# LAND SUITABILITY EVALUATION FOR SOME SELECTED LAND USE TYPES IN THE INSTITUTE FOR AGRICULTURAL RESEARCH FARM, ZARIA, NIGERIA.

**BY**

**HUSSAINI, GBONGBO MOHAMMED B.Sc. Geology, PGD/GIS**
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**DEPARTMENT OF SOIL SCIENCE**
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**DECEMBER, 2011**

## DECLARATION

I hereby declare that this thesis has been undertaken by me and that it is a record of my research work. All the sources of information have been duly acknowledged through references and citations. The subject matter herein has not been presented in any previous application for a higher degree at Ahmadu Bello University or any other university.

| Hussaini, Gbongbo Mohammed | ……..... | DECEMBER 6, 2011 |
|---|---|---|
| Name of Student | Signature | Date |

**CERTIFICATON**

This thesis entitled "LAND SUITABILITY EVALUATION FOR SOME SELECTED LAND USE TYPES IN THE INSTITUTE FOR AGRICULTURAL RESEARCH FARM, ZARIA, NIGERIA" by Hussaini, Gbongbo Mohammed meets the regulations governing the award of the degree of MASTER OF SCIENCE of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

| | | |
|---|---|---|
| Prof. B.A. Raji | ……..... | ……..... |
| Chairman, Supervisory Committee | Signature | Date |
| Dept. of Soil Science, ABU, Zaria | | |
| Prof. J.O. Ogunwole | ……..... | ……..... |
| Member, Supervisory Committee | Signature | Date |
| Dept. of Soil Science, ABU, Zaria | | |
| Dr. W.B. Malgwi | ……..... | ……..... |
| Member, Supervisory Committee | Signature | Date |
| Dept. of Soil Science, ABU, Zaria | | |
| Prof. I.Y. Amapu | ……..... | ……..... |
| Head, Dept. of Soil Science | Signature | Date |
| Ahmadu Bello University, Zaria | | |
| Prof. A.A. Joshua | ……..... | ……..... |
| Dean, Post-graduate School | Signature | Date |
| Ahmadu Bello University, Zaria | | |

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## DEDICATION

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**ABSTRACT**

The sustainable use of the soil resource requires extensive knowledge about its morphology and other properties. Consequently, soil data are basis for improved land use management and soil conservation. Land evaluation provides information on the potential (capability or suitability) of the soil resources for use. The present study carried out at the Institute for Agricultural Research farm, Ahmadu Bello University, Zaria, situated in the Northern Guinea Savanna zone of Nigeria; include morphological, physical and chemical properties, and suitability evaluation of the soils. The soils were evaluated for their suitability for the production of cotton (Gossipium hirsutum), cowpea (Vigna unguiculata, L), maize (Zea mays, L) and sorghum (Sorghum bicolar, L) on a sustainable basis, using the additive and limiting methods of *Sys et al.* Parent materials (Granites and Schist), topography and drainage had a pronounced effect on the soil properties. The main pedogenetic processes occurring in the soils were argillation, organic matter mineralization, eluviations, illuviation, textural and structural differentiation, and horizonation. From the results obtained, the soil showed more variation in morphological and physical properties than in chemical properties. Three distinct soil units were scattered in the various landscape positions. Soil unit A occupied the upper slope position, soil unit B occupies the middle slope position and soil unit C occupies the lower slope. The soils were shallow to very deep (4 to 166cm depth), depth increased down slope. Soil Unit B was higher in clay than the other soil units. Silt dominated the particle size fraction of the fine earth (< 2mm) portion of the soils. The bulk density was higher in surface soils. The chemical properties indicate strongly acid to neutral pH (4.7 to 7.2), medium to high exchangeable bases and high base saturation. The CEC ($NH_4OAc$, ECEC) and CEC (Clay) did not differ significantly among the soil units. The organic carbon of the surface soils was generally rated low. The soils are

classified as Typic Haplustalfs for soils of units A and B, except pedon A2 that was classified as Lithic Ustipsamment and soil unit C1 and C2 as Typic Endoaqualfs and Typic Endoaquepts respectively, according to the USDA Soil Taxonomy, or as Lixisols and Gleysols for soil units A and B, and soil unit C respectively, except pedon A2 classified as Leptosols, according to the classification system of the World Reference Base for Soil Resources. The principle of matching fertility and climatic requirements of crop to the characteristics of the land was used as a basis for developing a land suitability classification for the selected crops. Land characteristics needed to assess the land suitability were obtained from the soil survey, while crop requirements were obtained from literatures. The soils of the three soil units identified were grouped into three land units namely land unit one (LU1), land unit two (LU2) and land unit three (LU3) for soil unit A, soil unit B and soil unit C respectively. Land units LU1 and LU2 were moderately suitable (S2) for cotton and maize, and highly suitable (S1) for cowpea and sorghum. LU3 was moderately suitable (S2) for cowpea and sorghum and not suitable (N) for cotton and maize.

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# CHAPTER 1

# INTRODUCTION

## 1.1 GENERAL BACKGROUND

Soils are indispensable resources that have been used for thousands of years. However, their multipurpose and long-term exploitation has various consequences: inappropriate agricultural methods, overgrazing of grassland and deforestation cause different types of soil degradation (Roose, 1996; Blum, 1997; Eswaran *et al*., 2001). Since humans, during the Neolithic shifted from hunting and gathering to farming and herding, the soil has undergone intensive exploitation. Some 10,000 years of irrational soil use by humans has transpired, with no objective beyond seeking maximum yield from every kind of soil use. As a result, the soil has reached the present day, intensely degraded to the point that a great part of arable land, especially in arid and semiarid regions, is in a situation of irreversible deterioration. To stop this dramatic trend, the only solution is to institute rational soil use, that is, to use each soil in a way that best suits its characteristics and to programme its management for minimal degradation. This is precisely the final aim of land evaluation.

Physical, chemical and biological soil deterioration has already become a critical problem in many countries all over the world (FAO, 2000). For example, out of the appropriately 2,796 million ha of the total land area in Africa, 2,146 million ha are problem soils; (72%) with different production constraints. Of these areas, about 490 million ha are affected by different types of degradation (FAO, 2000). Soil degradation is the most critical environmental problem affecting sub-Saharan Africa. In many parts of sub-Saharan Africa, fallow periods are being considerably reduced and farmers increasingly extending cultivation to marginal lands susceptible to soil degradations.

This is manifested by declining yields, decreasing vegetation cover, salinization, and fertility decline and increasing erosion (FAO, 2000). Therefore, improved land use management and soil conservation are urgently required to save the foundation that supplies food for present and future generations (FAO, 2000). The sustainable use of soil resources requires an extensive knowledge about its genesis, morphology and properties. Consequently, soil data are the basis for the assessment of soil conservation (Sanchez *et al*., 1982; Eswaran *et al.,* 1988; Oelkers, 1993). Sustainability is a concept that is becoming more and more accepted among planners.

## 1.2 LAND EVALUATION

Land evaluation is an applied classification system that assesses the capacity of the soil for its optimal use, that is, to derive maximum benefits with minimum degradation. This can be defined, according to van Diepen et al. (1991), as "any method to explain or predict the use potential of land".

Different types of soils present widely different properties, and therefore the response to each use differs. Land evaluation is based on the idea that this response is a function of these properties, and, hence, knowing these, one can predict the behaviour of the soil under a given use. From the study of such properties, different degrees of suitability of the soil can be inferred for each end proposed. These degrees are reflected on maps of use capacity or suitability, on which the corresponding recommendations are made for the rational planning of soil use.

As land evaluation is intended to offer practical results that can be plotted on territorial maps, such endeavours cannot be limited to the analysis of the physical medium of the earth, but rather must be complemented by the corresponding socio-economic studies that enable cost-benefit analyses of the profitability of the land use. Thus, land

evaluation enables predictions on the biophysical and economic behaviour of land for current and potential uses.

The above implies that land evaluation must be undertaken by an interdisciplinary team comprised of soil scientists, agronomists, ecologists, geographers, sociologists and economists, among others. Such a multifarious team is difficult to join together, given such diverse scientific training, scientific terminology and focus of each specialist. Consequently, as shown by many authors (Aandhal, 1958, Bie et al., 1973; Sys, 1985; van Diepen et al., 1991; Rossiter, 1995 and 1996), complete studies (biophysical and economic) of land evaluation have to date been scarce, the great majority being restricted to examinations of the physical medium, thus leaving the term of land evaluation quite confused.

