THE RELATIONSHIP OF TOE^OGRAPHY TO SOILS AND VEGETATION IN THE NORTHERN GUINEA ECOSYSTEM, NIGERIA

By

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DECLARATION

I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree

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The above declaration is confirmed

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ABSTRAC

The relationship between topography, soil and vegetation in the Northern Guinea ecosystem of Nigeria has been investigated. The results of the investigations revealed a strong inter, action between topography, soil development and both the species distribution and the general vegetation growth performance-

Soil depth increased down the slope. Soil i^xture became finer with decreasing altitude. The upland soils were generally more acidic than the lower slope soils. The soil organic carbon content and the general soil nutrient status increased down the sifrpe The soils of the crests and the upper siepes were classified as Lithic Ustorthents and Plinthustults. Those of the middle slopes were; classified as Ultic Paleustalfs and Ultic Haplustalfs while Vertic Tropaque^ts occupied the lowerslope positi»ns.

The distribution of the vegetation cover was found to be the apparent results of the local drainage condition of the area. The vegetation cover of the crest and the upperslope surfaces was sparse and sbort while that ef the loweralopes was tall and dense with good ground^coverage. The distribution of the vegetation species revealed that Isoberlinia d*fea, and I. tomenttese dominated the shrub layer of the uplands whereas Pilio-stigma thonningii and Ziziphus mauritiana dominated the vegetation cover (shrub) of the lower slop.

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1 INTRODUCTION

1.1 Topography Defined

Topography refers to the outline of the earth's surfaces and it is synonymous with relief (Goosen, 1967). Topography is one of the five external factors of soil formation. Its role is very unique in that it severely modifies the nature and magnitude of the other four factors: namely, climate, organisms, parent materials and time. The concept of soil catena is a further testimony to the unique importance of topography in soil formation. This concept arises because of the important bearing topography has on several soil forming processes, such as eluviation, illuviation, leaching, erosion and enrichment. Topography influences slopeforms, and particular slopeforms are associated with particular soil sequences which in turn influence the type and amount of vegetation cover (Goosen, 1967). This forms the basis of the concept of topographic-plant-soil interrelations.

1.2 Justification for The Study

The study of these interrelations between topography, soils and vegetation is of great importance because vegetations are increasingly being used to indicate the environmental conditions and potential land productivity (Pregitzer et al., 1983).

In Nigeria this is one of the major criteria used by the traditional subsistence farmers in their choice of land for specific crop production. For instance, an exuberant grass vegetation cover commonly gives an indication that crop plants of similar nature, for example of the same family, could be successfully grown on that piece of land. Secondly, in many toposequences the vegetation appears to be scantier and more heterogenous on the crest and upperslopes than on the lowerslope. In the Northern Guinea Savanna ecosystem, for instance, the valley bottoms and the lowerslopes have denser vegetation, with taller grasses and trees than the crests and the upperslopes which are mainly composed of short scanty grasses and shrubs. This pattern of vegetation distribution must be governed by some edaphic factors which are worthy of investigation.

Although a number of investigations have been carried out on topographic - soil relationship, only very few of such investigations involved vegetation studies. In other words, there have not been much attempts to correlate the amount and species composition of the vegetation cover to topographic and soil properties. This forms a very important part of this study. Furthermore, most of these investigations were carried out outside the Northern Guinea Savanna ecosystem which is the present study area.

Topographic-plant-soil interrelations vary from place to place depending on the climate and the nature of the parent materials found in the areas. This implies that past studies on the subject have their limited applicability, such that what obtains in the Derived Savanna ecosystem, for example, may not be applicable to the Northern Guinea ecosystem or other ecosystems.

The objectives of this study are, therefore,

(i) to quantify the physical and chemical properties of the soils of the Northern Guinea ecosystem,

(ii) to study the influence of topography on soil development,

(iii) to classify the soils according to their characteristics and

(iv) to relate the amount and species composition of the vegetation cover to topographic and soil properties.

2. LITERATURE REVIEW

2.1 Pedology, Soil Survey and Soil Classification

Pedology refers to the study of soils in their natural setting - the field (Clarke, 1971). Certain aspects such as genesis of the soil, its description, classification and geographical distribution are involved in pedology. Under this concept the soil is considered as a natural organised body, evolved or evolving under the influence of the factors of soil formation, and minor emphasis is placed on its immediate practical utilization (Brady, 1974).

The study of soils in their natural setting involves field investigation and characterization of soils based on the morphogenic properties as observed in the field (Clarke, 1971). It also includes the collection of data or information gathered from laboratory studies of soils sampled from the field. Soil survey can therefore be defined as the process of studying, classifying and mapping the earth's surfaces in terms of soil units called types (Clarke, 1971; Buol et al., 1973, Dent and Young, 1981). Soil Survey is an integral part of pedology and provides the immediate means by which the aims and objectives of pedology are materialized. A complete soil survey consists of a soil map and a soil survey report (Dent and Young, 1981). The soil map is a cartographic

demarcation of the different soil units covered in the survey area while the soil survey report gives full description of the area covered by the map.

Three main types of soil surveys are recognised, namely, exploratory, reconnaissance and detailed surveys (Soil Survey Staff, 1951). The choice of whichever type of survey to be employed in any particular situation is largely dependent upon the purposes to which the intended survey will be put as well as the prevailing field conditions of the area to be surveyed (Soil Survey Staff, 1951; Dent and Young, 1981; Ugwu, 1983). Field methods also vary depending on the type of soil survey employed. Whichever types of survey and field methods are employed, the ultimate aim of the soil survey is to group the soils into units or types based on their morphological differences. Such differences arise because of the differences in the types and intensities of factors of soil formation. It is on the basis of these differences that soils are mapped and classified.

The history of soil classification dates back to time immemorial. The earliest classification systems had continually been improved upon until the present systems were developed. The general trend in the modification or improvement of the older systems shows that three different concepts had been used in the classification at different

stages. These concepts are those of soils as natural habitats for crops, soils as a superficial mantle of weathered rocks and soils as natural organised bodies formed or forming under the influece of soil forming factors (Buol et al., 1973; Brady, 1974).

The crop habitat concept was the oldest method employed in soil classification probably because of its significance to practical agriculture. Soils were grouped together on the basis of their productive capacity as "good" or "bad" soils. These two broad groups were further subdivided depending on the type of crops most suitable to them. For example, terms like black cotton soils, black klei-heavy wheat soils or strong rice soils were used.

The second method of soils classification based on the concept of soils as superficial mantle of weathered rocks came into limelight only after geology had become a scientific discipline of its own (Buol et al., 1973). The geologic origin and the lithologic composition of the parent materials of the soils were the two basic principles used in the classification, so that such terms as glacial, alluvial and colluvial soils were freely used (Brady, 1974). It is pertinent to mention here that some of these terms persist to-date in pedological literatures.

The third method of classification which is the most scientifically oriented method among its contemporaries, and which formed the basic foundations for the present classification systems, was initiated by Dokuchaev (Buol et al., 1973). He developed the concept of soils as natural independent bodies subject to classification by man. Such classifications were based primarily on factors of soil formation and other soil properties. Some of his older terms like chernozem, podzol, etc., formed the very basis for the present naming of soil taxa in the Russian system of soil classification (FitzPatrick, 1980).

Although Dokuchaev's concept of natural body took precedence over the older two systems, it had some limitations, the greatest of which was its strong genetic bias. This is a severe limitation because of the difficulty of ascertaining which genetic processes are responsible for the formation of a given soil. For this reason, Dokuchaev's concept had been modified and the emphasis is now shifted from genetic factors to morphogenetic characteristics of soils in modern day classification systems. Some of these systems include the United State Department of Agriculture system, USDA (Soil Survey Staff, 1975), Canadian system (1961), FAO/UNESCO system (1974), Russian system (1968). Of these systems, the USDA (1975) and the FAO/UNESCO (1974) systems are the

most widely used in Nigeria. For this reason, the classification of soils of the present study area will be restricted to these two systems.

2.2 Topography - Soil Properties Relationship

The role of relief in soil formation is very unique in that it severely modifies the nature and magnitude of the other four soil forming factors, with the results that it has a dominating influence on the distribution of soils in the landscape (Gerrard, 1981). This is evidenced by the fact that soils of markedly contrasting morphologies and properties merge laterally and imperceptibly with one another on toposequences and yet are in equilibrium under the existing local conditions. This general observation gave rise to the catenary concept of soil. Milne is known for his extensive work on soil catena which he defined as "a grouping of soils which while they fall apart in a natural system of classification on account of fundamental and morphological differences are yet linked in their occurrence by conditions of topography and are repeated in the same relationship to each other wherever the same conditions are met with" (Milne, 1935).

Milne's work opened a new era of catenary studies which engaged the attention of both pedologists and geomorphologists. Their primary concerns were not with the formal appearance of the soil catena, but rather with the essential factors and processes responsible for catenary differentiation. Later studies and field investigations revealed that the formal appearance of a soil catena is a consequence of the interraction between topography and the other soil forming factors as well as the action of the fluvial processes operating on slopes (Buol et al., 1973; Birkeland, 1974; Gerrard, 1981).

2.2.1 Topography related to other soil forming factors

Although, the catenary concept was primarily thought of as being the direct handwork of topography, recent studies reveal that catenary differentiation is brought about not solely by the inequalities of the earth's surfaces, per se, but by the direct and/or indirect influences of topography on other soil forming factors such as climate, organisms, parent material and time (Birkeland, 1974).

Topography induces the microclimate of an area by influencing the distribution of climatic forces of heat and water (Buol et al., 1973). This induced microclimate is most evidenced in slope aspect as commonly observed in the temperate zone (Chang, 1968).

table refers to the level below which the soil is saturated with water (Buol et al., 1973). It is closer to the surface at depressions than on elevated landscapes. In the study area, the groundwater table may rise to the surface at depressions and maintains that level for 30 to 90 days during the rainy season thereby rendering the soils waterlogged. Such a saturated soil condition alters many physical and chemical reactions in the soil, for example

(a) anaerobic reactions predominate because of limited supply of oxygen and this may retard root growth;

(b) percolation of water is restricted and instead, lateral movement of water within the saturated zone tends to predominate, and

(c) the specific heat of a saturated soil is increased and the soil tends to be colder than the surrounding unsaturated soils (Buol et al., 1973).

These three conditions render climatic influences ineffective in regulating soil development, with the results that soils of the valley bottoms (especially in the humid environments) are mere bodies or sediments of non-coherent materials or at best of massive structure.

In addition to the differential levels of the groundwater table within a soil catena, there is also the problem of seasonal fluctuation of the water table. It rises in the rainy season and falls in the dry season with the zone of fluctuation falling deeper in the soil profiles upslope, but at or close to the surface at depressions. This is commonly true in areas with a pronounced dry season such as the Zaria area. Such seasonal fluctuation of water table causes gleying or mottling in soil profiles at and below the zone of the fluctuating water table. Consequently soil colour variations exist along the slope in most toposequences worldwide. This general observation compelled some early soil scientists to define soil catena as a topo-drainage sequence (Gerrard, 1981).

The influence of topography on organisms is manifested in the differential vigour or growth performances of vegetation along a toposequence. The vegetation cover of lower slope and valley bottom is normally taller and of higher density than that found on the crest and upper slope positions. The direct consequence of this is that lower-slope soils have higher organic matter content and thicker A horizons than soils of the crests and upper slopes. This is moreso since the soils of the lower-slope have lower soil temperature regimes and therefore a lower rate of organic matter decomposition.

Topography also influences soil parent materials and time through some fluvial processes operating on slopes. Soil materials from the crest and upper slope are removed, transported and deposited at the lower slope to form the parent materials of soils downslope (Gerrard, 1981). Where slopes are very steep (free face), the soil materials are removed as soon as weathered, so that enough time is not allowed for soil formation (Buol et al., 1973).

2.2.2 Fluvial processes on slopes

The variation of soils properties with topographic positions is also attributable to the influence of some fluvial processes operating on the slope. The most readily observable influence of topography on soil development is summed up in the statement "water runs downhill" (Buol et al., 1973). This statement specifically refers to the surface water running downslope, but some lateral water movements within the profile (chemical denudation or throughflow) occur and, to some extent, influence soil development. Soil materials are moved across the slope along with this downhill water movement. The results of this movement are the redistribution of these soil materials due to natural processes of erosion and deposition. The crest and upper slope

may experience erosion while the lower slope and valley bottom may witness erosion and/or deposition. The main processes involved are surface wash, chemical denudation and mass movement (Young, 1976).

Surface wash is most important in the tropical climates ranging from semi-arid to moist savanna, but decreases towards the savanna-rainforest transitional zone due to increased protective effect of vegetation on soil. Chemical denudation occurs in all climates, its rates probably increase linearly with rainfall, while mass movement predominates on very steep slopes in all climates (Young, 1976). By virtue of the location of the present study area (Northern Guinea savanna) and the nature of the slope involved (gently to moderately steep), the processes of surface wash and chemical denudation are considered the most important in catenary differentiation and therefore will be discussed in more detail.

Surface wash involves a sheet of water moving more or less uniformly downslope with sediments (Twidale, 1976). The occurrence of surface wash depends on two major factors viz rainfall intensity and soil erodibility factors (Thornbury, 1969; Gerrard, 1981). For soil materials to be easily washed, they have to be in loose detached forms.

The detachment is aided by the high rainfall intensity with its associated large dropsize and great terminal velocity (Ologe, 1971). The rainfall in the Northern Guinea Savanna is known to be of high intensity and, therefore, capable of detaching soil particles and keeping them loose, and ready for removal by surface runoff (Kowal and Knabe, 1972). Soil erodibility on the other hand is the measure of the resistance of soil to erosion. It is influenced by those soil factors that affect infiltration rate, permeability and total water holding capacity, and also by those factors that resist dispersion, splashing, abraision and transporting forces of rainfall and runoff (Foth, 1972). Soil studies in the Zaria area have revealed that the soils of the region have coarse texture, poor structural development and stability, low water holding capacity and low infiltration rate (Awujoola, 1979; Malgwi, 1979). These soils, therefore, have poor erodibility and as such are bound to be highly prone to erosion hazards under the prevailing high rainfall intensity.

The immediate cause of surface wash is the availability of excess water which accumulates on the surface and moves downslope under the influence of gravity (Ologe, 1971; Gerrard, 1981). This is only possible when rainfall intensity exceeds the soil infiltration rate. The already detached and loose

soil materials are removed and transported downslope along with the moving water. The consequence of this process is the exposure of the underlying materials of the crest and upper slope to climatic forces which start the formation of soils all over again. At lower slope soil materials are being brought in from the crest and upperslope as well as removed downwards, whilst still further downslope, there may be intermittent deposition, ' These differential erosion rates between the upper and lower parts of the slope lead to a tendency for the regolith to become shallow and less highly weathered towards the crest (Young, 1976). This is particularly true on slopes whose pediments are generally concave in profile form thereby causing the less highly weathered soils to occur close to the hill slope-pediment junction.

The rate of natural erosion by surface wash increased with the steepness of slope and the distance of overland flow. The rate of increase with slope steepness lies somewhere between being linear with slope angle and being the square of the angle, varying with local conditions (Young, 1976; Gerrard, 1981). On very steep slopes (slope angle above 45°) the rate of erosion is so fast that no soil accumulates. Bare rock outcrops are found exposed on such slopes, as commonly observed on

inselbergs in most parts of Nigeria. As regards the distance of overland flow, the increase in the rate of erosion is approximately proportional to the square root of the distance from the crest (Young, 1976).

Chemical denudation is the downslope movement of water within the soil profiles (Gerrard, 1981). It is so termed because such water does not move in isolation, but as a solution containing all the soluble end-products of weathering, like silica, iron and exchangeable bases. There is therefore, a considerable removal of these soluble compounds from the crest and upperslope soils and a corresponding concentration of them (soluble compounds) at the lowerslope profiles. Soils of the crest and upperslopes therefore have less content of soluble salts and as such are more acidic in reaction than those of the lowerslope.

Sometimes, the soluble iron transported from the crest and upperslope becomes precipitated at seepage sites in the lowerslopes forming laterites. Such laterites are common features along most stream channels in the Northern Guinea Savanna. They are so compactly aggregated that they give a false picture of ironpan outcrop. This type of laterite is commonly referred to as secondary ironpan or pseudo-ironpan outcrop (Valette, 1973; Young, 1976).

Clay is also believed to be laterally translocated downslope by chemical denudation, but whether or not this occurs in appreciable quantity is still a subject of controversy (Young, 1976). Chemical denudation, however, has a pronounced effect on clay mineral formation. For example, the increased concentration of silica and exchangeable bases in soil solution at the base of the slope permits the synthesis of montmorillonite in areas climatically unfavourable for its formation (Young, 1976).

In summary, therefore, the following soil properties can be said to be topography related. These are:

(i) depth of the solum
(ii) thickness and organic matter content of the A horizon
(iii) relative wetness of the profile
(iv) colour of the profile
(v) degree of horizon differentiation
(vi) soil reaction
(vii) soluble salt content
(viii) kind and degree of pan development and
(ix) soil temperature.

The above soil properties change gradually or abruptly from the mountain summit to the valley footslope in many toposequences. Pregitzer and

in vegetation distribution is governed by some edaphic factors which are influenced by topography.

Osanoto (1975) investigated the general trend of environmental gradients from the valley bottom to the lateral mountain summits in Aber Valley, Northern Wales. His observations are summarized as follows:-

(a) there was a general increase in soil depth from mountain tops to the valley,

(b) soil water becomes progressively scantier with increasing altitude because inspite of the higher precipitation on the tops due to orographic rainfall, the rate of water loss through lateral and vertical flows was high. Besides, rain falling on valley sides and mountain tops is likely to wash soil particles downhill across the upper and middle slopes to the lowerslope.

