a product of drainage condition as lower slope positions usually suffer from poor aeration condition than the upper slope positions, due either to an accumulation of runoff water from the later positions or the influence of high water tables (3.1). (Brady, 1974; Kononova, 1966; Jones, 1973; Jones & Wild, 1975).

CHAPTER VI

RESULTS: III THE CHEMICAL PROPERTIES OF THE SOILS

6.0 INTRODUCTION

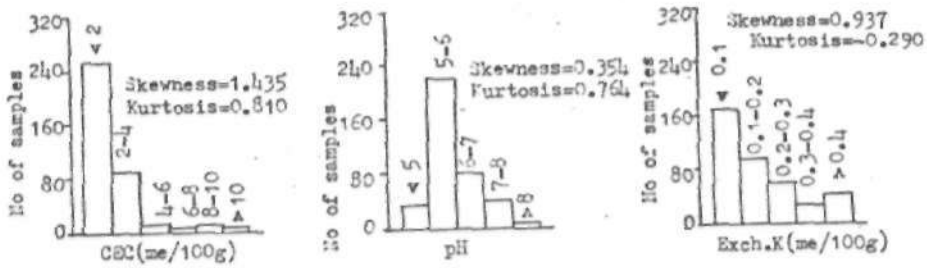
The soil chemical characteristics considered in this chapter are the cation exchange capactiy (CEC), soil pH, base status (exchangeable K, Ca, Mg & Na) and percentage base saturation (%BS), that is, the extent to which the exchangeable conplex of a soil is saturated with exchangeable cations other than hydrogen. And just as for the preceeding chapters, the objectives are to present and discuss the results obtained from the analysis of the spatial variability of the soil chemical properties, in relation to the factors of parent material, climate and relief.

6.1 TOPSOILS

6.1.1 The nutrient status and chemical condition

The CEC of the soils were highly variable but generally quite low. Over 60% of the samples had values below 6me/100g. The major contributory factors to this are the relatively low organic matter and clay contents of the soils. Equations (6.1) and (6.2) show that these parameters have strong relationships with the property. Nevetheless, it may also be a refleftion of the mainly kaolinitic nature of the soil clay minerals (FitzPatrick, 1971; Mohr et. al.,1972; Brady, 1974; Young, 1976).

The pH values ranged between 4.30 and 8.10 and averaged 5.86. In keeping with the generally acidic conditions, most



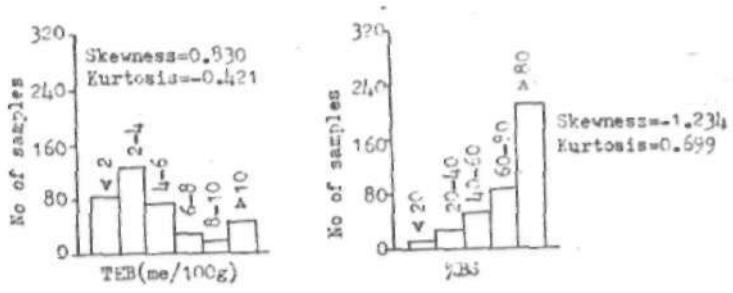


Fig.6.1 The chemical properties of the topsoils

of the soils were quite low in the exchangeable bases. The cations were also highly variable but on the whole, they occured in the order of Ca > Mg > K > Na. The conbined value of the four cations (i.e. the total exchangeable base or TEB) ranged between 0.22me/100g and 43.70me/100g and averaged 5.07me/100g. The relatively low pH and exchangeable bases of the soils may be explained partially in terms of the low CEC and/or the blocking of the negative electrical charges on the soil micells by strongly adsorbed hydroxyl aluminium cations (Pierre & Scarseth, 1931; Peech, 1941; Mehlich, 1941; Yuan, 1963; Hus et. al., 1964; Coleman & Thomas, 1967). It also no doubt, reflects the high degree of leaching that has taken place in the soils.

The predominance of Ca and Mg over the other exchangeable cations in the soils may be due to the relatively fast rate of release of the ions from the mineral matter decomposition and/or the occurence of exchangeable sites in the soils which showed specific affinity for the ions (Beckett, 1965; Brady, 1974).

The %BS, though varying considerably too (10-100%), relative to the pH of the soils, was generally high on the average (77.8%), reflecting presumably the low CEC of the soils. It could however be due, at least partially, to the fixation of hydroxyl aluminium ions earlier on referred to.

Table 6.1: The chemical properties of the topsoils and parent material

Parent Material		SEDENTARY							TRANSPORTED			
		Granite	Gneiss	G/gneiss	Schist	Sandstone	Basalt	Schale	Alluvium	Colluvium	Aeolian	Ironpan
No of samples		36	32	38	34	36	40	42	30	32	38	22
CEC	$\bar{x}$	3.93	5.57	3.98	5.67	3.26	14.72	8.71	7.85	4.38	4.17	3.98****
	S.D	3.08	3.34	2.37	4.17	2.42	8.74	6.96	6.86	6.23	3.30	2.51
pH	$\bar{x}$	5.78	5.79	5.90	5.89	5.63	6.13	5.95	5.76	5.87	6.07	5.81*
	S.D	0.56	0.54	0.53	0.59	0.53	0.67	0.64	0.60	0.62	1.71	0.46
Exch.K	$\bar{x}$	0.17	0.21	0.18	0.22	0.11	0.46	0.30	0.23	0.21	0.21	0.17****
	S.D	0.12	0.31	0.09	0.11	0.07	0.34	0.28	0.19	0.17	0.16	0.15
Exch.Ca	$\bar{x}$	2.15	2.74	2.36	2.96	1.77	7.82	4.66	3.70	2.58	2.53	2.62****
	S.D	1.77	2.55	1.50	1.93	1.53	6.34	3.58	3.02	4.73	1.73	1.99
Exch.Mg	$\bar{x}$	0.96	1.12	1.88	1.24	0.55	3.81	1.90	1.28	0.66	0.71	0.81****
	S.D	2.08	0.93	0.74	1.12	0.48	3.39	2.28	1.18	0.70	0.48	0.51
Exch.Na	$\bar{x}$	0.03	0.05	0.06	0.04	0.02	0.09	0.05	0.15	0.03	0.04	0.01***
	S.D	0.08	0.09	0.09	0.07	0.05	0.11	0.07	0.04	0.11	0.07	0.03
TEB	$\bar{x}$	3.34	4.21	3.56	4.47	2.45	12.34	6.91	5.36	3.63	3.50	3.76****
	S.D	3.43	3.41	2.14	2.82	2.01	9.52	5.89	4.17	5.69	2.19	2.27
%BS	$\bar{x}$	75.0	72.4	79.8	81.6	76.7	74.8	77.7	69.6	80.6	87.6	79.4
	S.D	23.6	24.5	24.4	18.2	25.9	16.9	22.9	22.2	24.3	20.7	21.9

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

S.D = Standard deviation.

6.1.2 Relationships between the soil chemical properties and the soil-forming factors

6.1.2.1 Parent material

The differences in the soil CEC and exchangeable bases, between the parent materials, were highly significant. Reflecting higher orgnic carbon and clay contents, the values for soils over basalt and shale were relatively higher than those for soils over the granitic rocks and sandstone, and over alluvial deposits than over the rest of the transported materials (Table 6.1).

The soil pH ranged between a mean of 6.13 over basalt and 5.63 over sandstone, in the case of the sedentary parent materials, and between 6.07 over aeolian deposit and 5.76 over alluvium. Differences in the property between the parent materials, on the whole, were statistically significant at the 0.02 probability level. In contrast to the pH, the %BS revealed no significant different values between the parent materials.

6.1.2.2 Climate

As is shown in Figure 6.2, the regression of the CEC on the mean annual rainfall was significant at the 0.001 level. Analysis of variance also revealed highly significant differences in the property between the rainfall zones (Table 6.2). The value ranged from a mean of 2.38me/100g in the driest rainfall zone (600-900mm) to 10.09me/100g in the wettest zone (1500-1800mm), reflecting presumably

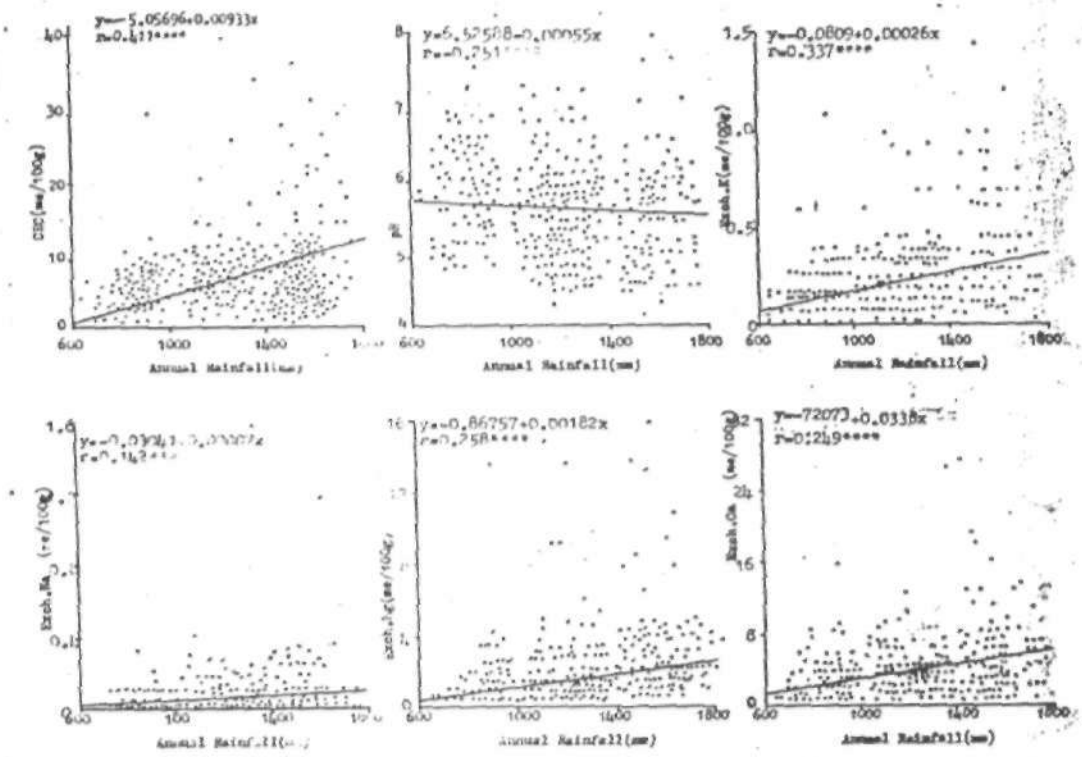


Fig.6.2 The chemical properties of the soils and rainfall

the increasing clay and organic matter contents of the soils with increasing rainfall (chapters IV & V). The soil pH too showed quite strong relationship with the mean annual rainfall. In contrast with an increased trend for CEC however, the trend with the factor was generally a decrease, suggesting an increasing leaching and/or an increasing biological respiration and organic matter production and decomposition with increasing rainfall amount (Atkinson & Wright, 1957; Pitty, 1978; FitzPatrick, 1971; Stauffer, 1972; Kilmer, 1974).

By both the regression analysis and analysis of variance, all the exchangeable bases, and the TEB, showed positive and significant relationships with rainfall. This suggests that the rate of losses of the elements, presumably through leaching, have been much slower than the rate at which they are being released from the mineral structure of rocks by chemical weathering.

The %BS value also showed quite significant relationships with rainfall, the general trend being a decrease, with increase in rainfall amount. Such a negative trend with rainfall reflects, presumably, a more proportionate increase in the CEC of the soils with increase in rainfall, vis a vis the exchangeable bases, due possibly to an increasing displacement on the soil exchangeable complex by exchangeable H^+.

Table 6.3 summaries the results obtained when the relationships between the soil chemical properties and rainfall were examined over the different parent materials

Table 6.2: The chemical properties of the topsoils and climate

Climatic factor	No of Samples	CEC $\bar{x}$	CEC S.D	pH $\bar{x}$	pH S.D	Exch.K $\bar{x}$	Exch.K S.D	Exch.Ca $\bar{x}$	Exch.Ca S.D	Exch.Mg $\bar{x}$	Exch.Mg S.D	Exch.Na $\bar{x}$	Exch.Na S.D	TEB $\bar{x}$	TEB S.D	%BS $\bar{x}$	%BS S.D
Rainfall (mm)																	
600-900	74	2.38	1.83	5.97	0.60	0.13	0.12	1.85	1.78	0.45	0.34	0.01	0.04	2.49	2.14	85.0	23.8
900-1200	103	5.51	4.26	6.11	0.51	0.19	0.14	3.29	2.58	1.33	1.84	0.05	0.09	4.90	4.12	83.7	19.3
1200-1500	130	6.64	6.78	5.72	0.55	0.27	0.24	3.52	4.69	1.45	2.14	0.06	0.16	5.37	6.90	75.2	21.8
1500-1800	78	10.09 ****	7.25	5.64 ****	0.63	0.32 ****	0.24	0.64 ****	0.74	1.96 ****	2.03	0.07 **	0.16	7.04 ****	5.50	68.1 ****	22.5
Temperature (°C)																	
20-25	108	6.26	4.27	5.74	0.55	0.25	0.17	3.11	2.17	1.11	0.91	0.04	0.85	4.51	2.96	74.2	23.2
25-27	125	4.95	5.42	5.91	0.60	0.20	0.18	2.84	3.41	1.21	1.87	0.08	0.20	4.48	5.11	80.2	23.4
27-28	148	7.31 **	7.51	5.90 *	0.62	0.24	0.25	4.03 *	4.54	1.61	2.35	0.04	0.07	5.92 *	6.82	78.6	21.1

Analysis of variance levels of significant: **** = 0.001, *** = 0.01; ** = 0.02; * = 0.05.

Table 6.3: Simple correlation coefficients between the chemical properties of the topsoils and rainfall over the different parent materials and slope positions.

FACTOR	No of Samples	CEC	pH	Exch.K	Exch.Ca	Exch.Mg	Exch.Na	TEB	%BS
Parent material									
Granite	36	-0.08	0.44**	0.19	-0.22	-0.21	0.05	-0.14	-0.42**
Gneiss	32	0.39*	-0.11	0.35**	0.21	0.92****	0.25	0.23	-0.28*
G/gneiss	38	0.20	-0.45**	-0.11	-0.30*	-0.14	-0.30*	-0.06	-0.12
Schist	34	-0.09	-0.18	0.09	-0.22	-0.11	0.58***	-0.20	-0.30*
Sandstone	36	0.20	-0.25	0.22	0.12	0.16	0.16	0.14	-0.12
Basalt	40	-0.15	-0.65***	-0.19	-0.22	-0.29*	-0.18	-0.26	-0.43**
Shale	42	0.10	-0.39**	0.01	-0.05	-0.03	0.04	-0.04	-0.47**
Alluvium	30	-0.03	-0.29	0.31*	0.07	-0.01	-0.36*	-0.02	-0.01
Colluvium	32	0.56***	-0.31*	0.57***	-0.01	0.37*	0.46**	0.17	-0.52***
Aeolian	38	0.44**	-0.41**	0.38*	-0.06	0.30*	0.46**	0.10	-0.66****
Ironpan	22	-0.13	-0.28	-0.21	-0.12	-0.25	-0.21	-0.15	-0.04
Slope position									
Basal	116	-0.02	-0.28****	0.04	-0.12	-0.06	0.20**	-0.12	-0.37****
Middle	148	0.11	-0.27****	0.15*	0.02	0.02	-0.01	0.14	-0.20***
Crest	119	0.23**	-0.28****	0.14	0.19*	0.06	0.06	0.16*	-0.29****

Analysis of significant levels: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

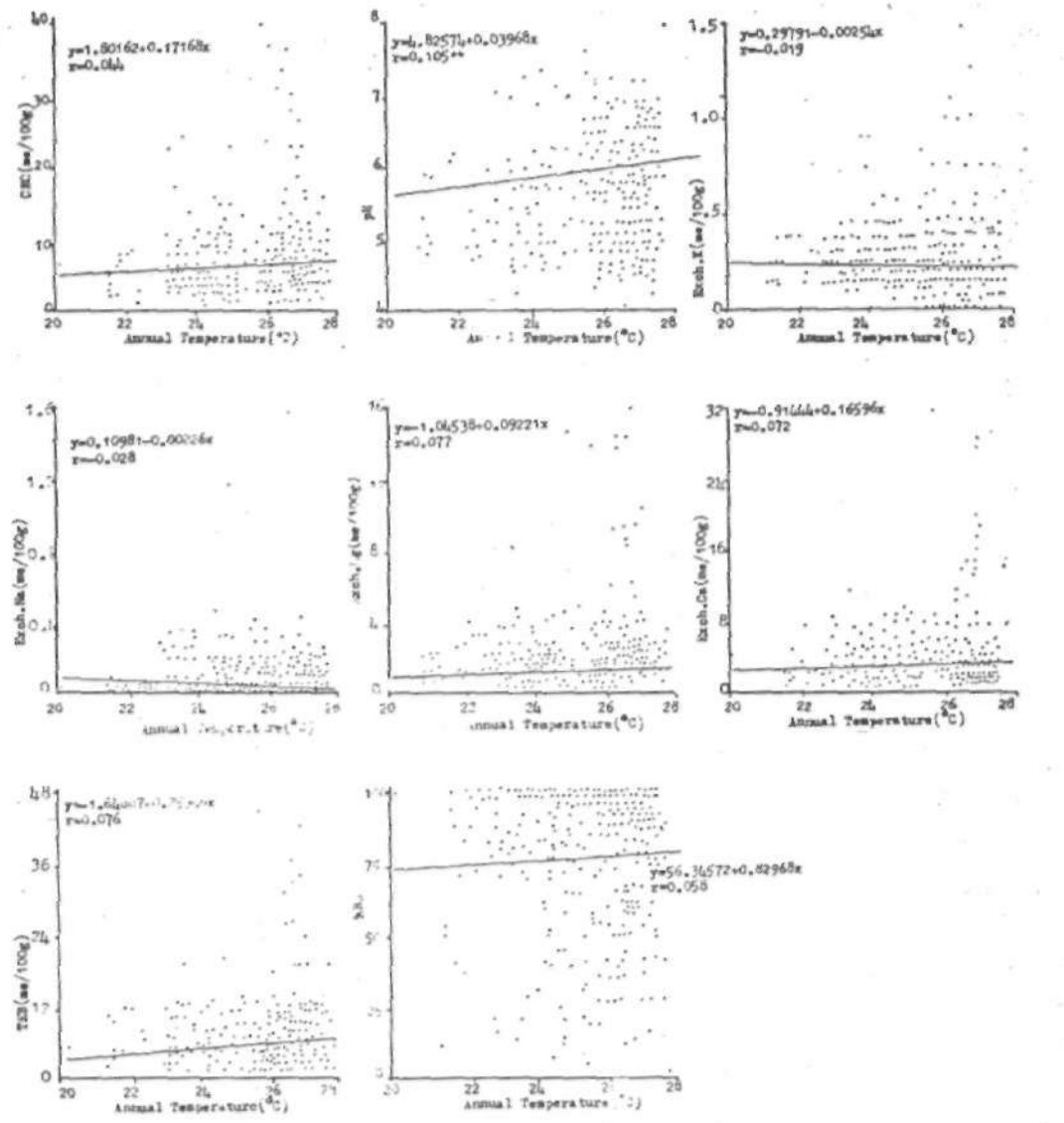


Fig.6.3 The chemical properties of the tonsoils and temperature

and over the different slope positions. Not only did the properties show varying degrees of correlations with the mean annual rainfall over the various parent materials, but also often contrasting trends, except the pH and %BS which were negative all throughout. The correlation coefficients of the CEC and rainfall increases upslope but only significant statistically, at the interfluve, position. There were no consistent variations in the values for the TEB and the exchangeable bases. Those for the pH and the %BS were less variable and were all negative.