To date, in land evaluation projects, production has been valued over all other concerns, but the time has arrived to concede the importance of environmental and human-health issues, as well as sustainability (FAO, 2001). Rossiter (1996) highlighted the need to adapt land evaluation to the demand of the clients and not, as previously, with an exclusively scientific perspective. Also, it would be useful to provide the degree of uncertainty in these studies, and thereby reinforce the credibility of the use recommendations (Rossiter, 1996).

The evaluation of land is normally carried out to determine their suitability for specific uses. The information obtained can be used for a more realistic land use recommendation and present constraints (FAO, 1995; Abdulkadir, 1998; Braimoh, 2000). It also enables management guidelines in order to promote a suitable use of soil and environmental resources. The present shortage of good land for food production as

caused by competing demand for other land uses such as industrialization, grazing, fuel wood, cash crop and their degradation as caused by unsuitable land use practices (FAO, 1983 and Raji, 1999) called for a reliable land evaluation.

## 1.3 JUSTIFICATION

The studied area is being considered for more production of cotton, cowpea, maize and sorghum due to new initiatives for their production for consumption, and as raw materials for local use and export in Nigeria. The starting point towards sustainable management is adequate information on the land resources. Equally important is suitability evaluation but these are not in proper form in Nigeria in spite of several spots studied (Ogunkunle, 2004). One of the strategies for achieving food security as well as sustainable environment remains studying the soil resources to details through the process of soil characterization and land evaluation for various land utilization types (Esu, 2004).

The productivity of Nigerian soils is decreasing; the fragile savanna soils where this study was conducted need to be used in a sustainable way to avoid soil degradation. Lands have been utilized intensively for all purposes at the expense of its suitability capability thereby resulting in land degradation and altering of the natural ecological conservatory balances in the landscape (Senjobi, 2007). In view of this, it is mandatory to carryout land suitability in order to ensure that the study area is suitable and capable of sustaining long term production of the selected crops.

## 1.4 OBJECTIVES

The objectives of this study were to:

- determine the variation in morphological and physicochemical properties and assess status of the soils in the study area.
- classify the soils using the criteria of the USDA Soil Taxonomy (Soil Survey Staff, 1999), and FAO World Reference Base for Soil Resources (FAO-ISRIC-ISSS, 1998).
- evaluate the soil for its suitability to grow on sustainable basis cotton, cowpea, maize and sorghum.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 SOILS OF THE NIGERIAN SAVANNA

The Nigerian savanna is commonly divided into the Sahel, Sudan, Guinea, and Derived savanna zones based on moisture distribution and vegetation (Higgins and Klinkenberg 1968; Aduayi *et al* 2002). The soils of the savanna are characteristically low in fertility (Jones and Wild, 1975; Mokwunye and Batiano, 2002). Most of the soils are under continuous cultivation, so they rapidly lose their fertility due to rapid decline in organic matter, leaching of basic cations and high rates of acidification (Jones and Wild, 1975; Ogunwole, 2008; Vanlauwe and Saginga, 2004). There are also large losses of organic matter as a result of land clearing and cultivation, especially with the breakdown of the traditional land use systems such as shifting cultivation and bush fallowing (Kowal and Kassam, 1978).

The soils of the Nigerian savanna are largely classified as tropical ferruginous, and specifically are classified as Acrisol in the FAO System or Alfisols (Typic Haplustalf) in the USDA soil Taxonomy System (Jones and Wild, 1975; Ogunwole *et al*., 2001). The soils are formed on loess materials overlying basement complex and are predominantly kaolinite (Gallez *et al*., 1975; Ojanuga, 1978). They are also typically high in Fe and Al oxides. Kaolinite and Fe-oxyhydroxide are shown to form 80 – 90% of the constitution of the clay fraction (Moberg and Esu, 1991). These basic characteristics have far reaching implications on the fertility and crop production potentials of the soils and the main soil constraints in the savanna are more chemical than physical. The available P status of the savanna soils is a function of P content of the parent material which is low

for most soils of Nigerian savanna (Jones and Wild, 1975; Uyovbisere and Elemo, 2000; Agbede, 2009).

The agricultural value of these soils is usually rated poor to average, nutrient levels are often low and with very low buffering capacities (Jones and Wild, 1975; Vanlauwe and Saginga, 2004). The soils of the savanna are to a large extent, highly weathered, coarse textured, low in organic matter content and cation exchange capacity. The total P content is generally low with values ranging from 13 to 630 ppm. An average of about 100 to 400 ppm in savanna soils have been reported (Mokwunye, *et al* 1986). Of these amounts, less than 10% is said to be in active/labile Al-P, Fe-P and Ca-P forms (Uyovbisere, 1979). These make soil fertility maintenance difficult. As a result, for cotton crop production to be successful, supplementary fertilization have to be made, especially for high yield and good lint quality of cotton.

Generally, there is a variation in the soil reaction processes in savanna soils which is associated with the nature of the surface activity of the dominant clay. Crystalline oxide fractions are predominant in savanna soils relative to the amorphous forms. The potential of the soil to fix P and their P supply to growing plants should vary accordingly with the state of crystallinity of Fe and Al oxides in soils (Uyovbisere, 1994; Abdu, 2009). Therefore P fixing capacity may not be excessive but high enough to reverse a large amount of P applied to savanna soils. Most of the savanna soils are highly weathered and poorly buffered with meager amounts of nutrients in the rooting zone. A large part of the soils are therefore susceptible to nutrient depletion with intensive farming because of their low buffering capacity (Balasubramanian and Nnadi, 1980).

## 2.2 BOTANY AND AGRONOMY OF COTTON

Cotton is a heat loving crop; presently cotton is cultivated in all parts of the world with sufficiently warm climate. In Africa, rainfed cotton is grown almost everywhere in the Sudano-Guinean and Sudan savannas. Generally the yield of cotton is very sensitive to weather, it is widely grown in tropical and subtropical countries. The crop is particularly useful where agriculture is being developed because it can be grown satisfactorily in small farm holdings (Whalen and Chong 2001; Pettigrew 2004, Peeters *et al*, 2001;Aduayi *et al*, 2002).

All cotton species are originally perennial plants but are cultivated as annuals. They have a strong and well-developed tap-root which can reach a depth of 3m. The main stem is monopodial (vegetative with leaves only) and branches dimorphically: monopodial branches at the lower part of the stem and sympodial branches (with flowers) at the upper part. The leaves are arranged spirally as monopodia and alternatively in two rows as sympodia. Some varieties have an almost fully cut or laciniate leaf. Depending on the variety, the leaves are variable in size, shape, texture and hairiness. The hairines is heritable and of considerable importance in breeding for insect residence. The leaves, stem, bolls and seeds contain glands that produce gossypol. The gossypol content is influenced by genotype and environmental conditions (0.3 – 1g/kg in leaves, 3 – 10 g/kg in flower buds, 12 -18 g/kg in seed kernel) (Peeters *et al*., 2001).

The first floral bud is formed 30 – 40 days after emergence and 20 to 25 days before flowering, the flowering follows spiral patterns, starting with the inner most bud on the lowest fruiting branch and finishing with the outmost bud on the upper fruiting branch with most flowers. Cotton is mainly self-pollinating and fertilization is accomplished

after 48 hours. The petals turn pink the day after anthesis and drop off within a few days.

It is an accepted fact that cotton must satisfy half its nutritional requirements by the 64$^{th}$ day of its growth. Early application of fertilizer is therefore needed and it is applied at sowing or at emergence, to ensure good nitrogen availability. During the greater part of the vegetative periods, the nitrogenous fertilizers are usually split into two dressings,. The phosphate and potash fertilizers are applied at sowing together with half the nitrogen and incorporated in the row (Peeters *et al,* 2001). The remaining N is usually applied at final thinning, about a month after sowing, as side dressing about 10 cm away from the row. As a general rule, N and P are the elements that are most often deficient in tropical soils for cotton production. Nitrogen deficiency arises from the naturally low fertility of those soils and the highly leacheable character of this element. Phosphorus is usually present in the soil but is largely insoluble (Holford, 1997, Yonathal, *et al*., 2008, Abdu, 2010). Potassium, sulphur and boron deficiencies tend to appear as cultivation becomes more intensive and fallow interval shortened.