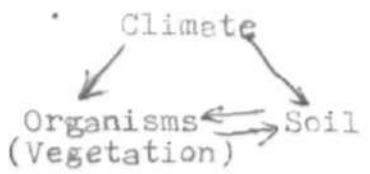
(c) percolating and lateral waterflow also transport soluble mineral products of weathering from the summit and subsummit soil profiles to the lower soil profiles. The subsequent loss of these soluble minerals generates acid soils on and around the summit while the lowerslope and valley soils have high pH.

These three major conditions are accountable for the broad gradations in the vegetation composition and structure along the slope from the valley bottom to

the crest. The progressively better soil conditions downslope as conditioned by relief encourage more widely composed and better structured vegetation at the lowerslope than at the crest. Local variation may, however, occur along the slope as a result of microrelief, lithological discontinuity and human intereference.

2.4 Vegetation-Soil Properties Relationship

Of the five factors of soil formation, it is perhaps only with organisms that the soil has a reciprocal relationship. This means that the soil influences organisms and at the same time it is influenced by organisms. The two factors are however influenced by climate as depicted below by Jenny (Birkeland, 1974).



In as much as the soil provides the immediate physical and nutritional support, ranging from physical anchorage through biological oxygen demand of roots to water and mineral nutrient requirements, for most plants the physical appearance of the vegetation cover in any locality can be an indication of the soil condition of that locality. In this way, the soil acts as a direct control on plant distribution and performance. This

control was emphasized in the classification of plants usually found on acid soils as oxylophytes, those on saline soils as halophytes, those on sands as psammophytes and those on rock surfaces as lithophytes (Daubenmire, 1962).

Further evidence of the influence of soil on vegetation can be seen in the existence of savanna vegetation in generally forested areas, such as the Congo basin. Here, forest trees' invasions are prevented by waterlogging which encourages grassess and woody plants comprising this "edaphic savanna". It is interesting to note that the species composition of such savanna is quite different from those of drier savanna in the same region (Eyre, 1968). The very heavy and impervious nature of the subsoil, which allows for complete wetness of the soil in the rainy season and complete dryness in the dry season, prevents the germination and development of tree species in this "edaphic savanna".

Similar problems are encountered in the low plateau areas of Surinam and parts of Trinidad where the rainfall is sufficient to support a semi-evergreen forest if not a tropical rainforest, but the level land and pervious soils carry only grassland with scattered bushes. Eyre (1968) attributed this condition to the very poor soils which have resulted from old erosion surfaces that

have been exposed to weathering and leaching for a very long time. Such poor soils cannot support a rich forest vegetation which the climate would otherwise permit.

Soil also influences plants by way of its reaction. Some plants are acid tolerant, while others are not. Plant sensitivity to soil acidity is caused mainly by deficiences of Ca, Mg, K, etc. and/or the concentration to toxic levels of Al, Fe, Mn, etc. (Brady, 1974). Depending on their nutrient requirements, plants have been classified into two broad groups - calciphytes and oxylophytes. The calciphytes grow on basic soils containing free $CaCO_3$ or on neutral soils from which the Ca has not yet been lost from the colloids. They always disappear from an area as the soil becomes acidic and the Ca is lost. The oxylophytes on the other hand are plants with low Ca requirements or exceptional abilities to obtain it from meagre sources. They thrive very well on acid soils and may possibly be excluded from alkaline soils (Daubenmire, 1962).

As mentioned earlier, the relationship between soil and vegetation is a two-way system. Soil influences vegetation and vegetation contributes to making soil what it is. It has been argued by many writers that no true soil ever comes into existence

without the influence of plants (Eyre, 1968; Ahn, 1970). Raw soil materials consisting of nothing except mineral particles develop into true soils only when such materials are colonized by plants and receive additions of organic matter. For example, a bare consolidated rock could develop into a true soil over an unimaginably long period of time by first being colonized by primitive plants such as the blue-green algae. These plants initiate the process of soil formation by secreting organic acids which dissolve soluble minerals and thereby disintegrate the rock. As the conditions improve, a more advanced plant community adapted to the particular condition begins to establish until a true soil is formed in equilibrium to a climatic climax, if left undisturbed. In this way, plants are said to be the primary initiators of soil formation from bare rock surfaces, bare sand dunes, raised seafloor and even on a plain of glacial till (Eyre, 1968; Ahn, 1970).

Apart from initiating soil formation, particular vegetation covers are known to impart unique properties to the soil. For example, soil under coniferous forest are known to be acidic due to the acidic nature of the litter, while soils under the oak trees have a basic reaction because the litter is rich in bases (Eyre, 1968). Similarly, soils of the tropical savanna have less organic matter content than those under tropical rainforest (Ahn, 1970; Jones and Wild, 1975). This is

because of the less dense vegetation cover (grasses) in the savanna as opposed to thick forest vegetation with its associated deep litter in the rainforest.

2.5 Previous Work In The Area

Much of the available information about soils of the Northern Guinea Savanna are contained in soil survey reports mainly carried out at reconnaissance level. Tomlinson (1964) and Klinkenberg and Higgins (1968) classified the dominant soils of Zaria area as Tropical Ferruginous soils based on D'Hoore legend of soil map of Africa. Pullan (1970) grouped the Tropical Ferruginous soils into two. One group is represented by those soils in which the pedon is relatively shallow, the colour brownish and often pale, and few to common iron concretions are present. The second group consists of leached pedons characterized by red colour with associated common iron concretions or lateritic ironstones. Other features of the soils include good drainage, high sand content and moderate to strong structure. The organic matter content is generally low, possibly reflecting the frequent burning of the vegetation and its destruction by grazing animals and cultivators.

Higgins (1963) grouped upland soils of the Samaru area into two, corresponding to the geomorphological pattern of the area. One group is represented by soils on the upper erosion surface, and the second by soils on the second erosion surface. Soils of the upper erosion surface are said to be sedentary, usually derived from quartz schist overlain by variable depth of drift material. Whenever the depth of the drift materials was less than 15 cm the soils were classified as the Shika series. The series are usually underlain by ironpan containing quartz. The Biye series falls into group one, but is deeper reaching up to 60 cm depth. The soils of the second erosion surface are represented by the Bassawa series which are lower-lying consisting essentially of a few centimetres of loamy sand overlying pale brown and subsequently light grey clay loam. The intensity, size and hardness of mottles increase with depth, and soil structure is weak subangular blocky.

Valette (1973) observed the occurrence of different soil types along some toposequence in the Zaria area, and related such phenomena to the influence of topography. He classified the well drained soils of the crest as Lithosols, the well-drained deep soils of the upper and middle slopes as Nitosols and Luvisols, while the medium textured, sandy clay loam "fadama" soils were classified as Dystric and Eutric Fluvisols.

In a related study over a toposequence in Samaru, Awujoola (1979) classified the soils of the crest, upper and middle slopes as Oxic Haplustalf, Oxic Paleustalf and Typic Paleustalf. The lower-lying "fadama" soils were classified as Typic Tropaquept. Similar findings were reported by Malgwi (1979) and Valette and Ibanga (1984).

3 THE STUDY AREA

3.1 Location

The study area lies about 14.2 km north-west of Zaria and south of the main road linking Zaria with Funtua (Fig. 3.1). It is bounded on the north by the old Zaria-Funtua road, and on the west and south by river Kekaa and its tributary. The eastern boundary is provided by an ironstone ridge that slopes down to the tributary of river Kekaa in the south. The length of the area is approximately 1 km along the road from the crest to river Kekaa, and the width is about 0.75 km from the old road southwards to river Kekaa's tributary, giving a total area of about 75 hectares.

3.2 Climate

Climatic data for the study area are not available, but can be inferred from those of Samaru. This is because, the study area is 14.2 km north of Samaru and moreover, they lie almost in the same latitude of 11° 11' (Kowal and Knabe, 1972). There is not likely to be any statistically significant climatic variations between the two locations. This view is strongly supported by Kowal and Knabe (1972) who used an area of about 36,400 km^2 for a climatic station.

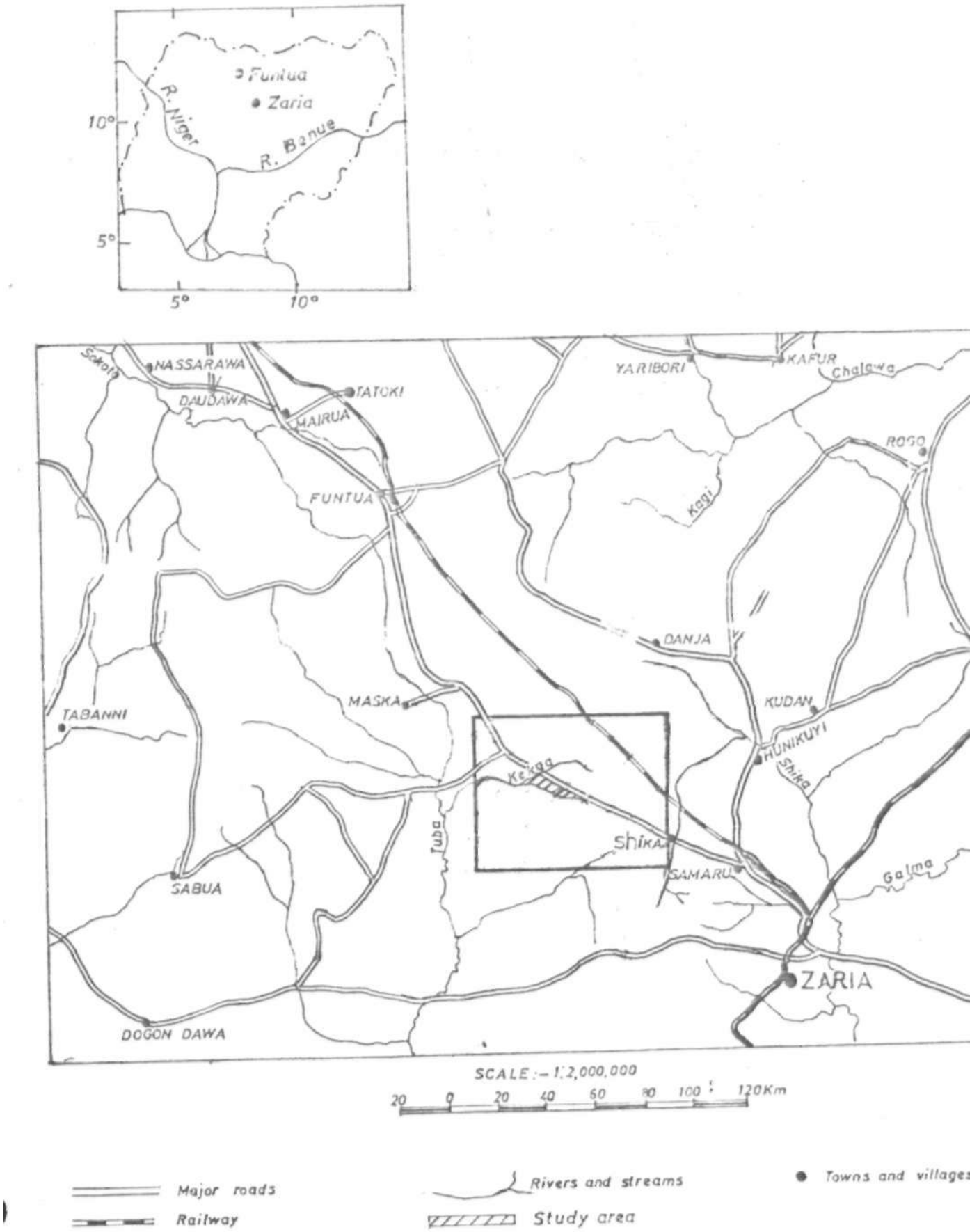


Fig. 3:1. Location of the study area.

Samaru has a subhumid tropical climate that is characterized by distinct wet and dry seasons d ictated by the movement of the Inter Tropical Front, ITF. (Rackham and Innes, 1978). The ITF itself is the meeting zone of two principal airmasses, the maritime and the continental airmasses, that affect the climate of Nigeria in general. The maritime airmass is warm and moist and moves inland off the ocean in a north-east direction, while the continental airmass, locally known as the harmattan. is warm and dry, and moves from the continental desert in the opposite direction,

The ITF migrates north and south, its location being situated approximately on latitude 8° N in January and 20° N in July (Rackham and Innes, 1978). Thus it crosses Samaru (11° 11' N) twice a year, once on its northward passage and again during its southward migration. However, the time interval between the two passages is so short that Samaru experiences a unimodal rainfall peak in August as against a bimodial rainfall peak in areas south of latitude 9° N (Hore, 1970).

A characteristic feature of the climate of Samaru is its extreme rainfall variability in terms of both amount and duration. In some years the rain may start very late in June and stop abruptly in September as was the case in 1983. Still in other years it

could start early in March and end in the early part of November, for example in 1976. In all cases, however, it is only within the months of June to September that rainfall exceeds evapotranspiration, while other months of the year record a soil moisture deficit. The soil moisture regime is therefore, inferred to be ustic (Malgwi, 1979).

The mean annual rainfall between 1928 and 1980 for Samaru is about 1093 mm with most of it falling between the months of April and October (Owonubi, 1980). The mean monthly rainfall increases rapidly from 36.2 mm in April to 280.4 mm in August, followed by a sharp decrease to 37.0 mm in September (Table 3.1).

The mean monthly minimum air temperature (13.8 to 13.9°C) at Samaru is lowest during the periods of strongest and most constant drying winds (harmattan), that is December to January. The highest mean monthly minimum temperature (21.7°C) is recorded in the month of April. This decreases gradually to 17.7°C in October. The mean monthly maximum air temperature is highest (35.7°C) prior to and during the onset of rains in April, and lowest (27 7°C) during the period of heaviest rainfall in July/August (Table 3.1).

Table 3.1 Long term means of rainfall, air temperature and relative humidity at Samaru.

Months	Rainfall (mm) 1928 - 1980	Air temperature (^{o}C) 1938 - 1980			Relative Humidity (%) 1954 - 1980	
		MIN	MAX	MEAN	A.M.	PM
January	0.2	13.9	30.3	22.1	17.1	13.9
February	0.9	16.0	32.7	24.4	15.2	10.8
March	7.1	19.5	35.3	27.4	25.6	14.2
April	36.2	21.7	35.7	28.7	47.9	29.0
May	121.1	21.2	32.9	27.4	63.6	43.4
June	161.6	19.9	30.7	25.4	72.6	57.3
July	225.7	19.5	28.4	23.9	79.5	66.2
August	280.4	19.3	27.7	23.5	81.7	69.7
September	221.4	19.1	29.3	24.2	75.9	62.9
October	37.0	17.7	31.4	24.8	60.6	43.1
November	1.2	15.4	31.6	23.5	29.2	21.4
December	0.1	13.8	30.3	22.1	21.1	16.4

The pattern of the air relative humidity closely follows that of rainfall, The relative humidity is very low in the months of January to March, but suddenly picks up with the onset of rains in April, reaching its peak in August (81 %). There is an inverse relationship between relative humidity and air temperature. When the air temperature is high, the relative humidity is low and vice versa, for example, there is a steady increase in relative humidity from April to August corresponding to a steady decline in air temperature for the same period (Table 3.1).

The surface soil temperatures vary from month to month corresponding to the monthly variations in the air temperatures. They are highest in April and lowest in January. However, there are less charges in soil temperatures with depth. The difference in the soil mean monthly temperatures between the warmest and the coolest months at depths beyond 30.5 cm is less than $5^{o}C$. The soil temperature regime is therefore said to be isohyperthermic (Soil Survey Staff, 1975). There is also only a slight difference ($\leq 1.5^{o}C$) between the morning and afternoon readings at such depth (Table 3.2).

Evaporation is lowest in August when the relative humidity is highest (Table 3.2). As the relative humidity decreases gradually from September through December to February, the evaporation increases, reaching its peak just before the onset of rains in March/April.

Table 3.2 Long term means of soil temperatures and evaporation at Samaru

	Soil temperatures ^{o}C (1954 - 1980)						Evaporation	
	At 5 cm		At 30.5 cm		At 122 cm		Open pan	Piche Evaporimeter
	A.M	PM	A.M	PM	A.M	PM	(cm)	(mm)
January	21.8	30.8	23.4	23.9	24.0	25.2	191.6	332.2
February	24.6	34.6	25.5	25.9	24.5	25.8	205.9	353.2
March	28.7	35.2	28.5	29.2	26.4	27.6	246.0	376.0
April	30.6	39.9	30.2	30.9	28.2	29.2	210.9	259.4
May	29.4	37.2	29.3	30.0	28.6	29.5	196.2	177.8
June	27.2	33.0	27.6	28.0	27.0	28.5	162.4	116.5
July	25.5	30.2	26.3	26.6	26.9	27.6	136.9	73.0
August	25.0	28.9	25.5	25.8	26.7	26.7	123.1	59.4
September	26.0	30.7	26.1	26.5	26.1	26.7	134.2	67.4
October	26.7	31.5	26.6	27.0	27.6	27.2	144.4	132.6
November	24.2	30.7	24.9	25.5	27.8	26.7	166.5	252.6
December	22.2	30.1	23.4	24.1	26.3	25.7	175.3	303.7

3.3 Geomorphology

The study area itself represents a typical toposequence in the Zaria - Funtua area. The area is gently undulating. It is part of an extensive peneplain of northern Nigeria extending from Sokoto to Lake Chad and from south of Kaduna to Agades in the Niger Republic (McCurry, 1970). Occasionally, the peneplain is broken in places by ironstone capped mesas and inselbergs which are erosion remnants of older laterite sheets. The study area is drained by rivers Tubo and Galma which flow southwards into river Kaduna, (Fig. 3.2). These rivers have a common watershed that stretches east-west from Gimi and Makarfi to Funtua (Russ, 1959). Although the scale of available topographic map of the area is so small to show differences in elevation, physical observation reveals that the area is nearly flat or level to moderately sloping. From the crest, the land slopes westwards to river Kekaa and southwards to river Kekaa's tributary. The landscape is concavo-convex in profile. The upperslope is convex in shape and merges imperceptibly with an extensive concave slope that dips into the river valleys. An isolated ironstone ridge which measures approximately 6 m high and 30 to 50 m in diameter is found about 40 m east of the study area. This seems to be the remnant portion of the ironstone capped mesas that had survived the active weathering and erosion of the surrounding areas (Malgwi, 1979).