With the exception of the soil pH which showed positive and significant relationship, none of the soil chemical properties revealed significant correlation with temperature (Fig. 6.3). By analysis of variance on the other hand, differences in the CEC, exchangeable Ca and the TEB, including the pH, were significant, statiscally (at the 0.02 level for the CEC and 0.05 level each for the rest). There were however no distinctive linear trends in the means of the properties with the temperature zones, as values in the median zone were either greater than, or lower than those in the first and third zones (Table 6.2).

6.1.2.3 Relief

The CEC showed a positive but non-significant correlation with altitude (Fig. 6.4). Differences in the means of the property between the altitudinal zones were however significant (at 0.05 level) by analysis of variance and the general trend positive after an initial decrease

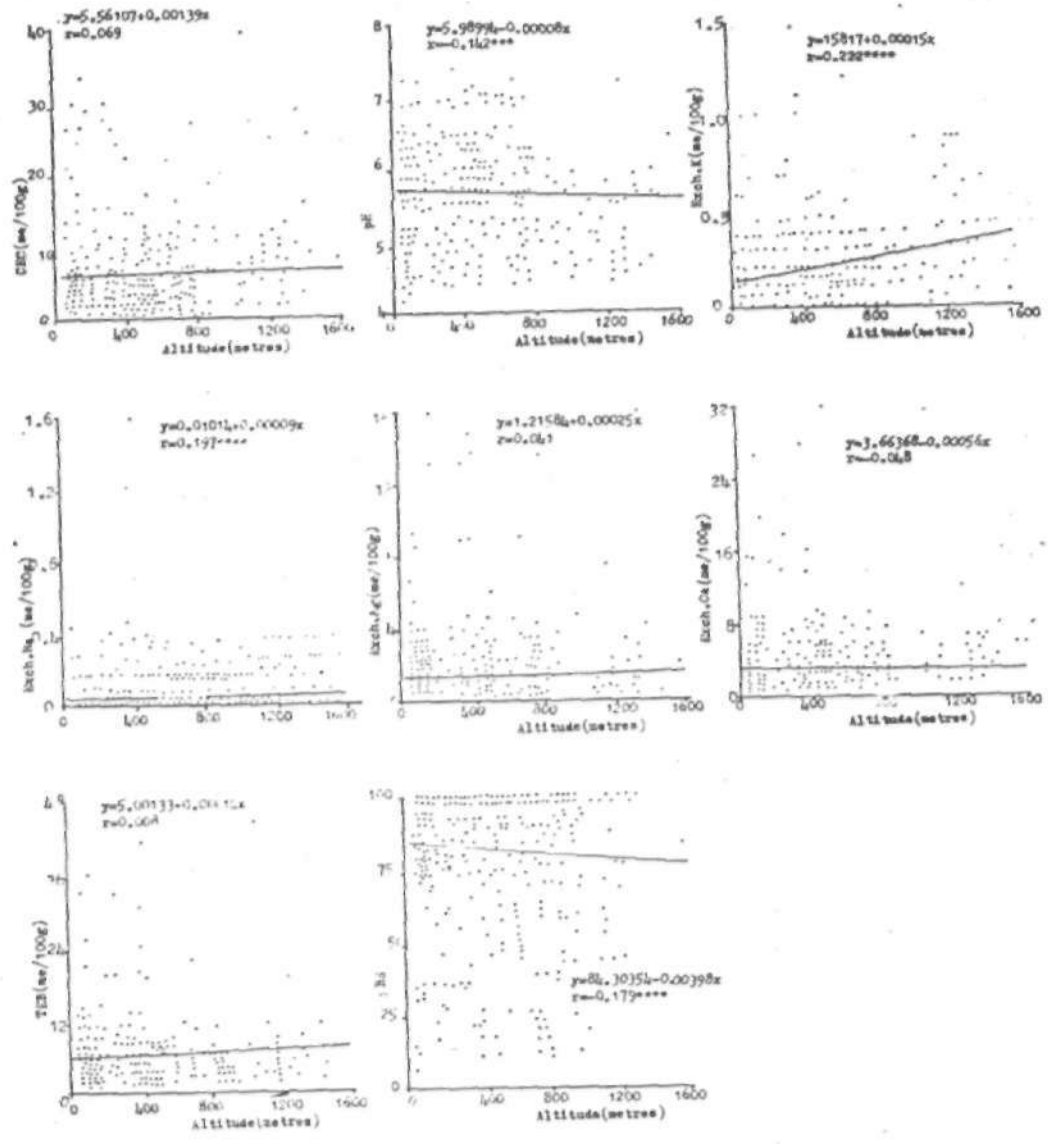


Fig.6.4 The chemical properties of the topsoils and altitude

Table 6.4: The chemical properties of the topsoils and relief

Relief factor	No. of samples	CEC $\bar{x}$	CEC S.D	pH $\bar{x}$	pH S.D	Exch. K $\bar{x}$	Exch. K S.D	Exch. Ca $\bar{x}$	Exch. Ca S.D	Exch. Mg $\bar{x}$	Exch. Mg S.D	Exch. Na $\bar{x}$	Exch. Na S.D	TEB $\bar{x}$	TEB S.D	%BS $\bar{x}$	%BS S.D
Altitude (metres)																	
<300	110	6.52	6.46	5.83	0.64	0.22	0.18	3.72	3.99	1.36	1.80	0.03	0.06	5.36	5.57	77.1	21.9
300-600	167	5.59	5.92	6.01	0.53	0.20	0.21	3.32	3.48	1.29	2.04	0.06	0.17	4.89	5.49	84.2	20.5
600-900	71	6.19	4.73	5.70	0.62	0.24	0.18	2.98	2.40	1.10	1.07	0.02	0.05	4.38	3.37	70.8	24.9
>900	34	8.73 *	8.04	5.54 ****	0.50	0.42 ****	0.26	3.50	5.33	2.01	2.55	0.17 ****	0.11	6.65	8.14	64.1 ****	18.9
Slope gradient																	
<5°	326	6.43	6.41	5.85	0.60	0.23	0.21	3.51	3.84	1.39	1.99	0.05	0.13	5.22	5.72	78.5	22.2
5-10°	48	4.70	2.89	5.86	0.58	0.25	0.17	2.35	1.75	0.91	0.68	0.06	0.10	3.63	2.28	73.5	25.4
>10°	8	8.19	7.65	5.89	0.44	0.30	0.12	4.40	3.88	1.86	2.07	0.02	0.04	3.18	5.97	77.4	15.3
Slope position																	
Crest	119	4.17	4.13	6.03	0.57	0.17	0.13	2.62	2.96	0.83	0.93	0.04	0.16	3.70	3.69	84.7	19.2
Middle	148	5.34	4.23	5.86	0.57	0.23	0.17	2.98	2.49	1.14	1.56	0.05	0.18	4.40	3.87	87.5	22.3
Basal	116	9.53 ****	8.25	5.68 ****	0.61	0.30 ****	0.29	4.67 ****	4.99	1.12 ****	2.63	0.08 *	0.07	7.34 ****	7.62	69.3 ****	21.5

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

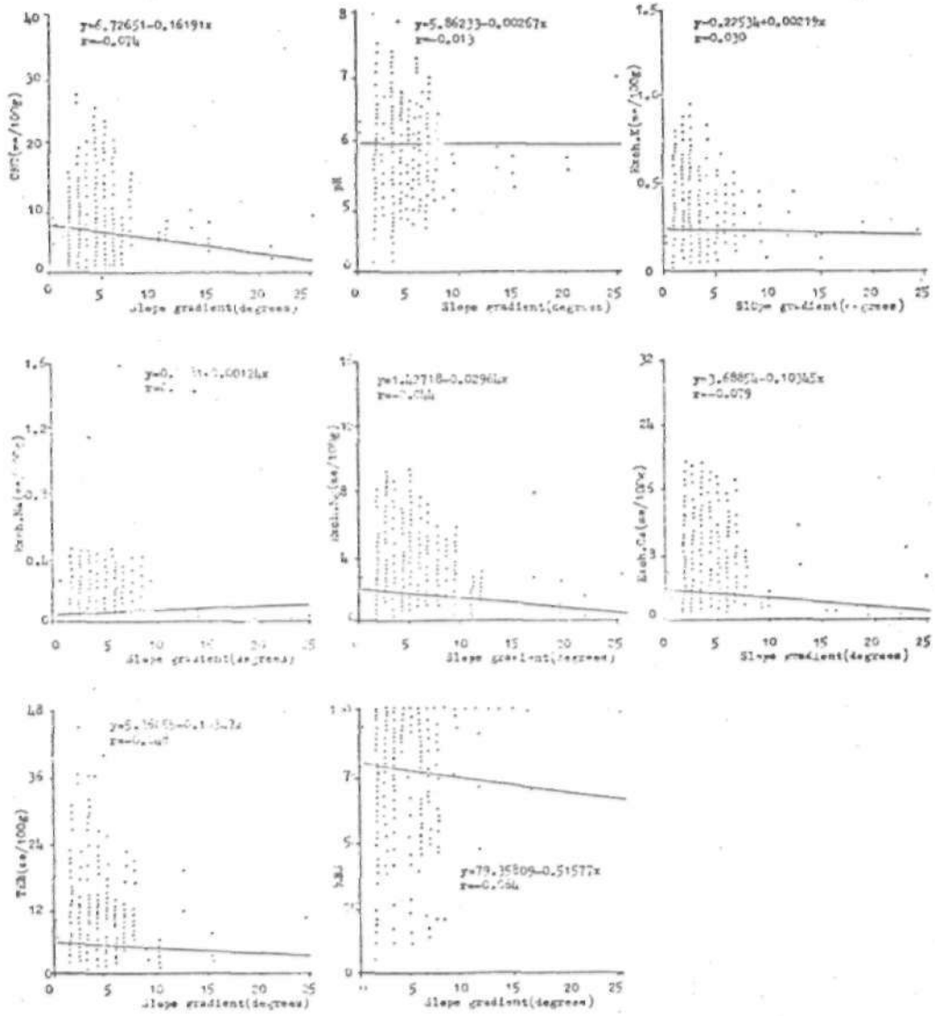


Fig.6.5 The chemical properties of the top soils and slope gradient

from the first to the second zone (Table 6.4). Both the pH and the %BS on the other hand revealed negative and significant correlations with the factor. Analysis of variance partially supported this negative and significant trends. As is observable in Table 6.4, the differences in the means of each of the properties, between the altitudinal zones, were highly significant and the general trend an increase from the first to the second altitudinal zone but thereafter a decrease.

The regression of the TEB and the individual exchangeable bases, except Ca, on altitude was positive. The trend was significant however, only for K and Na. Analysis of variance also supported this, in that only the two elements (i.e. K and Na) showed statistically significant different values between the altitudinal zones.

Neither the regression analysis, nor the analysis of variance revealed significant relationships between any of the soil properties and the slope gradient factor (Fig.6.5 & Table 6.4). By contrast, all the properties showed highly statistically significant differences between the slope positions and the general trend a downslope increase in value for the CEC, each of the exchangeable cations and the TEB, but a decrease for both the pH and %BS (Table 6.4).

6.1.3 Relationships between the soil chemical properties and the soil organic carbon and clay content

The relationship between the CEC and the organic carbon and clay were highly significant (Figs. 6.6 & 6.7). The

organic carbon content however accounted for much greater variability in the property than did the clay content. While the r^2 (coefficient of determination) between the property and organic carbon is 59.2%, it is only 34.1% with respect to clay. As suggested by equations (6.1) and (6.2), each additional 1% organic carbon in the soil contributes an extra 6.43me/100g to the CEC, and a 10% increase in the clay content, about 3.2me/100g. The differences

$$CEC = 0.82447 + 6.43314 \text{ carbon} \quad \ldots\ldots\ldots\ldots \quad (6.1)$$

$$CEC = 1.62416 + 0.32279 \text{ clay} \quad \ldots\ldots\ldots\ldots\ldots \quad (6.2)$$

in the means of the property between both the organic carbon and clay percent classes, by analysis of variance, were also quite significant and the general trend positive (Table 6.5).

The correlations between the pH and both the organic carbon and clay contents were highly significant but negative. The simple regression lines, which are expressed by Equations (6.3) and (6.4),

$$pH = 5.95930 - 0.11931 \text{ carbon} \quad \ldots\ldots\ldots\ldots \quad (6.3)$$

$$pH = 6.02084 - 0.01166 \text{ clay} \quad \ldots\ldots\ldots\ldots\ldots \quad (6.4)$$

indicate that whereas each 1% increase in the soil organic carbon is associated with about a unit crop in the soil pH, that of clay is with about 0.01 drop. Analysis of variance also revealed quite significant differences in the property between the organic carbon and clay percent groups and the