In regions where crop debris is not restored to the soil, the compensatory amendment must consist of at least 50 units of N, 20 units of P, 30 units of K and 3 units of sulphur/ha. Boron deficiency can be avoided by applying 10 – 20 kg of borax per ha (14.5% B) (Peeters *et al*., 2001). A quantitative study by Husain (1987) revealed that crop nutrient harvests are far in excess of recommended rates, suggesting in real terms, the contribution from sources not easily quantifiable, such as N-fixation, weathering and organic matter mineralization. These play a large part in the scheme of plant nutrient supply and uptake (Uyovbisere *et al*., 2000 and Uyovbisere and Elemo, 2000). The common phenomena in the savanna is that yields are depressed at the application of

large doses of inorganic nutrients to soils, possibly as a result of nutrient imbalance created in the soil medium by some constituents of the fertilizer formulation. The application of some of these nutrients is often incidental, being chemical components of the fertilizers, such as sulphur in single superphosphate (Uyovbisere and Lombin, 1991).

## 2.3 COWPEA PRODUCTION

Cowpea (*Vigna unguiculata L.*) *Walp* is an important legume crop in Nigeria. In some areas of humid tropics, it provides more than half the plant protein in human diets (Amatobi *et al.,* 2005). As food, it is eaten in form of dry seeds, green pods, and leaves. It is also utilized for fodder and as cover crops. It fixes its own nitrogen, requires little external supply and improves the soil fertility by leaving a fixed nitrogen deposit of up to 60-70kgha$^{-1}$ for the succeeding crop (Amatobi, 2005).

Currently, Nigeria produces about 1 million tonnes per annum at an average yield of 300kgha$^{-1}$ (Amatobi and Maigida, 2005). The low yield can be attributed to insufficient information on existing varieties, non availability of improved seeds, poor cultural practices, and prevalence of disease and insect pests. Other factors contributing to low yield include soil problems such as low pH, high aluminium content, saline soil, excessively high temperature, excessive moisture, etc. Cowpea can be grown all over Nigeria except in the swamp zone near the seas or rivers.

Cowpea is a tropical crop and grows best in areas with temperature range of 23$^0$C to 30$^0$C during the growing season. Some varieties can do well in the dry season under irrigation. Cowpea can grow in a wide variety of soils, ranging from predominantly clay soil to predominantly sandy soils with pH ranging from 4.5 to 8.5. Cowpea is sensitive

to water logging, and therefore prefers well-drained soils. It is more tolerant to drought and stress than most cereal and other legumes (Amatobi, 2005).

## 2.4 MAIZE PRODUCTION IN NORTHERN GUINEA SAVANNA

Maize (*Zea mays L.*) is believed to have originated at least 5,000 years ago in the highlands of Mexico, Peru and Ecuador. It is a major cereal and one of the most important food crops in Nigeria. Its genetic plasticity has made it the most widely cultivated crop in the country from the wet evergreen climate of the forest zone to dry ecology of the Sudan Savannah. Maize is the most dominant cereal crop in the Southern part of the county. It however thrives and gives the best grain yield per unit area in the Savannah zone. A remarkable expansion in hectarage under maize cultivation in the Guinea Savannah has been recorded within the last 25 years where maize was a minor crop. Because of scientific improvement, yields per hectare have increased to the extent that it has become an important cash crop. Yield in the Savannah zone are twice those of the forest ecologies owning to more solar radiation, better rainfall distribution and less incidence of fungal and ear rots.

Maize crop requires warmth all throughout its active life period and it is sensitive to frost at all stages. Practically, no maize is grown where the growing season temperature is less than $19^0$C or where the average night temperature falls below $13^0$C. The greatest production is where the warmest month isotherms range between $21^0$C and $27^0$C. Its responses to temperature vary with the stage of the crop. During germination, the optimum temperature appears to be around $18^0$C.

For maize, excessive rainfall decrease yield. The amount and distribution of rainfall are highly important factors in successful maize production. Pre-planting precipitation or

initial soil moisture contributes a great deal towards meeting crop requirements in Northern Nigeria. The moisture requirement of the crop is small during the early stages of development, but increases rapidly up to the flowering stage before decreasing again as the crop matures. Requirements of water depend upon several factors, but in general, minimum range of 480-880mm of rainfall, well distributed to meet the needs of the crops during the season is adequate.

Maize is grown on a wide range of soil types. For excellent yields, maize is best grown on deep freely drained, medium to moderately heavy textured soil, well saturated with adequate organic matter and weatherable minerals within the rooting depth.

Nutrient demand of maize is very high. Inherent soil supplies cannot meet nutrient demands of maize (especially of nitrogen) for more than 1-2 years (and in some soils, cannot even support a first cropping). It is therefore necessary to supply inorganic and organic fertilizer. It has been reported that open pollinated maize requires about 100-120kg Na/ha for optimum yield in the Savannah agro-ecological zone (Balasubramanian and Nnadi, 1980).

## 2.5 ECOPHYSIOLOGY OF SORGHUM

Sorghum (*Sorghum bicolar L.) moench* is one of the commercial cereal crops in the world with more than 40 million hectares dedicated to its cultivation (FAO, 1993). It ranks fifth in importance among cereal grain crops in the world behind wheat, rice, maize and barley (Smith and Bhaskaran, 1986). Although, tropical in origin it is cultivated geographically between latitudes $45^0$N and $35^0$S (Aba *et al.,* 2004). In terms of hectarage, about 6 million hectares of land is put under sorghum production with average yields of 1.7 $tha^{-1}$ and a total production of 6 million tonnes annually

(NAERLS, 1996). In the savanna and semi-arid sahel regions, millions of people consume sorghum in their daily diets as staple food.

Sorghum is a cereal crop that grows in a wide variety of soils ranging from heavy clay in the Southern Guinea Savanna to sandy loam in the Sudan/Sahel ecologies. It does best in soils with high moisture retention capacities that are well drained and fertile clay loam in nature (Aba *et al.,* 2004). It is fairly tolerant to alkalinity and salinity. It can tolerate some drought situations, which is why it is described as a hardy crop.

Sorghum need high temperature for good growth (27-29$^0$C optimum), most cultivars are heat and drought tolerant. For good growth and grain yield, 400-500mm rainfall is necessary. It grows on a wide range of soil; sand, loam, sandyloam, well drained, badly drained, etc. It grows in pH of 4-8.5 and can tolerate salt and alkaline soils. Good nutrient containing nitrogen, phosphorus and potassium are needed for good yield. Sorghum is widely grown in derived savanna, southern, northern guinea savannas and sudano-Sahelian zones of Nigeria (Showemimo *et al.,* 2000).

## 2.6 LAND EVALUATION METHODS

### 2.6.1 Evaluation Characteristics

Soil evaluation can be performed directly or indirectly. In the former case, the evaluation stems from field tests (experimental stations, random agricultural sampling in the field) or from yield production provided by individual farmers (farm records) and cooperatives, or else from agricultural statistics. These data are usually local, spotty, and sometimes not reliable and are generally difficult to extrapolate. Therefore, the evaluation is normally conducted indirectly on the basis of the soil properties, assuming

that yield of a given soil depends on its properties and its level of management. The evaluations made in this manner should be validated finally with real yield data.

In an indirect evaluation, it is evident that to define a degree of suitability, it does not suffice to choose only one property, but rather it requires a group of properties, possibly the more the better. The properties to choose will depend on the proposed use of the soil. The values of these evaluation parameters can be derived from disparate sources (remote sensing, maps, the literature and directly from the field or laboratory) and with sharply differing degrees of precision.

In addition, these evaluation characteristics can be combined in many ways in various assessment systems used in soil evaluation, so that even for the same use, the results for a given soil can differ markedly, depending on the evaluation system chosen. Therefore, we propose that it is useful to define in a general manner the properties that most influence soils as well as their degree of suitability.

It has been recognized that the quality of land suitability assessment and hence, the reliability of land use decisions depend largely on the quality of soil information used to derive them (FAO, 1976; Ghaffri *et al.,* 2000; Bourma, 2001; Mermut and Eswaram, 2001; Bogaert and D'Or, 2002; Salehi, *et al.,* 2003).

### 2.6.2 Evaluation Systems

A plethora of evaluation methods are used under diverse philosophies and techniques. Some methods value the degree of suitability of the properties, while others place more emphasis on the possible limiting factors for soil use. These latter methods are more consistent, since, as we know, the true limits on soil use are the negative characteristics

(according to Liebig's law of the minimum), regardless of the degree of suitability of the most favourable properties.

Some methods use qualitative criteria while others use quantitative. The qualitative systems are normally used in examinations aimed at a general evaluation of broad zones. The quantitative methods are used more often in detailed studies and thus need more information on the soils, both to construct the evaluation system as well as to apply it, but they are more objective and the results are therefore more reliable. Other methods begin with qualitative data which are weighted to reach a final numerical result.