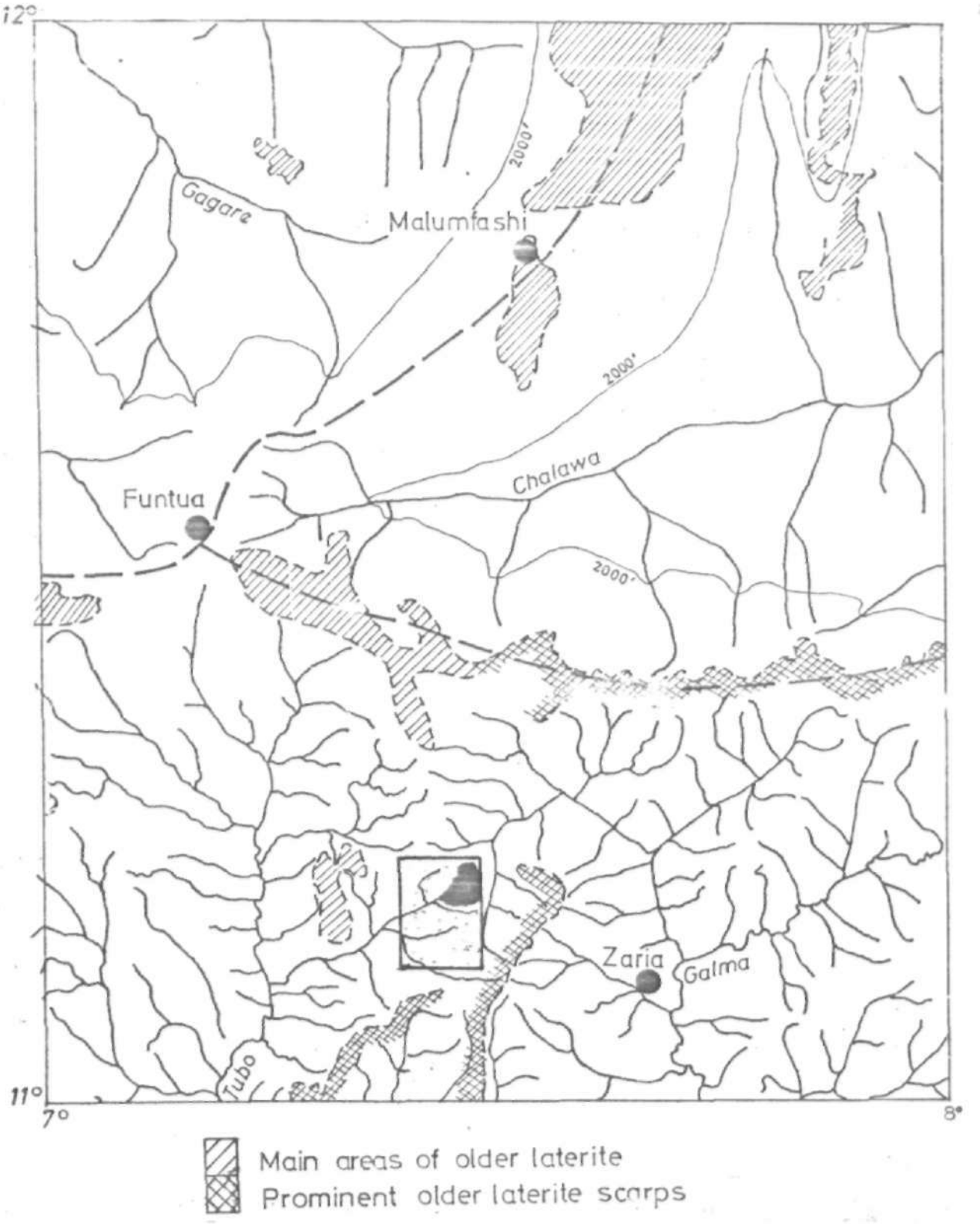


Fig. 3:2. Physical features of the Zaria area.

(Source: Mc curry, 6

Another striking feature of the area is the extensive work of sheet erosion, exposing ironstones in places, particularly in the upper and middle slopes. The sheet erosion advances into rill erosion in the middle slopes and gullies at lowerslope. The gullies are quite numerous and deep, some measuring up to 200 cm deep. The occurrence of these gullies could be explained by the rejuvenation of all rivers flowing south of the area as a result of an uplift along the watershed axis in the tertiary times (McCurry, 1970).

3.4 Geology

A walk through the study area reveals a myriad of rock types, the most frequent being granites, gneisses and schists (Higgins, 1961). These three rock types largely constitute the igneous-metamorphic complexes of the pre-Cambrian to early Palaeozoic age which are referred to as the Northern Nigerian Basement Complex because of their intricate pattern of occurrence (McCurry, 1970).

Granitic rocks cover most of the area as shown by the widespread occurrence of coarse granitic quartz and quartzite fragments in almost all the profiles, except in these at the lowerslope. Such quartz fragments contain small amounts of muscovite and are presumed to be resistant remnants of older granites which have been detached and reshaped during weathering and transportation (Higgins, 1961).

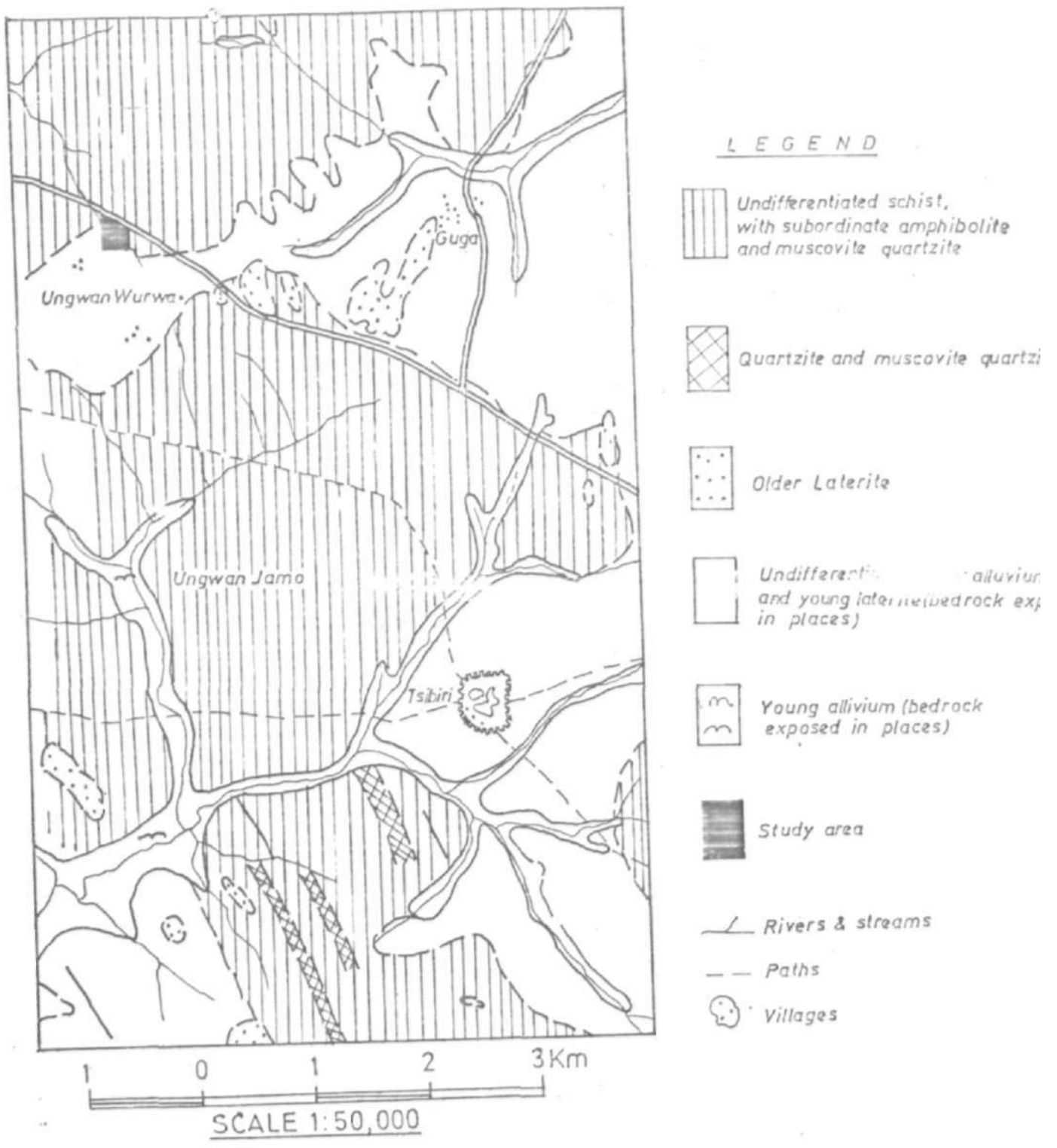


Fig.3:3: Geological map of the study area.

(Source: Mc Curry, 1968-9)

what could be referrred to as Young Laterites. They are believed to have been formed from the recementation of the Older Laterite transported from the crest and upperslope (Valette, 1973). Some of them could be formed in situ (Young, 1976).

3.5 Vegetation

The vegetation cover of the study area has been described by Keay (1952) as the Northern Guinea Savanna, a designation which implies a woodland vegetation type characterized by broad-leaved species reaching a height of 9 to 15 m and sometimes 20 m if left undisturbed. The Northern Guinea Savanna zone stretches from Kaima (Kwara State) in the west through Zaria and Kaduna (Kaduna State) to Jalingo (Gongola State) in the east (Higgins, 1961). Some common plant species found in the area are Isoberlinia doka, I. tomentosa and Uapaca togoensis with a well developed grass layer of tufted Andropogonae (Jackson, 1970). Wherever the vegetation is well developed, the crowns of the trees are more or less touching with sparce or less developed understorey of short shrubs and grasses. But where the canopy is disturbed, many grass species such as Andropogon spp, Hyparrhenia spp, Schizachyrium spp and Monocymbium spp are dominant.

It is worth mentioning here that the present day vegetation cover of the Savanna region is greatly influenced by human activities, namely farming, burning, tree felling and grazing (Keay, 1959; Ramsay, 1963). For this reason, a climax vegetation in the restricted sense of it does not exist anywhere in the Northern Guinea Savanna zone because much of the land is subject to annual burning and has at one time or another been under cultivation. The stable states are usually fire or cultivation climaxes or sub-and pseudo-climaxes respectively. The effects of periodic fires have been the elimination of fire-tender and the promotion of fire-tolerant species in the savanna woodland (Rackham and Innes, 1978). This accounts for the abundance of some of the following species. Isoberlinia dalzielii, Monotes kerstingii, Terminalia avicennioides, T. macroptera, Piliostigma thonningii, Combretum binderianum, Bridelia ferruginia and Vitex doniana. The common economic trees found in the area are shea-butter (Butyrospermum parkii) and the West Africa locust bean (Parkia clappertoniana). Mango (Mangifera indica) is also found but not very common.

.6 Land Use

The various land use practices in Northern Nigeria can be broadly grouped into two viz: crop production and livestock rearing (Rackham and Innes, 1978). In the study area, five main categories of land cultivation have been recognised by Prothero (1957) as follows:

(a) Land under permanent cultivation

(b) Land recently reverted to fallow after cultivation

(c) Fallow land of greater age

(d) Heavy bush, and

(e) "fadama" (Hausa, meaning seasonally waterlogged land).

These categories of land use are usually arranged in concentric zones around settlements. The areas immediately surrounding the settlement, extending up to a maximum distance of 1.5 km, are under - permanent cultivation. Croplands within this zone are manured by household wastes and sweepings from the settlements. These are transported by pack donkey and sometimes by lorry. Beyond the zone of intensive cultivation, soil fertility is maintained by bush fallowing of varying length. Lands are cleared and cultivated for three to five years and then left fallow for at least five years to regain its fertility. Such soil fertility recovery can be adduced from the size and diversity of the bush (Sanchez, 1974). The zone of heavy bush lies between 3.5 and 5 km outside the settlement. It is normally put under shifting cultivation mainly because land is abundant, and so can be left to fallow for thirty years or more . It is also a zone of intensive tree felling.

The "fadama" comprises the seasonally waterlogged depressions or lowlands which are more intensively cultivated than the "gona" (Hausa word for upland field). The "fadama" supports more labour intensive and higher value crops such as sugarcane and vegetables (Mortimore, 1970).

In general, a variety of crops are produced in the area. These include maize (Zea mays), millet (Pennisetum americanun), sorghum (Sorghum bicolor), cowpea (Vigna sinensis), groundnut (Arachis hypogaea), cassava (Manihot esculenta) and cotton (Gossypium spp) which are mainly grown in the upland fields under rainfed conditions. In the dry season, other crops such as onion (Allium cepa) tomatoes (Lycopersicum esculentum), cocoyam (Colocasia esculenta) and sugarcane (Saccharum officianarum) are grown on the "fadama". The lowlands are therefore being increasingly exploited for crop production at the expense of grazing (Mortimore, 1970).

The area also supports large numbers of cattle, sheep, and goats. These animals are reared by three categories of stock owners: The nomadic, semi-nomadic and the settled stockowners (Prothero, 1957). The nomadic and to some extent the semi-nomadic herds live in a state of "perpetual" wandering, moving southwards at the beginning of every dry season and "homeward" on the arrival of rains. In the early part of dry season the animals are fed on crop residues

4 MATERIALS AND METHOD

4.1 Field Studies

The rigid grid soil survey method was employed in the field studies to investigate the morphological characteristics of the soils of the area. The old Zaria-Funtua road which provides the northern boundary of the study area, and which runs at 290° east-west from the crest to river Kekaa, was taken as the baseline. Traverses were cut at right angles (200°) to the baseline, running southwards to the tributary of river Kekaa. In all there were 11 traverses at 100 m intervals.

Soil investigations were carried out by augering to a minimum depth of 100 cm unless where obstructed by impenetrable obstacles. There was no obstruction from the groundwater table anywhere on the field, even at 200 cm depth. The observation points were 100 m apart along the traverses. Auger samples were described at 10 - 20 cm depth intervals depending on soil colour and textural changes. Soil colour, texture, consistence and inclusions were described at each auger point. Wherever these properties differ between two consecutive points, additional augerings inbetween the two points were made to determine the proper soil boundaries.

A provisional soil map was prepared based on the above auger points investigations, and at least, two profile pits were sited in each of the 4 (four), identified soil units (Fig. 5.1). In all there were 11 profile pits. These pits were drug to a depth of 200 cm wherever there were no major obstacles. All the profile pits were described and soil samples were collected from the identified soil horizons into cloth cotton cloth bags, neatly labelled and taken to the laboratory for physical and chemical analyses.

The vegetation studies consisted of taking records of the arboreal species present in a stand of approximately 50 m radius round each profile pit and making a subjective assessment of the abundance of each species within the stand. This assessment was made on a three-point scale as follows:-

3 - abundant > 50 % areal coverage
2 - common 10 - 50 % coverage
1 - few < 10 % coverage

Laboratory studies

The soil samples were air-dried, ground using a mortar and pestle, and sieved through a 2 mm sieve. The particles retained on the sieve were weighed and the percentage weight recorded. They were then discarded as gravels. The fine earth fraction (< 2 mm) were stored in paper containers, neatly labelled and kept until needed for physical and chemical analyses. The samples were

4.2.6 Total nitrogen

Total N was analysed using the Kjeldhal procedure with some modifications (Bremner, 1965). Two grammes of the soil samples were mixed with 10 ml of distilled water inside a 500 ml Kjeldhal flask. Three grammes of Kjeldah, catalyst, 15 ml of concentrated H_2SO_4 and glass chips were added to the mixture. The content of the flask was heated for an hour to ensure a complete digestion.

The digested soil material was cooled, and 100 ml of distilled water, 75 ml of 10N NaOH and granular zinc were added to it. The mixture was then distilled into 50 ml of 2 percent H_3BO_3 and the distillate titrated against 0.05N H_2SO_4.

4.2.7 Available phosphorus

$HCl-H_2SO_4$ extracting solution was used in this analysis (Olsen and Dean, 1965). Five grammes of soil and 200 mg of charcoal were mixed in a 50 ml conical flask. Twenty millilitres of the extracting solution was added into the flask and the content shaken with a mechanical shaker for 6 minutes. The content of the flask was immediately filtered using Whatman No. 42 filter paper.

Four millilitres of the filtrate was taken into a glass tube and 1 ml of distilled H_2O and 1 ml of molybdate-vanadate solution were added to the tube. The solution was allowed to stand for 20 minutes before the available P was determined colorimetrically.