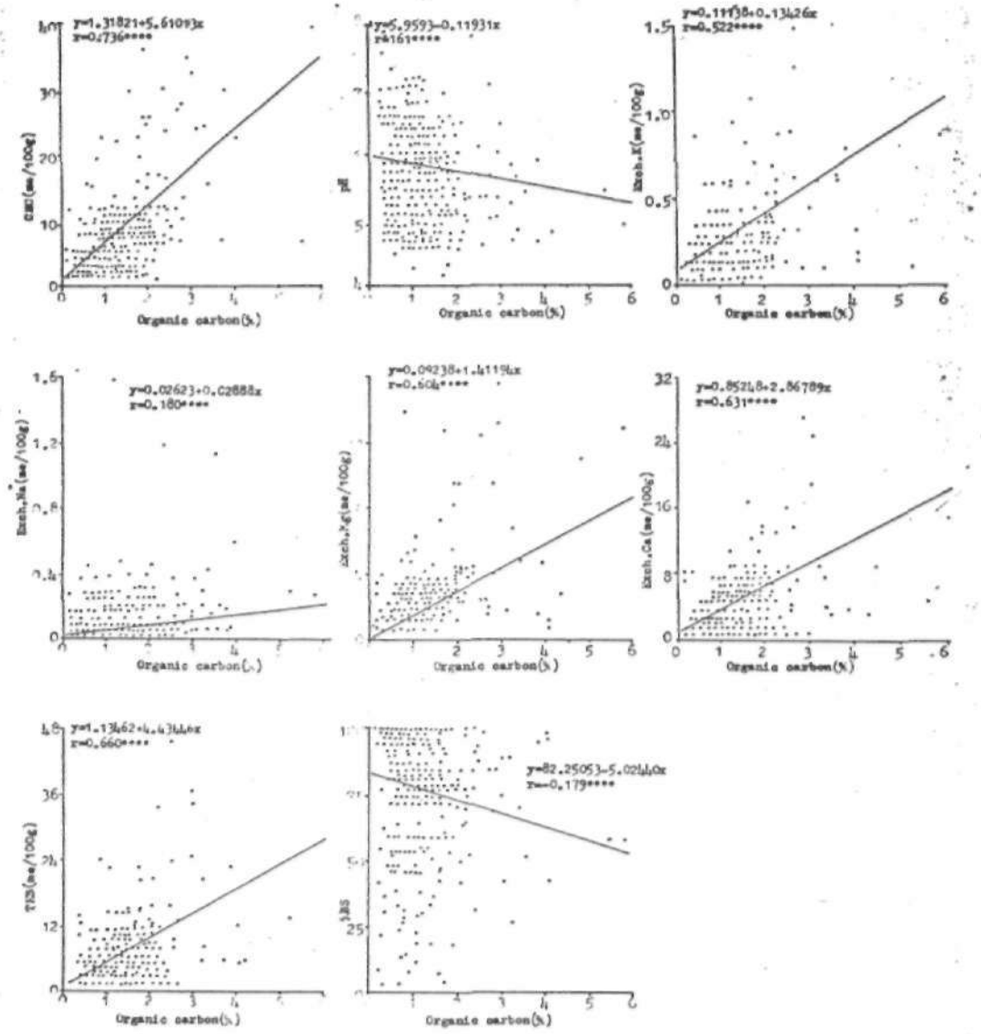


Fig.6.6 The chemical properties of the top soils and organic carbon

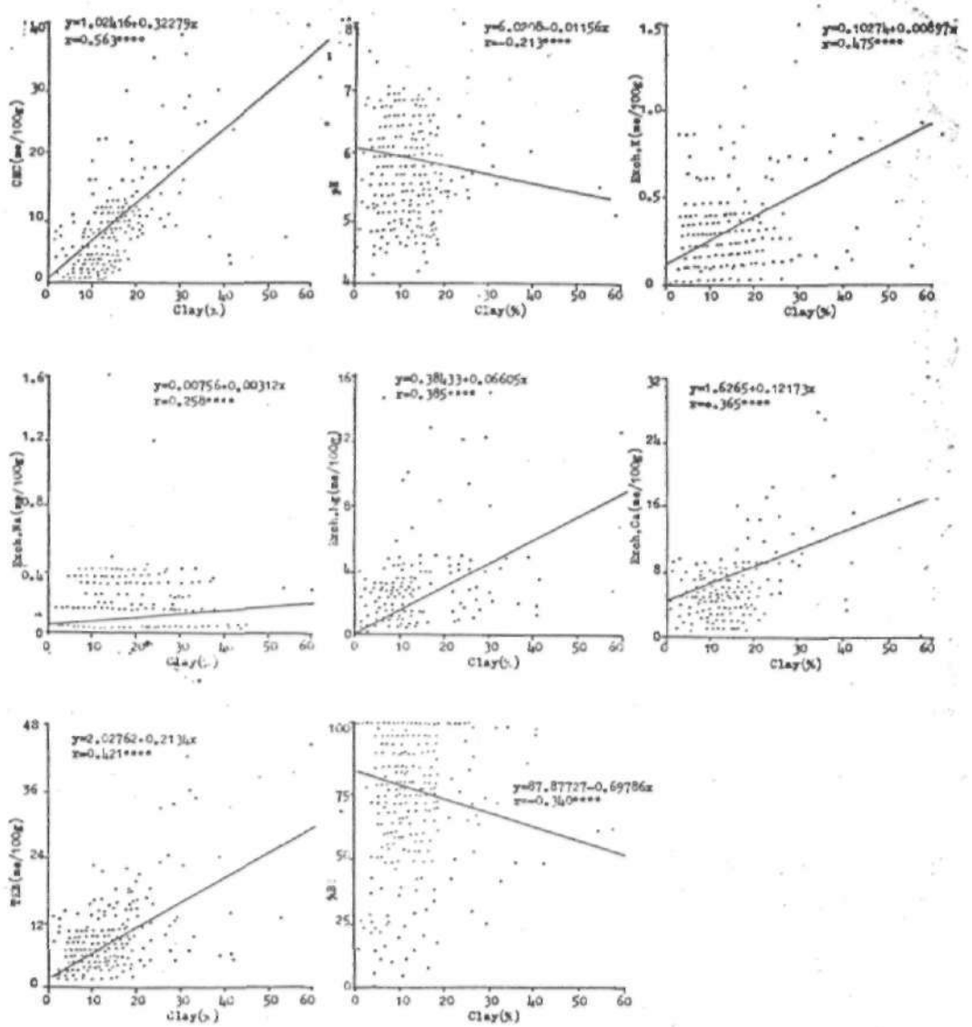


Fig.6.7 The chemical properties of the topsoils and clay

Table 6.5: The chemical properties of the topsoils and organic carbon and clay

	No of samples	CEC $\bar{x}$	CEC S.D	pH $\bar{x}$	pH S.D	Exch. K. $\bar{x}$	Exch. K. S.D	Exch.Ca $\bar{x}$	Exch.Ca S.D	Exch. Mg $\bar{x}$	Exch. Mg S.D	Exch.Na $\bar{x}$	Exch.Na S.D	TEB $\bar{x}$	TEB S.D	%BS $\bar{x}$	%BS S.D
C(%)																	
< 0.5	151	2.84	1.85	5.99	0.59	0.15	0.14	1.84	1.43	0.58	0.44	0.03	0.07	2.65	1.80	84.5	20.9
0.5-1.0	127	5.25	2.92	5.79	0.53	0.21	0.13	2.80	1.82	1.08	1.26	0.05	0.08	4.17	2.68	75.8	22.3
1.0-1.5	45	8.08	3.31	5.73	0.61	0.26	0.13	4.01	2.22	1.61	1.38	0.07	0.25	6.02	3.45	70.2	23.8
1.5-2.0	28	11.69	5.62	5.64	0.68	0.39	0.26	5.66	3.64	2.43	2.39	0.06	0.10	8.54	5.72	67.8	25.1
> 2.0	31	19.39 ****	10.36	5.79 ***	0.69	0.57 ****	0.37	10.22 ****	7.70	4.66 ****	3.69	0.13 ***	0.23	15.58 ***	10.83	73.9 ****	18.8
Clay (%)																	
<10	171	3.40	2.76	5.95	0.55	0.15	0.10	2.30	1.80	0.68	0.53	0.02	0.05	3.19	2.28	84.6	20.5
10-20	127	6.39	5.08	5.90	0.58	0.23	0.17	3.58	3.66	1.47	1.93	0.06	0.17	5.34	5.32	77.6	21.9
20-30	48	9.66	7.56	5.58	0.57	0.38	0.28	3.90	3.78	2.03	2.55	0.07	0.10	6.58	6.42	65.1	23.4
>30	36	14.74 ****	8.58	5.59 ****	0.71	0.43 ****	0.31	7.11 ****	6.45	3.04 ****	3.01	0.13 ****	0.22	11.36 ****	9.24	63.4 ****	19.5

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

general trend is again that of decreasing values with the organic carbon and clay content.

Each of the exchangeable bases, and thus the TEB, showed highly significant and positive relationships with both the soil organic carbon and clay contents. Again on the whole, the TEB and the exchangeable bases, with the exception of Na, were more strongly correlated with the soil organic carbon content than with the clay content (Figs. 6.6 & 6.7, Table 6.5).

The regression of the %BS on both the organic carbon and clay contents were negative and quite significant. As suggested by Equations (6.5) and (6.6), on the average, every 1% increase

$$\%BS = 82.24053 - 5.02440 \text{ carbon} \quad \ldots\ldots\ldots\ldots \quad (6.5)$$

$$\%BS = 87.87727 - 0.69786 \text{ clay} \quad \ldots\ldots\ldots\ldots\ldots \quad (6.6)$$

in the organic carbon and 10% increase in the clay content is associated with about 5.02% and 7.0% decrease in the soil's %BS, respectively. Such significant and positive correlations of the property with both the organic carbon and clay contents of the soils were also supported by the results obtained from using the analysis of variance statistical method (Table 6.5).

While the observed positive relationship in the exchangeable bases and the TEB with both the organic carbon and clay contents of the soils is in general agreement with the results of several other workers, and

could be explained in terms of greater exposure of exchangeable sites, the negative trends with respect to both the pH and the %BS are in conflict with the observations of several others. As pointed out by Buol et. al for example, with increase in clay content, a soil becomes less permeable and so there is reduction in the rate of losses of exchangeable bases through leaching. Most authors have also suggested a positive linear relationship between the rate of organic matter mineralization, and the amount and rate of accumulation of basic cations in the soil system (Brady, 1974; Forth, 1978). Under the generally sandy topsoils prevailing over much of the present study area however, it would appear that leaching has been universally quite effective. Furthermore, recent studies on the characteristics and behaviours of silicate minerals have indicated that although they have the potential of increasing the pool of basic cations, they also havethe effect of increasing the acidic cations, for the greater the exchangeable complex of the soil, the more the polymerized hydroxy-aluminium ions accumulation between the layers of the clay crystal (Jackson, 1960 & 1963; Yaun, 1963; Hus & Bates, 1964; Bohn, 1979). In a similar way, it is now widely known that organic matter not only produces acidic radicals upon decomposition but also plays an important role in the complexing or chelating of available cations (Clark & Nichol, 1966; Brady, 1974; Pitty, 1978; Bohn, 1979).

Table 6.6: The topsoils chemical properties: Percentage variance explained by the soil-forming factors considered

Factor		CEC		pH		Exch. K		Exch. Ca		Exch. Mg		Exch. Na		TEB		%BS	
Parent material		30.9		2.6		19.8		24.6		24.2		6.9		25.0		5.0	
Climate	Rainfall	3.2	3.6	9.6	11.2	3.2	3.2	0.8	1.1	4.2	4.3	2.7	2.7	2.4	2.8	8.9	10.0
	Temperature	0.4		1.6		0.0		0.3		0.1		0.0		0.4		1.1	
Relief	Altitude	0.0		2.7		3.9		1.3		0.1		4.3		0.4		4.6	
	Slope gradient	0.1	4.3	0.5	9.8	0.0	5.4	0.0	2.6	0.0	2.0	0.0	4.4	0.0	2.1	0.1	11.0
	Slope position	4.2		6.6		1.5		1.3		1.9		0.1		1.7		6.3	
Explained		38.8		23.6		28.4		28.3		30.5		14.0		30.8		26.0	
Residual		61.2		76.4		71.6		71.7		69.5		86.0		69.2		74.0	

6.1.4 The relative importance of the soil-forming factors in determining the spatial variability of the soil chemical properties

Table 6.6. shows the soil chemical properties of the topsoils considered and the percentage variance of each of them explicable in terms of the examined soil-forming factors. As is suggested in the table, the CEC, each of the exchangeable bases and the TEB of the soils were more strongly related to the parent material factor then to the other factors.

In contrast to the CEC and the exchangeable bases, the rainfall factor clearly assumed the greatest role in explaining the variability of both the pH and the %BS, out of the environmental factors considered. The percentage variance of the properties explained by altitude ranged between 0.0% for the CEC and 4.6% for the %BS and that of slope position between 0.1% for Na and 6.6% for the pH.

As with the organic carbon and nitrogen, and the textural properties of the soils, only very minor proportions of the variances of each of the soil chemical properties were accounted for by the temperature and the slope gradient factors.

6.2 SUBSOILS

6.2.1 Nutrient status and chemical condition

Due, presumably, to the greater clay content, and perhaps, presence of partially weathered mineral fragments, at depth, the CEC and the exchangeable bases showed

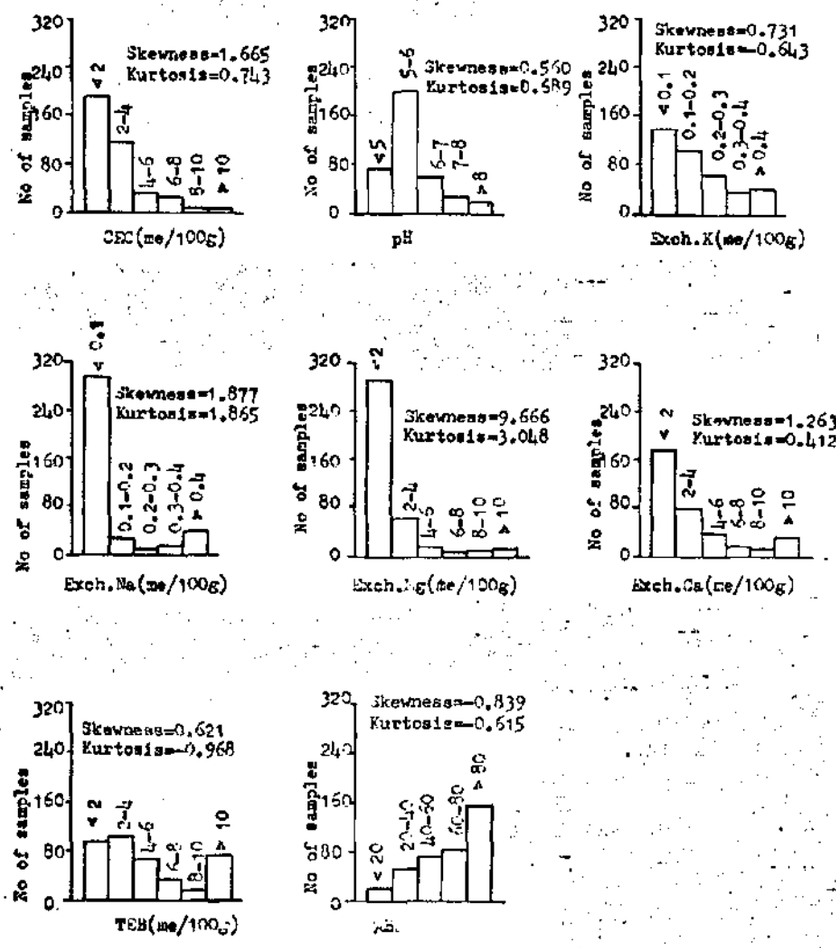


Fig.6.8 The chemical properties of the subsoils

comparatively higher mean values at the subsoils, than at the topsoils. Moreover, the coefficient of variability of each of the properties was also lower. The %BS showed a lesser mean value but greater coefficient variability value. By contrast, both the mean and the coefficient variability values of the soil pH were not markedly different from those for the topsoils.

6.2.2 Relationships between the soil chemical properties and the soil-forming factors

6.2.2.1 Parent material

As was observed for the topsoils, differences in the mean values of the CEC, the exchangeable bases with the exception of Na, and the TEB, between the different parent materials, were statistically significant and the trend with the materials somewhat similar, particularly in the case of the sedentary parent materials. That is, each of the elements showd comparatively higher mean values over basalt and shale, than over the granite rocks and sandstone, and except K and Ca (with respect to alluvium), over alluvium and aeolian materials than over colluvium and ironpan.

The pH also showed significant differences between the different lithologies. Unlike in the topsoils however, there were no marked differences between basalt and shale on the one hand and the granite rocks and sandstone on the other.

The %BS, unlike in the topsoils, revealed statistically significant different values between the parent materials.

Table 6.7: The chemical properties of the subsoils and parent material

PARENT MATERIAL		SEDENTARY							TRANSPORTED			
		Granite	Gneiss	G/gneiss	Schist	Sandstone	Basalt	Shale	Alluvium	Colluvium	Aeolian	Ironban
No of samples		36	32	38	34	36	40	42	30	32	38	22
CEC	$\bar{x}$	7.45	7.58	8.12	7.62	4.99	13.68	11.57	7.40	6.28	7.63	3.97****
	S.D	5.47	4.03	5.52	5.39	4.74	9.88	8.90	5.92	7.68	5.49	2.17
pH	$\bar{x}$	6.03	5.74	5.91	5.55	5.36	5.90	5.54	5.73	5.88	5.96	5.50***
	S.D	1.16	0.85	0.79	0.79	0.79	0.92	0.76	0.94	0.74	0.74	0.47
Exch.K	$\bar{x}$	0.24	0.25	0.24	0.24	0.16	0.33	0.26	0.16	0.26	0.28	0.15*
	S.D	0.15	0.15	0.12	0.14	0.13	0.24	0.15	0.14	0.21	0.60	0.14
Exch.Ca	$\bar{x}$	4.34	3.32	4.12	2.90	2.36	6.19	5.04	3.57	3.79	4.64	2.03**
	S.D	6.58	3.04	4.27	2.83	3.76	5.17	5.78	3.69	6.94	4.40	2.33
Exch.Mg	$\bar{x}$	1.69	2.05	1.57	1.60	1.01	3.88	2.19	1.34	0.93	1.48	0.71****
	S.D	2.25	2.48	1.20	1.20	1.63	4.81	2.63	1.47	1.09	1.38	0.49
Exch.Na	$\bar{x}$	0.28	0.14	0.27	0.12	0.11	0.23	0.22	0.21	0.10	0.60	0.01
	S.D	0.68	0.24	0.61	0.23	0.30	0.50	0.42	0.46	0.24	1.70	0.03
TEB	$\bar{x}$	6.54	6.77	6.20	4.87	3.86	10.48	7.72	5.27	5.07	6.99	2.90*****
	S.D	7.98	5.08	5.44	4.72	5.17	9.59	8.00	5.07	7.86	6.69	2.73
%BS	$\bar{x}$	71.3	66.6	74.1	58.4	56.4	69.6	59.1	66.4	70.5	81.3	63.4*****
	S.D	27.9	25.5	19.9	25.4	28.8	22.9	27.1	26.0	26.3	24.5	26.9

Analysis of variance levels of significance: *** = 0.001; ** = 0.01; ** = 0.02; * = 0.05.

The pattern of the mean values, over the materials, moreover **diferred** from that observed in the topsoils. For example, in the topsoils, and for the sedentary materials, the value was highest over schist and lowest over gneiss. Here in the subsoils, the value was highest over granite-gneiss and lowest over sandstone.

6.2.2.2 Climate

As in the topsoils, while the CEC showed a significant increase in value with increase in rainfall, the soil pH showed a decrease.

Unlike in the topsoils, where all the exchangeable bases showed a uniformly positive trend with rainfall, the regression of the elements on the factor was positve only for K and Mg. Furthermore, none of the regression correlation coefficient values was significant, statistically. By analysis of variance however, except Na, all the elements and thus the TEB showed significant differences between the rainfall zones. The spatial variability of the mean value of each of the elements was such that there was a low value in the direst rainfall zone, followed by a high value in the second zone, and thereafter quite similar or very slowly decreasing values. It could be that in the lowest rainfall zone, subsoil chemical weathering has been less effective and hence only few bases are released into the soil system for clay formation and/or adsorption onto the soil exchangeable complex. On the other hand, although favouring greater weathering and the release of bases, the rainfall

amount in the second zone has probably remained insufficient for the leaching of the greater proportion of the librated bases. Moving to the third and the fourth zones however, conditions have probably been more favourable for not only the rapid chemical weathering processes, but also greater leaching. The relatively low CEC of the soils, in general, may be expected to have greatly accentuated this latter process. Another possible explanation for such distinctive trend in the soil exchangeable cations with rainfall amount is the past climatic oscillation over the study area (3.3.4).