Some systems group the classes into a series of levels of importance (order, class, subclass, type, etc.), and are thus hierarchical systems. Other systems have one category, and these are frequently parametric. In these latter systems, mathematical formulae are applied so that the final result is expressed in numerical terms. These can be additive (Index = A + B + C + D + ...) or with a multiplicative scheme (Index = A x B x C x D x...), the latter offering better results for following the minimum law. The additive systems give an evaluation that is usually correct from the theoretic standpoint but can give evaluations that are not realistic in as much as they do not represent the serious consequences implicit in a highly limiting soil factor. It is generally accepted that the parametric methods are, according to McRae and Burnham (1981): simple, objective, quantitative, reliable, easy to understand and apply, even by the non-specialist, and easy to modify and adapt to new uses. Their main disadvantage is precisely that their objectivity and precision are illusory. Their formulation is difficult and, if they are not well applied; their results can be completely erroneous. The scheme is too artificial and the relationship between the soil properties and the result of the evaluation is poorly

defined. The results from this type of system, perhaps more than any other, need careful validation by values for soils under practical use.

Some systems pursue agricultural ends while others seek exclusively engineering uses (such as the support and placements for structures, roads, septic tanks, etc). Within the systems for agricultural uses, some, called land capability, evaluate the capacity of the soil for general use (crops, pasture, forestry), while others, called land suitability, evaluate the suitability of the soil for specific uses, such as a specific crop (e.g., wheat, potato) and with a particular kind of soil management. The classifications of land capability define the degrees of capacity in generally vague terms, focusing fundamentally on the limitations for the general use. Land suitability provides more practical results but need more data both for the land as well as for concrete specifications for each type of crop. An important compilation of data on the optimal and marginal conditions of many crops is provided for the tropical and subtropical regions by Sys *et al.* (1993).

### 2.6.3 Land Capability Classification

This method was established by the Soil Conservation Service of USA according to the system proposed by Klingebiel and Montgomery (1961) and has been widely used throughout the world with numerous adaptations. It is a categorical system that uses qualitative criteria. The inclusion of a soil within a class is made in the inverse manner that is, without directly analysing its capacity, but rather its degree of limitation with respect to a parameter according to a concrete use. Some factors that restrict soil use can be used to define the productive capacity (intrinsic: soil depth, texture, structure, permeability, rockiness, salinity, soil management; extrinsic: temperature and rainfall) and yield loss (slope of the terrain and degree of erosion). Five systems of permanent

agricultural exploitation are considered: permanent soil cultivation, occasional soil cultivation, pasture, woods and natural reserves. This system seeks maximum production with minimum losses in potential. Three levels of classification were established: classes, subclasses and units. Also, 8 classes with increasing limitations in use are defined from I to VIII. As a function of the permitted uses, 4 use groups can be distinguished: permanent soil cultivation (or any type of exploitation; Class I, suitable soils; Class II, good soils but with some limitations; Class III, soils acceptable but with severe limitations), occasional soil cultivation (pastures, woods or natural reserves; Class IV, not recommended for agricultural use for severe limitations and/or required careful management); no soil cultivation, only pastures (in forests or natural reserves; Classes V, VI and VII) and natural reserves (Class VIII).

Depending on the type of limitation, various subclasses of capacity are established: e, for erosion risks; w, for wetness and drainage; s, for rooting and tillage limitations resulting from shallowness, drought risk, stoniness, or salinity; c, for climatic limitations. The capability units represent similar proposals of use and management.

Many authors have amplified the number of limiting characteristics used. Furthermore, it is frequent that in their application, quantitative criteria are introduced (Bibby and Mackney, 1969; Burnan and McRae, 1974; Bartelli, 1978) and have even changed the number of classes and subclasses defined (in Portugal, Azevedo and Cardoso, 1962; in Pakistan, Islam, 1966; in India, Murphy et al., 1968; in Ghana, Obeng, 1968; in England, Bibby and Mackney, 1969; in Nigeria, Carroll, 1974; in Spain, Sánchez *et al.*, 1984).

This system presents unquestionable advantages, although it does not lack disadvantages. The classes are defined with criteria that are very general, simple and

easy to understand as well as adapt to very diverse regions, but it proves difficult to apply with objective criteria. All the evaluation characteristics that make up the agricultural capacity have identical weight. The same class, with only one parameter (the maximum limiting factor) that classifies the soil within a certain class, embraces highly different soils. This system provides a highly general classification of soil capacity, since it dispenses with many soil characteristics of undeniable interest, but has the advantage of not requiring a detailed knowledge of the soil. On not using all the limiting factors that affect the use capacity of a soil, important information is lost for the user (Año *et al.*, 1997). Its use proves quite subjective, though it adapts well to the experience of the evaluator. Its results materialize very well on a map, avoiding the erroneous evaluations that parametric methods can produce (McRae and Burnham, 1981).

### 2.6.4 Storie Index

This represents the first parametric approach that was developed by Storie (1933). It is an index that uses the multiplicative scheme. In addition, it uses intrinsic properties of the soils (genetic profile, parent material, profile depth, texture, drainage, nutrients, acidity an alkalinity), characteristics of the soil surface (slope and microrelief) and aspects of soil conservation (degree of erosion). The evaluation properties are grouped into four factors that are quantified in the corresponding tables. The factors are weighed *a priori*, the more important being related on a scale from 5 to 100 and the less important factors from 80 to 100.

With this index, general agricultural soil uses can be evaluated (hence it is a soil-capability evaluation method). To formulate the index, the four factors are multiplied together and the index is expressed as a percentage. Six classes are defined at the degree

level, with decreasing values from 1 to 6. The degrees 1 to 3 are for agricultural use, degree 4 for very limited agricultural use, 5 for pasture and 6 without use. Subdegrees are established according to limiting factors: “s” for depth, “p” for permeability, “x” for texture, “t “slope, “d” for drainage and “a” for salts. It is important to emphasize that this system does not consider climatic characteristics. Thus the evaluation is of the soil itself, valid for comparing the soils of a certain region with the same type of climate.

This evaluation index was developed for California, and thus application to other regions of the world has involved numerous modifications (in Canada by Bowser, 1940; in India by Shome and Raychaudhuri, 1960; in tropical countries by Sys and Frankart, 1972; in arid regions by Sys and Verheye, 1974).

### 2.6.5 Productivity Index

The basic concept of this method developed by Riquier et al. (FAO, 1976) is that agricultural-soil productivity, under optimal management conditions, depends on the intrinsic characteristics. This is a multiplicative parametric method to evaluate soil productivity, from a scheme similar to the Storie index. The concept of productivity is defined as the capacity to produce a certain quantity of harvest per hectare per year, expressed as a percentage of optimal productivity, which would provide a suitable soil in its first year of cultivation. The introduction of improvement practices leads to a potential productivity or potentiality. The quotient between the productivity and the potentiality is called the improvement coefficient. The evaluation is made for three general types of use: agricultural crops, cultivation of shallow-rooted plants (pastures), and deep-rooted plants (fruit trees and forestation).

The determining factors of soil depth are: wetness, drainage, effective depth, texture/structure, base saturation of the adsorbent complex, soluble-salt concentration,

organic matter, cation-exchange capacity/nature of the clay and mineral reserves. The parameters of the soil surface (e.g., slope, erosion, flood tendency, or climate) are not considered. The different parameters are evaluated in tables and, as in the Storie index, the evaluation factors present different weights.

Productivity is expressed as the product of all these factors expressed in percentages. Five productivity classes are defined: class P1 = excellent; class P2 = good, valid for all types of agricultural crops; class P3 = medium, for marginal agricultural use, suitable for non-fruiting trees; class P4 = poor, for pasture or forestation or recreation; class P5 = very poor or null, soils not adequate for any type of exploitation. The improvement coefficient is the ratio between the productivity and the potentiality and represents a good index for evaluating the feasibility of these possible improvements.

This is a quantitative method, precise (although the partial scoring of the different parameters is quite arbitrary), objective (the only objective is the mathematical method), simple and easy to calculate. The evaluations reflect the degree of suitability of the different evaluation parameters, so that it proves easy to determine the possible improvements for each soil. The evaluation parameters as well as the resulting assessment can be adapted to local conditions.

### 2.6.6 Soil Fertility Capability Classification (FCC)

This was proposed by Buol *et al.*, (1975) and modified by Sanchez *et al.* (1982) to evaluate soil fertility. In this system, three levels or categories were established. The first, the type, was determined by the texture of the arable layer, or of the first 20 cm, if this is thinner. Its denomination and range are: S, sandy (sandy and sandy loam); L, loams <35% clay (excluding sandy and sandy loam); C, clayey > 35% clay; O, organic > 30% organic matter to 50 cm or more.