4.2.8 Total aluminium and iron

The analyses were carried out by first fusing or completely digesting the soil samples using anhydrous Na_2CO_3 (Kanehiro and Sherman, 1965). One gramme of soil and 5 g of Na_2CO_3 were used in the fusion process which resulted in the conversion of Al and Fe into soluble forms. Analysis for total Al and total Fe were carried out as described by Olsen (1965).

Eight millilitres of 60 percent perchloric acid were added to the fused soil sample and the content was heated gently over a hot electric plate. The content was allowed to cool and 5 ml of distilled H_2O and 2 ml of 6N HCl were added. It was quantitatively transferred into a 50 ml centrifuge tube and centrifuged at 1,800 revolutions per minute (rpm) to remove silica as a precipitate.

The supernatant solution was transferred into another 60-ml centrifuge tube. Three drops of bromocresol purple indicator were added and the solution was heated in a boiling water bath. Ammonium hydroxide was added to the tube to precipitate Fe and Al as hydroxides and the supernatant solution after centrifugation was discarded.

The precipitate contained Fe and Al hydroxides. Fe was removed as $Fe(OH)_3$ by dissolving the precipitate in hot HCl and adding NaOH. Reprecipitations were done to avoid occulsion and

5. RESULTS AND DISCUSSIONS

5.1 Soil Morphology

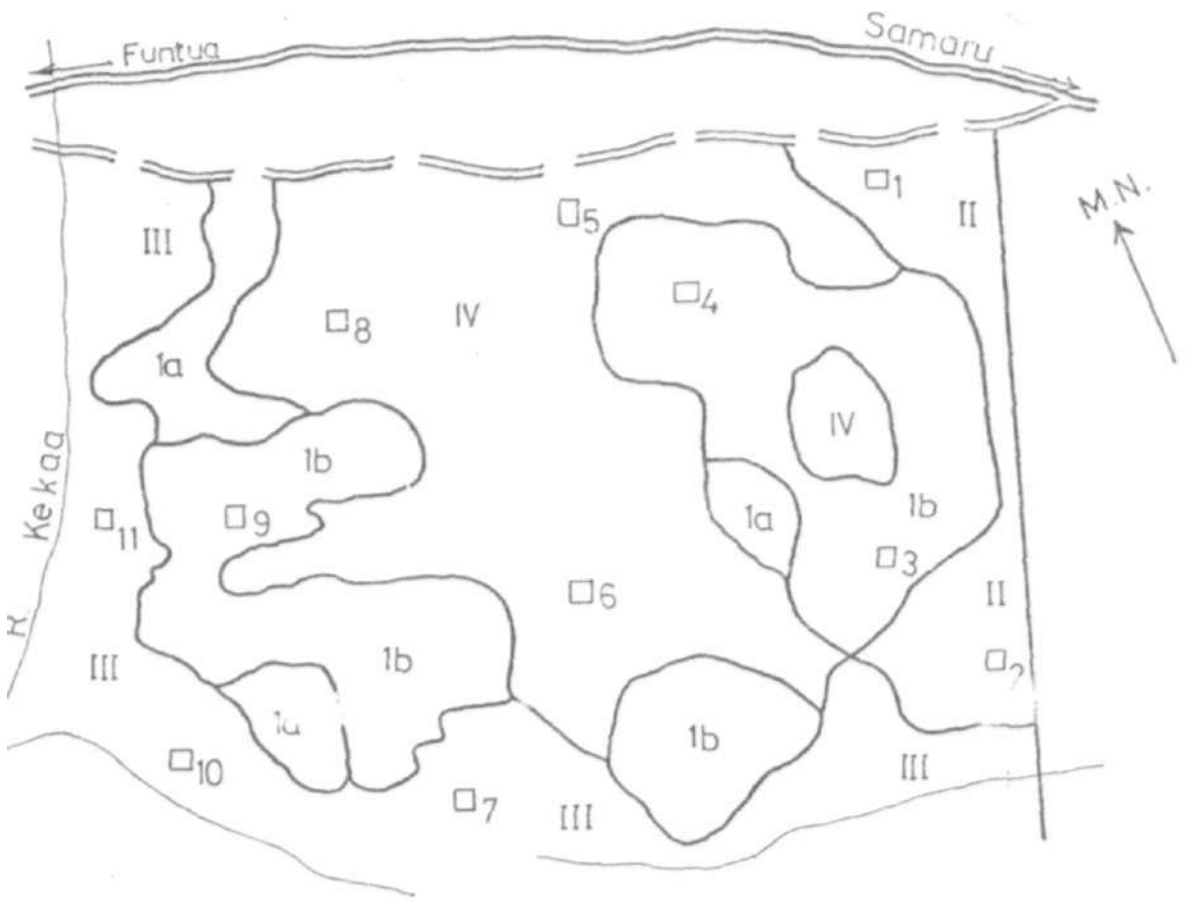
From the auger point investigations, the soils of the area were grouped into four mapping units based on their different morphological properties, namely depth, colour, texture and the nature of the underlying material. The spatial distribution of the four soil mapping units is shown in Fig. 5.1.

5.1.1 Soil mapping unit I

This unit covers about 20 percent of the study area and generally comprises shallow soils underlain by ironpan at varying depth. The depth to ironpan varies from zero(surface exposure) to 75cm. The soils of this unit occupy both the upper and lowerslopes.

The soil parent material consists essentially of aeolian drift sediments of variable thickness over ironpan. A distinguishing feature of this unit is the presence of concretionary gravel layer at the subsoil. The layer provides a lithological discontinuity within the profile since it consists of gravelly concretionary nodules overlying the solid ironpan.

The soils are well drained and the colours (moist) are brown (7.5YR 4/6) and yellowish red (5YR 4/6) at the surface and subsoil respectively.



g. 5.1: Soil map of the study area

Scale 1:8,000

Soil Legend

Units	Distinguishing characteristics
I	Shallow soils over iron pan
Ia	Soils < 10cm depth
Ib	Soils > 10cm depth
II	Soils over schist materials
III	Soils of Alluvial and/or Colluvial origin
IV	Very deep well drained reddish soils of the midslope
□	Profile pits

Bt	9 - 19	Yellowish red (5YR 4/8, moist) clay loam; strong medium subangular blocky structure; hard dry, firm moist, very sticky and very plastic wet; common medium and few coarse roots; few interstitial pores; clear smooth boundary.
BC	19 - 31	Yellowish red (5YR 5/8, moist) sandy clay loam; moderate coarse subangular blocky structure; hard dry, firm moist, very sticky and very plastic wet; common medium black and red iron concretions; cracked surfaces with few and distinct clay cutans, clear wavy boundary.
C	31 - 70	Strong brown (7.5YR 5/8, moist) gravelly sandy clay loam; masive tending towards weak subangular blocky structure: very hard dry, very firm moist very sticky and very plastic wet; few fine roots; many gravelly iron concretions.

5.1.2 Soil mapping unit II

Soils of this unit are the least extensive, covering about 10 percent of the study area. The soils are commonly found in all topographic positions stretching from the crest to the lowerslope. The most important distinguishing feature of this unit is that the soils are underlain by schist materials. These materials become very hard and impenetrable at varying depths along the landscape. The occurrence of coarse quartz fragments within the pedon is another important feature of this unit.

The soils are well drained with a dominant colour hue of 5YR. The soil texture is loam at the A horizons changing to clay loam and sandy clay loam at the B and C horizons respectively. Soil structure is subangular blocky in the subsoil. The description of the representative pedon is given below.

Profile No.	: 2
Classification	: Plinthustult/Plinthic Acrisol
Local relief/slope	: Lowerslope, gently sloping (2- 4 %)
Drainage	: Well drained
Erosion	: Very severe sheet erosion
Parent material	: Aeolian deposits over schist
Vegetation	: Grasses and shrubs.

Horizon	Depth (cm)	Description
A	0 - 6	Dark brown (7.5YR 4/4, moist)

loam; weak fine crumb tending towards weak medium to coarse subangular blocky structure; soft dry, very friable moist slightly sticky and non-plastic wet; common fine and few coarse roots; many tubular and vesicular pores; abrupt wavy boundary.

Bt1 6 - 23 Yellowish red (5YR 5/6, moist) clay loam; strong medium to coarse subangular blocky structure; hard dry, firm moist, very sticky and very plastic wet; common medium roots, many tubular and interstitial pores; gradual smooth boundary.

Bt2 23 - 65 Yellowish red (5YR 5/8, moist) clay loam; moderate medium subangular blocky structure; hard dry, very firm moist; very sticky and plastic wet; common medium to coarse roots; few indistinct clay cutans' common tubular pores, gradual smooth boundary.

BC	65 - 90	Yellowish red (5YR 5/8, moist) clay loam; moderate to strong medium subangular blocky structure; hard dry, firm moist very sticky and very plastic wet; few coarse roots; common tubular pores; few distinct clay cutans; few fine black iron concretions; gradual smooth boundary.
C1	90 - 110	Yellowish red (5YR 5/8, moist) clay loam; moderate medium subangular blocky structure; very hard dry, very firm moist very sticky and very plastic wet; common fine to medium iron concretions; clear smooth boundary.
C2	110 - 130	Yellowish red (5YR 5/8, moist) sandy clay loam; massive tending towards weak coarse subangular blocky structure; very hard dry very firm moist, very sticky and very plastic wet; many coarse iron concretions.

5.1.3 Soil mapping unit III

Soils of this unit cover about 40 percent of the study area. They are found in the lowerslopes close to the river channels. The soils are derived from alluvial and/or colluvial materials, and are characterized by the presence of buried horizons and fine sand lenses within the profile. They are very deep soils, (> 200 cm) but are poorly to very poorly drained. The presence of mottles right from the surface gives an indication that the soils are seasonally water logged. The texture is predominantly loam and clay loam while soil colour hue is 10YR. The structure is generally massive and there are very soft small and rounded black iron concretions. A detailed morphological description of a representative pedon is given below.

Profile No	:	7
Classification	:	Vertic Tropaquept/Dystric Gleysol
Local relief/slope	:	Valley floor, nearly level (0 - 2 %)
Drainage	:	Very poorly drained
Parent material	:	Alluvial deposit
Vegetation	:	Grasses, shrubs and scattered trees.

Horizon	Depth (cm)	Description
A	0 - 22	Light brown (7.5YR 6/4, moist) clay loam; few fine faint

reddish yellow (5YR 6/8) mottles confined to root channels; weak fine crumb tending to weak fine subangular blocky structure; very hard dry, very firm moist, very sticky and very plastic wet; many fine to medium roots; few tubular macropores and common vesicular micropores; diffuse smooth boundary.

AB 22 - 54 Reddish brown (5YR 5/4, moist) loam; common fine faint yellowish red (5YR 4/6) mottles; massive structure; very hard dry, firm moist, slightly sticky and slightly plastic wet; many fine to medium roots; many fine tubular pores; abrupt irregular boundary.

2A 54 - 74 Greyish brown (10YR 5/2, moist) clay loam; many medium to coarse distinct yellowish red (5YR 4/8) mottles; moderate medium to coarse subangular blocky structure; hard dry, very firm moist very sticky and very plastic wet; common fine roots;

	few tubular macropores and many fine tubular micropores; clear smooth boundary.
2AB 74 - 97	Grayish brown (10YR 5/2, moist) loam; common fine faint yellowish red (5YR 5/8) mottles; massive structure tending to weak coarse subangular blocky structure; hard dry, firm moist, sticky and plastic wet; few fine roots; few vesicular macropores and many fine tubular micropores; abrupt smooth boundary.
2C1 97 - 121	Brownish yellow (10YR 6/6, moist) loam; common coarse faint strong brown (7.5YR 5/8) mottles, massive structure; hard dry, firm moist, slightly sticky and slightly plastic wet; few fine roots; few macropores, many fine tubular micropores; diffuse smooth boundary.
2C2 121 - 200	Yellowish brown (10YR 5/6, moist) loam; many coarse faint strong brown (7.5YR 5/8) mottles; massive

structure, hard dry, friable moist, non-sticky and non-plastic wet; few fine and medium roots; many medium tubular pores.

5.1.4 Soil mapping unit IV

Soils of this unit are generally very deep (> 200 cm) and well drained. They are not underlain by ironpan and schist materials and are neither of alluvial nor colluvial origin. The soil parent material is made up of aeolian materials deposited on very deeply weathered granitic-gneissic complex rocks. The soils predominantly occupy the middleslope position and constitute about 30 percent of the study area. The soil structure is weak at the surface, well developed at depth, but becomes massive at greater depth. The surface soil colour is brown (7.5YR 4/3, moist), but changes to yellowish red (5YR 5/8) and red (2.5YR 5/8) with depth. The soil texture is loam in the A horizons and clay loam in the underlying B horizons. The morphological description of a representative pedon is given below.

Profile No	: 8
Classification	: Ultic Haplustalf/Chromic Luvisol
Local relief/slope	: Middleslope, nearly level (0 - 2 %)
Drainage	: Well drained
Parent material	: Aeolian deposits over granites, gneisses.

Vegetation : Grasses, shrubs and scattered trees.

Horizon	Depth (cm)	Description
A	0 - 12	Brown (7.5YR 4/3, moist) loam; weak coarse subangular blocky structure; soft dry, friable moist slightly sticky and non-plastic wet; many fine roots; common tubular macropores; abrupt wavy boundary.
AB	12 - 26	Yellowish red (5YR 5/8, moist) loam; weak coarse subangular blocky structure; soft dry, very friable moist, slightly sticky and non-plastic wet; common fine and few medium roots, many vesicular macropores and few tubular micropores; gradual smooth boundary.
Bt1	26 - 40	Yellowish red (5YR 5/8, moist) clay loam; moderate medium subangular blocky structure; hard dry, firm moist, sticky and slightly plastic wet; many medium to coarse roots; gradual smooth boundary.

Bt2	40 - 72	Red (2.5YR 6/8, moist) clay loam; strong medium to coarse subangular blocky structure; hard dry, firm moist very sticky and very plastic wet; few medium roots, few indistinct clay cutans; gradual smooth boundary.
Bt3	72 - 117	Red (2.5YR 5/8, moist) clay loam; strong coarse subangular blocky structures; hard, dry very firm moist, very sticky and very plastic wet; few medium roots; common distinct clay cutans; gradual smooth boundary.
C1	117 - 135	Red (2.5YR 5/8, moist) clay loam; massive tending towards coarse subangular blocky structure; hard dry, firm moist sticky and plastic wet; few soft reddish brown (2.5YR 5/4, dry) iron concretions; gradual smooth boundary.
C2	135 - 200	Red (2.5YR 5/8, moist), loam; massive structure; very hard dry, firm moist, sticky and

plastic wet; many soft reddish brown (2.5YR 5/4, dry) iron concretions.

5.2 Soil Physical Properties

5.2.1 Soil particle size distribution

The data in Table 5.1 indicate that all the soils of the study area are gravel-free in the A and B horizons. However, soils of mapping units I and II are characterized by concretionary gravel layers at the subsoil, directly overlying consolidated impenetrable layers. These gravels are mainly iron oxide nodules or regoliths of laterite ironstone and quartz. They represent the old peneplain remnants upon which aeolian materials have been deposited to form the existing parent materials of the soils (Mohr et al., 1972; Jones and Wild, 1975; Malgwi, 1979). These ironstones are presumed to have been weathered in situ at the crest and upperslope and later formed downslope from recementation of transported iron oxide from Older Laterites (Mohr et al., 1972; Young, 1976).

Total sand fractions remain very high (44 - 60 percent) in the A horizons for all the soil units except unit III which has only 26 percent. The high sand content is characteristic of most savanna soils and is mainly due to the nature of the parent materials,

type of weathering and the downward translocation of clay (Higgins, 1961; Ahn, 1970; Valette, 1973). The general tendency among the soils is a decrease in the sand content with depth. The only exception is soil mapping unit III where there is a progressive increase in sand content with depth. For example, the total sand content increases with depth from 26 to 50 percent and from 26 to 58 percent in pedons 7 and 11 respectively (Table 5.1). This "unusual" phenomenon results from the differential rate of settlement of materials brought down from the upperslope by fluvial processes operating on the slope, into the depression (lowerslope). Coarse materials like gravels settle first, followed by sand, silt and clay in that order. It is pertinent to point out here that the preponderance of the fine sand fraction to coarse sand fraction among the "fadama" soils results from the high content of fine sand lenses brought down by water. In the case of the upland soils (units I, II and IV) the fine sand to coarse sand ratio is not so high probably because of lower rate of weathering.