Table 6.8: Simple correlation coefficients between chemical properties of the subsoils and rainfall, temperature, altitude, gradient and clay

	Rainfall	Temperature	Altitude	Gradient	Clay
CEC	0.153****	0.025	0.042	-0.164****	0.470****
pH	-0.343****	-0.072	0.006	-0.107**	-0.106**
Exch.K	0.062	-0.130***	0.160****	-0.016	0.237****
Exch.Ca	-0.062	0.008	-0.048	-0.165****	0.256****
Exch.Mg	0.063	0.072	0.005	-0.120***	0.290****
Exch.Na	-0.072	-0.053	0.027	-0.072	0.093*
TEB	-0.025	0.010	-0.023	-0.166****	0.301****
%BS	-0.370****	-0.094*	-0.082	-0.122***	-0.244****

Levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05

As in the topsoils, the soil properties revealed no apparent significant correlations with temperature. The only exceptions were the %BS and exchangeable K, both of which showed an inverse relationship with the factor.

Table 6.9: The chemical properties of the subsoils and climate

Climatic Parameter	No of Samples	CEC $\bar{x}$	CEC S.D	pH $\bar{x}$	pH S.D	Exch.K $\bar{x}$	Exch.K S.D	Exch. Ca $\bar{x}$	Exch. Ca S.D	Exch. Mg $\bar{x}$	Exch. Mg S.D	Exch. Na $\bar{x}$	Exch. Na S.D	TEB $\bar{x}$	TEB S.D	%BS $\bar{x}$	%BS S.D
Rainfall (mm)																	
600-900	74	5.04	4.63	6.01	0.67	0.19	0.45	3.42	3.92	1.04	1.07	0.17	0.86	4.87	5.47	81.2	19.3
900-1200	103	9.55	7.17	6.21	0.97	0.27	0.16	5.38	5.85	2.30	2.97	0.44	1.00	8.38	8.07	75.5	24.6
1200-1500	130	8.16	7.69	5.40	0.64	0.25	0.18	3.48	5.01	1.71	2.97	0.09	0.16	5.59	7.28	58.7	25.9
1500-1800	78	9.17 ****	6.30	5.47 ****	0.73	0.23 **	0.16	3.52 ***	5.3	1.80 **	1.82	0.19	0.42	5.62 ***	4.87	57.6 ****	25.9
Temperature (°C)																	
20-25	108	8.44	4.39	5.78	0.72	0.28	0.16	4.09	3.96	1.55	1.27	0.56	0.86	6.18	5.14	67.6	24.7
25-27	125	6.36	6.19	5.90	0.86	0.23	0.36	3.40	4.59	1.54	2.82	0.24	0.80	5.36	7.14	72.2	26.6
27-28	148	9.45 **	8.59	5.60 ***	0.88	0.22	0.17	4.40	5.55	2.11	2.77	0.18	0.38	6.96	7.72	62.8 **	26.5

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

6.2.2.3 Relief

By regression analysis, only exchangeable K showed significant relationship with altitude and, as in the topsoils, the trend was positive. The pH, %BS, exchangeable Na and the CEC were all not significantly correlated with the factor (Table 6.8). Although the differences in the means of the pH, Na and %BS, between the altitudinal zones, were statistically significant, by analysis of variance, none of the set of values revelaed any systematic altitudinal trend. Each of the properties was marked by an initial low value in the lowest altitudinal zone, followed by a relatively higher value in the second zone and then a decrease again (Table 6.10). Except exchangeable K and Na, all the properties showed significant correlations with slope gradient and the trends were negative (Table 6.8). These were partially supported in the result obtained from analysis of variance in which each of the properties, except K, showed relatively higher mean values in the less than 5° slope angle class (suggesting lower losses and/or greater supplies of basic cations) as compared to the remaining $5-10^{\circ}$ and greater than 10° groups.

Unlike in the topsoils, where the differences were all statiscially significant, only the CEC and exchangeable Mg showed significant differences between the slope positions, and the trend a general downslope increase in value.

Table 6.10: The chemical properties of the subsoils and relief

Relief Parameter	No of Samples	CEC $\bar{x}$	CEC S.D	pH $\bar{x}$	pH S.D	Exch.K $\bar{x}$	Exch.K S.D	Exch.Ca $\bar{x}$	Exch.Ca S.D	Exch.Mg $\bar{x}$	Exch.Mg S.D	Exch.Na $\bar{x}$	Exch.Na S.D	TEB $\bar{x}$	TEB S.D	%BS $\bar{x}$	%BS S.D
Altitude (metres)																	
<300	110	7.99	6.57	5.43	0.74	0.21	0.15	3.70	5.06	1.66	2.12	0.12	0.33	5.73	6.30	60.8	26.7
300-600	167	7.99	7.54	6.05	0.89	0.23	0.32	4.55	5.29	1.90	2.73	0.33	0.95	7.06	7.75	76.3	23.2
600-900	74	7.82	5.78	5.62	0.65	0.26	0.15	3.32	3.19	1.48	1.44	0.09	0.38	5.15	4.51	62.5	26.9
>900	34	10.26	7.35	5.53 ****	0.77	0.36 *	0.18	3.87	4.52	2.04	3.64	0.26 *	0.27	5.98	7.97	52.9 ****	23.9
Slope gradient																	
<5°	326	8.54	7.29	5.79	0.88	0.24	0.26	4.29	5.12	1.87	2.61	0.24	0.74	6.64	7.28	68.3	26.5
5-10°	48	5.98	3.67	5.60	0.57	0.24	0.19	2.18	1.79	1.12	1.08	0.12	0.20	3.70	2.69	61.2	23.1
>10°	8	5.90 *	5.27	5.50 *	0.51	0.26	0.11	2.65 **	3.21	1.33 *	1.79	0.04 *	0.05	4.28 **	4.81	57.6 *	32.9
Slope position																	
Crest	119	6.69	6.17	5.82	0.83	0.22	0.17	3.61	5.36	1.38	2.23	0.19	0.53	5.43	6.70	69.9	25.5
Middle	148	7.67	5.41	5.70	0.84	0.25	0.33	3.76	4.27	1.58	1.72	0.20	0.71	5.85	5.96	65.8	25.9
Basal	116	10.30	8.77	5.74	0.85	0.25	0.18	4.66	4.93	2.40	3.27	0.28	0.79	7.51	7.98	66.2	27.4

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

6.2.3 Relationship between the soil chemical properties and clay

Table 6.11: The chemical properties of the subsoils and clay

Clay (%)		<15	15-30	30-45	>45
No of samples		58	108	144	72
CEC	$\bar{x}$	2.89	7.04	8.50	13.43****
	S.D	2.98	4.96	5.39	9.69
pH	$\bar{x}$	5.70	5.92	5.72	5.59*
	S.D	0.69	0.83	0.89	0.83
Exch.K	$\bar{x}$	0.11	0.25	0.24	0.32****
	S.D	0.11	0.37	0.16	0.21
Exch.Ca	$\bar{x}$	1.54	3.93	4.12	5.79****
	S.D	1.62	4.23	4.94	6.28
Exch.Mg	$\bar{x}$	0.61	1.43	1.78	3.12****
	S.D.	0.63	1.61	2.04	4.12
Exch.Na	$\bar{x}$	0.04	0.17	0.29	0.30
	S.D	0.11	0.50	0.93	0.58
TEB	$\bar{x}$	2.39	5.79	6.43	9.44****
	S.D	2.11	5.69	6.75	9.37
%BS	$\bar{x}$	73.2	73.5	63.6	60.0****
	S.D	25.9	23.4	26.2	28.1

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05

Similar to the topsoils, the correlation between each of the soil chemical properties considered and clay percent was highly significant. Furthermore, while the correlation coefficient values for the CEC, the exchangeable bases and thus the TEB were positive, those for the pH and the %BS were negative (Table 6.8).

By analysis of variance, however, although the differences in each of the properties, except Na and the pH, were still

quite significant, the trend of the mean of each of them with the clay classes showed less systematic increase, as was the case in the topsoils (Table 6.11). This was possibly due to the generally high content of clay in the subsoils.

6.2.4 The relative importance of the soil-forming factors in determining the spatial variability of the soil chemical properties

Table 6.12 gives the summary of the percentage variance of each of the soil chemical properties explained by the factors considered. The percentage variance of the CEC, TEB and the individual exchangeable bases explained by the lithological factor was, as in the topsoils, considerably higher than that explained by any of the factors. The pH and the %BS also had a considerable percentage of their variances explained by the parent material factor. However, as in the topsoils, the proportion of the variances of each of the two properties explicable in terms of the rainfall factor was clearly higher than that of any other factor.

Unlike in the topsoils, and with the exception of the %BS, the percentage variance of each of the properties explicable in terms of altitude was generally below 2%. The variances of each of the properties explicable in terms of the slope position factor except the CEC and Exch. Mg was generally below 1%

As in the topsoils, the percentage variance of each of the properties explained by the parameter of slope gradient was generally below 1%.

Table 6.12: The subsoils chemical properties: Percentage variance explained by the soil-forming factors considered

Factor		CEC		pH		Exch. K		Exch. Ca		Exch. Mg		Exch. Na		TEB		%BS	
Parent material		14.6		6.5		4.4		6.1		3.6		4.7		8.1		7.9	
Climate	Rainfall	1.0	1.0	13.2	13.5	1.0	1.4	2.0	2.5	1.9	3.1	0.4	0.4	1.9	3.1	12.9	13.6
	Temperature	0.0		0.3		0.4		0.5		1.2		0.0		1.2		0.7	
Relief	Altitude	1.3		1.4		0.3		1.6		0.0		0.1		1.3		5.3	
	Slope gradient	0.0	2.7	0.0	1.9	0.0	1.4	0.6	2.3	0.4	4.4	0.0	0.5	0.5	2.2	0.0	6.1
	Slope position	1.4		0.5		1.1		0.1		4.0		0.4		0.4		0.8	
Explained		17.3		21.9		7.2		10.9		11.1		5.6		13.4		21.6	
Residual		82.7		78.1		92.8		89.1		88.9		94.4		86.6		78.4	

6.3 DISCUSSION

The effects of parent material on soil chemistry are mainly indirectly through its influence on the texture, clay mineralogy, and nutrient availability and thus the organic matter content of the soils (Buol et. al., 1974; Young, 1976). As acid rocks usually contain a great deal of free silica and little alumina and iron compounds, they naturally supply a very limited range and quantity of ions essentially for secondary clay formation and adsorption onto the soil exchangeable complex. The cycling of ash elements and organic matter turnover are therefore relatively low.

In contrast, the higher content of alumina - and ferrisilicate in basic rocks often produces a considerable range and amount of bases upon weathering, favourable not only for secondary clay formation, but also for a more active cycle of ash elements and the accumulation of stable forms of organic substances and associated organic acids. The CEC, pH, exchangeable cations and the %BS of the soils are therefore greater over the basic rocks than over the acid rocks.

The relationship between parent material and soil chemical properties is however definitely more complex than stated simply above over the present study area. This is because, in the subsoils, both the pH and the %BS values over granite and granite-gneiss, which are acidic rocks, were in fact higher (reflecting greater illuviation) than those over basalt and shales. Even much more important is

the fact that the pH values and base status from all the parent materials, including the base-rich parent materials like basalt are low and virtually all the soils are in fact acidic. A probable cause of these conditions may be the high degree of leaching that is taking place or has taken place in these soils. The periods with a more humid climate during the Pleiestocene (Grove, 1958) may have provided conditions favourable to weathering and intense leaching of bases, and to the formation of kaolinitic clay minerals.

The effects of rainfall on soil chemical properties are both direct and indirect. Rainfall not only exerts its influence on soil chemical properties by its action on the dissolution of materials, transport of materials from one part of the soil to the other and by its control of chemical and physical reactions taking place in the soil, but also by its control of plant growth and other organisms that contribute organic materials to the soil. The indirect relationship between rainfall and soil chemical properties is presumably that in which an increasing annual rainfall tends to favour increasing vegetative growth and therefore the production of organic material. In the drier areas of the north,in the present study area, where not only is there little organic matter owing to low biological production and high oxidation rates, but also very little clay formation resulting from mild chemical weathering, the CEC of soils is quite low, often below 0.5me/100g.

The pH and %BS of both the topsoils and the subsoils showed inverse relationships with the mean annual rainfall

since both properties are related to the intensity of leaching. Leaching in soils involves several complex sequences of events. In general, however, the stage is set when either through soluviation (ordinary dissolution in water of elements from minerals) or cheluviation (chelation or complexing by organic molecules) elements are prepared for transport (Atkinson & Wright, 1957). The material thus dissolved can either be leached completely out of the soil, or simply translocated down within the profile.

With reference to the effect of temperature, its relationship with the soil chemical properties is usually that in which increasing mean annual values tends to favour increasing base status and pH values, a phenomenon that is often explained in terms of the reduction in the rate of leaching and/or the movement of dissolved materials from deep down the solum to or near the surface by capillary action (due to increased evapotranspiration). In addition, within limit, and provided water is available, an increasing temperature is also usually associated with greater chemical weathering and thus greater supply of cations. Under the present conditions however, the situation looks rather different. With the exception of the pH, the correlation coefficients between the soil chemical properties and the mean annual temperature are quite low, and infact negative for some of them. This again was possibly due to the relatively low range of the factor over the area.

Topography influences soil chemical properties via clay formation and organic matter content, mainly by modifying

the moisture regime of the soils and the biosphere. It has been observed by many workers that under conditions of poor drainage, lateral water movement tends to predominate over vertical movement, hence there is a reduction in the rate of losses of bases through leaching (Brady, 1974; Forth, 1978). However, by encouraging greater organic matter accumulation, such conditions also tend to increase soil acidity. Apart from an acidic condition directly imparted by the presence of humic acids, by-products of organic matter decomposition, complexing of metalic ions by such substances may also assume a significant role in the losses of basic cations in soil (Pitty, 1978). Furthermore, it has been observed that poorly-drained contitions, or soils that remain moist for the greater part of the year, are more susceptible to volatilization (i.e. processes under which several soil cations are lost to the air) than well-drained conditions.

Topography also affects soil chemical properties through transport of organic materials, and inorganic substances, either in solution or in suspension, by colluviation and lateral eluviation (Chapter IV & V). Possible reasons for the relatively low level of correlations between the chemical properties and altitude, or the lack of a consistent altitudinal trend especially for the subsoils in the present study area are the prevalence of shallowly weathered rocks and steeper slopes, resulting in greater loss of the bases by lateral eluviation, in the higher lying areas than the low lying areas.(Section 3.6).

CHAPTER VII

RESULTS: IV THE GRADE OF STRUCTURE, BULK DENSITY AND EFFECTIVE DEPTH OF THE SOILS

7.0 INTRODUCTION

This chapter focusses on the grade of structure, i.e. degree of structural development (the distinctiveness and durability of peds) and bulk density of soils over the study area. Both the class (size) and type (shape) of sturctural units have not been given independent consideration because of the very high degree of skewness in the distribution of the values encountered over the region. As much as 65% of the samples considered have blocky (angular & subangular) structure with predominantly medium size (10-20mm diameter).

In addition to the grade of the soil structure and bulk density, the chapter examines the effective depth of the soils. This parameter has been taken in this study to mean that portion of the soil profile overlying the parent material and free of such dense horizons as fragipan. Although tree crops have much greater power of finding sufficient soil mantle in more deeply weathered pockets or between horizons and tree plantations (e.g. pines & eucalyptus) are known to be capable of establishing on soils too thin for cultivation, the roots of most crops do not normally go beyond this depth (young, 1976).

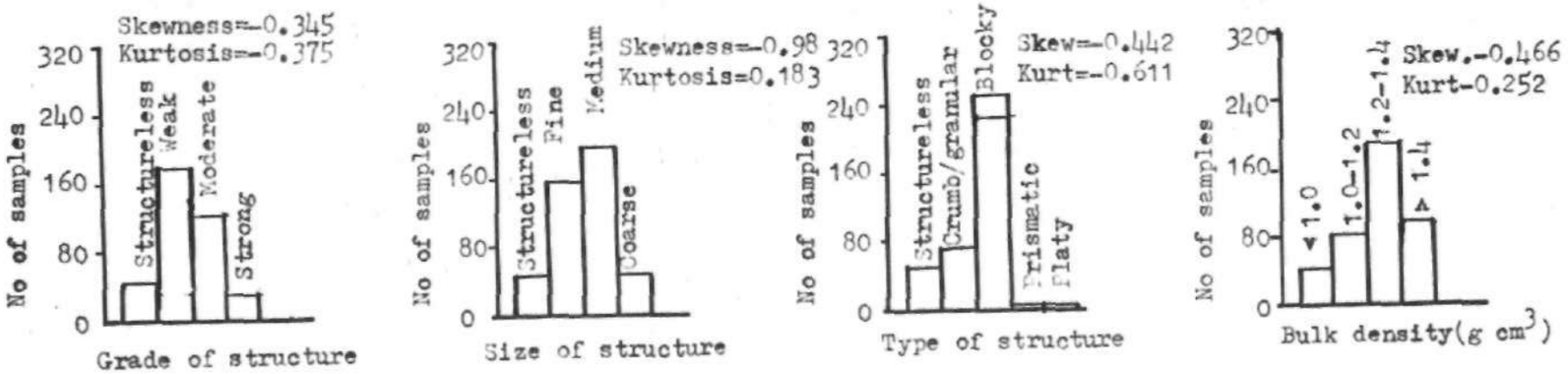
7.0.1 The structural development and bulk density

A relatively high proportion of the samples considered have weak to moderately developed structures and as much as 13% are structureless (Fig. 7.1). The relatively low proportion of the samples with strongly developed structure and the high proportion with no observable structural units reflect, presumably, the low organic matter and clay contents of the soils. It probably also reflects the high kinetic energy of rainfall over the region (Kowal & Kassam, 1977; Leow et. al., 1983).

Clay particles, under several physico-chemical forces (e.g. the van der Waals forces, the electrostatic force of adhesion and cohesion), not only cohere to form larger secondary units, but also entrap or act as bridges between larger particles (Grim, 1953; Martin et. al., 1955; Hartmann, 1979; Pitty, 1978). This implies that with an increase in clay content, the degree of development of the soil structure also improves. Similarly, with increase in soil organic matter content, the degree of development of the structural units usually increases. Apart from its direct mechanical binding effect on soil primary particles, by preventing or decreasing the swelling and slacking of soil materials, organic matter may also contribute indirectly towards the formation and preservation of water-stable aggregates (Pitty, 1978).