The type of substrate is the second level and is used when there is a significant textural change in the first 50 cm of the soil. It is expressed with the same letters, adding "R" when a rock or a hard layer is found within this depth.

The third level is comprised of the modifiers, which are the chemical and physical parameters that negatively influence soil fertility. These are numerous and are represented by lower-case letters. In the denomination of the soil class, the principle limitations for use are directly represented. For example, for an Orthic Solonchak, the FCC class that represents it is LCds, which signifies that it is a soil susceptible to severe erosion (L), limited drainage (C), dry soil moisture regime (d) and with salinity (s).

### 2.6.7 Major Systems for Land Agricultural Suitability Evaluation

The methods of land suitability evaluate the aptness of soils for certain crops and specific management. These are doubtless the most logical systems, as each soil use has its own demands, while the evaluations of land capability, of general uses, are considered limitations with mean values that affect the most usual uses. In these specific evaluations, socio-economic factors take on great importance. It requires that the benefits exceed the necessary investment, and for the evaluation, the local or national determinants should be considered. The evaluation has two focuses: to determine either which lands are best for a certain crop or which crop is suitable for each type of land. These evaluation systems can be as numerous as the soil uses. To homogenize the criteria, the FAO has proposed an evaluation system which, more than a complete system, is a scheme with general guidelines to formulate specific evaluation systems.

*2.6.7.1 The FAO Framework for Land Evaluation*

The FAO Framework for Land Evaluation (FAO 1976 and subsequent guidelines: for rainfed agriculture, 1983; forestry, 1984; irrigated agriculture, 1985; extensive grazing, 1991) is considered to be a standard reference system in land evaluation throughout the world (Dent and Young, 1981; van Diepen *et al.*, 1991), and has been applied both in developed as well as developing countries.

This framework is an approach, not a method. It is designed primarily to provide tools for the formulation of each concrete evaluation. The system is based on the following concepts: i) the land is qualified, not only the soil. ii) Land suitability must be defined for a specific soil use (crop and management). iii) Land evaluation was to take into account both the physical conditions as well as economic ones; iv) The concept of land evaluation is essentially economic, social and political. v) The evaluation requires a comparison between two or more alternative kinds of use. vi) The evaluation must propose a use that is sustainable. vii) A multidisciplinary approach is required (Purnell, 1979; van Diepen et al., 1991).

In the scheme, four categories are recognized. The highest category is the order that it reflects, in broad features, whether a soil is suitable or not for a given use. Two orders are recognized:

S = Suitable. Land in which the benefits exceed the costs and sustained use does not incapacitate the soil over a sufficiently long period of time.

N = Not suitable. Land can be classified as not suitable for a certain use for diverse reasons. The use proposed may be deemed technically impractical, as in irrigation of abrupt rocky terrain, or that it causes serious environmental degradation, as in

cultivation on steep slopes. Frequently, however, the reason is economic, in that the profit expected does not justify the cost required.

The second category is the class that reflects degrees of suitability within the order. These are numbered consecutively in Arabic numerals.

For the order S, three classes are considered:

S1 = Highly suitable. Without limitations for sustained use or minor limitations that do not affect productivity nor appreciably increase costs.

S2 = Moderately suitable. Moderately serious limitations that reduce profits or involve risks of degradation in the sustained use of the soil.

S3 = Marginally suitable. The limitations for the sustained use are serious and the balance between the costs and benefits make the use only marginally justifiable. Its use is normally justified on other than economic grounds.

In the order N, three classes are also recognized:

N1 = Not currently suitable. Land with limitations that could be eliminated by technical means or investment, but that these changes are at present unfeasible.

N2 = Permanently unsuitable. Serious limitations of generally a physical nature, which are assumed to be beyond solving over the long term.

X = Land for conservation. Unsuitable for exploitation, being lands of special protection, due to their conservation, wildlife, of special scientific, ecological or social interest (e.g., parks, reserves or recreational zones).

The limits between the orders (S and N) and between the different classes (S1, S2, S3 and N1, N2) are established by the presence of limiting factors. One limiting factor is a characteristic of the soil that hampers its use, reduces productivity, increases costs and implies degradation risk, or all of the above.

These limiting factors are used to define the third category of the system, which is the subclass. In the symbol of each subclass, the number of limitations involved should be kept to the minimum one letter, or, rarely, two. The limitations proposed include: t, slope; e, erosion risk; p, depth; s, salinity; d, drainage; c, bioclimatic deficiency; r, rockiness; i, flood risk.

Finally, the fourth category is the unit that establishes the differences within the subclasses as a function of the desired use. All of the units within a subclass (S2rA, S2rM, ...) have the same degree of suitability at the subclass level (S2) and analogous characteristics of limitation at the subclass level (r). The units differ from each other in their characteristics of production or in secondary aspects of their management demands. Their examination enables a detailed interpretation at the planning level of the exploitation. The units are distinguished by upper-case letters that are placed at the end. There is no limit at all for the number of units examined within a subclass. These defined are: A, intensification in the agricultural use without need of great improvements; M intensification in the agricultural use with need of major improvements (irrigation, etc.); P, use for pasture for livestock; F, forestation. In some cases, the designation “conditionally suitable” can be added so long as certain conditions are satisfied.

A very important role in this framework is represented by the concept of Land Utilization Type (LUT). It represents a thorough description of soil use for a proposed

use, in terms of crop (type and rotation), soil management (working of the soil, additives and possible irrigation) and socio-economic framework (labour cost, market, distribution, expenses, profits and subsidies). To propose a certain LUT, the crop must meet certain requirements of the land that satisfy the LUT and these are grouped under the concept of Land Use Requirements (LUR). For these requirements to be fulfilled, the land must have certain features, known as Land Qualities (LQ), which are supported by particular characteristics of the land, called Land Characteristics (LC). The LCs represent characteristics of the soils that can be examined and measured in the profile or in the laboratory, while the LQs are complex qualities that are not directly measurable but rather are estimated from a certain combination of LCs. The LQs are a direct result of the LCs. The LQs used for defining the LUT are numerous (although much less than the LCs) and as diverse as nutrient availability, workability, flooding hazards, resistance to degradation, or accessibility of the terrain.

In addition, each of these LQs are based on a set of LCs, and thus, for example the LQ "nutrient availability" is a combination of the following LCs: organic matter, nutrients (N, K, P), cation-exchange capacity, degree of saturation, pH, salinity, carbonates, depth and gravel. Meanwhile, the LQ "water availability" is based on the following LCs: texture, structure, drainage, available water and water reserve. In our opinion, to facilitate the elaboration of a certain LUT, it might be useful to use the support of LQ organized as soil qualities (SQ), climate qualities (CQ), topography qualities (TQ), management qualities (MQ) and socio-economic qualities (EQ), which are calculated on the basis of their corresponding characteristics SC, CC, TC, MC and EC.

Altogether, the Framework FAO represents a highly useful and flexible system which is easily adapted to local characteristics. The main drawbacks are: i) the conceptual

confusion caused by using pre-existing terms; ii) the poor distinction between the physical, social and economic characteristics.

An evaluation requires: i) the selection and description of the LUTs; ii) definition of the necessary LQs on the basis of the LCs; iii) definition of the suitable values of the LCs; iv) measurements of the LCs in the land units; v) an economic and social study; vi) presentation of the final suitability evaluation and reflection on a map with the corresponding evaluation units. For the LUTs, LQs and LCs, 5 conditions are established according to suitability (S1, S2, S3, N1 and N2). As the differentiating feature, the greatest limitation alone may be used. A LUT would be defined as pertaining to class S2ab if it presented the LQa and LQb of level S2 and the LQc of level S1. Or a combination of limitations (number and intensity) can be taken. The previous LUT would be defined as belonging to class S3 for having two LQs with an S2 value. Also, a correction factor can be introduced according to the soil depth at which the limitations are found.

The characteristics to take into account when making a land evaluation can be chosen by means of a statistical treatment. For example, to identify which land characteristics have repercussions in the production of a certain crop, a principal-components analysis can be performed, followed by an analysis of variance (ANOVA) to differentiate the significant characteristics. The simple regression highlights the significant properties most directly related to production. Finally, the establishment of the multiple-regression equation can establish the values of the characteristics chosen that define the suitability levels (S1, S2, S3 and N).

Boixadera and Porta (1991) calculated land capability by beginning with a series of values for land suitability for different crops. They developed a “value index” for the

Ministry of Economy and Internal Revenue of Spain, making an evaluation for 8 LUTs (corn, wheat, tomato, lettuce, potato, peach, apple and alfalfa) with two management intensities. The value index represents the mean of 16 individual evaluations.