The silt content is generally high, in the order of 22 to 44 percent in all the pedons. This finding is contrary to the observation that tropical soils have less than 15 percent silt content (Young, 1976). The high silt content may be attributed to the harmattan dust deposited on the soil. This view is

Table 5.1 Particle size distribution of selected pedons

SOIL UNIT I

Pedon 4 Plinthustults/Plinthic Acrisol

Horizon	depth	gravel (%) (>2 mm)	coarse sand (.2-2m)	fine sand (.02-.2)	total sand (.02-.2)	silt (.002-.02)	clay (<.002)
A	0 - 8	-	4.8	43.2	48	42	10
AB	8 - 17	-	3.6	38.4	42	30	28
Bt1	17 - 26	-	3.4	34.6	38	32	30
Bt2	26 - 42	-	2.4	37.6	40	28	32
C	42 - 75	60	5.6	34.4	40	32	28

Pedon 9 Plinthustults/Plinthic Acrisol

A	0 - 9	-	5.4	46.6	56	34	10
Bt	9 - 19	-	5.4	34.6	40	30	30
BC	19 - 31	-	6.4	33.6	40	34	26
C	31 - 70	62	8.2	35.8	44	30	26

Soil unit II

Pedon 1 Typic Ustorthents/Dystric Regosols

A	0 - 10	-	10.6	49.4	60	32	8
BC	10 - 28	-	7.2	40.8	48	28	24
C	28 - 70	-	13.6	36.4	50	26	24

Horizon	depth	gravel	coarse sand	fine sand	total sand	silt	clay
		Pedon 2	Plinthustults/Plinthic Acrisol				
A	0 - 6	-	5.2	38.8	44	38	18
Bt1	6 - 23	-	2.4	29.6	32	36	32
Bt2	23 - 65	-	2.0	30.0	32	30	38
BC	65 - 90	-	4.2	35.8	40	32	28
C1	90 - 110	-	4.0	34.0	38	34	28
C2	110 - 130	-	5.8	34.2	40	34	26
		Soil unit III					
		Pedon 7	Vertic Tropaquept/Dystric Gleysol				
A	0 - 22	-	0.2	25.8	26	36	38
AB	22 - 54	-	0.2	29.8	30	34	36
2A	54 - 74	-	0.2	25.8	26	34	40
2AB	74 - 97	-	4.0	36.0	40	44	16
2C1	97 - 121	-	6.4	41.6	48	38	14
2C2	121 -200	-	3.0	47.0	50	36	14
		Pedon 11	Vertic Tropaquept/Dystric Gleysol				
A	0 - 28	-	0.6	25.4	26	30	44
AB	28 - 39	-	0.2	27.8	28	36	36
Bt	39 - 70	-	0.2	23.8	24	32	44
C1	70 - 101	-	0.4	35.6	36	44	20
C2	101 - 128	-	6.8	41.2	48	38	14
C3	128 - 200	-	8.6	59.4	68	22	10

Soil unit IV

Horizon	depth	gravel	coarse sand	fine sand	total sand	silt	clay
			Pedon 6 Ultic Paleustalf/Dystric Nitosol				
A	0 - 15	-	4.5	44.5	49	40	11
AB	15 - 28	-	3.2	43.8	47	34	19
Bt	28 - 38	-	4.0	44.0	48	30	22
BC1	38 - 75	-	1.5	38.5	40	30	30
Bt2	75 - 130	-	2.0	28.0	30	38	32
C	130 - 200	-	4.2	33.8	38	35	27
			Pedon 8 Ultic Haplustalf/Chromic Luvisol				
A	0 - 12	-	4.8	43.2	48	42	10
AB	12-- 26	-	4.4	43.6	48	36	16
Bt1	26 - 40	-	4.0	36.0	40	36	24
Bt2	40 - 72	-	.6	37.4	38	30	32
Bt3	72 -117	-	2.2	37.8	40	30	30
C1	117 -135	-	2.6	29.4	32	40	28
C2	135 -200	-	3.2	36.8	40	34	26

strongly supported by the distribution of the silt in the profile whereby topsoils tend to have higher silt content than the subsoils. The high silt content of soils of unit III can also be attributed to the silt size particles deposited during the rainy season.

The clay content is generally low (8 to 10 percent) in the A horizons and increases to a maximum in the B horizons in soils of units I, II and IV. On the contrary, soils of unit III show a clay content that decreases irregularly with depth, for example, from 44 percent to 10 percent in pedon 11. The low clay content of upland soils (pedons 1 and 4) and the high clay content of the "fadama" soils (pedon 11) might have resulted from lateral clay translocation. The clay materials from the crest and upperslope were removed and deposited on the lowerslope by surface wash, as shown by the high surface clay content of the lowerslope pedons.

.2.2 Soil structure

Generally speaking, three groups of soil structures are recognised in the study area. These are:

(a) weak fine crumbs, characterizing the A horizons of some pedons,

(b) moderate to strong subangular blocky types, characteristics of the B horizons of most pedons and

(c) massive structures commonly observed in the horizons of most pedons and in the A horizons of the "fadama" soils.

The spatial distribution of these three structural groups among the soil units of the area are due mainly to the following reasons:-

(a) amount and distribution of clay within the profile

(b) organic matter level of the soils

(c) free iron and aluminium oxides content of the soils

(d) position and seasonal fluctuation of the groundwater table, and

(e) presence of high amount of sodium.

The A horizons of soil units, I, II and IV have predmoninantly weak fine crumbs to weak coarse subangular blocky structures because of their low clay content. By virtue of its small size and large surface area, clay is the most active mineral fraction of the soil components. It aids aggregation of

primary soil particles and ensures the stability of such aggregates. This is the reason behind the good structural development of the B horizons with higher clay content compared with the A horizons.

The desirable effects of organic matter in the formation of soil granules and in stabilizing soil aggregates have been reported by Brady (1974), Jones and Wild (1975), and Young (1976). In addition plant roots and root exudates help to bind soil particles together. The poor structural development of the soils could therefore be a consequence of the low contents of organic matter among the soils of the area.

Almost all the soils in units, I, II and IV have strong, medium to coarse subangular blocky structures in their B horizons. The reason for this could be found in the corresponding increase in the iron and aluminium oxides contents of the subsoils. The presence of high amounts of free iron oxides has also been linked with soils structural development of the B horizons (Jones and Wild, 1975). Aluminium oxides on the other hand is said to form interlayers with clay minerals and probably act as bonding cement in holding soil particles together (Taylor, 1972).

The massive structures at the lower parts of the subsoils are due to the weight of the overlying horizons, as well as the presence of concretionary gravels. Among the "fadama" soils such massive structures result from the high sand content coupled with the effect of the overlying weight. The A horizons of these "fadama" soils, although rich in clay, have poorly developed structures because of the high water table and its seasonal fluctuation. Water has a marked effect on soil aggregates. When soil crumbs are wet, they easily break apart especially when the wetting forces exceed those forces that tend to bind the particles together (Taylor, 1972). The poor structure could also be due to the high silt content and probably the high amount of sodium which encourages dispersion of soil aggregates.

.3 Soil colour

Soil units I, II and IV are similar in terms of soil colour. They predominantly have brown (7.5YR 4/6, moist) A horizons overlying yellowish red (5YR 4/8 and 5/8, moist) B horizons. In soil unit IV the above layers overlie well developed red (2.5YR 4/8 and 5/8, moist) C horizons, which contain soft red iron concretions.

Soils of unit III are very poorly drained and mottled right from the surface horizons. The soil matrix colour consists of a brown (7.5YR 6/4, moist) A horizon overlying reddish brown (5YR 5/4) and greyish brown (10YR 5/2) subsoils. The underlying C horizons are brownish yellow (10YR 6/6) and yellowish brown (10YR 5/6). Mottles are reddish yellow (5YR 6/8) in the A horizons and yellowish red (5YR 4/6) in the B horizons, while the C horizons have strong brown (7.5YR 5/8) mottles.

The brown (7.5YR 4/6) surface horizons are due to the presenee of organic matter which is the main colouring agent in the topsoil (Nuhu, 1983). The colour is very light because of the low organic matter levels associated with most tropical soils and their non-humified nature. The yellowish red (5YR 5/8) to red (2.5YR 4/6) subsoil colours may be due to the presence of unhydrated iron oxide probably haematite (Ibanga, 1980). The well developed red colour of the C horizons of soil unit IV signified a relatively old or intensively weathered soil over a considerable period of time (Nuhu, 1983). The fact that unhydrated iron oxide is unstable under moist or saturated conditions accounts for the total disappearance of the red colour in soils of unit III which are very poorly drained. The predominantly yellow matrix colour of soil unit III is due to the hydration of the free iron oxides. The yellowish red

mottles result from the seasonal fluctuation of the groundwater table. Such mottles are mainly confined to root channels because of the oxidizing effect of oxygen which enters the channels as soon as the watertable recedes.

5.3 Soil Chemical Properties

5.3.1 Soil reaction

Soil reaction is one of the outstanding physiological characteristics of the soil solution. It is measured in terms of the activity of the H^+ ion concentration expressed by the term pH. The reaction could be in acid range (pH 1 to 6.5), in neutral range (pH 6.5 to 7.5) or in alkaline range (pH 7.5 to 14). Soil reaction so markedly affects crops and soil micro-organisms that it usually tops the lists of questions that come to the mind wherever poor crop performances are observed in the field. With the exception of the fungi whose population and activities remain more or less constant throughout any range of soil reactions (from acidity, through neutrality to alkalinity), the population and activities of all other soil organisms (plants and animals) as well as the chemical constituents of the soil solution vary with different conditions of soil reaction (Brady, 1974). Most plants, for instance, thrive very well only under moderately acid to slightly alkaline (pH 5.5 to 8.5) soil reactions (Foth, 1972).

Table 5.2 shows that soils of the area are moderately to weakly acid (pH 5.56 to 6.30) in the surface horizons. These relatively high pH values for savanna soils have been reported by other workers notably Jones and Wild (1975), Malgwi (1979) and Agbu (1982). Jones and Wild (1975) advanced some reasons for the relatively unexpected high pH values for most West African Savanna soils. These include

(a) the return of bases to the surface by the pumping effect of the vegetation,

(b) the effect of burning

(c) the restriction on leaching of bases imposed by the low anion content of the soil solution

(d) the low content of humus.

(e) low net rate of removal of bases by cropping because of low yields and the return to the soil of much of the crop residue,

(f) the very small and non-intensive use of ammonium fertilizers and urea, and

(g) the absence of industrial pollution by acidic gases.

With all these in mind, it can be safely asserted that soil pH <u>per se</u> does not pose a major problem to natural vegetation growth in the Northern Guinea Savanna ecosystem.

Table 5.2 Chemical characteristics of selected pedons

Soil unit I

Horizon	Depth (cm)	pH H_2O	pH $CaCl_2$	Org. C %	Total N %	Avail. P Pm	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	Total Bases (meq/100g)	CEC (meq/100g)	B.S (%)	Fe (%)	Al (%)
						Pedon 4			Plinthustults/Plinthic Acrisol						
A	0 - 8	5.65	4.84	0.99	0.05	3.86	1.45	0.64	0.10	0.06	2.24	9.40	31	1.30	0.80
AB	8 - 17	5.00	4.28	0.68	0.04	2.06	1.90	1.30	0.11	0.07	3.37	10.60	32	1.80	1.10
Bt1	17 - 26	4.90	4.20	0.46	0.03	1.45	1.65	1.32	0.12	0.06	3.15	11.20	28	2.75	1.60
Bt2	26 - 42	4.90	4.24	0.40	0.02	2.22	1.32	1.12	0.02	0.07	2.62	11.00	24	3.10	1.40
C	42 - 75	4.92	4.36	0.40	0.03	1.78	1.20	1.11	0.16	0.07	2.51	8.45	30	5.25	0.90
						Pedon 9 - Plinthustults/Plinthic Acrisol									
A	1 - 9	5.56	4.65	0.84	0.04	3.25	1.75	1.02	0.07	0.06	2.90	8.35	34	1.10	0.95
Bt	9 - 19	5.40	4.60	0.55	0.04	2.84	1.96	1.34	0.19	0.09	3.58	10.60	33	1.68	1.36
BC	19 - 31	5.38	4.50	0.35	0.03	2.15	1.34	1.36	0.19	0.07	2.96	10.60	28	2.60	1.68
C	31 - 70	5.40	4.54	0.21	0.02	2.35	1.70	1.08	0.19	0.07	3.04	9.72	31	4.56	1.00

Soil unit II

Horizon	Depth	pH H_2O	pH $CaCl_2$	Org. C (%)	Total N (%)	Avail. P (Ppm)	Exch. Ca	Bases (meq/100 g) Mg	K	Na	Total bases	CEC (meq/100g)	B.S. (%)	Fe (%)	Al (%)
					Pedon 1 -		Typic ustorthents/Dystric Regosols								
A	0 - 10	5.54	4.90	0.86	0.05	2.41	1.52	0.74	0.14	0.05	2.45	7.46	33	1.25	0.94
BC	10 - 28	5.10	4.20	0.65	0.04	1.96	1.78	0.70	0.24	0.06	2.78	10.93	25	2.20	1.60
C	28 - 70	5.06	4.20	0.35	0.04	2.65	1.25	0.98	0.48	0.06	2.77	8.64	32	2.40	1.89
					Pedon 2	-	Plinthustult/Plinthic Acrisol								
A	0 - 6	5.56	4.78	0.95	0.06	1.97	1.76	1.26	0.18	0.07	3.27	8.96	36	0.95	0.78
Bt1	6 - 23	5.10	4.35	0.58	0.03	2.04	1.84	1.65	0.17	0.07	3.73	11.83	31	1.20	1.42
Bt2	23 - 65	5.10	4.33	0.44	0.02	1.18	1.35	2.06	0.25	0.07	3.85	12.00	31	1.64	1.89
BC	65 - 90	5.07	4.22	0.32	0.02	0.83	0.90	1.37	0.44	0.07	2.78	12.64	24	2.10	2.00
C1	90 - 110	4.68	4.17	0.30	0.02	0.63	0.90	1.03	0.37	0.08	2.38	8.88	27	2.20	1.26
C2	110 - 130	4.88	4.26	0.25	0.02	0.33	1.46	1.37	0.54	0.09	3.46	8.84	39	1.96	1.48

Soil unit III

Horizon	Depth	pH		Org. C	Total N	Avail. P	Exch. Bases (meq/100 g)				Total bases	CEC (meq/100g)	B.S. (%)	Fe (%)	Al (%)
		H_2O	$CaCl_2$	(%)	(%)	(Ppm)	Ca	Mg	K	Na					
						Pedon 7 - Vertic Tropaquept/Dystric Gleysol									
A	0 - 22	6.05	5.26	1.17	0.13	1.28	3.87	2.50	0.25	0.10	6.72	16.00	42	1.56	2.40
AB	22 - 54	6.10	5.28	0.76	0.08	1.40	4.12	2.39	0.20	0.08	6.79	14.60	47	1.30	2.05
2A	54 - 74	6.00	5.21	0.56	0.06	1.46	3.09	1.84	0.15	0.07	5.15	14.90	35	0.98	1.00
2AB	74 - 97	6.00	5.22	0.54	0.04	1.18	2.35	1.18	0.12	0.06	5.71	11.00	34	1.00	0.75
2C1	97 - 121	5.95	5.16	0.45	0.01	0.06	1.55	1.17	0.12	0.07	2.91	8.71	33	1.10	0.74
2C2	121 - 200	5.80	5.17	0.31	-	1.26	1.74	1.08	0.10	0.08	3.00	8.32	36	1.20	0.68
						Pedon 11 - Vertic Tropaquept/Dystric Gleysol									
A	0 - 28	6.10	5.28	2.31	0.15	1.70	6.49	2.30	0.44	0.15	9.37	19.82	47	1.40	1.88
AB	28 - 39	6.25	5.25	0.85	0.08	0.67	4.56	1.91	0.23	0 11	6.80	13.80	49	1.10	2.00
Bt	39 - 70	6.05	5.19	0.83	0.06	0.33	4.24	1.99	0.46	0.13	6.81	15.60	44	1.00	1.10
C1	70 - 101	6.01	5.21	0.44	0.02	0.50	1.80	1.07	0.16	0.10	3.13	10.60	30	0.85	0.84
C2	101 - 128	6.00	5.19	0.36	0.02	1.09	2.08	1.10	0.12	0.06	3.36	9.20	37	1.50	0.60
C3	128 - 200	5.90	5.01	0.30	0.10	2.63	1.37	1.04	0.06	0.06	2.54	6.30	40	2.00	0.40

Soil unit III

Horizon	Depth	pH		Org. C	Total N	Avail. P	Exch. Bases (meq/100 g)				Total bases	CEC (meq/100g)	B.S.	Fe	Al
		H_2O	$CaCl_2$	(%)	(%)	(Ppm)	Ca	Mg	K	Na			(%)	(%)	(%)
Pedon 7 - Vertic Tropaquept/Dystric Gleysol															
A	0 - 22	6.05	5.26	1.17	0.13	1.28	3.87	2.50	0.25	0.10	6.72	16.00	42	1.56	2.40
AB	22 - 54	6.10	5.28	0.76	0.08	1.40	4.12	2.39	0.20	0.08	6.79	14.60	47	1.30	2.05
2A	54 - 74	6.00	5.21	0.56	0.06	1.46	3.09	1.84	0.15	0.07	5.15	14.90	35	0.98	1.00
2AB	74 - 97	6.00	5.22	0.54	0.04	1.18	2.35	1.10	0.12	0.06	5.71	11.00	34	1.00	0.75
2C1	97 - 121	5.95	5.16	0.45	0.01	0.06	1.55	1.17	0.12	0.07	2.91	8.71	33	1.10	0.74
2C2	121 - 200	5.80	5.17	0.31	-	1.26	1.74	1.08	0.10	0.08	3.00	8.32	36	1.20	0.68
Pedon 11 - Vertic Tropaquept/Dystric Gleysol															
A	0 - 28	6.10	5.28	2.31	0.15	1.70	6.49	2.30	0.44	0.15	9.37	19.82	47	1.40	1.88
AB	28 - 39	6.25	5.25	0.85	0.08	0.67	4.56	1.91	0.23	0.11	6.80	13.80	49	1.10	2.00
Bt	39 - 70	6.05	5.19	0.83	0.06	0.33	4.24	1.99	0.46	0.13	6.81	15.60	44	1.00	1.10
C1	70 - 101	6.01	5.21	0.44	0.02	0.50	1.80	1.07	0.16	0.10	3.13	10.60	30	0.85	0.84
C2	101 - 128	6.00	5.19	0.36	0.02	1.09	2.08	1.10	0.12	0.06	3.36	9.20	37	1.50	0.60
C3	128 - 200	5.90	5.01	0.30	0.10	2.68	1.37	1.04	0.06	0.06	2.54	6.30	40	2.00	0.40