With respect to rainfall action, under high intensity rainfall, with large drops, even well developed surface soil structures may become so compacted by raindrop impact that it

TOPSOILS



SUBSOILS

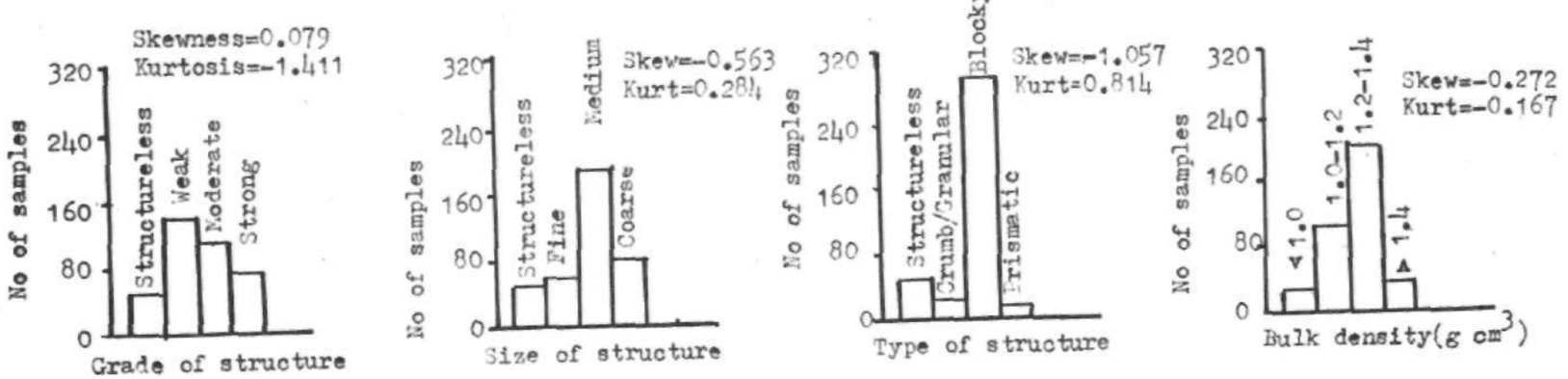


Fig. 7.1 The structure and bulk density of the soils.

becomes virtually impermeable. Under such conditions, infiltration will be low and the majority of the water will run off the surface, leading to soil erosion and flooding.

The bulk-density values of the topsoils vary between 0.73g cm^{-3} and 1.65g cm^{-3} and averages about 1.29g cm^{-3}. At the subsoils, the values vary from 0.85g cm^{-3} to 1.66g cm^{-3} with a mean of about 1.34g cm^{-3}. This slight increase in mean values reflects, presumably, the marked increase in clay content but decrease in organic matter at depth (Briggs, 1977). Several human activities are also known to be important in hastening the decay of soil aggregation and in inducing a high degree of subsoil compaction. Prominent among such activities are continuous tillage operations and grazing (Jaiyeoba & Leow, 1984).

Equation (7.1) may be applied to calculate the total pore spaces of the soils

$$\% \text{ pore space} = 100 - \frac{Db}{Dp} \times 100 \quad \ldots\ldots\ldots\ldots \quad (7.1)$$

where Db = bulk density, oven dry

Dp = particle density

If it is assumed that the predominant minerals making up the soils are quartz, feldspars and colloidal silicates, with an average particle density of 1.65g cm^{-3} (Briggs, 1977), the mean percentage pore spaces of the topsoils and subsoils would be about 21.2% and 18.8% respectively. The direction and rate of flow of water in the soil is not

determined by the gross amount of pore spaces alone, but also by the size and configuration of the pores (Brady, 1974). Nevertheless, these mean values do indicate that soils over the study area have high infiltration capacities.

7.0.2 Relationship between the grade of structure and bulk density of the soils and the soil-forming factors

7.0.2.1 Parent material

The relationship between the degree of development of the soil structures and parent material, by chi square analysis, and between bulk density and parent material, by analysis of variance, are summarized in Table 7.1. On the whole, the differences in the degree of structural development between the parent materials, in respect of both the topsoils and the subsoils, were statistically significant at the 0.001 probability level. The percentages of the samples that were structureless and weakly developed were considerably higher over the granitic rocks and sandstone than over basalt and shale. The frequency of the samples with moderately and strongly developed structures on the other hand were higher over basalt and shale than over the granitic rocks and sandstone. In the case of the transported parent materials, the values for the proportion of the sample with moderately and strongly developed structures were generally greater over alluvial and ironpan materials than over colluvial and aeolian materials. The only exception to this trend is the value for the strongly developed structures in respect of colluvium at the subsoils; the value being higher than that of any of the transported materials. The comparatively

Table 7.1: The degree of development of structure and bulk density of the soils and parent material

PARENT MATERIAL	SEDENTARY							TRANSPORTED			
	Granite	Gneiss	G/gneiss	Schist	Sandstone	Basalt	Shale	Alluvium	Colluvium	Aeolian	Ironpan
No of samples	36	32	38	34	36	42	42	30	32	38	22
TOPSOILS											
Grade of structure											
Structureless %	19.4	12.5	7.9	14.7	11.1	0.0	7.1	3.3	28.1	31.6	9.1)
Weak %	61.1	50.0	47.4	50.0	33.3	31.0	35.8	63.3	50.0	57.9	40.0) **
Moderate %	19.5	35.0	36.8	20.6	44.4	45.2	45.2	23.4	9.4	10.5	40.9)
Strong %	0.0	12.5	1.9	14.7	11.1	23.8	11.9	10.0	12.5	0.0	10.0)
Bulk density $\bar{x}$	1.35	1.28	1.33	1.29	1.38	1.07	1.22	1.24	1.36	1.37	1.35**
(gcm^{-3}) S.D	0.11	0.13	0.12	0.10	0.12	0.13	0.14	0.18	0.15	0.10	0.12
SUBSOILS											
Grade of structure											
Structureless %	13.9	9.4	15.8	14.7	19.4	2.4	6.7	16.7	14.4	15.8	13.6)
Weak %	52.8	40.6	39.5	35.3	38.9	14.3	21.4	33.3	50.0	42.1	34.5) **
Moderate %	22.2	25.0	24.1	32.4	22.2	61.9	38.6	36.7	15.6	31.6	38.2)
Strong	11.1	25.0	20.7	17.6	19.4	21.4	31.0	13.3	20.0	10.5	13.6)
Bulk density $\bar{x}$	1.28	1.20	1.27	1.29	1.28	1.08	1.20	1.20	1.25	1.29	1.31**
(gcm^{-3}) S.D	0.10	0.12	0.11	0.09	0.13	0.13	0.12	0.12	0.14	0.08	0.14

Levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

higher proportion of the samples with moderately and strongly developed sturctures over basalt and shale, possibly reflects the greater organic matter and clay contents, and perhaps greater microbial activity and vegetative growth in general in soils formed from the materials than from the granitic parent materials. The relatively high degree of structural development over alluvial and ironpan, as compared to the other transported materials, on the other hand, may be explained in terms of the activities of iron and aluminium colloids, substances which in most cases become almost completely hardened upon dehydration, a process known to be seasonally intense in these materials.

The bulk-density values of both the topsoils and subsoils revealed highly significant differences between the parent materials. In either case moreover, the values over basalt and shale were comparatively lower than those for the other sedentary materials and over alluvium than over the other transported materials.

7.0.2.2 Climate

The regression of the degree of development of the soil structures on the mean annual rainfall is positive and statistically significant at the 0.001 probability level (Table 7.2). The frequency of the property also revealed significant differences between the rainfall zones, and the general trend an increasing structural development with

increase in rainfall amount (Table 7.3)

In both the topsoils and the subsoils, the regression of the bulk-density values on the mean annual rainfall was negative and significant at the 0.001 probability level. Analysis of variance also confirmed this. As is observable in Table 7.3, in both the topsoils and the subsoils, the differences in the means of the property between the rainfall zones were highly significant (0.001 level). The values themselves varied from 1.44g cm^{-3} in the driest rainfall zone to 1.15g cm^{-3} in the wettest zone, for the topsoils, and from 1.36g cm^{-3} to 1.14g cm^{-3} in the case of the subsoils.

The differences in the degree of structural development in the topsoils between the temperature zones were statistically significant at the 0.02 level. As is observable in Table 7.3 while the percentages of the samples with weakly and moderately developed structural units showed a general increase in trend with the temperature zones, those for the strongly-developed strtuctures showed a decrease in trend.

Unlike in the topsoils, there were no statistically significant differences in the degree of development of the structural units of the subsoils between the temperature zones. The regression of the values of the structural developments on temperature was also not significant statistically.

Table 7.2: Regression of grade of structure and bulk density of the soils on the soil-forming factors

Factors	Grade of structure	Bulk density
TOPSOILS		
Rainfall	r = 0.447****	r = -0.578****
	y = 0.1566 + 0.0019x	y = 1.6943 + 0.0003x
Temperature	r = 0.104**	r = 0.073
	y = 0.1947 + 0.0751x	y = 1013 + 0.0073x
Altitude	r = 0.024	r = 0.237****
	y = 2.1008 + 0.00003x	y = 1.3484 - 0.0001x
Slope gradient	r = 0.063	r = -0.026
	y = 2.0677 + 0.0258x	y = 1.2935 - 0.0015x
SUBSOILS		
Rainfall	r = 0.217****	r = -0.519****
	y = 1.5589 + 0.0002x	y = 1.5460 - 0.0003x
Temperature	r = 0.035	r = 0.054
	y = 1.6558 + 0.0290x	y = 1.1087 + 0.0049x
Altitude	r = 0.022	r = -0.230****
	y = 2.2481 + 0.00003x	y = 1.2838 - 0.0001x
Slope gradient	r = -0.026	r = -0.056
	y = 2.4279 - 0.0120x	y = 1.2428 - 0.0026x

Levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

Table 7.3: The degree of development of structure and bulk density of the soils and climate

Climatic factor	Rainfall (mm)					Temperature (°C)		
	600-900	900-1200	1200-1500	1500-1800		20-25	25-27	27-28	
No of samples	71	103	130	78		108	122	148	
TOPSOILS									
Grade of structure									
Structureless %	38.0	11.7	6.9	2.6		13.9	21.0	6.0	
Weak %	57.7	48.5	43.1	43.6	****	51.9	48.4	43.3	**
Moderate %	4.3	29.1	37.7	39.7		24.1	24.2	38.0	
Strong %	0.0	10.7	12.3	14.1		10.2	6.5	12.7	
Bulk density $\bar{x}$	1.44	1.32	1.27	1.15****		1.26	1.32	1.29	
S.D	0.07	0.11	0.13	0.17		0.13	0.17	0.16	
SUBSOILS									
Grade of structure									
Structureless %	18.3	11.7	14.6	9.0		10.2	14.5	14.7	
Weak %	56.3	44.7	28.5	24.4		42.6	46.0	26.0	
Moderate %	14.1	18.4	40.8	39.7		34.3	24.2	30.7	
Strong %	11.3	25.2	16.2	26.9		13.0	15.3	28.6	
Bulk density $\bar{x}$	1.36	1.27	1.21	1.14****		1.21	1.26	1.23	
S.D	0.08	0.10	0.13	0.13		0.12	0.15	0.13	

Levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

Analysis of variance showed that the bulk-density values, of both the topsoils and subsoils, were not statistically different between the temperature zones (Table 7.3). Similarly, neither of the sets of values revealed a statistically significant relationship with the factor by simple linear regression analysis.

7.0.2.3 Relief

The regression of the degree of development of the structural units of the topsoils on altitude revealed no significant correlation (Table 7.2). By chi square analysis, however, the property showed quite significant differences between the altitudinal zones. As is observable in Table 7.4, there was an increase in the proportion of the samples that were structureless from the lowest to the second altitudinal zones but thereafter a decrease. By contrast, the proportion of the samples with both moderately-and strongly-developed structures first showed a decrease, from the lowest to the second zone, and thereafter, increasing values.

Unlike in the topsoils, the regression of the degree of development of the structural units of the subsoils showed significant positve correlation with altitude. The difference in the frequency of the sturctural development between the altitudinal zones were significant at the 0.001 level by chi square analysis. Only the proportion of the samples with strongly-developed structures however showed fairly linear relationship with the altitudinal zones. The values for the

Table 7.4: The degree of development of structure and bulk density of the soils and relief

Relief factor	Altitude (metres)				Slope gradient			Slope position		
	<300	300-600	600-900	>900	<5°	5-10°	>10°	Crest	Middle	Basal
No of samples	110	167	71	34	326	48	8	166	147	119
TOPSOILS										
Grade of structure										
Structureless %	6.4	18.6	15.5	2.9	14.1	8.3	0.0	16.8	13.6	8.6
Weak %	35.5	58.1	50.7	26.5	47.2	54.2	12.5	50.4	46.3	45.7
Moderate %	47.3	15.6	23.9	52.9	28.2	31.3	75.0	25.2	32.7	30.2
Strong %	10.9	7.8	9.9	17.6	10.4	6.3	12.5	7.6	7.5	15.5
Bulk density $\bar{x}$	1.30	1.32	1.27	1.14****	1.29	1.31	1.16	1.36	1.31	1.20**
S.D	0.15	0.15	0.13	0.16	0.16	0.14	0.13	0.13	0.12	0.18
SUBSOILS										
Grade of structure										
Structureless %	15.5	12.6	15.5	5.9	13.5	12.5	12.5	13.4	41.5	12.1
Weak %	25.5	44.9	49.3	11.8	39.0	27.1	25.0	41.2	25.9	27.6
Moderate %	34.5	23.4	18.3	67.6	26.4	46.8	62.5	29.4	18.4	34.5
Strong %	24.5	19.1	16.9	14.7	20.9	14.6	0.0	15.2	0.0	25.9
Bulk density $\bar{x}$	1.23	1.27	1.22	1.10****	1.24	1.22	1.17	1.26	1.23	1.21**
S.D	0.13	0.13	0.10	0.15	0.13	0.15	0.14	0.12	0.13	0.14

Levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

others on the other hand were marked by somewhat alternating high and low values over the altitudinal zones (Table 7.4).

By both the regression analysis and analysis of variance, the bulk-density value showed statistically significant relationship with altitude and the general trend was negative (Tables 7.2 & 7.4).

Neither the regression analysis, the chi square analysis, nor the analysis of variance revelaed any statistically significant relationship between the degree of development of the structural units and the slope gradient factor. The same thing was true of the bulk-density of the soils.

The differences in the degree of development of the structural units between the slope positions were significant, statistically, only in respect of the topsoils. In general, the proportions of the samples with no observable structural units and weakly-developed units showed a downslope decrease, while those for the moderately- and strongly-developed structural units showed a downslope increase. In both the topsoils and subsoils however, differences in the mean values of the bulk density between the slope positions decreased significantly downslope.

7.0.3 The relative importance of the soil-forming factors in determining the spatial variability of the grade of structure and bulk density of the soils

Table 7.5 summarises the result obtained from the analysis of variance and covariance involving the degree of

Table 7.5: The degree of development of structure and bulk density: Percentage variance explained by the soil-forming factors considered by analysis of variance and covariance

Soil-forming factor		TOPSOILS				SUBSOILS			
		Structural development		Bulk density		Structural development		Bulk density	
Parent material		15.4		25.1		4.9		22.3	
Climate	Rainfall	10.2	10.3	13.5	13.9	2.0	2.3	13.6	13.7
	Temperature	0.1		0.4		0.3		0.1	
Relief	Altitude	0.1	1.2	1.8	7.5	0.1	0.8	2.5	4.8
	Slope gradient	0.3		0.0		0.1		0.0	
	Slope position	0.8		5.3		0.6		2.3	
Explained		26.9		46.5		8.0		40.8	
Residual		73.1		53.5		92.1		59.2	

development of sturctural units and bulk density of soils over the study area. As with most of the properties considered, parent material accounted for the greatest percentage variances of the properties. In the topsoils, the percentage variance of the parameters explained by the factor is 15.4% for the degree of development of the structural units and 25.1% for bulk density. In the subsoils, the corresponding values are 4.9% and 22.3%. By contrast, the temperature and slope gradient factors each accounted for a relatively small percentage of the variances of the individual properties (less than 1%).

In the topsoils, rainfall accounted for about 10% of the variances of the degree of development of the structural units, but in the subsoils, only 2.0%. The percentage variances of the bulk density explicable in terms of the factor in respect of both the topsoils and subsoils are about the same (about 14%).

The altitudinal and slope position factors are more important in the spatial variability of the soil bulk density than in the variability of the degree of development of the structural units. While the percentage variance of the bulk density accounted for by either of the factors is over 2%, the value for thedegree of development of the soil structure is below 1%

7.0.4 The effective depth of the soils and relationship with the soil-forming factors

The effective soil depth encountered over the area varies considerably. It ranges from a low value of 4cm to as high a

value as 260cm. In spite of this however, the overall mean value is generally high, about 135cm. The number of samples involved notwithstanding, this value is comparable to those found for some tropical lowland forest soils of southern Nigeria (Ojanuga, 1971) but higher than those reported for some podzol soils of America (Lag, 1951). As is observable in Figure 7.2, out of the total samples considered, only 5% had effective soil depth of less than 50cm. About 18% of the samples had values lying between 50 and 100cm and as much as 30% fell at depth between 100 and 150cm. In all, 76% of the soils had value exceeding 100cm depth. This suggests that the bioclimatic factors of rainfall, temperature and vegetation have for a long period of time provided favourable conditions for the operation of the pedogenic processes of chemical weathering and clay mineral formation, aggregation, translocation, humification and the like over the region.