Aguilar and Ortiz (1992) used the FAO Framework, combining it with the parametric Riquier index to define the suitability classes (S1, S2, S3, N1 and N2). Furthermore, the classes were defined for land capability instead of for land suitability as proposed in the FAO Framework.

A land evaluation can be made with the FAO Framework automatically with the useful computer program ALES (Rossiter and van Wambeke, 1995), which enable an easy construction of an expert system for land evaluation. This is not an expert system in itself, as it provides no information, but rather is an empty system that enables evaluators to introduce their own evaluation characteristics (choose their own LUTs, LQs and LCs), according to their own knowledge and data availability. The MicroLEIS of De la Rosa et al. (1992) is a complete computer program to evaluate according to the FAO Framework adapted to the Mediterranean environment.

*2.6.7.2 The Irrigation Suitability Classification*

The classification was developed by Unites States Bureau of Reclamation (USBR) in 1953**.** The estimation of the land capacity for irrigation is basic in the plans for development, as irrigated crops constitute the most productive form of agriculture and are especially profitable in arid and semi-arid regions.

The characteristics and qualities of the soil, needed in the evaluation related to irrigation, concern soil, drainage, hydrology, topography, vegetation, technical

problems, economics, and social as well as political matters. Therefore, regional planning of an irrigation project requires multidisciplinary solutions.

This is a classic system, widely used, which is based on the correlations between the different factors affecting production under irrigation. The consideration of economic determinants, as a starting basis, gives rise to more realistic capacity classes. The variability of the transformation is measured by the capacity for potential payment with a view towards the amortization of the project, the maintenance of long-term productivity of the land, preventing erosion, the degradation of the structure, salinity and the continuous flooding. The payment capacity compares the costs of transformation and production against the potential productive capacity. This latter concern is a function of climate, soil, topography (slope, relief, and position), quantity and quality of the irrigation water, and the drainage system.

The Land Class is defined as a "category of land having similar physical and economic attributes which affect the suitability of land for irrigation" (McRae and Burnham, 1981). The USBR system establishes six classes to evaluate the suitability of the soils for irrigation. The parameter used and its ranges are reproduced in the corresponding tables. To facilitate the reading of the evaluation maps on each cartographic unit, a formula is written in which all the representative data are reflected.

# CHAPTER 3

# MATERIALS AND METHODS

## 3.1 DESCRIPTION OF STUDY AREA

### 3.1.1 Location of Study

The study area is located along Zaria-Sokoto road, north of Ahmadu Bello University Teaching Hospital, Zaria, which is situated in north-western Zaria, approximately between latitude $11^0$10'43''N and $11^0$11'18''N, and longitude $7^0$ 36'36''E and $7^0$ 36'57''E. Its area is about 125 hectares. The northern boundary of the project site is bordered by Kurmi village.

### 3.1.2 Geology and Geomorphology

The geological map of the study area is shown in Figure 3.1. The geology of Samaru-Zaria area has been studied by Olowu (1967); McCurry (1970); Wright and McCurry (1970); Tokarski (1972); Karofi (1972) and Akpoborie (1972). The Zaria area is underlain by metamorphic and igneous rocks termed "the Basement Complex" because of their intricate pattern.

The Basement Complex rocks in the Samaru –Zaria area has been highly weathered, and has been generally referred to as weathered mantle (du Preez, 1956; Olowu, 1967; Wright and McCurry, 1970). It may be for this reason that many authors report of the area as being underlain by undifferentiated "Basement Complex" (Geological Survey of Nigeria, 1974; Bennet *et al.,* 1977). This weathered material is marked by a network of superficial harmattan deposits where deposition has been influenced by landforms as well as alternating dry and wet seasons. Three groups of Basement Complex rocks were recognized in Zaria area. The first group is a complex, including Pre-Cambrian gneisses

of variable composition and migmatite which is medium to coarse grained and moderate to weakly foliated. These types of rocks predominate the low lying surface or plain.

A second group consists of low grade metamorphic rocks derived from early Paleozoic to Cambrian sediment. These include schist, quartzite, and psammitic rocks. These rocks are interbedded into the synclinal belts of the gneisses and migmatite. These rocks form a narrow belt of parallel ridges, low rounded hills and valley bottomlands, which trend roughly north-south across the headstream of the Tubo to the west of Zaria.

The third group consists of intrusive rocks of late Paleozoic to Cambrian age, which were intruded into the gneisses and migmatites. These rocks are generally referred to as 'Older Granites. They are mainly porphyritic biotite granite, and hornblende granites with large feldspar phenocryst. These rocks are more resistant to weathering and form inselbergs. Other rocks in the group are granodiorites and aplites. In Zaria area, the 'Older Granites' cover a very small area, with their largest outcrops forming the Kufena Inselbergs.

The geomorphology of Zaria is complex, owning to iron pan formations of different ages and the partial marking of erosion surfaces by recent drift deposits. An account of the geomorphologic and profile descriptions of some of the Samaru soils with their analytical data had been given by Higgins (1963).

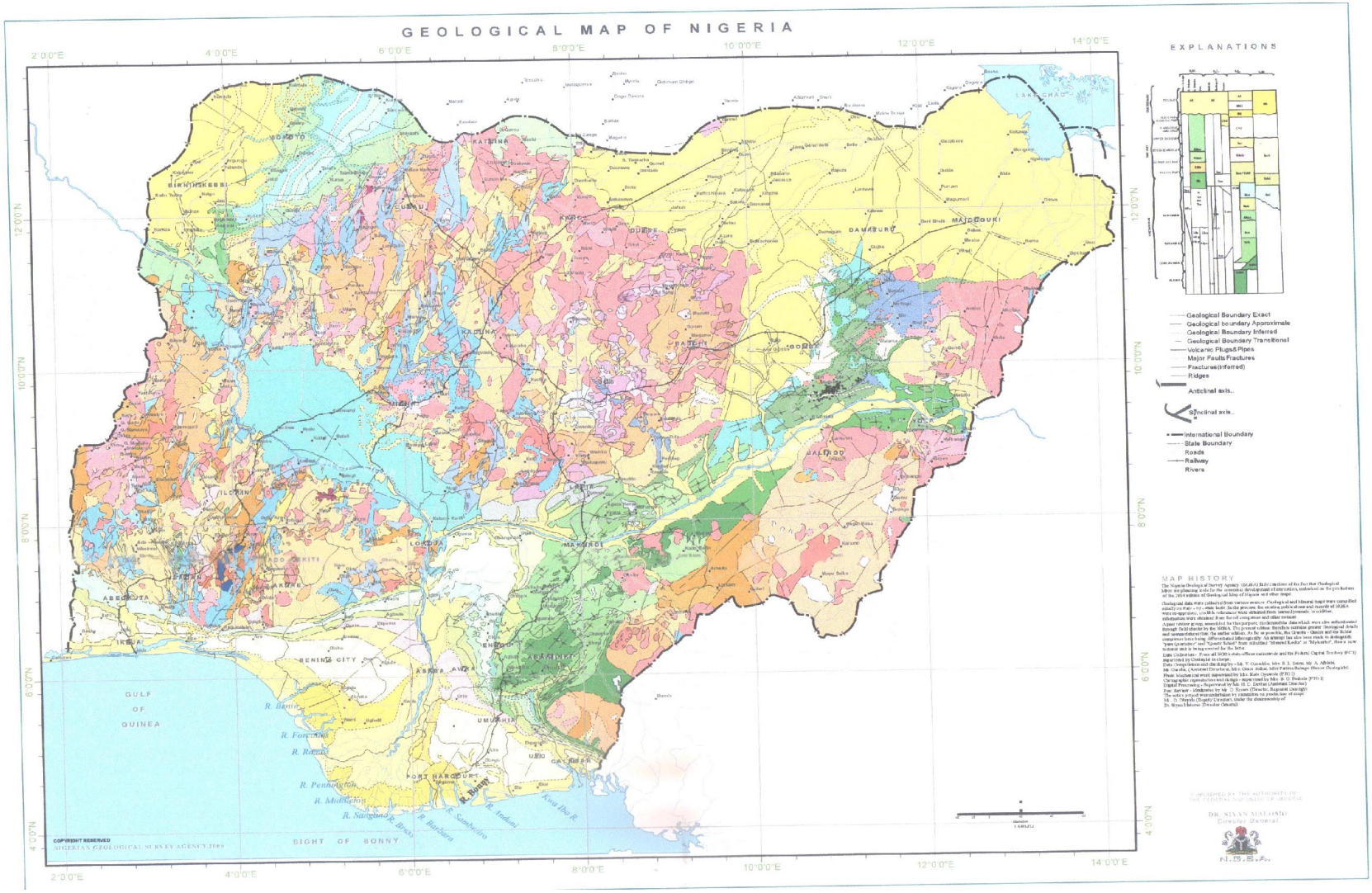



Fig 3.1: Geological map of Nigeria

Source: Geological survey agency

### 3.1.3 CLIMATE

Zaria is located at a height of about 669m above sea level in the centre of northern Nigeria. The climate of the study area is characterized by the occurrence of distinct wet and dry seasons (Owonubi et.al., 1991). It belongs to the dry subhumid tropics with a severe deficit in rainfall from October to May and surplus from June to September (Table 3.1). This implies that water is not available all year round for crop production. This low and seasonal distribution of rainfall makes its marks on the vegetation of the area, which assumes various shades of green in the wet season and turns brown, pale or yellow in the dry season.