Soil unit IV

Horizon	Depth	pH		Org. C	Total N	Avail. P	Exch. Bases (meq/100 g)				Total bases	CEC	B.S	Fe	Al
		H_2O	$CaCl_2$	(%)	(%)	(Ppm)	Ca	Mg	K	Na		(meq/100g)	(%)	(%)	(%)
						Pedon 6 - Ultic Paleustalf/Dystric Nitosol									
A	0 - 15	6.15	5.30	1.00	0.06	4.95	1.95	1.18	0.15	0.05	3.30	6.00	55	1.00	0.68
AB	15 - 28	5.20	4.60	0.58	0.04	2.00	1.88	1.16	0.14	0.08	3.28	8.00	41	2.15	0.78
B1	28 - 38	5.10	4.59	0.40	0.03	0.85	1.95	1.75	0.22	0.06	3.99	10.50	38	2.85	1.00
Bt1	38 - 75	5.15	4.60	0.35	0.03	0.35	2.38	1.17	0.24	0.06	4.86	10.80	45	3.40	1.89
Bt2	75 - 130	5.17	4.62	0.28	0.03	0.33	3.12	2.30	0.21	0.06	5.50	11.00	50	4.32	1.66
C	130 - 200	5.19	4.62	0.25	0.01	0.30	2.22	1.66	0.22	0.07	4.16	8.00	52	4.50	1.34
						Pedon 8 - Ultic Haplustalf/Chromic Luvisol									
A	0 - 12	6.30	5.64	0.96	0.06	4.79	1.82	1.07	0.13	0.05	3.07	5.80	53	0.93	0.64
AB	12 - 26	5.38	4.78	0.58	0.04	1.35	1.35	1.15	0.10	0.07	2.68	7.30	37	1.24	0.86
Bt1	26 - 40	5.30	4.68	0.40	0.03	1.52	1.65	0.15	0.06	3.32	3.32	10.35	32	2.60	1.08
Bt2	40 - 72	5.28	4.68	0.36	0.03	0.33	2.10	2.12	0.24	0.03	4.55	11.20	40	3.20	1.98
Bt3	72 - 117	5.30	4.70	0.28	0.02	0.33	1.95	2.46	0.26	0.08	4.75	9.30	51	4.60	1.56
C1	117 - 135	5.32	4.71	0.20	0.02	0.33	2.05	2.45	0.23	0.07	4.80	9.80	49	4.60	1.43
C2	135 - 200	5.32	4.72	0.21	0.01	0.33	1.75	2.47	0.20	0.07	4.98	9.00	50	5.00	1.34

Another characteristic feature of the soils is the progressive decrease in soil pH with depth. This decrease in pH with depth could be due to the pumping effect of the vegetation, whereby plants remove nutrients from the root zone and build up their tissues, leaves, seeds and so on. When such plants die and decompose the various elements which have been used to build up the plant tissues are liberated again. Since the surface horizons provide the immediate recipients of the aerial parts of plants (seeds, stems, leaves and branches) and the zone of most tremendous activities of soil organisms, they usually have higher contents of these released plant nutrients than the subsoils. This results in higher pH values for the surface soils.

The pH value for the "fadama" soils, unit III (5.80 - 6.10) are higher than those for units I and II (4.68 - 5.65) probably because of lateral translocation of soluble plant nutrients from the crest and upperslope to the floodplain. The consequences of this translocation are that soils of the crest and upperslopes have less content of soluble nutrients than those of the valley floor. These are reflected in their pH values. The high pH values of the "fadama" soils are also enhanced by the high water table which may impose a restriction on the leaching of bases. On the other hand soils of unit III have slightly less pH values (6.05) than those of unit IV (6.30) probably because of their higher organic matter content.

5.3.2 Soil organic carbon

Soil organic matter can be represented as percent organic carbon or it can be expressed as total organic matter by use of a multiplication factor 1.724, being based on the assumption that soil organic matter contains about 58 percent organic carbon (Hesse, 1971). Results, in Table 5.2 show that the organic carbon contents of the topsoils vary from 0,76 to 2.31 percent and that these decrease gradually down the profile. There are no significant differences in the percentage organic carbon contents between soil units I, II and IV (0.76 to 0.99 %). However, the percentage organic carbon content of soil unit III (1.17 to 2.31) is considerably higher than those of the other three units.

In general terms, the results show a relatively low organic carbon content when compared with soils of the southern forest zones in Nigeria (Ahn, 1970). However, unlike the forest soils there is no sharp decline in the organic carbon content with depth in the study area. This agrees with the findings of Ahn (1970) and Brady (1974). Among the reasons advanced for the low organic carbon content of the soils are native vegetation cover, climate, and human interference.

The major sources of soil organic matter are the organic residues of plant and animal origin. The population, growth and activities of these plants and animals are in turn influenced by the climatic factors of rainfall and temperature. Whereas temperatures in the Northern Guinea Savanna ecosystem are more than adequate for vigorous vegetation growth throughout the year, rainfall is a limiting factor in total biomass production. This results in poor native vegetative growth and, therefore, low amounts of plant residues added to the soil annually. Moreover, the scanty rainfall limits the population and activities of soil fauna to the barest minimum. For instance, earthworm casts which are indicative of earthworm population and activities are very few in these soils.

Organic matter accumulation is favoured in areas of high rainfall, low temperatures, luxuriant native grass vegetation or poor drainage. The rate of organic matter decay is the key to organic matter accumulation. For example, tundra soils are known to accumulate a layer of organic matter even though total plant production is minimal because decay proceeds very slowly due to low temperatures. On the other hand the high temperatures of the tropical savanna environments help to increase the rate of decomposition of organic residues such that no appreciable amount of organic matter accumulates even on the topsoils. The seasonal variation in soil temperatures and moisture

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regime also contribute to the high rate of organic matter decay. This is because, when a soil or any other system for that matter is kept under a fairly constant condition, its biological activity and the stabilization of its organic substances operate efficiently and the net mineralization seems to decline to a low level. However, if the current state is interrupted by unfavourable conditions, and thereafter re-established, a stimulation of biological activity often follows (Campbell, 1978).

In addition to the above factors, the effect of human activities, burning and animal grazing, contribute to the low organic matter content of savanna soils. Most of the above ground parts of savanna grasses are eaten by grazing animals or burnt off when the grasses die back, and do not decay to humus (Ahn, 1970), hence the low organic matter content of the soils. The relatively higher organic carbon contents of the "fadama" soils are due to the exuberant vegetation and the slow rate of decay caused by waterlogging.

4.3 Soil nitrogen and phosphorus

The amount and distribution of soil nitrogen and phosphorus correlate very positively with the amount and distribution of soil organic carbon, an indication that organic carbon exists in fixed ratios with nitrogen and phosphorus. It is said that

organic matter accounts for 90 to 98 percent and 60 to 75 percent of soil nigrogen and phosphorus respectively (Kononova et al., 1966). Soil nigrogen and phosphorus are low corresponding to the low organic carbon content. Their values in the surface soils range from 0.04 to 0.15 percent for total N and 1.28 to 4.79 ppm for available P. These amounts decrease with depth in most pedons except in pedon 9 (Soil unit I?) where the available P is more or less uniform irrespective of depth.

From the established relationship between soil organic carbon, N and P, it is obvious that climate, vegetation and human activities contribute to the low levels of N and P. The low content of these elements is further confirmed by the high C:N:P ratio (Ahn, 1970; Brady, 1974; Jones and Wild, 1975).

In the case of soil N, the problem is compounded by the low population and activities of soil bacteria (both symbiotic and non-symbiotic N-fixing bacteria) which constitute a major source of soil N. Although leguminous grasses and shrubs abound almost everywhere in the Northern Guinea Savanna, they do not often support many N-fixing bacteria (Jones and Wild, 1975). This finding could be due to the host specificity of most symbiotic N-fixers (Lie et al., 1969). Moreover, most N-fixers (symbiotic and non-symbiotic) are known to be very sensitive to soil reaction. Apart from Clostridium spp, most N-fixing organisms, for example,

Azotobacter and the blue green algae are not known to grow or fix N where soil pH is below 6.00 (Lie et al., 1969; Alexander, 1977). The great abhorence of high temperatures above 45°C by most N-fixers and the low content of P and Mo in West African Savanna soils are other factors militating against soil-N build-up by bacteria. In addition tropical legumes such as pigeon peas, cowpeas and soyabeans are very poor N-fixers as against the temperate alfalfa, clovers and lupines which are vigorous N-fixers (Alexander, 1977).

The only important contributor to soil N in tropical environment is lightning but unfortunately this accounts for only about one percent of total soil N. Such fixed N mostly NH_4-N is sorbed by the crystalline lattice of soil minerals in the subsoil (Kononova et al., 1966). Despite the low N content of tropical soils, the little amount fixed is lost through burning and leaching. Jones and Wild (1975) estimated soil N losses through burning at 28 kg/ha/year. Leaching losses are also high, but occur only during the rainy season at an approximate rate of 0.5 mm/mm rain. The relatively high content of N in soils of unit III, 0.13 and 0.15 percent in pedons 7 and 11 respectively, are due to the high organic matter content as well as the restriction imposed on leaching by the high groundwater table.

Similarly, much of the P present in the topsoils are organic while those in the subsoils are mostly inorganic in nature. The phosphorus content is moderately high in pedons 1, 4 and 9, and could be attributed to the nature of the parent rocks (schists) which are moderately rich in P (Jones and Wild, 1975). On the other hand, the deeply weathered soils of unit IV have very low P (0.33 ppm) in their subsoils as shown in pedons 6 and 8. The P contents of these pedons are mostly organic as shown by the moderately high amount (4.79 ppm) in their topsoils. In other words, where weathering is very intensive, P is released from the parent rocks and lost through leaching. A good example is pedon 2, which even though underlain by schist materials, has very low P content (0.33 ppm) in the subsoil because of the high weathering intensity and duration. The same argument can be advanced for the low P content of soil unit III, whose transported parent materials are deficient in inorganic P, hence their P contents are mostly in organic forms and confined to the topsoil.

3.4 Cation exchange capacity (CEC)

CEC refers to the total exchangeable cations that can be held by a soil. This special ability of the soil to hold cations in exchangeable forms is almost entirely a property of its fine mineral particles and of its humus component (Hesse, 1971). These soil components have negative charges which could be

permanent or pH-dependent, and can attract and hold cations. The CEC of the soil therefore is a reflection of the total number of negative charges available in the soil at a particular time.

Results of CEC determination are shown in Table 5.2. The CEC of the soils ranges from 5.8 to 19.8 meq/100 g of soil, which is rated as very low to moderate (Hill et al., 1974). Soils of units I, II and IV do not differ considerably in terms of their levels of CEC. The values for the surface soil range from 5.8 in pedon 8 to 9.4 meq/100 g soil in pedon 4, and increase with depth reaching a maximum of 12 meq/100 g in the B horizons, it declines again to 8.8 meq/100 g in the C horizons (pedon 2). This shows a general bulge at 20 - 65 cm depth corresponding to the pattern of clay distribution in those pedons. On the other hand, soils of unit III gives a significantly different picture in the amount and distribution of CEC. The CEC values are moderately high, 16.0 and 19.8 meq/100 g in pedons 7 and 11 respectively in their A horizons. These values decline steadily with depth reaching a minimum of 8.3 meq/100 g in pedon 7 and 6.3 meq/100 g in pedon 11.

As earlier mentioned, the components of soil that influence CEC are the organic and inorganic colloids. Organic colloids have CEC values of 200 - 300 meq/100 g while the inorganic colloids have values of

3 - 100 meq/100 g (Brady, 1974). The low CEC values of the A horizons of soil units I, II and IV are, therefore, due to very poor contents of organic matter and clay. The clay eluviated from the A horizons accumulates in the B horizons and this is responsible for the high CEC of the B horizons. The low organic matter content had been discussed in section 5.3.2. The decreasing values of CEC in the C horizons is attributable to the decreasing clay content as much of the materials are coarse sand derived from the regolith of parent rocks.

As regards soils of unit III, moderately high CEC values were obtained because of the high contents of organic matter and clay (sections 5.2.1 and 5.3.2). The CEC steadily decreases with depth, from 19.8 to 6.3 meq/100 g in pedon 7. This trend closely follows the distribution of organic matter and clay within the pedons. The high CEC values could also be linked with the high silt content of the A horizons. The positive correlations between the silt fractions of soils and total CEC have been reported by Buursink, (1971).

The generally low CEC of the soils of the area could pose major fertility problems in terms of management. The low CEC values imply poor ability of the soils to hold large amounts of exchangeable cations, such as Ca^{++}, Mg^{++}, K^{+}, and NH_4^{+}. Because these soils have a low capacity to hold cations, nutrients added through fertilizers can be easily leached,

(Jones and Wild, 1975). Leaching therefore becomes a big problem especially when nitrogenous fertilizers are applied and this could lead to soil acidity as the NO_3^- ions are leached in association with the exchangeable cations. The development of strongly acid soils in the Kano Agricultural Research Station Farm in Kano within less than 20 years of continuous application of ammonium sulphate fertilizers is a good example (Idoga, 1981).

5.3.5 Total exchangeable bases

Results on total exchangeable bases are shown in tables 5.2. There is a general range of 2.4 meq/100 g in pedon 4 (soil unit I) to 9.37 meq/100 g in pedon 11 (soil unit III). These values are rated as very low to moderately high (Hill *et al.*, 1973). In all the soil units except unit III, the total exchangeable bases are relatively low in the A horizons, but increase with depth reaching a maximum value in the upper half of the B horizons. In some pedons, there is a slight decrease in the amount of bases in the lower half of the B horizons and then a slight increase in the C horizon. However, in the case of soils of unit III, there is a general decrease in the amount of exchangeable bases with depth. Soils of this unit contain the highest amount of exchangeable bases in their A horizons reaching 6.72 and 9.37 meq/100 g for pedons 7 and 11 respectively.

The very low to moderate values of exchangeable bases of these soils may be attributed to a number of factors, notably, the nature of the underlying parent rocks, intensity of weathering and leaching, and the lateral translocation of the bases. The dominant underlying parent materials of the soils of the area are granitic rocks, schist and alluvial materials. Jones and Wild (1975) have shown that soils on alluvium are usually rich in exchangeable bases while those on schists and granite have moderate and very low bases respectively. These findings are, to some extent, confirmed by the results on exchangeable bases obtained in the present study especially with regards to soils of unit III, which are of alluvial origin. In the case of soils of units I and II, the results are not quite in agreement with Jones and Wild's findings, probably because of two main factors - influence of harmattan dust on parent materials of soil unit 1, and the intensive weathering in soil unit II, The relatively high amount of exchangeable bases in the B horizons of soils of unit I may be attributed to the contribution of the harmattan dust which is known to contain some high fractions of Ca as CaC (Malgwi, 1979). As the dust is leached down into the B horizon, so also is the associated Ca. The relatively high amount of exchangeable calcium (1.96 meq/100 g) in pedon 9 in the B horizon is some good evidence.

In the case of soils of unit II which are underlain by schist materials, one would expect them to have higher amounts of exchangeable bases than soils of unit I. However, this is not so probably because the schist materials are predominantly quartz schist, and because of the high degree of weathering and leaching, as well as lateral translocation. The soils are exposed to high intensity of weathering, leaching and runoff because of their topographic positions (moderately sloping). The consequences are that the exchangeable bases are liberated by the intensive weatheing and are either leached down the profile or are laterally translocated to the "fadama" soils. In other words, soils of unit II are deprived of exchangeable bases by the fluvial processes in favour of soils of unit III. The higher amount of exchangeable K (0.48 and 0.5 meq/100 g) in the C horizons of pedons 1 and 2 respectively as compared to soils of units I and IV could be an indication of the role of parent rock.

The relatively higher amounts of total exchangeable bases in soils of unit III could be due to the effects of lateral translocation, vegetation, groundwater table and high clay content. The soils occur in depressions, and receive soil materials from the high-lying areas. Some soluble salts are therefore, bound to accumulate downslope. Secondly the pumping

mechanism of vegetation, recycling available basic cations from the subsoil to the surface soils, is an important factor here because it is a region of very active vegetation growth. The third possible factor is the high level of the groundwater table which imposes a restriction on the leaching of the bases hence their confinement to the A horizons. The amount and distribution of clay within the profile is also another very important factor. The high amount of exchangeable bases in pedons 7 and 11 correlate very positively with the amount and distribution of clay as was also reported for the other soil units.

A striking feature in the results of the total exchangeable bases is the dominance of Ca in the exchange complex. The amount of exchangeable Ca ranges from 0.90 meq/100 g in pedon 2 to 6.49 meq/100 g in pedon 11. The more common range is from 1.8 to 6.48 meq/100 g of soil. Magnesium comes second to Ca with a range of 0.64 meq/100g in pedon 4 to 2.5 meq/100 g in pedon 7. In some cases the amount of exchangeable Mg slightly exceeds that of Ca especially in the lower B and C horizons. This is particularly true among the highly weathered soils of unit IV. This could be due to the loss of Ca through leaching. Exchangeable potassium and sodium are generally very low to moderate. Exchangeable K values range from 0.06 to 0.54 meq/100 g while exchangeable Na values range from 0.002 to 0.15 meq/100 g of soil.