The long period of geomorphological stability of the region may have provided favourable conditions for the operation of the pedogneic processes as well. By geomorphological stability is meant land surface which is slowly changing as a result of the operation of geomorphological processes (Ologe, 1985; Thomas, 1974). As pointed out in Chapter III, the study area as a whole is a region of plains and plateaux and, except in a few localities, where stream rejuvenation and accelerated erosion resulting from epeirogenetic uplift, sea level changes and changes in the bioclimatic environment has caused much disruption, has been so for a very long period of time. The area has not been

subject to violent earth movements since early Palaeozoic times (Ologe, 1985) and, like other parts of the tropics, escaped the Pleistocene glaciation which stripped off weathering profiles in areas such as the Canadian shield and the Fenno-Scandian Shield. Moreover, for most parts of the region, land slopes are gentle and relative relief low. These conditions could be assumed to have provided favourable conditions for rapid chemical weathering and at the same time for the preservation of existing weathering profiles.

In Table 7.6 is presented the summary of the relationships between the soil effective depth and the soil-forming factors considered, using analysis of variance.

The differences in the means of the soil effective depth between the parent materials were statistically significant at the 0.001 level and, in general, values over sandstone and the transported materials of alluvium and aeolian deposits, were comparatively higher than those over the other parent materials. This was not unexpected since weathering tends to progress faster in unconsolidated materials or stratified rocks, unless they are cemented with silica, than litified or crystalline rocks (Ollier, 1970; Thomas, 1974; Ologe, 1985). It could however be as a result of differences in the degree of resistance, to chemical weathering, of the mineralogical compositions of the materials.

There were no statistically significant differences in the effective depth of soils between the rainfall zones.

Table 7.6: The effective depth of the soils and the soil-forming factors

Factor	No of samples	$\bar{x}$	S.D	CV%
Parent Material				
Granite	36	144.3	48.2	33.4
Gneiss	32	133.4	45.9	34.4
Granite gneiss	38	134.8	41.8	31.0
Schist	34	135.5	44.0	32.5
Sandstone	36	157.2	26.9	17.1
Basalt	42	133.0	46.5	35.0
Shale	42	132.1	38.7	29.3
Alluvium	30	150.8	35.8	23.7
Colluvium	32	130.1	40.2	30.9
Aeolian	38	143.5	34.9	24.3
Ironpan	22	83.6	35.6	42.6
		****		
Rainfall (mm)				
600-900	77	135.9	36.1	26.6
900-1200	103	137.8	42.7	31.0
200-1500	130	135.2	45.4	33.6
500-1000	78	130.9	45.6	34.8
Temperature (°C)				
20-25	108	137.9	42.4	30.7
25-27	122	130.3	44.2	33.9
27-28	148	137.2	42.3	30.8
Altitude (metres)				
300	110	146.9	42.6	29.0
300-600	167	133.1	41.2	31.0
600-900	71	137.3	45.1	32.8
900	34	125.2	49.2	39.3
		*		
Slope gradient				
5°	326	137.4	42.5	30.9
5-10°	48	123.9	44.3	35.8
10°	8	110.3	39.1	39.4
		****		
Slope position				
Basal	119	143.8	44.9	31.2
Middle	147	134.4	44.8	33.3
Crest	166	127.5	38.9	30.5
		***		

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05

Simple linear regression analysis also confirmed this. Although negative, the correlation coefficient value between the property and rainfall was insignificant, statistically (Fig. 7.2). This might be as a result of slower rate of pedogenesis vis a vis the rate of removal of materials by denudational processes, particularly surface wash, as rainfall amount increases over the region.

Neither the analysis of variance, nor the regression analysis revelaed a statistically significant relationship between the effective depth of the soils and temperature. By contrast, the differences in the values of the property between both the altitudinal zones and slope angle classes were statistically significant. The regressions of the property on both factors were also significant, statistically. As suggested by equations (7.2) and (7.3), derived from the regression analysis, the soil effective depth decreases by about 1.2cm and 25.9cm for every 1000m rise in altitude and 10° increase in slope gradient respectively over the study area. Such negative relationship between soil

$$\text{Depth} = 137.08462 - 0.00118\,Al \quad \ldots\ldots\ldots\ldots\ldots \quad (7.2)$$

$$\text{Depth} = 142.81333 - 2.59192\,Sg \quad \ldots\ldots\ldots\ldots\ldots \quad (7.3)$$

where Al = altitude (metres), Sg = slope gradient (degree).

effective depth and both altitude and slope gradient in the region may be due essentially to variations in chemical weathering rates and surface wash brought about by variations in soil moisture (and, perhaps, temperature) with the factors.

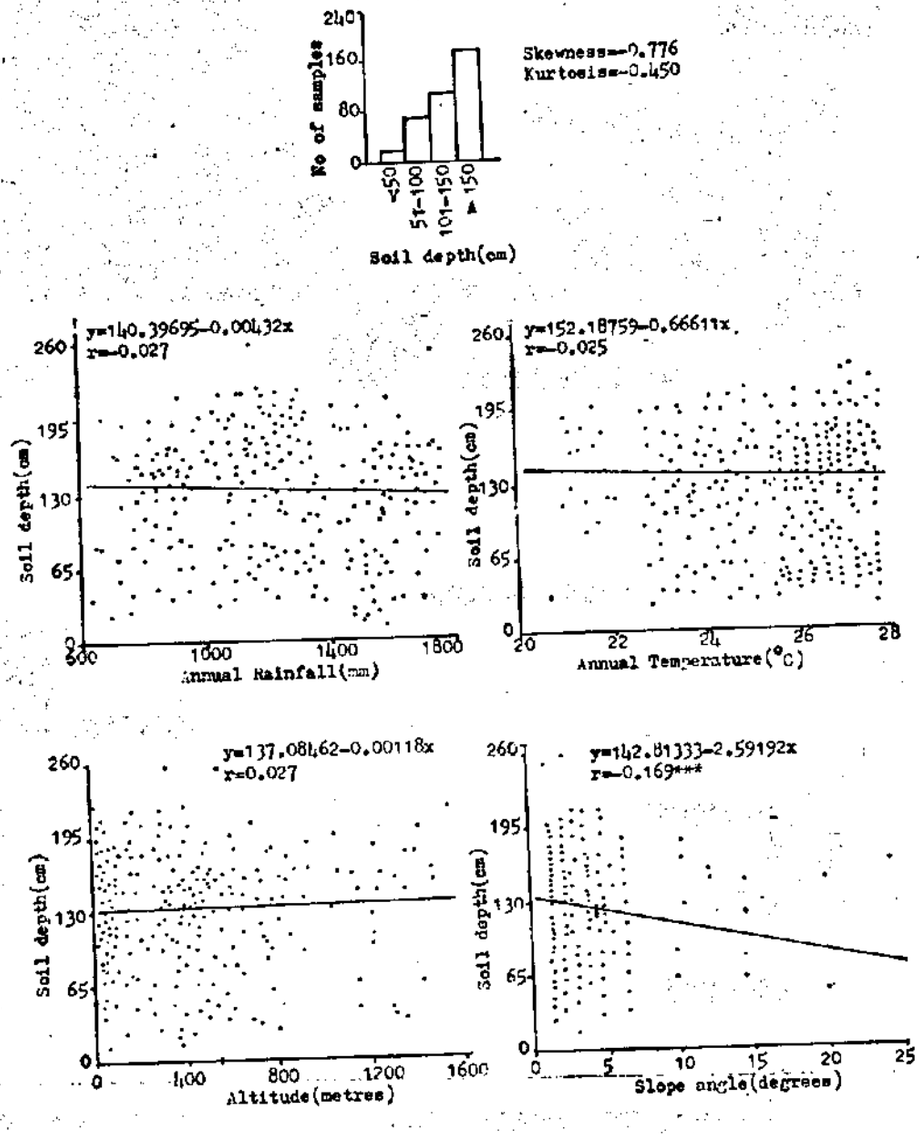


Fig.7.2 The effective depth of the soils and climate and relief

Differences in the average values of soil depth between the slope positions increased significantly downslope (Table 7.6).

When the relationship between the effective depth of the soil values and the soil-forming factors considered were combined in an analysis of variance and covariance, the result obtained showed quite clearly that parent material is the most important single factor affecting the effective depth of soils over the study area. Out of the total 31.8% of the variance of the parameter accounted for by all the factors considered, parent material alone accounted for about 12%. The next most important factor is slope gradient. Unlike the result obtained in respect of the several other soil properties considered in this study, over 10% of the variances of this parameter is explicable in terms of the slope gradient factor. Altitude and slope position are also important in the spatial variability of the property accounting for about 5.0% and 3.7% of the variances, respectively, while rainfall and temperature are relatively unimportant.

7.1 DISCUSSION

7.1.1 Degree of sturctural development and bulk density

The constitution of soil aggregates and their degree of development, together with the amount and sizes of the pore spaces between and within the aggregates, is a complicated set of processes that is still poorly understood (Baver et. al., 1972). Some of the probable and major

processes that have been suggested as being involved however are the "shrink and swell" phenomenon during wetting and drying and the binding together of particles by organic material and microbial synthesis products and clay minerals (Baver, et. al., 1972; Pitty, 1978; Jaiyeoba & Lecw, 1984). Other factors that may affect soil aggregation are the almost irreversible, or slowly reversible, inorganic colloids. All these suggest that the effects of the soil-forming factors considered on the grade of soil structure and bulk-density over the present study area are mainly exercised, indirectly, through the soil colloidal materials.

Other most probable factors that might be involved in the spatial variability of the degree of structural development and bulk density of soils over the study area are the nature of the vegetation cover and biological activities in general. Apart from being the chief source of the raw materials for organic matter synthesis, the effect of vegetation is also usually manifested via the protection the canopy and litter cover provides to the surface, against direct insolation and raindrop impact. In general, soils under effective cover of vegetation, with thick litter cover, tend to be well structured, low in bulk density and thus high in percentage pore spaces. Soils that are exposed for a relatively long period of time on the other hand, even if initially well structured, tend to be characterized by poor or weak structural grades and high degree of compaction.

Another aspect of the plant cover that can be of some signifcance is the root system. The effect of the root system on aggregate formation has traditionally been explained in terms of the pressure exerted by growing roots. This not only causes a separation of the soil particles adjacent to the root, but also a pressing together of these units into aggregates (Daji, 1970). Recent works have however indicated that the dehydration of the soil materials in the vicinity of the root system may assume great significance (Pitty, 1978). Moreover, several workers have suggested that it is possible that the root secretions per se and/or the microbiological conversion of the secretions should have certain binding action on the soil materials (Pitty, 1978).

Thus, the comparatively high degree of development of the structural units and low bulk-density values in soils formed from and over basalt and shale, relative to the grantic rocks and sandstone, may be ascribed to higher clay and organic matter contents,and greater biological activity, in the former rock type than in the latter (Chapters V & VI). Similarly, the downslope increase in the degree of development of soil structures and decrease in bulk-density values downslope is probably as a result of the downslope increase in the organic matter and source materials, and clay, of the soils and/or downslope increase in the density of plant cover. The same colloidal materials and biological actions could also be responsible for the significant increase in the former, and decrease in the latter, with increase in rainfall and altitude over the region.

7.1.2 Effective soil depth

The relationship between the soil effective depth and the soil-forming factors is exercised mainly indirectly through the rate of operation of the various pedological and geomorphological processes. Prominent among such processes are surface wash, leaching, the bio-chemical weathering of minerals and translocation of materials. Where the environmental factors are conductive to greater removal of materials from the surface by surface wash, vis-a-vis the rate at which the soil solum is being increased from below by bio-chemical weathering processes and translocation of materials, the soil solum will sooner or later become completely stripped off, leaving only the parent material, and in some places the solid rock. However, where erosion is proceeding at a much slower rate, relative to the rate at which the soil profile is being augmented from below, all things being equal, the soil solum naturally continues to increase in thickness (Thomas, 1974; Thorp, 1970; Ologe, 1985).

The relative resistance of a particular rock type to weathering is affected by characteristics such as the mineralogical composition, texture, shape and arrangement of the mineral grains; the structure, frequency, disposition and openness of fractures such as joints, faults and microfissures, as well as the presence or otherwise of bedding plains (Ologe, 1985). Minerals which were formed under high temperatures and/or pressures (e.g. the ferromagnesian minerals and calcic plagioclase feldspars

are usually more susceptible to thorough decomposition than those formed under relatively low temperatures and pressures (e.g. muscovite and quartz). Similarly, rocks with coarse grain textures tend to weather fairly rapidly, due to the large void spaces and high permeability. Although in some cases, high permeability factor is partially balanced by the greater surface area which accompanies decreasing grain size so that many fine-grained rocks are infact highly susceptible to weathering (Ollier, 1970). Arrangement of mineral grains is important since random arrangement of crystals tends to interfere with free water movement and the movement of soluble end-products than those arranged in a parallel or sub-parallel fashion (Ologe, 1985). Thus for example, all things being equal, acidic rocks, such as granite and rhyolite, which are characteristically high in silica but relatively low in the ferromagnesian minerals, may be expected to weather less readily than basic and ultrabasic rocks, such as basalt and gabbro.

For the effect of rock fissility, the greater the joint densities, the greater the permeability of the rock, and the greater the surface area that is exposed to chemical reaction.

Other things being equal, the faster the rate of rock weathering, the thicker would be the depth of the resultant sedentary parent material, the greater its water-holding capacity, and the higher the rate of subsequent chemical weathering. This relationship is not indefinite however, for as the weathering profile becomes very deep, ground water

drainage, which is responsible for the removal of the soluble end-products of weathering so that weathering reactions can continue, slows down (Ologe, 1985). The rate of throughput of water in the weathering environment is therefore of great importance and is in turn a function mainly of the degree of permeability of the parent material itself. Rapid throughput of water is facilitated by a parent material which is permeable while it is hindered by relatively impervious parent material.

The variances in the degree of permeability of parent materials and thus the rate of throughput of water in the weathering environment may help to explain, at least partially, why over the present study area, the effective depth of soils is generally higher over alluvium (which are generally coarse in texture) and on sandstone (which commonly weather to give a rather coarse residum) than over the other materials and lithologies. It could also explain why mean values over basalt and shale, which over the present study area are characterized by somewhat clayey parent materials, were not materially different from those over gneiss and granite-gneiss and infact lower than over granite, which are characterized by rather coarse rexture parent materials (Chapter III). Yet, it is known that basaltic rocks and shales tend to contain more readily weatherable minerals, than the granitic rocks.

Rainfall affects not only the rate of removal of material from the surface mainly by wash process, but also the rate of advancement, downward, of the weathering profile,

leaching and translocation of materials and hence the thickness of the parent material and soil solum. Usually, the greater the volume and speed of water moving through the weathering environment, including the soil, the faster the rate of weathering, particularly by hydrolysis, and leaching and development of acidic conditions. By providing favourable conditions (particularly in terms of plant growth and food supply) for the activities of soil animals, rainfall also, indirectly, contributes to the operation of pedogenic processes of chemical weathering, humification, ammonification, translocation of materials and the like, in the soil system. The net effect of some or all of the above processes is usually an acceleration in the rate of maturity of the soil profile and hence the deeper the soil solum.

With respect to surface wash, the role played by rainfall looks rather more complex. Usually, with an increase in rainfall amount, the effectiveness of surface wash also increases. This relationship is not indefinite however, for as rainfall amount increases, the density of plant cover tends to increase as well and once a continuous vegetation cover is achieved, the rate of erosion normally falls off rapidly.

Over the present study area, although negative, the relationship between soil effective depth, as defined in the study, and rainfall, was insignificant statistically.

The observed negative and significant relationship between the effective depth of soils and altitude over the

study area may be as a result of the rather close relationship between the bio-climatic factors of rainfall, temperature and vegetation cover, and altitude. However, in view of the result obtained between the property and both the parent material and slope gradient factors, such [illegible] relationship could be a reflection, at least partially, of the somewhat distinctive altitudinal relation of lithology on the one hand, and the relationship between slope angle and altitude on the other hand, over the region. As pointed out in Chapter III and IV, while basaltic rocks are to be found mainly in the higher altitudes, sandstones and shales occur largely in the lower elevations. Similarly, over the region, slopes are more varied and generally steeper at high altitudes than at lower elevations.

The relationship between effective soil depth and the factors of slope gradient and slope position, in the study area, can be explained in terms of the variabilities in chemical weathering rate and the rate of removal of surface materials by the denudational processes of surface wash and perhaps mechanical eluviation, with the factors. Provided the underlying materials are permeable, gentle slopes are characterized by higher infiltration rate, greater vegetative cover and hence greater bio-chemical decomposition of rock minerals, than steep slopes. Moreover, erosion generally increases with slope angle up to a point where the accumulation of a deep chemically weather mantle is impossible.

Similarly, in addition to receiving soil materials intermittently, from higher-lying surrounding areas, lower

slope positions tend to be much more favourable for the operation of several of the major pedological processes, than the upper slope positions. Thus the signifcant decrease in soil effective depth values with increase in slope angle, and upslope, observed in the present study area may be as a result of an increase in surface removal of materials and decrease in the rate of bio-chemical weathering of minerals, with increase in slope angle, and upslope position.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

8.0 INTRODUCTION

This chapter presents an highlight of the major findings of this study. This is followed by concluding remarks.

8.1 THE SOIL PROPERTIES AND RELATIONSHIP WITH THE SOIL-FORMING FACTORS

8.1.1 Soil texture

The frequency distribution of particle-sizes of the soils is marked by the presence of maximum sand with minima of silt and clay. The proportions of coarse sand and fine sand vary considerably. In general, however, fine sand predominate. The sand fraction shows a marked decrease at the subsoils and the clay an increase. Consequently, virtually all the soils are characterized by the presence of a textural B (Bt) horizon.

The main factors, out of those considered in this study, governing the texture of the soils are found to be parent material and rainfall. The relief parameters of altitude and slope position are also important. On the other hand, temperature and slope gradient play relatively minor roles.