The area experiences a tropical continentality and is well pronounced in the dry season particularly in the month of December and January. It has a mean annual rainfall of about 1100mm and duration of 2-3 hours, average intensity of 50mm/hr (Edoga et.al, 2000). The mean annual rainfall attains it highest value in August and drops rapidly to its lowest in October (Table 3.1).

The prime source of energy injected into the atmosphere is the sun. Sunshine is a major source of energy for the physical disintegration and chemical transformation of rocks. It is a major source of energy for the physiological development of plant. Radiant energy is converted into chemical energy by leaves and stored by the plants for further uses. The amount of solar radiation in the study area is adequate for photosynthetic function of cereal crops (Ogunwole et.al., 2004). The abundance of solar radiation in the savanna is a further indication of the high cereals production potential of the region (Ogunwole and Owonubi, 1998).

Availability of water, radiation, together with temperature determines crop species, type of cultivars and management methods that are suitable for cereal crop production in any

area (Ogunwole et.al., 2004). As a result of the high solar radiation in the savanna, air temperatures in the study area are generally uniformly high with a slight drop in December and January (Table 3.2). Temperature affects cereals and cotton production by controlling the rate of physiochemical reactions and that of evaporation of water from the crops and soil surfaces. Besides, temperature affects the rate at which the products of photosynthesis are used for growth, respiration and accumulation of food reserves. Maximum yields are obtained when each species are grown under temperature conditions which allow for optimum photosynthesis. Crops and crop species vary in their temperature requirements for optimum rates of photosynthesis.

### 3.1.4 Vegetation

The description of the natural vegetation of the study area is given by Ramsay and de Leeuw (1966) and Keay (1989). The area falls into the Northern Guinea Savanna zone (Keay, 1959) (Fig.3.2). The Northern Guinea Savanna zone comprises of open sub-humid broad-leaved savanna woodland with a well-developed short to medium grass layer. In the study area, the cultivated portions are made up of shrubs, few trees, herbs and grasses. The shrubs and trees include *Isoberlina doka* (Craib and Stapf), *Guiara senegalensis, Combretum glutinosum, and Terminchia avicennoides.*

The ground layer is made up of the following major grasses, *Pennisetum pedicallatum* (Linn.), *Andopogon pseudapricus* (Hack), *Andropogon gayanus* (Hack). The herbs and grasses made up the common weeds of the arable parts of the area. The uncultivated areas usually carry a vegetation of open shrub woodland in varying stage of re-growth.

**Table 3.1: Monthly and annual mean rainfall (mm) in 5 years intervals over period 1991 - 2010**

| Periods | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total of annual mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1991-1995 | 0.00 | 0.00 | 0.00 | 29.84 | 118.20 | 142.62 | 203.58 | 278.26 | 131.24 | 37.70 | 0.52 | 0.00 | 941.96 |
| 1996-2000 | 0.00 | 0.00 | 0.00 | 46.42 | 92.98 | 169.28 | 207.14 | 268.32 | 178.52 | 55.98 | 0.00 | 0.00 | 1018.64 |
| 2001-2005 | 0.00 | 0.00 | 0.00 | 34.66 | 95.18 | 154.58 | 216.42 | 307.34 | 194.12 | 31.40 | 0.00 | 0.00 | 1033.70 |
| 2006-2010 | 0.00 | 0.00 | 0.34 | 50.08 | 129.02 | 131.82 | 230.38 | 338.88 | 186.96 | 71.22 | 0.00 | 0.00 | 1138.70 |
| **Mean Monthly Rainfall (1991 - 2010)** | 0.00 | 0.00 | 0.09 | 40.25 | 108.85 | 149.58 | 214.38 | 298.20 | 172.71 | 49.08 | 0.13 | 0.00 | 1033.27 |

Source: Institute for Agricultural Research, Meteorological Unit, ABU, Zaria.

**Table 3.2: Mean monthly air temperature, soil temperature, relative humidity and sunshine hours for year 2009**

| Month | Air Temp. ($^{o}$C) | | Soil Temp. ($^{o}$C) 30cm | | RH (%) | | Sunshine (Hr) |
|---|---|---|---|---|---|---|---|
| | Min | Max | am | pm | am | pm | |
| **Jan** | 14.13 | 33.81 | 24.3 | 25.6 | 14.84 | 14.71 | 8.57 |
| **Feb** | 16.86 | 36.29 | 26.4 | 27.8 | 9.43 | 8.79 | 8.30 |
| **Mar** | 19.65 | 38.00 | 28.9 | 30.4 | 10.03 | 9.58 | 6.80 |
| **Apr** | 23.17 | 38.43 | 31.4 | 32.9 | 48.67 | 31.17 | 8.24 |
| **May** | 22.23 | 35.48 | 28.8 | 31.2 | 60.87 | 45.45 | 8.22 |
| **June** | 21.00 | 33.20 | 28.0 | 29.3 | 71.23 | 55.72 | 8.07 |
| **July** | 20.00 | 31.29 | 26.5 | 27.4 | 73.39 | 66.10 | 7.38 |
| **Aug** | 20.42 | 29.97 | 26.0 | 26.7 | 80.61 | 70.30 | 5.70 |
| **Sept** | 20.03 | 26.69 | 26.7 | 27.5 | 75.50 | 64.48 | 6.74 |
| **Oct** | 20.26 | 32.77 | 26.9 | 27.8 | 71.03 | 62.65 | 6.63 |
| **Nov** | 14.80 | 32.37 | 25.0 | 26.9 | 37.47 | 31.13 | 8.12 |
| **Dec** | 13.26 | 33.45 | 23.8 | 25.3 | 16.52 | 16.65 | 9.14 |

Source: Institute for Agricultural Research, Meteorological Unit, ABU, Zaria.