Similar results have been reported by other workers (Jones and Wild, 1975; Malgwi, 1979; Nuhu, 1983; Ugwu, 1983). These workers attributed the high dominance of exchangeable Ca in the exchange sites of the soils to the high Ca - affinity of the West African Savanna soils. The relatively high exchangeable K content of soils of unit II may be linked with the nature of the underlying materials - schists, while that of Na in soils of unit III may be due to the effects of lateral translocation. Na is a very mobile element in the soil and, therefore, easily removed and washed down the slope in slope fluvial processes. This relatively high Na content might have also contributed to the poor structural development of soils of unit III.

5.3.6 Base saturation

The percentage base saturation was calculated based on the sum of exchangeable bases expressed as the percentage of the cation exchange capacity. The calculated figures show a general range of 24 - 55 percent, and rated as low to moderate amounts. Soils of unit IV have the highest amounts of base saturation with a range of 32 to 55 percent and a mean of 47 percent in pedon 6 while soils of unit I have the lowest amount with a range of 24 to 34 percent and and a mean of 29 percent in pedon 4. Soils of units II and III have intermediate values of base saturation.

As expected, the percentage base saturation is commonly higher in the topsoils (31 - 55 %) than in the underlying B horizons (26 - 43%). There is also a gradual increase in the percentage base saturation at greater depth, that is, at the lower half of the B horizons and in the C horizons. Similar findings have been reported by Awujoola (1979) and Malgwi (1979). This pattern of the amount and distribution of the percentage base saturation shows a definite correlation with soil CEC. Where the CEC values are high, the base saturation values are low and vice versa, In this way, the higher base saturation values of the topsoils could be attributable to the low CEC values associated with the A horizons. In like manner, the lower values of base saturation of the B horizons is attributed to the higher values of CEC of the horizons. In other words, the available cations are not sufficient to saturate the greater amount of exchange sites associated with this horizon with the result that much of the exchange sites became occupied by H^+ and/or Al^{3+} ions. Moreover, the lower parts of the A horizon and the upper parts of the B horizons represent the zone of most active eluviation resulting into low amount of exchangeable bases. Such eluviated bases accumulate in the deeper subsoils giving rise to the relatively higher values of base saturation at the lower B horizon and the C horizon.

Malgwi (1979) and Awujola (1979) attributed the high values of base saturation of surface soils to the active plant litter decomposition process which incorporates cations from the litter into the soil, as well as the contribution by the harmattan dust which is known to contain some high fractions of cations, especially Ca (Malgwi, 1979). The presence of these cations in this zone of limited available exchange sites accounts for the high base saturation of the topsoils.

There is a positive correlation between the caloulated base saturation values and the soil pH. Where the base saturation is high, the pH is usually correspondingly high and vice versa. The high values of base saturation of soils of units III and IV are reflected in their high pH values. The sharp decrease in both the base saturation and pH values in the AB horizon of pedon 8 is a clear indication of the relationship between pH and base saturation. The slightly lower values of base saturation of soils of unit III may be attributed to the high CEC. On the other hand, the higher values of base saturation in soils of unit IV is attributed to the low values of CEC as well as the degree of development of the soil. It is deeply weathered and well drained.

The contribution of the underlying materials to the amount of the base saturation cannot be overlooked. Pedon 4 has the lowest amount of base saturation with a mean of 29 percent probably because of the underlying granitic rocks. Soils of unit II have a higher mean value of 32 percent because they are underlain by schist materials while those of units III and IV have high values because of their alluvial nature and the effect of deep weathering respectively.

5.3.7 Total iron oxide (Fe_2O_3)

The results of total Fe_2O_3 as determined by the sodium carbonate fusion method are shown in table 5.2. The percentage total Fe_2O_3 is less than 6 percent for all the pedons. The range is less than 0.93 to 5.25 percent. The A horizons have the least amount of total Fe_2O_3 with a range of 0.93 to 1.56 percent while the C horizon contain the highest amounts with a range of 1.20 to 5.25 percent. The high amounts of Fe_2O_3 in the C horizon is particularly evident in soils of unit I. Soils of units II and IV have their Fe_2O_3 mostly concentrated in the lower half of the B horizons corresponding to the zone of high clay content. The generally low levels of Fe_2O_3 in the A horizons and its high concentrations in the subsoils in most pedons is a clear indication

of the vertical translocation of Fe_2O_3, with the percolating water. This vertical translocation of Fe_2O_3 has been reported by many other workers as the major reason behind Fe_2O_3 distribution within the profile (Ojanuga, 1977; Malgwi, 1979; Awujoola, 1979). Iron oxides and indeed aluminium oxides (sesquoxides) translocation is usually associated with clay vertical movement as the concentration of these sesquoxides are often confined to the argillic horizons (Adams and Moore, 1983).

In the case of soils of unit I the exceptionally high concentration of Fe_2O_3 in their C horizons is expected because these horizons contain high amounts of iron concretions overlying the consolidated ironpan. Soils of units II and III have considerably lower Fe_2O_3 contents than units I and IV probably because soils of unit II are underlain by schists while soils of unit III have high groundwater table. The watertable is so high that no appreciable quantity of Fe_2O_3 could accumulate since Fe_2O_3 is very unstable under moist conditions (Nuhu, 1983). This explains why the A horizons of soils of unit III have relatively higher content of Fe_2O_3 than the subsoils which are more vulnerable to the high water table influence. The occurrence of soft red spots especially along root channels in the A horizons of the profiles is also an evidence of the influence of the water table recession

on Fe_2O_3 precipitation. The relatively higher amounts of Fe_2O_3 in the C_3 horizon of pedon 11 may be due to the presence of soft reddish black concretions which are thought to be ferromagnesian in nature. These concretions have formed at the bottom of the pedon due to the differential settling velocities of particles brought down by slope fluvial processes.

5.3.8 Total aluminium

Results on total aluminium (Table 5.2) show a range of 0.68 to 2.40 percent. The surface horizons have the lowest amount of total aluminium while the B horizons have the highest quantities. This is particularly true with soils of units I, II and IV. In soils of unit III, however, the reverse is the case, Al-ions are more highly concentrated in the topsoil than in the underlying B and C horizons.

In general, the results show relatively higher levels of Al when compared with the results obtained by Pregitzer et al., (1983). This could be due to the difference in the environment. While Pregitzer and others worked on temperate soils the present study is on tropical soils. The relatively high Al content could, therefore, be due to the high content of kaolinite whose original Al content in the clay structure remains more or less unsubstituted by elements of lower valencies (Brady, 1974). Furthermore, tropical soils are known to be very rich in hydrous oxide clays

because their entire clay particles either consist of oxides of Al and Fe or that the silicate layers are covered by thick stable coats of such oxides (Sanchez, 1974).

The relatively low Al content of upland soils may be due to lateral translocation, while the higher content of Al in the B-horizon is attributed to the vertical eluviation. Soils of unit III have high Al contents in their surface horizons probably because of the high clay content which could be coated with the laterally translocated oxides of Al from the upperslope positions. The high Al content of the soils of this unit could account for the low base saturation even though total exchangeable bases are high when compared to other soil units.

5.4 Soil Classification and Correlation

5.4.1 Classification According to the USDA Taxonomy

The soils of the area (except unit III) contain some appreciable amounts of clays in their B horizons. This presence of an argillic horizon is a common feature to soils of units I, II and IV.

Soils of units I and II have a base saturation less than 35 percent; they do not have tongues of albic materials in the argillic horizon that have vertical dimensions of as much as 50 cm; and are therefore classified as Ultisols. The ustic soil

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moisture regime further places the soils under the suborder Ustults. In all the pedons the soils are underlain by plinthite that forms a continuous phase and constitute more than 50 percent by volume of the soil matrix within 125 cm of the surface. They are therefore further classified as Plinthustults. There are no defined subgroups within the Plinthustults, (Soil Survey Staff, 1975).

Pedon 1 of unit II and soils mapped unit Ia do not have a diagnostic horizon other than an ochric epipedon, have less than 30 percent clay within 50 cm of the surface, and the soil temperature regime is isohyperthermic and so are classified as Entisols. In addition, the soils are not permamently saturated with water, have a texture finer than loamy above the petroferric contact which is encountered shallower than one metre depth. They are therefore classified as Orthents, and further into Ustorthents because of the ustic soil moisture regime. Soils of unit Ia are classified as Lithic Ustorthents because of the presence of a petroferric contact within 50 cm of the surface. Pedon 1 of unit II classifies as Typic Ustorthent because it does not have a petroferric contact within 50 cm of the surface.

Soils of unit III have hydromorphic properties with clay content greater than 35 percent in the surface horizons that are more than 50 cm thick. They have umbric epipedons, but lack spodic, natric, argillic and

oxic horizons. All these properties qualify them as Inceptisols. They are further placed in the suborder Aquepts because of the aquic soil moisture regime. Since these soils have a difference of less than 5°C between the mean summer and mean winter soil temperatures at 50 cm depth, and do not have plinthite that forms a continuous phase or constitutes more than half of the matrix within 125 cm of the surface, they are further classified as Tropaquepts. The presence of gilgai microrelief and cracks that are 1 cm wide at 50 cm depth in most years qualify these soils as Vertic Tropaquepts.

Soils of unit IV have an argillic horizon that has a base saturation of more than 35 percent. They do not have spodic, mollic or oxic epipedon overlying the argillic horizon and do not have plinthite that forms a continuous phase within 30 cm of the surface. They are, therefore, classified as Alfisols, and further classify as Ustalfs because of the ustic soil moisture regime and the isohyperthermic soil temperature regime, of the area.

Pedon 8 has a clay content distribution such that the percentage content of the clay decreases from the maximum by 20 percent or more of that maximum within 150 cm of the surface. The argillic horizon of this pedon is also red (2.5YR 5/8, moist) and has a value more than 4. There is no lithic or paralithic contact

within 200 cm of the surface and the base saturation is less than 75 percent, therefore, the pedon fits closely into the subgroup Ultic Haplustalf.

Pedon 6 of the same unit IV has a clay distribution such that the percentage of clay does not decrease from its maximum amount by as much as 20 percent within 150 cm of the surface, and is therefore, classified as a Paleustalf. Because the pedon has a base saturation less than 75 percent, and has an abrupt upper boundary of the argillic horizon, it is further classified as Ultic Paleustalf.

5.4.2 Classification According to FAO/UNESCO Legend

Soils of unit I and II are classified as Acrisols because they have an argillic horizon that has a base saturation less than 50 percent, and because they lack a mollic horizon and an aridic soil moisture regime. The presence of plinthite that forms a continuous phase within 125 cm of the surface qualifies the soils as Plinthic Acrisols. Pedon 1 classifies as a Regosol because it is formed from unconsolidated materials mainly aeolian deposits, and lacks any diagnostic horizon other than an ochric epipedon. It further classifies as a Dystric Regosol because it has less than 50 percent base saturation. The very shallow soils designated as Ia are limited in depth by a continuous coherent and hard ironstone that was once plinthite, within 10 cm of the surface. They therefore classify as Lithosols.

Soils of mapping unit III have formed from unconsolidated alluvial materials, but exclusive of recent alluvial deposits. They show hydromorphic properties right at the surface and have no diagnostic horizon other than an ochric epipedon. The surface horizons have high clay content (> 30 %) and the structure is massive with hard, dry consistence. These soils, therefore, classify as Gleysols, Since they have a base saturation less than 50 percent throughout the depth of the profile, they are further classified as Dystric Gleysols,

In soil mapping unit IV, pedon 8 has an argillic horizon in which the base saturation is 50 percent in the lower parts, it lacks mollic, and albic horizons overlying the argillic horizon, and is, therefore, classified as Luvisol. Because the colour of the argillic horizon is red (2.5YR 5/8, moist), the pedon further, classifies as, Chromic Luvisol.

Pedon 6 has a clay distribution such that the percentage of clay does not decrease from its maximum amount by as much as 20 percent throughout 150 cm of the surface, and therefore, classifies as a Nitosol. Because the organic matter content of the argillic horizon is very low (< 0.4 % organic carbon) and the base saturation is less than 50 percent in parts of

the argillic horizon within 125 cm of the surface, the soil is further classified as a Dystric Nitosol. A summary of the soil classes of the area is given below in Table 5.3.

Table 5.3 Summary of soil classes of the area.

Units	Pedons	Soil Taxonomy	FAO/UNESCO
Ia		Lithic Ustorthents	Lithosols
Ib and II		Plinthustults	Plinthic Acrisols
	1	Typic Ustorthents	Dystric Regosols
III		Vertic Tropaquepts	Dystric Gleysols
IV	6	Ultic Paleustalf	Dystric Nitosol
	8	Ultic Haplustalf	Chromic Luvisol

5.4.3 Soil Correlation

Soil correlation is a scientific method by which the set or combination of all the significant characteristics of each soil is specifically compared with the set of characteristics of the already defined soil in the natural or taxonomic system of soil classifications to establish relationships (Kellog, 1959).

The soils of the present study can be correlated with earlier soil studies in the Zaria area, especially those of Awujoola (1979), Malgwi (1979) and Valette and Ibanga (1984). Wherever possible references will also be made to Higgins (1963) work. Soils of units I and II in the present study correlate

very positively with Awujoola's soil unit 2 and Valette and Ibanga's soil unit Pp. The soils are well drained and generally less than 100 cm deep. An outstanding feature of these soils is the presence of gravelly concretionary layers between the overlying soil materials and the underlying ironpan. The surface horizons of these soils are brown to dark brown sandy loams that are weakly structured, while the subsoils are yellowish red loam to clay loam, and have moderate to strong subangular blocky structure. Soils designated as Ia correlate closely with Higgin's Shika series on the basis of depth ($\leq$ 10 cm).

Apart from the relatively higher clay content in the top 70 cm of soils of unit III of the present study, the unit can be correlated with Awujoola's unit 5, Malgwi's unit 1, Vallette and Ibanga's unit A1 and Higgin's Bassawa series. The soils are alluvial in origin, very poorly drained and are seasonally waterlogged. They are commonly referred to as "fadama" soils and have very high organic matter content compared to upland soils.

Soils of unit IV of this study can be correlated with Awujoola's unit 1, Malgwi's unit 6 and Vallette and Ibanga's unit P_2. The soils commonly occur on midslopes and are deep and well drained. They have argillic horizons with a well developed subangular blocky structure. The subsoil colour varies from yellowish red through strong brown to red, while the surface horizon is brown to dark brown.

6 VEGETATION STUDIES

As discussed earlier, the influence of bush burning is very high in the present day Savanna vegetation which owes its existence to the possible effects of fire (Redhead, 1966). Evidence of fierce bush burning in the African Savanna zones has been reported as early as the 5th century (Eyre, 1968). The yearly burning during the prolonged dry season destroys the original deciduous and semi-evergreen forest with dense undergrowth, so that most species in the climatic forest climax perished. These were replaced by herbaceous plants and few indigenous woody plants whose barks are sufficiently thick or fire-resistant to permit their survival.

The species composition of the vegetation cover over the area is listed according to their degree of abdundance in appendix 1. Generally, the density and height of the vegetation cover increase steadily from the crest to the lowerslope. A cursory glance through the appendix reveals the presence of few very tall trees in the area, This has been largely attributed to the frequent sweepings of the vegetation by fire. The fires are so frequent and at such regular intervals that any woody plants which are not higher than the surrounding grasses are destroyed when the fires occur. It is doubtful if young plants ever become established under this condition, hence the presence of very few tall trees.

A closer look at the appendix shows an interrelationship between soils, vegetation and topography. Milne formally pointed out this interdependence in his definition of the catena. He postulated an inter-relationship between soil, vegetation and topography, the three formed a definite and recognisable pattern in a descent from hill-top to valley bottom. This pattern is repeated over a uniform parent material and climatic regime (Ramsay, 1963). This observation is equally true in the study area. The vegetation cover of the crest and upland topographic positions is very similar in terms of species composition and growth. The lowerslope topographic position has a unique vegetation cover, while the vegetation cover of the middleslope position is intermediate between the crest/upperslope and the lowerslope so that there is a general vegetation gradient along the slope.

The complete absence of tall trees of canopy layer on the crest and upperslope is primarily due to the shallowness of the soils. The underlying hard ironpan constitutes a physical impedance to root penetration for tall trees and shrubs with well defined taproot system. The only shrubs found growing on these topographic positions are those which are able to cope with the situation by way of lateral spread of their roots. Some of the plants also take advantage of cracks within the hard layer since the

ironpan is not uniformly solid. The common shrubs as shown in appendix I are Isoberlinia tomentosa, I, doka, Terminalia avicennioides and Monotes kerstingii, I. tomentosa is more abundant and taller than other species probably because it is most suited to the unfavourable conditions. It is also known to thrive very well on slopes of low hills capped by remnants of indurated laterite (Jackson, 1970). Terminalia avicennioides and Monotes kerstingii are also known to be closely associated with shallow soils (Nielsen, 1965; Jackson, 1970). The wide occurrence of Monotes kerstingii on dry eroded slopes has also been reported by Nielsen (1965) and Keay (1952). Dichrostachys cinerea, Detarium senegalense and Balanites aegyptiaca are other shrubs of lesser abundance found on the crest and upperslope. They are also linked with shallow soils even on detritus slopes below escarpment outcrops of laterite (Jackson, 1970). Balanites aegyptiaca is a plant with Sudan and Sahel savannas' affinities, but has found its way into the Northern Guinea Savanna because of the unabated advance of the desert coupled with the badly eroded nature of the slopes (Clayton, 1964).