In general, in both the topsoils and subsoils, soils formed from basalt and shale are less sandy and more clayey, than those formed from the granite rocks and sandstones. Soils developed on aeolian deposit and ironpan are more sandy, less silty and less clayey at the topsoils than those over

alluvium and colluvium. In the subsoils, however, the reverse is the case.

In both layers of the soils, the fine sand subfraction and thus the total sand fraction show a negative trend with the mean annual rainfall while the others show a positive trend. While the sand fraction and subfractions show a decrease trend with rise in altitude, and downslope posittion, the silt and clay show an increase.

8.1.2 Organic carbon and nitrogen contents

The organic carbon and total nitrogen contents of the topsoils are generally low. In general, soils formed over basalt and shale are higher in both elements, compared with those formed over the granitic rocks and sandstone. In the case of the transported parent materials, soils formed from alluvial materials contain the highest mean values and compare favourably with those over the sedentary basaltic and shale parent materials.

Both elements show significant increase in value with increase in rainfall amount and altitude, and downslope position. By contrast, neither of the two reveal statistically significant relationship with the temperature and slope gradient factors.

The C/N ratio shows a significant relationship with only rainfall and the general trend is negative, implying an increase in the degree of humification with increase aridity.

8.1.3 Soil nutrients and chemical conditions

Reflecting, presumably, the low organic carbon and clay contents of the soils, the CEC and thus the exchangeable bases are quite low but show an increase in value down the profile. The reaction of the soils are on the whole weakly to moderately acid. The %BS values are generally high, reflecting mainly the low CEC values.

Of the soil-forming factors considered, parent material accounts for the greatest percentage variance of the soil CEC and the exchangeable bases. By contrast, the rainfall factor shows the greatest correlation with the pH and %BS values. For the sedentary materials, both the CEC and each of the exchangeable bases show comparatively higher mean values over basalt and shale than over the granite rocks and the sandstones, for both layers of the soils. The pH and %BS also showed comparatively higher values over basalt and shale in the topsoils, but in the subsoils, the values are higher over granite and granite-gneiss than over the other materials. For the transported materials, while the mean of each of the properties is highest over alluvium in the topsoils, it is highest over aeolian materials in the subsoils.

In the topsoils, the CEC and exchangeable bases show a positive relationship with rainfall, while the pH and %BS show negative. The spatial variation of each of the properties with rainfall in the subsoils is quite similar to that for the topsoils, except Ca and Mg which show negative trend.

In both the topsoils and the subsoils, the relationship between the CEC and each of the exchangeable bases, except Ca, and the altitudinal factor is positive while that for the pH and %BS is negative. Although each of the properties shows some statistically significant relationship with slope gradient in the subsoils, a relatively minor proportion of the variances of the properties is explained by the factor. The same is true of the temperature factor.

At the topsoils, all the properties show significant differences between the slope positions, the general trend being a downslope increase for the CEC and exchangeable bases, and a decrease for the pH and %BS.

8.1.4 Degree of structural development, bulk density and effective soil depth

The sturcture of the soils are predominantly moderately developed (the sizes mostly medium and the shapes blocky-angular and subangular). In spite of this, the soils shows little compaction.

Out of the factors considered, parent material and rainfall are the most important in the spatial variabilities of the properties. In general, the structures of soils over basalt and shale are more developed, and the bulk-density values lower, than those over the granite rocks and sandstones; over alluvial and ironpan than colluvial and aeolian materials. With respect to the rainfall factor, the relationship with the degree of development of the structural units is positive but with the bulk density, negative.

The altitudinal factor and slope position also play some significant role in the spatial variability of the properties, the relationship being an increase in the degree of structural development with increase in altitude and downslope position, and a decrease with respect to bulk-density. In contrast with the rest of the factors considered, neither the degree of development of the soil structural units nor the bulk-density value reveals statistically significant relationships with the temperature and slope gradient factors.

Except on particularly steep slopes, the effective depth of the soils is generally high. On the whole, parent material assumes the most important role in controlling the spatial variability of the property. In general, values over sandstones and the transported materials of alluvium and aeolisn deposits are comparatively higher than those over the other parent materials. Slope gradient is the second most important factor, the relationship with the property being negative. Next is the slope position and altitude. The relationships of the property with these factors are, a downslope increase in value with the former, and an increase with the latter. Both the temperature and rainfall factors are not significantly related to the property.

8.2 CONSLUSIONS

It is clear from this study that climate, parent material and relief exert a strong influence on tropical

soil formation and that the factors, especially the first two, are likely to be of approximately equal importance in the distribution of soil types. If a soil classification were primarily dependent on, for example, soil pH, then climate would exert the greater influence on distribution of soil classes, Conversely, in a classification greatly dependent on texture, parent material would be the more important.

There has been a tendency to treat the zonal influence as the primary determinant of soil type, perhaps because it operates at the continental scale with which introductory accounts of soils are concerned. Based on such principle, the succession of zonal soils in the lowland tropics, in order of decreasing rainfall from rainforest to desert is leached ferrallitic soil, ferruginous soils, brown calcimorphic soils, sierozems, grey and red desert soils, and desert detritus(Young, 1976). Since the data come from ecological zones of limited areas, it is difficult to use the result obtained in this study to construct a general predictive model for regional distribution of soils. Nevertheless, as a primary conclusion, the results do indicate that under savanna condition, the climatic zone at best provides a necessary frame of reference in soil distribution but a real differentiation of soil types is very much more dependent on the pattern of parent material and slope position.

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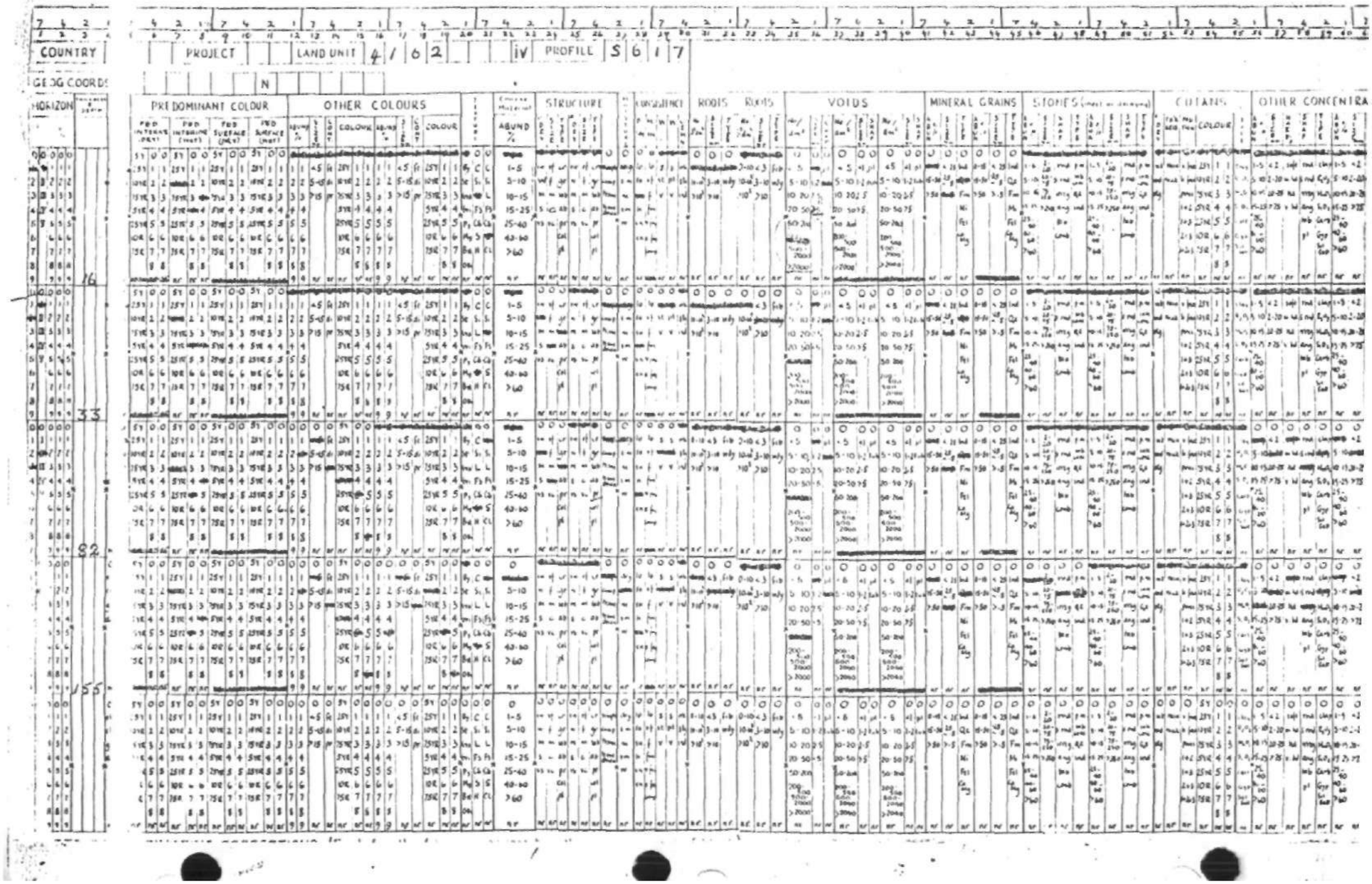
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APPENDIX 1 : SOIL PROFIL DATA SHEET



APPENDIX 2: SITE DATA SHEET

OUNTRY		PROJECT	LAND UNIT	PROFILE	GEOG COORDS E / N
EOM UNIT	4/62	GEOM/SOIL UNIT	LAND SYSTEM	AUTHOR	PROJECT
EOM FACE	IV	GEOM/SOIL FACET	FACET	DATE	PROFILE S617
OPO SHEE	58 SW	ALTITUDE	STEREO PAIR	GROUND PHOTOS	

SITE

	SLOPE				% OUTCROP ROCK	% OUTCROP INDURATED LAYER	% GROUND COVER STONES	LITTER			MICRO-RELIEF		CRACKING		CULTIVATION		LAND USE				SITE DRAINAGE	PED. DRAIN CLASS
																	Dominant		Subsidiary			
	Order	Form	Degrees	Minutes				Type	% Ground cover	Depth cm	Type	Amplitude cm	Pattern	Width cm	Type	Height cm	Type	% Area	Type	% Area		
	0	0	0	0											0	0		0		0	0	
	1	Conv	1	1	1	1	1	Leaf	1	1	1	Signi	1	1	1	Hex	1	Neck	Furrow	1	1	Forest	Treecrop	1	1	Ponded	Poor
	2	Upper	2	2	2	2	2	Grass	2	2	2	Termite	2	2	2	Rect	2	Animal	Mound	2	2	Thicket	Arable	2	2	Slow	Poor
	3	Mid	3	3	3	3	3	Undiff	3	3	3	Worm	3	3	3	Irreg	3			3	3	Closed	Imp. past	3	3	Med.	Imp.
	4	Lower	4	4	4	4	4	1+2	4	4	4	Erosion	4	4	4		4		Flat	4	4	Open	Fallow	4	4	Rapid	Rapid
	5	V. bel	5	5	5	5	5		5	5	5	Soil-holes	5	5	5		5		Terrace	5	5	Tr. sav		5	5		
	6	V. hig	6	6		6	6		6	6	6	Tree fall	6	6	6		6			6	6	Sh. sav		6	6		
	7		7	7		7	7		7	7	7	Termite-ecke	7	7	7		7			7	7	Grass		7	7		
	8		8	8		8	8		8	8	8		8	8	8		8			8	8			8	8		
	9		9	9		9	9		9	9	9		9	9	9		9			9	9			9	9		

GEOLOGY

PARENT MATERIALS

	Layer	Type	Igneous Text.	Igneous Comp.	Met	Sed	Pyr	Pedog	Uncons	Layer	Type	Igneous Text.	Igneous Comp.	Met	Sed	Pyr	Pedog	Uncons	Layer	Type	Igneous Text.	Igneous Comp.	Met	Sed	Pyr	Pedog	Uncons	Layer	Type	Igneous Text.	Igneous Comp.	Met	Sed	Pyr	Pedog	Uncons
	0	0							0	0	0							0																		
	I	Ign	Plut	Acid	Schist	Cong	Sstone	Ferr	Alluv	I	Ign	Plut	Acid	Schist	Cong	Sstone	Ferr	Alluv	I	Ign	Plut	Acid	Schist	Cong	Sstone	Ferr	Alluv	I	Ign	Plut	Acid	Schist	Cong	Sstone	Ferr	Alluv
	II	Met	Med	Inter	Gneiss	Breccia	Agg	Silic	Colluv	II	Met	Med	Inter	Gneiss	Breccia	Agg	Silic	Colluv	II	Met	Med	Inter	Gneiss	Breccia	Agg	Silic	Colluv	II	Met	Med	Inter	Gneiss	Breccia	Agg	Silic	Colluv
	III	Sed	Fine	Basic	Qzite	Sstone	Tuff	Calcic	Lac	III	Sed	Fine	Basic	Qzite	Sstone	Tuff	Calcic	Lac	III	Sed	Fine	Basic	Qzite	Sstone	Tuff	Calcic	Lac	III	Sed	Fine	Basic	Qzite	Sstone	Tuff	Calcic	Lac
	IV	Pyr	Undif	U.Basic	Peg	Shale	Ash	Bauxite	Marl	IV	Pyr	Undif	U.Basic	Peg	Shale	Ash	Bauxite	Marl	IV	Pyr	Undif	U.Basic	Peg	Shale	Ash	Bauxite	Marl	IV	Pyr	Undif	U.Basic	Peg	Shale	Ash	Bauxite	Marl
	V	Pedog		Undif	Undif	M.stone	Lgnite	Undif	Acol	V	Pedog		Undif	Undif	M.stone	Lgnite	Undif	Acol	V	Pedog		Undif	Undif	M.stone	Lgnite	Undif	Acol	V	Pedog		Undif	Undif	M.stone	Lgnite	Undif	Acol
	VI					L.stone	Undif		Glac	VI	Uncons				L.stone	Undif		Glac	VI	Uncons				L.stone	Undif		Glac	VI					L.stone	Undif		Glac
	CG	Undif				Dolom			Org	CG	Undif				Dolom			Org	CG	Undif				Dolom			Org	CG	Undif				Dolom			Org
	Undif					Undif			Undif	Undif					Undif			Undif	Undif					Undif			Undif	Undif					Undif			Undif

UNDERLYING ROCK

Type	Igneous Text	Igneous Comp	Met	Sed	Pyr
0	0	0	0	0	0
Ign	Plut	Acid	Schist	Cong	Sstone
Met	Med	Inter	Gneiss	Breccia	Agg
Sed	Fine	Basic	Qzite	Sstone	Tuff
Pyr	Undif	U.Basic	Peg	Shale	Ash
Pedog		Undif	Undif	M.stone	Lgnite
				L.stone	Undif
				Dolom	
				Undif	

NOTES AND DIAGRAM

APPENDIX 3: LABORATORY ANALYSIS SHEET

ANALYSES.

N. NIGERIA PREFID S LAB Nos 245 → 248.

Characteristic	Horizon (depth in cm) 1 2557 0-16	2 2558 16-33	3 2559 33-83	4 2560 83-155	5	6
% coarse o.d.s.	0·3	0·4	1·6	1·8		
bulk density g/ml o.d.s.	1·41	1·38	1·29	1·28		
pH 1: 5 H_2O	6·8	6·4	8·9	9·0		
cond. mhos 1:5 H_2O 25°C	0·03	0·02	0·17	0·20		
Exch. Na meq %	0·0	0·1	3·2	2·7		
Exch. K meq %	0·1	0·1	0·5	0·7		
Exch. Mg meq %	0.6	0·9	1·8	2·6		
Exch. Ca meq %	2·3	2·0	5·9	18·0		
Exch. acidity meq/100 g	3·0	3·1	11·4	24·0		
CEC meq/100 g	2·6	3·3	9·3	9·5		
Base saturation %	100	94	100	100		
% total N o.d.s.	0·03					
% org. C o.d.s.	0·24					
Total contents ppm P						
K						
Mg						
% $CaCO_3$				1·5		
Available P ppm (Olsen)						
(NH_4F + HCl)						
Mechanical analysis %						
2000μm - 500μm	2	2	3	3		
500μm - 200μm	7	6	5	5		
200μm - 100μm	27	28	22	21		
100μm - 50μm	45	43	38	37		
50μm - 20μm	12	12	10	11		
20μm - 2μm	2	2	4	4		
< 2μm	5	7	18	19		

APPENDIX 6: THE TEXTURE OF THE TOPSOILS AND SLOPE POSITION

Slope position		1st Rainfall Zone Crest	Middle	Basal	2nd Rainfall Zone Crest	Middle	Basal	3rd Rainfall Zone Crest	Middle	Basal	4th Rainfall Zone Crest	Middle	Basal
No of samples		30	28	13	47	37	19	34	55	39	8	25	45
Sand	$\bar{x}$	82.0	80.6	76.5	65.8	62,9	56.6**	68.2	61.4	54.5***	77.8	63.5	47.1*
		12.2	10.8	11.4	14.2	14.3	14.2	18.1	19.1	20.4	15.2	17.6	22.8
Coarse sand	$\bar{x}$	19.1	16.1	22,6*	31.1	28,7	19,9***	32.0	31.4	25.1*	53.9	31.7	21.6***
		13.1	10.3	10.9	16.9	17,8	16.2	21.5	17.9	13.7	11.7	15.3	16.8
Fine sand	$\bar{x}$	62.9	64.5	53.9	34.7	34,2	36.7	36.2	30.0	29.5	23.9	31.8	25.6*
		14.4	10.5	12.0	15.2	13.5	12.8	17.1	14.8	15.4	11.1	12.0	13.8
Silt	$\bar{x}$	21.4	13.4	14.9	22.9	25,1	30.0*	19.5	23.4	24.4	10.4	19.8	26.1***
		8.7	7.5	10.3	10.7	12,0	13.1	13.0	13.3	14.3	7.3	11.1	13.6
Clay	$\bar{x}$	5.6	6.2	8.6*	11.4	12,1	13.4	12.3	15.2	21.1***	11.9	16.7	26.8***
		3.1	5.0	3.6	8.3	5.3	6.0	8.1	10.3	12.1	9.1	10.9	13.5