The common grasses found on the crest and upperslope positions are Andropogon pseudapricus, Ctenium newtonii Andropogon gayanus, Elionuras sp, Microchloa indica and Schizacherium exile. Although these grasses are found on the deep and moist soils of

the middleslope position, they have broader leaves and are taller than on the crest and upperslope, thus signifying the importance of soil depth and moisture condition on vegetation growth. Among the herbs, Vernonia perrotteti, Monechma ciliata, Borreria radiata and Cochlospermum tinctorium are the most common. Monechma ciliata and Vernonia perrotteti are mostly found on eroded sites.

Although there is no significant difference in the species composition of the vegetation cover found on the crest and upperslope, two species of tall trees, notably Butyrospermum parkii and Parkia clappertoniana occur only on upperslope. This may be attributed to the relatively deeper soils (reaching up to 130 cm). Their good depth also implies higher water holding capacity than soils of the crest, since the ability of the soil to hold water is largely dependent on depth and texture. Other slight differences are in the densities and size of the vegetation. As high as 80 percent bare areas are observed on the crest while only about 40 percent bare surfaces are observed on the upperslope. The vegetation on the upperslope are taller and have higher densities and broader leaves than that on the crest. I. doka is more abundant here than I. tomentosa probably because of the slight improvement in the physical conditions of the soils. In addition, the following species are also found on the upperslope. Combretum glutinosum. Securidaca longipedulata,

Monocymbium ceresiiforme, Pennisetum pedicellatum, Aristida spp and Stylosanthes spp. Aristida kerstingii are good indicators of slight to moderate sheet erosion.

The vegetation cover of the lowerslope is very unique in two ways. One, it is more homogenous than those found on the upland soils which are indeed highly diverse. Secondly, there is almost a complete absence of the upland species in this topographic position. The possible reasons for these phenomena could be the moisture condition and the texture of the soils of the lowerslope. The common trees of ecological importance are Anogeissus leiocarpus, Butyrospermum parkii and Parkia clappertoniana. There are few stands of Anogeissus leicocarpus which are remarkedly tall reaching the height of about seven metres. The plant is said to be a lover of high soil moisture condition and is mostly found in the moist Southern Guinea ecological zone (Nielsen, 1965). Its occurrence on the "fadama" soils of Northern Guinea Savanna is therefore not surprising. Moreover, the plant establishes in the area because of the heavy grazing activity which offers a certain degree of fire protection to the young plants. In addition, the plant itself is not liked by the grazing animals. Butyrospermum parkii and Parkia clappertoniana are found on the less waterlogged colluvial soils of the lowerslope.

Common shrubs associated with the lowerslope are Piliostigma thonningii, Ziziphus mauritiana and Mimosa pigra. They are all known to be common shrubs of the moist savanna environments and have found their place here due to the prevailing favourable soil moisture regime. Mimosa pigra is a hydrophyte which is known to thrive well even in standing water throughout the year, hence its occurrence in the waterlogged gilgai relief area of the lowerslope. Common grasses found in the area include Hyperrhenia rufa, Vertiveria nigritana, Paspulum commersonii and Eragrostis sp. Some of them, especially Vertiveria nigritana, are commonly found in flat mature valley bottoms where the rivers overflow in the wet season and also maintain a high perennial water table throughout the year (Jackson, 1970). The grasses are very tall reaching an average height of about 1.5 m where they are protected from grazing animals by thorny shrubs, otherwise they are mowed down and trampled upon by the animals.

Urena lobata, Paullina pinata and Nelsonia canas are the common herbs found on the lowerslope position. They are all herbs with Southern Guinea affinities. Whenever they occur in the drier zones, they are normally found associated with fringing forests where damage by fire is less severe (Jackson, 1970).

6.1 Distribution of Ecological Species Groups

The distribution of plant species has long been known to be very useful in indicating site quality (Pregitzer et al., 1983). Such spatial distribution of plants are governed by some factors. In Nigeria vegetation distribution is apparently a product of soil moisture regime. The latitudinal zonation of vegetation from the rainforest along the coast to the Sahel savanna in the far north is a clear pointer to the soil moisture effect (Adejuwon, 1969). The occurrence of local variabilities within the zones, possibly, suggests the influence of other factors such as local relief, soil depth and, to some extent, soil nutrient status. In the present study the various plant species could be grouped into three major ecological associations based on their environmental requirements. These are the Monotes, Isoberlinia, and Piliostigma associations.

The Monotes association includes other notable species such as Dichrostachys cinerea, Detarium senegalense, Balanites aegyptiaca and Terminalia avicennioides in the shrub layer. Others are Microchloa indica and Monechma ciliata in the ground layer. Most species of this association are often present under relatively dry conditions commonly found in the Sudan and Sahel savannas. Some of them are confined to the rock-outcrops and shallow soils characteristic of the crest and upperslope in the present study.

The Isoberlinia association includes I. doka I. tomentosa, Terminalia glaucescens and Combretum sp, in the shrub layer. In the ground layer are found Andropogon gayanus, Monocymbium ceresiiforme, Ctenium newtonii and Stylosanthes sp. The dominant species is I. doka. The species is very much associated with the Northern Guinea Savanna. Its abundant arealcoverage and the relatively taller appearance as observed over the middleslope may be linked with the fertility status of the soil. The fertility status of the soils of the middleslope is reflected in the higher amounts of base saturation (Section 5.3.6). The good ground coverage recorded over the middleslope could also be a direct response to the high soil fertility. However, the species I. doka is not so tall probably because of the fierce seasonal burning. The thick vegetative undergrowth of soils of the middleslope encourages fierce burning that ravages the Isoberlinia woodland.

The Piliostigma group is associated with high soil moisture regime. Species of this group are probably more responsive to soil moisture than soil nutrient status, and are, therefore, strongly linked with the local drainage of the area. Other species of this group include Ziziphus mauritiana, and Mimosa pigra, in the shrub layer. Hyperrhenia rufa, Vetiveria nigritana, Paspulum commersonii and Paullinia pinnata are the major grasses of the group.

7. SUMMARY AND CONCLUSION

Most aerial surveys are carried out based on the assumptions that areas of uniform microclimate and with similar landforms will have a unique set of soil properties which lead to a unique set of vegetation and land use patterns (Ameyan, 1982). Where the landforms are moderately to strongly sloping, these unique sets of soil properties, vegetation and landuse patterns vary with topographic positions. While some workers are of the opinion that this interrelationship between topography, soil and biota is very weak, others see it as a very strong one that can be exploited for a high-rewarding landuse planning (Ameyan, 1982; Pregitzer et al 1983). The present study demonstrates a strong interrelationship between topography, soil and vegetation.

The study reveals a general gradation in soil properties from the crest to the valley footslope. Soils of unit I and II which commonly occupy the crest and upperslope topographic positions in the study area, are generally shallow and underlain by ironpan formulations. The ironpan is either in a relatively soft form, upto 30 cm below the surface or it occurs as a solid dark brown vermicular pan layer, a few centimetres below the surface. These soils of the crest and upperslope positions are generally coarse textured with a poorly developed structure at the surface and weak to moderate subangular blocky structure in the subsoil. They have thin A horizons which in some profiles

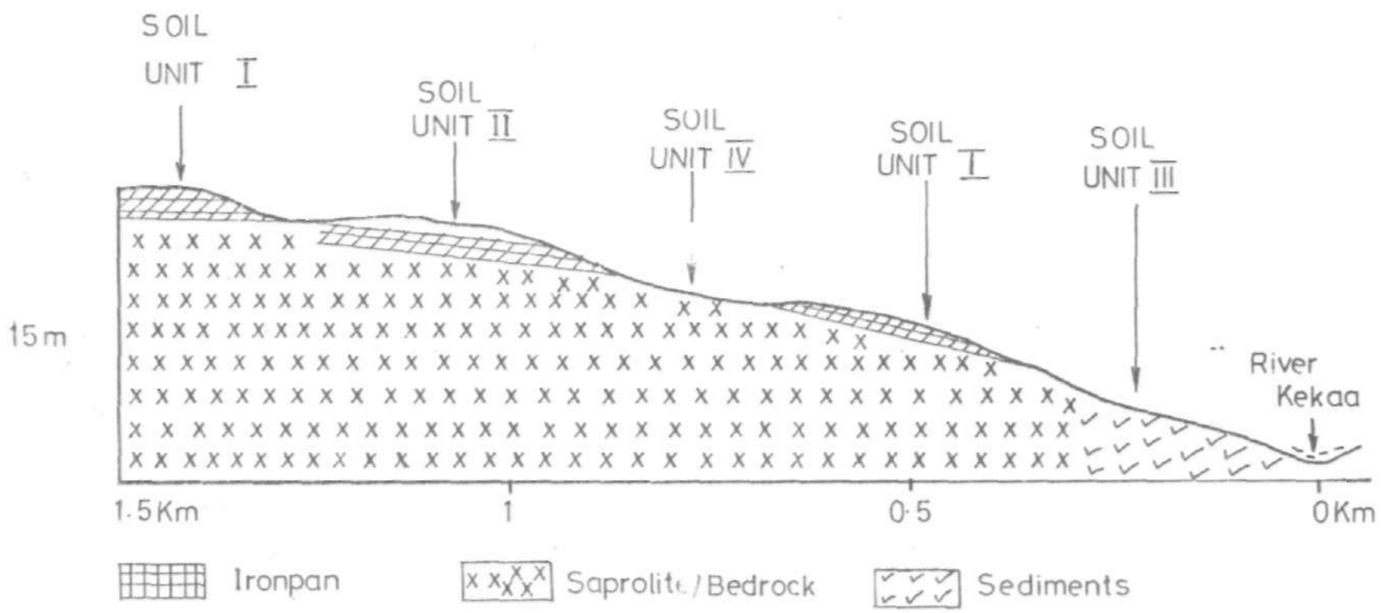


Fig. 7.1 Schematic cross section of the soil units.

overlie a BC horizon without any distinct well developed B horizons. The organic matter content and nutrient status of the soils are quite poor and soil pH is relatively low.

The midslope, on the other hand, has a unique set of soil properties quite distinct from those of the upper and lower slopes. Soil unit II which occupies this topographic position (midlsope) comprises very deep, well drained soils with relatively thick A horizons overlying well developed B horizons with distinct clay cutans. The thickness and organic matter content of the A horizons as well as the clay content of the pedons are intermediate between those of the upper and lower slopes being greater than those of the upperslope but less than those of the lowerslope. Soil pH and base saturation are quite high.

The soils of the lowerslope are also very unique in their properties by virtue of their topographic position. They are greyish brown (10YR 5/2, moist) to light brown (7.5YR 6/4) and have reddish yellow (5YR 6/8) to yellowish red (5YR 4/6) mottles. The soils are seasonally flooded and have high seasonal groundwater table. The clay content is very high (44 %) at the surface but decreases with depth reaching 10 percent at 200 cm. Soil structure is poorly developed. The surface horizon is fine weak crumb tending towards weak coarse subsangular blocky with very hard, dry consistence while the underlying horizons are massive with a hard, dry consistence. Soil

organic carbon content and the thickness of the A horizons are highest at lowerslope positions. Judging from the above, it is evident therefore, that soil properties correlate strongly with topographic positions within the study area. The depth of the solum, thickness and content of organic matter in the A horizons, relative wetness of the profile, clay content, soluble salt content and soil pH all increase downslope. Soil temperature decreases downslope while soil structural development is best in the midslope.

Based on the above properties, classification of the soils of the area ranged from Lithic Ustorthent and Plinthustult on the crest and upperslope positions through Ultic Haplustalf and Ultic Paleustalf at the midslope to Vertic Tropaquept at the lowerslope.

The species composition and the distribution of the vegetation of the study area also show a strong relationship with both soil and topographic properties. Although some vegetation species appear to be mixed up in the upper and middle slopes as revealed in Apendix 1 , their density and vigour (development) change with topographic positions.

Monotes kerstingii, Dichrostachys cinerea, Detarium senegalense, Balanites aegyptiaca and Terminalia avicennioides are the dominant shrubs of the crest and upperslope positions. Most of these shrubs are more often associated with the

drier conditions of the sudan and sahel savannas. Their abundance on seriously eroded, shallow, coarse-textured and low fertile soils is therefore not surprising. The more or less complete absence of tall trees of canopy layer on the crest and upperslope positions is attributed to the shallowness of the soils. Similarly, the presence of Monechma ciliata and Microchloa indica may be due to the severe sheet erosions associated with the topographic positions.

In the midslope are found tall trees notably, Butyrospermum parkii and Parkia clappertoniana. Their presence may be as a result of very deep soils and their attendant good soil moisture storage. The shrub layer is dominated by Isoberlinia doka, Terminalia glaucescens and Combretum spp. The dominant grasses are Andropogon spp, Monocymbium ceresiiforme, Ctenium newtonii and Stylosanthes spp. Although some of these species could be found in the upperslope position, they are better developed in the midslopes, being taller and with broader leaves than those on the upperslope.

The vegetation of the lowerslope is very unique in two ways; it is more homogenous than those on the crest, upper, and middle slopes, and secondly, there is almost a complete absence of upland species in the lowerslope. These phenomena could be accounted for more by the high soil moisture regime than the nutrient status. Tall trees of ecological significance in the lowerslope include

Anogeissus leiocarpus, Butyrospermum parkii and Parkia clappertoniana. The last two species are found on the less waterlogged soils of unit III. High soil moisture-loving shrubs such as Piliostigma thonningii, Ziziphus mauritiana and Mimosa pigra dominate the shrub layer while Hyperrhenia rufa, Vetiveria nigritana, Paspulum commersonii and Eragrostis sp. are dominant in the ground layer.

In consequence, therefore, the interractions between topography, soil and vegetation as demonstrated by the present study show that soil properties as well as the vigour and species composition of the vegetation vary with topographic positions. It also shows that the vegetation cover of the area is strongly influenced by soil depth, soil fertility status and soil moisture regime which are all influenced by topography. It is, therefore, left to man to understand and exploit this interrealtionship for meaningful land use planning as it affects our agricultural development.

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Appendix 1 Species composition of the vegetation cover

CREST AND UPPERSLOPE (SOIL UNIT I)

	SCORES	HEIGHT (m)
SHRUB LAYER		
Isoberlinia tomentosa	3	3
Isoberlinia doka	2	2
Terminalia avicennioides	2	1
Monotes kerstingii	2	1
Dichrostachys cinerea	1	1
Detarium senegalnse	1	1
Balanites aegyptiaca	1	0.5
Nimenia americana	1	0,5
China afzelli	1	0.5
Naythnus senegalensis	1	0.5
GROUND LAYER (GRASSES & HERBS)		
Andropogon pseudapricus	3	
Ctenium newtonii	3	
Andropogon gayanus	2	
Elimmuras spp	2	
Microchoa indica	2	
Schizacherium exile	2	
Pennisetum pedicellatum	1	
Panicum maximum	1	
HERBS		
Vernonia perrottetii	2	
Monechma cilliata	2	
Borreria radiata	2	

Cochlospermum tinitorium	2	
Waltheria indica	1	

CREST AND UPPERSLOPE (SOIL UNIT II)

CANOPY LAYER	SCORES	HEIGHT (m)
Butyrospermum parkii	1	5
Parkia clappertoniana	1	5
SHRUB LAYER		
Isoberlinia doka	3	2
Isoberlinia tomentosa	2	2
Securidaca longipedulata	1	1
Monotes kerstingii	1	2
Combretum glutinosum	1	0.5
Strychnos vomica	1	1
Vitex sp	1	
Prosopin africana	1	
Ficus ingens	1	
GROUND LAYER (GRASSES)		
Monocymbium ceresiiforme	3	
Elionuras sp	2	
Pennisetum pedicellatum	2	
Andropogon gayanus	2	
Andropogon pseudapricus	2	
Michrochloa indica	2	
Schizacherium exile	2	
Aristida kerstingii	2	
Aristida funi	1	
Ctenium newtonii	1	

HERBS	1	
Dischoriste perrottetii	3	
Monechma ciliata	2	
Borreria radiata	2	
Cochlospermum tinctorium	1	
Stylosanthes sp.	1	
Vernonia perrottetii	1	

LOWERSLOPE (SOIL UNIT III)

CANOPY LAYER	SCORES	HEIGHT (m)
Anogeissus leiocorpus	2	7
Parkia clappertoniana	1	6
Butyrospermum parkii	1	6
SHRUB LAYER		
Piliostigma thonningii	3	2
Ziziphus mauritiana	2	2
Mimosa pigra	2	
Carissa edulis	1	
Andira inermis	1	
GROUND LAYER (GRASSES)		
Hyperrhenia rufa	3	
Vertiveria nigritana	2	
Paspalum commersonii	2	
Eragrostis sp.	2	
HERBS		
Urena lobata	3	
Panninia pinnata	3	

Appendix I (Contd')

Nelsonia camas	2	
MIDDLESLOPE (SOIL UNIT IV)		
CANOPY LAYER	SCORES	HEIGHT (m)
Butyrospermum parkii	1	7
Parkia clappertoniana	1	7
SHRUB LAYER		
Isoberlinia doka	3	2
Dichrostachys nutans	2	3
Anona senegalense	1	
Carissa edulis	1	
Prosopis africana	1	
Parkia clappertoniana	1	
Combretum spp.	1	
Goudenia embescens	1	
Defourium senegalense	1	
Hymernocordia acida	1	
GROUND LAYER (GRASSES)		
Ctenium newtonii	3	
Andropogon pseudapricus	2	
Andropogon gayanus	2	
Monocymbium ceresiiforme	2	
Elionuras sp	1	
HERBS		
Dischoriste perrottetii	3	
Stylosanthes sp.	2	
Waltheria indica	2	

Appendix I (Contd')

Polygala sp	2
Hygrophila sp	2
Borreria indica	1