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

APPENDIX 7: THE ORGANIC CARBON AND NITROGEN CONTENTS OF THE TOPSOILS AND PARENT MATERIAL

Parent material		Granite	Gneiss	G/gneiss	Schist	Sandstone	Basalt	Shale	Alluvium	Colluvium	Aeolian	Ironpan
FIRST RAINFALL ZONE (600-900mm)												
No. of samples		9	2	3	1	7	-	3	6	17	19	7
C%	$\bar{x}$	0.15	0.28	0.23	0.32	0.18	-	0.67	0.18	0.32	0.64	0.13
	S.D	0.11	0.18	0.11	0.0	0.11	-	1.17	0.16	0.27	1.19	0.07
N%	$\bar{x}$	0.02	0.04	0.03	0.04	0.03	-	0.06	0.03	0.02	0.07	0.03
	S.D	0.01	0.02	0.01	0.0	0.12	-	0.01	0.02	0.01	0.12	0.04
C/N ratio	$\bar{x}$	6.8	7.9	8.4	8.0	7.4	-	11.1	7.3	14.5	9.6	6.4
	S.D	3.9	0.5	2.8	0.0	1.3	-	1.3	3.1	12.3	6.4	4.4
SECOND RAINFALL ZONE (900-1200mm)												
No of samples		16	7	20	9	10	7	9	4	7	10	4
C%	$\bar{x}$	0.65	0.56	0.50	0.76	0.45	0.91	0.93	0.52	0.55	0.48	1.02***
	S.D	0.30	0.12	0.26	0.40	0.20	0.26	0.43	0.22	0.21	0.28	0.75
N%	$\bar{x}$	0.05	0.05	0.05	0.06	0.13	0.08	0.08	0.05	0.05	0.05	0.08
	S.D	0.02	0.02	0.01	0.03	0.30	0.02	0.03	0.02	0.02	0.04	0.05
C/N ratio	$\bar{x}$	12.2	11.4	10.8	11.8	10.8	11.5	11.5	10.8	10.7	11.4	12.0
	S.D	2.7	2.1	2.8	1.9	4.4	3.0	1.7	3.3	1.8	6.9	2.0
THIRD RAINFALL ZONE (1200-1500mm)												
No of samples		9	14	15	13	18	11	20	8	6	7	8
C%	$\bar{x}$	0.59	0.81	0.59	0.93	0.68	2.14	1.09	0.91	1.60	0.68	0.73****
	S.D	0.20	0.27	0.24	0.48	0.41	1.46	0.35	0.51	0.92	0.23	0.31
N%	$\bar{x}$	0.06	0.07	0.05	0.15	0.06	0.15	0.10	0.11	0.12	0.14	0.06*
	S.D	0.02	0.02	0.02	0.26	0.03	0.09	0.04	0.08	0.04	0.22	0.02
C/N ratio	$\bar{x}$	11.2	11.6	12.2	11.1	11.9	13.5	11.8	10.0	12.9	10.3	12.5
	S.D	3.3	2.2	4.6	3.5	4.2	2.7	2.4	3.7	4.6	4.8	2.6
FOURTH RAINFALL ZONE (1500-1800mm)												
No of samples		5	9	-	13	-	24	10	12	2	2	3
C%	$\bar{x}$	0.56	1.3	-	0.87	-	2.17	2.05	1.71	0.60	0.92	0.84***
	S.D	0.25	0.61	-	0.43	-	0.91	1.30	1.01	0.13	0.36	0.30
N%	$\bar{x}$	0.05	0.20	-	0.07	-	0.18	0.17	0.16	0.05	0.09	0.08*
	S.D	0.02	0.30	-	0.03	-	0.08	0.11	0.10	0.0	0.03	0.02
C/N ratio	$\bar{x}$	12.0	11.1	-	12.1	-	13.4	11.8	10.8	11.9	10.0	10.3
	S.D	1.4	4.4	-	2.9	-	5.2	8.8	2.8	2.7	0.8	1.2

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

APPENDIX 8: SIMPLE CORRELATION COEFFICIENT MATRIX VALUES OF THE ORGANIC CARBON, NITROGEN AND CARBON/NITROGEN RATIO OF THE TOPSOILS AND THE SOIL-FORMING FACTORS AND CLAY

Soil-forming factor		No of samples	RAINFALL C(%)	RAINFALL N(%)	RAINFALL C/N	TEMPERATURE C(%)	TEMPERATURE N(%)	TEMPERATURE C/N	ALTITUDE C(%)	ALTITUDE N(%)	ALTITUDE C/N	SLOPE GRADIENT C(%)	SLOPE GRADIENT N(%)	SLOPE GRADIENT C/N	CLAY C(%)	CLAY N(%)	CLAY C/N
Parent Material	Granite	36	.30**	.30**	.19	-.44**	-.44**	-.19	.29*	.31*	.04	.03	.08	-.06	.48***	.52****	.20
	Gneiss	32	.55****	.25*	-.03	-.26	-.20	-.16	-.06	.34*	.12	.16	.15	.11	.45**	.36**	.09
	G/gneiss	38	.11	.10	.18	-.08	.07	-.02	.21	-.15	.05	.02	.04	.04	.30**	.35**	.03
	Schist	34	.26*	.07	.02	-.30*	-.40**	-.18	.22*	.40**	-.06	.07	.12	.14	.33**	.53***	.02
	Sandstone	36	.39**	.32**	.13	.21	.10	.22	-.26*	-.21	-.20	-.19	-.12	.26	.52****	.67****	-.17
	Basalt	42	.34**	.39**	.26*	.14	-.01	.20	.02	.11	-.20	.21	.05	-.01	.56***	.53****	-.21
	Shale	42	.37**	.41***	.14	.38**	.39**	.11	-.20	-.28*	.14	.04	.08	-.11	.53***	.61****	-.15
	Alluvium	30	.12	.15	.25	.33	.07	.05	.05	-.03	-.12	.12	.09	-.26	.15	.08	-.18
	Colluvium	32	.66****	.71****	.03	-.06	.09	-.20	.54***	.59***	.23	-.52***	-.61****	.20	.76****	.75****	-.27
	Aeolian	38	.54****	.40***	.02	-.05	-.25*	.05	.63***	.46***	.06	.13	.23	-.15	.63****	.37**	.16
	Ironpan	22	-.28*	-.13	-.20	.14	.08	.24	-.18	-.08	-.38	-.71****	-.70****	.10	.22*	.24*	-.16
Rainfall(mm)	600-900	71				.01	-.05	.18	.05	.08	.08	-.11	-.17	.25**	.26**	.17**	.27**
	900-1200	103				.04	.09	-.01	-.03	-.03	-.08	.19	-.01	-.02	.31****	.18**	-.13
	1200-1500	130				.01	-.03	-.03	.10	.08	-.03	-.08	.03	-.10	.35****	.16*	.10
	1500-1800	78				-.14	-.06	-.02	30**	.13	.06	-.04	.07	-.05	.33****	.25**	.07
Altitude(m)	300	110	.37****	.16*	.12	-.03	-.13	.14				.04	.14	.07	.56****	.22**	.12
	300-600	167	.57****	.31****	.19	.07	.11	.03				-.01	.03	.11	.54****	.34****	.16*
	600-900	71	.72****	.61****	.20	.25**	.25**	.14				-.17	-.19	.07	.44****	.63****	-.10
	900	34	.46***	.28*	.10	.21	-.01	-.24				-.20*	-.21*	-.17	.22**	-.25**	-.02
Position	Crest	119	.42****	.43****	.17				-.08	-.05	-.11	.29***	.26**	-.05	.47****	.56****	.08
	Middle	147	.31****	.28***	.03				.22**	.11	-.09	.08	.10	-.02	.45****	.44****	-.02
	Basal	116	.16*	.19*	.24**				.12	.12	.02	-.05	-.05	-.12	.60****	.64****	.15*

Significant levels: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

APPENDIX 9: THE ORGANIC CARBON AND NITROGEN CONTENTS OF THE TOPSOILS AND SLOPE POSITION

Slope Position		1st Rainfall Zone			2nd Rainfall Zone			3rd Rainfall Zone			4th Rainfall Zone		
		Crest	Middle	Basal	Crest	Middle	Basal	Crest	Middle	Basal	Crest	Middle	Basal
No of samples		30	28	13	47	37	19	34	55	39	8	25	45
O/C	$\bar{x}$	0.21	0.39	0.62	0.52	0.72	0.72**	0.76	0.84	1.27***	0.70	1.29	1.89***
	S.D	0.18	0.73	1.05	0.30	0.30	0.47	0.55	0.39	1.0	0.52	0.82	1.04
N%	$\bar{x}$	0.03	0.04	0.05	0.07	0.06	0.06	0.09	0.08	0.11	0.08	0.10	0.18**
	S.D	0.02	0.07	0.11	0.11	0.02	0.03	0.16	0.08	0.07	0.09	0.04	0.15
C/N ratio	$\bar{x}$	8.6	9.1	15.3**	11.3	11.5	12.2	11.8	11.9	11.5	9.1	12.7	12.1
	S.D	4.7	2.4	13.3	3.9	2.2	3.1	4.7	3.1	2.8	4.3	5.3	4.4

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

APPENDIX 4: THE TEXTURE OF THE TOPSOILS AND PARENT MATERIAL

	No of samples	Sand $\bar{x}$	Sand S.D	C/Sand $\bar{x}$	C/Sand S.D	F/Sand $\bar{x}$	F/Sand S.D	Silt $\bar{x}$	Silt S.D	Clay $\bar{x}$	Clay S.D
FIRST RAINFALL ZONE (600–900mm)											
Granite	6	80.0	17.6	15.7	13.0	64.3	11.8	15.0	14.5	5.0	3.5
Gneiss	2	71.0	16.9	15.5	16.3	55.5	0.7	20.5	13.4	8.5	3.5
G/gneiss	3	75.6	9.5	14.3	9.2	61.3	18.6	18.7	9.1	5.7	0.6
Schist	1	81.0	0.0	10.0	0.0	71.0	0.0	10.0	0.0	9.0	0.0
Sandstone	7	86.2	8.4	27.2	10.1	59.0	17.1	10.4	5.6	3.4	2.2
Basalt	-	-	-	-	-	-	-	-	-	-	-
Shale	3	56.0	19.5	5.3	4.2	50.7	15.8	28.7	16.7	15.3	7.8
Alluvium	6	85.8	9.1	21.5	11.7	64.3	7.8	8.7	7.6	5.8	2.3
Colluvium	17	84.6	8.0	23.9	9.2	60.7	12.9	9.8	6.5	5.7	4.8
Aeolian	19	81.7	4.1	11.6	5.3	70.1	5.4	13.1	3.1	5.2	1.5
Ironpan	7	83.6	14.6	27.6	18.9	56.0	17.3	9.9	7.6	6.4	3.5
		***		* **				***		***	
SECOND RAINFALL ZONE (900–1200mm)											
	16	57.5	15.9	23.9	19.7	33.4	9.2	30.7	14.5	11.8	5.9
	7	60.7	13.6	26.7	12.8	34.0	8.9	27.7	13.7	11.6	4.5
	20	69.0	12.7	39.8	14.2	29.2	15.5	20.9	11.2	10.2	5.1
	9	53.6	13.3	20.3	19.0	33.3	9.2	34.1	12.1	12.3	2.4
	10	73.6	13.8	36.2	17.1	37.4	16.2	17.0	8.1	9.5	6.6
	7	49.3	16.4	18.0	10.9	31.3	13.9	27.3	12.2	23.3	14.7
	9	55.9	12.5	13.4	14.3	42.4	9.0	30.1	11.2	14.1	4.0
	4	69.8	12.3	36.3	16.1	35.5	25.6	20.2	10.9	10.0	5.7
	7	53.3	8.3	19.2	11.4	34.1	6.8	33.1	10.9	13.6	7.9
	10	65.2	9.0	20.2	17.4	45.0	19.9	24.1	5.8	10.7	4.9
	4	74.0	4.8	27.5	5.1	46.5	2.1	16.3	2.5	9.8	3.0
		****		****				***		****	
THIRD RAINFALL ZONE (1200–1500mm)											
Granite	9	69.6	17.9	44.4	18.1	25.1	10.0	17.7	11.7	12.9	8.7
Gneiss	14	62.1	15.9	30.3	10.2	31.8	12.6	20.4	11.9	17.4	8.7
G/gneiss	15	63.5	15.4	33.7	11.2	29.8	13.1	23.5	11.7	13.1	5.4
Schist	13	63.5	19.2	25.9	13.0	37.5	14.4	21.2	14.2	15.8	6.6
Sandstone	19	77.6	17.8	40.9	28.7	36.7	16.4	15.4	15.5	7.0	5.0
Basalt	11	38.1	19.8	22.4	11.4	15.7	11.0	29.0	12.2	31.2	15.4
Shale	20	60.2	14.9	25.0	16.1	35.2	13.9	24.4	14.0	14.9	9.5
Alluvium	8	64.0	15.1	25.3	15.5	38.8	18.3	19.1	10.0	19.9	10.3
Colluvium	6	42.2	14.5	23.0	9.9	19.2	8.3	29.2	12.5	28.3	5.9
Aeolian	7	45.1	21.6	29.6	16.2	15.6	15.3	31.4	16.5	23.4	12.2
Ironpan	8	68.8	13.9	21.0	18.1	47.8	10.7	21.8	12.0	9.5	4.8
		****		**		****				****	
FOURTH RAINFALL ZONE (1500–1800mm)											
	5	77.0	11.1	48.6	11.3	28.4	2.4	14.4	5.6	8.6	6.1
	9	69.0	15.6	33.2	9.3	35.8	12.9	13.8	10.5	17.2	9.0
	-	-	-	-	-	-	-	-	-	-	-
	17	67.7	21.4	40.4	16.5	27.4	11.7	15.8	11.8	16.6	11.4
	-	-	-	-	-	-	-	-	-	-	-
	24	39.0	17.3	18.5	13.4	20.5	11.4	27.6	10.0	33.4	11.9
	10	50.2	22.1	22.1	19.9	28.1	17.4	27.8	16.4	22.0	11.4
	12	55.8	22.5	24.4	21.5	31.3	15.0	26.9	12.2	17.3	13.5
	2	82.5	2.1	43.5	4.9	39.0	2.8	5.0	1.4	12.5	4.7
	2	58.5	37.5	35.0	36.8	23.5	0.7	23.5	27.6	18.0	9.9
	3	64.3	24.9	31.7	23.6	32.7	9.6	20.7	16.8	15.0	8.7
		****		***		*		***		****	*

Analysis of variance levels of significance: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.

APPENDIX 5: SIMPLE CORRELATION COEFFICIENT MATRIX VALUES OF THE TEXTURE OF THE TOPSOILS AND THE SOIL-FORMING FACTORS

Forming	No of samples	RAINFALL						TEMPERATURE						ALTITUDE					
		Sand	Coarse sand	Fine sand	Silt	Clay	Silt/Clay	Sand	Coarse sand	Fine sand	Silt	Clay	Silt/Clay	Sand	Coarse sand	Fine sand	Silt	Clay	Silt/Clay
Granite	36	.06	.59****	-.71****	-.17	.21	-.31	.70****	.57****	.05	-.57****	-.68****	.11	.62****	.51****	-.03	.44****	.72****	.19
Gneiss	32	.19	.39**	-.03	-.52***	.32	-.61***	.36**	.37**	.47****	-.61****	-.02	-.41	-.40***	-.24	-.66****	.55****	.46***	.18
Gneiss	38	.08	.79****	.01	-.21	.20	-.37	.46***	.16	.27*	-.45****	-.10	-.21	-.51***	-.03	-.42***	.54****	-.50***	.08
Schist	34	.22	.82****	-.57***	-.50****	.11	-.44*	.54****	.66****	.19	.77****	-.48***	-.04	-.42***	-.46***	-.24	.42***	.78***	.01
Sandstone	36	-.03	.06	-.13	-.01	-.08	-.02	-.03	.06	-.13	-.01	.03	-.18	.11	.03	.09	-.08	-.12	-.16
Basalt	42	-.13	.09	-.23	-.14	.27*	-.36	.14	.06	.15	-.32*	.02	-.05	-.42***	-.18	-.41***	.49***	.23	.01
Shale	42	-.28	.14	-.39*	.19	.22	-.01	-.24	-.12	-.14	.03	.36**	-.04	.19	.04	.21	-.18	-.03	-.24
Alluvium	30	.07	-.02	-.07	.27	-.15	-.39*	.13	-.31*	.29	-.04	.08	.01	.07	.30*	-.19	-.13	-.06	-.15
Colluvium	32	-.53****	.63****	-.18****	.41**	.64****	-.54**	.48****	.39****	.20	.67****	.06	-.37**	-.72****	.18	-.77****	.32*	.82****	-.44***
Aeolian	38	-.04	.38*	-.17	.39*	.30	-.45*	.38**	.11	.30**	.56****	-.33**	-.03	-.70****	.25	-.76****	.67****	.78****	-.39**
Aeronpan	22	.04	.26	-.14	.09	.16	-.35	-.42***	-.45***	.14	.51****	.07	.26	.37*	.44*	-.19	-.49***	.02	-.34*
Forest	119	-.28***	.31***	-.45****	-.03	.37****	-.33***	.27**	.23**	.08	-.46****	-.08	.06	-.27**	-.10	-.23**	.30****	.25**	.07
Middle	147	-.05	.47****	-.53	-.12	.26***	-.23***	.35***	.13*	.24***	-.16*	-.16*	-.08	-.46****	-.11	-.37****	.37****	.40****	.11*
Basal	116	.09	-.09	-.17*	.09	.18*	.11	.12	.10	.15	-.13	-.13	-.06	-.27**	.02	-.44****	.11	.34***	.20*

Significant levels: **** = 0.001; *** = 0.01; ** = 0.02; * = 0.05.