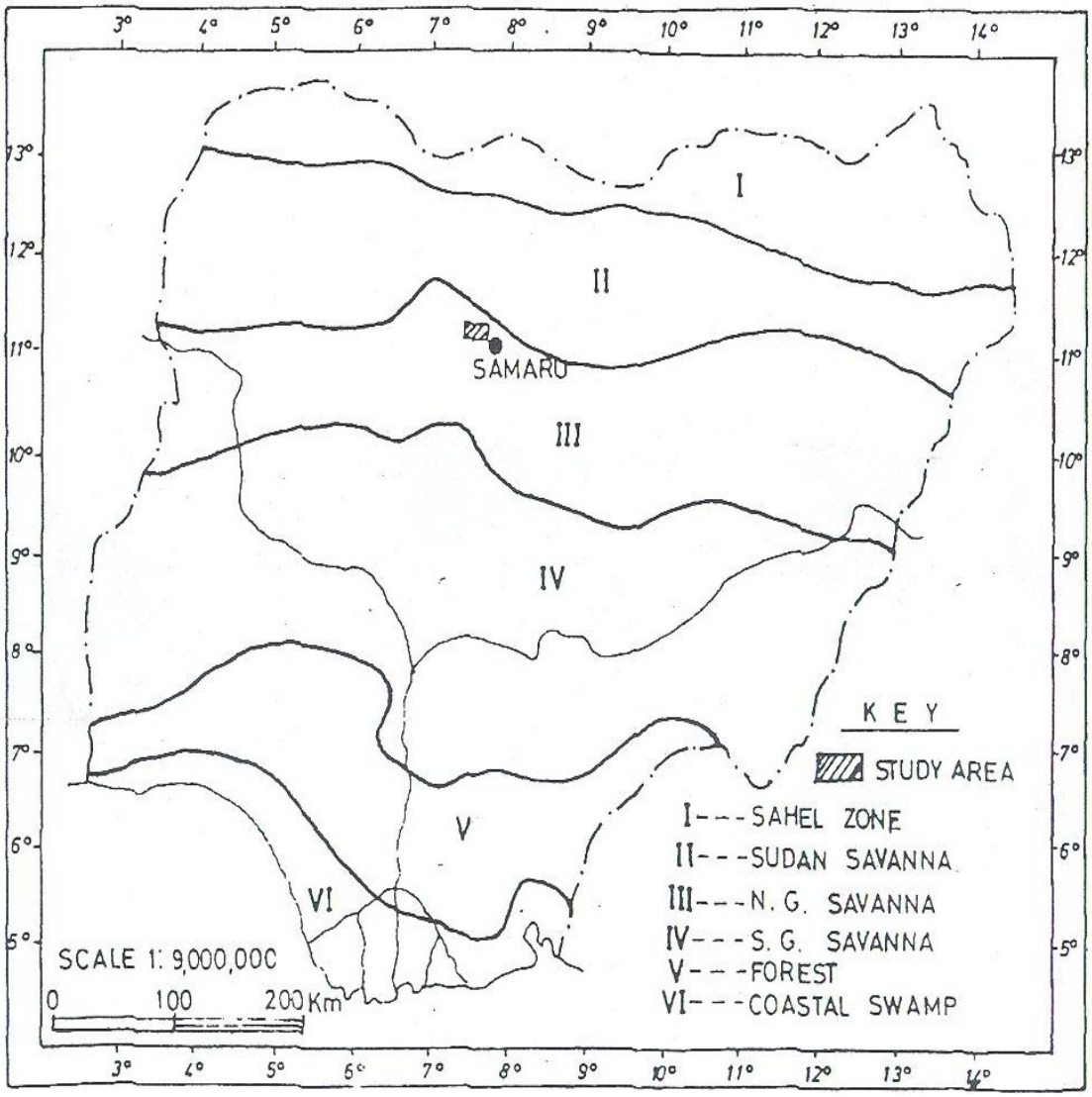



**Fig. 3.2: Ecological zones of Nigeria and the study area**

### 3.1.5 Relief and Drainage

Drainage and relief of the study area lies within the Kaduna Plains which forms a vast gently undulating topography with very long slopes, except at its junction with the East-West watershed near Funtua and the Southern Nupe plains. These parts are markedly dissected. The dissection of the East-West watershed is believed to be due to an uplift along the axis of the watershed, with subsequent rejuvenation of rivers south of it as supported by the development of terraces, gully erosion and increased number of stream tributaries (McCurry, 1973). The study area can be described as having a medium textured dendritic drainage pattern. There are mesas, few in number, generally un-conspicuous and located on interfluves within Samaru, Zaria.

The Zaria area of the Kaduna plain is drained by three major river catchment systems; the southward flowing Galma and seasonal Tubo rivers drain the Kaduna plain and empty into River Kaduna, which is a tributary of the Niger; the northwestern part is drained by the Sokoto/Rima and Gagare river system; while River Kano and Chalawa drain north eastwards to the inland basin of lake Chad. The study area is drained by the tributaries of the Shika River, which in turn is of the tributary of the Galma River.

### 3.1.6 Land Use

Gosden (1978) describes the agriculture of the Kaduna plains as being one of small-sale subsistence farming, in which cash crops play a very small but significant part. The crops are rain-fed and normally there is no assistance to land labour, except with draught animals.

The major types of landuse in the area include arable farming, firewood, forestry, firewood and timber exploitation, livestock farming as well as industrial and urban development. Arable farming consists of subsistence farming, characterized by intensive and continuous cultivation.

Livestock farming is practiced mainly by the Fulanis, who rear the stock either for milk production or fattening for slaughter. Some few forest reserves are found near the study area. The small forest plantations are Mairabo, Kabama, and Guga forest reserves. These forest reserves are mostly planted with eucalyptus and pines.

## 3.2 FIELD WORK

Field studies were concentrated on Institute for Agricultural Research farm, Shika located along Zaria-Sokoto road, north-east of the Ahmadu Bello University Teaching Hospital. The total area covered is about 125 hectares. The field studies included topographic survey and detailed soil survey.

### 3.2.1 Topographic Survey

The topographic survey was carried out with the help of a land surveyor from the Department of Geomatics Engineering of the Ahmadu Bello University, Zaria. The survey was carried out at a scale of 1:5000.

### 3.2.2 Detailed Soil Survey

The detailed soil survey of the area was carried out using the rigid grid method at a scale of 1:5000. The Baseline used was perpendicular to the Samaru-Shika road. Five transects were cut 100m apart along the baseline. Auger boring were made at 100m interval along the traverses, especially where soil depth at 75-100cm, colour and texture change were detected. Three distinct soil units were identified and mapped as Soil Unit A, Soil Unit B and Soil Unit C.

Two profile pits each were dug in soil unit A, soil unit B and soil unit C. The morphological characteristics of the soil profiles were then described following the procedure in soil survey manual (Soil Survey Division Staff, 1993). Following their descriptions, bulk soil samples from pedogenic horizons were collected in polythene

bags for laboratory studies. Similarly, undisturbed core samples were collected using $100cm^3$ – metal cylinders for bulk density.

## 3.3 LABORATORY ANALYSIS

### 3.3.1 Preparation of Soil Samples

The soil samples collected from the six pedons were properly labeled and taken to the laboratory, where they were air-dried. They were gently crushed to break up the peds, subsequently sieved with a 2mm sieve. Materials retained on the sieve were labeled 'gravel' (> 2mm) while materials that passed through the sieve were labeled 'fine earth' (< 2mm) fractions. Both the gravel (material > 2mm) and the fine earth (material <2mm) were weighed and the percentage composition of gravel were calculated. The <2mm soil separates were kept for further analysis.

### 3.3.2 Particle Size Distribution Analysis

Particle size distribution was determined by the method described by Day (1965). The gravel content was first determined by direct sieving, followed by weighing. Sand, silt and clay were determined by the Bouyoucos hydrometer using 5% Calgon (Sodium hexametaphosphate) solution, by shaking on a reciprocating shaker for 24 hours for proper or complete dispersion of the soil and determining sizes and amount of particles settling by employing progressive time intervals.

### 3.3.3 Bulk Density

Bulk density was determined by oven-drying the undisturbed soil samples collected in 100$cm^3$ –metal cylinders to constant weight at $105^0$C and dividing the dry weight of the sample by total volume of the sample.

Bulk density ($gcm^{-3}$) = $\frac{\text{weight of oven dry soil (g)}}{\text{Volume of soil}}$

### 3.3.4 Soil pH

Soil pH was determined both in $H_2O$, and 1*M*CaCl solutions in a 1:2.5 soil solution ratio using a Pye Unicam model 290 MK pH meter. Delta pH values (pH) $CaCl_2$ – (pH) $H_20$ was calculated.

### 3.3.5 Exchangeable Bases

Ten grams of soil were leached for two hours with ($NH_4OAc$) at pH 7.0 into a 100ml volumetric flask. The exchangeable bases (Ca, Mg, K and Na) were extracted with neutral (pH 7.0) ammonium acetate ($NH_4OAc$) solution by repeated extraction (Anderson and Ingram, 1993). Potassium and sodium were read from the undiluted extract on a Gallenkamo flame photometer, while calcium and magnesium in solution were read in a Pye Unicam Model Sp 192 atomic absorption spectrophotometer (AAS) at 423 and 485nm wavelength respectively.

### 3.3.6 Exchangeable Acidity

Exchangeable acidity was determined using 1*M* KCl (Peach, 1965). Ten grams of soil was leached for two hours with 1ml potassium chloride (KCl) into a 100ml volumetric flask. Three drops of phenolphthalein indicator was added to 50ml of the leacheate which was then titrated with 1.0*M* NaOH to the pink end point. It was the back titrated with a few drops of 0.1*M* NaF, and titration continued using 0.1*M* HCl till colourless end point which persisted for over 10 seconds was obtained. Exchangeable acidity was calculated from the milliequivalents of NaOH used.

### 3.3.7 Cation Exchange Capacity (CEC)

Cation Exchange Capacity (CEC) was determined by the neutral (pH 7.0) $NH_4OAc$ saturation method (Anderson and Ingram, 1993). The Cation Exchange Capacity of the mineral clay colloid was estimated from CEC ( $NH_4OAc$) and the percentage of organic carbon (% O.C.) as follows:

$$\text{CEC (clay)} = \frac{\text{CEC } (NH_4OAc) - (3.5 \times \%OC)}{\%\ \text{clay}} \times 100$$

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

### 3.3.8 Effective CEC

Effective CEC was determined as the sum of total exchangeable bases by (NH4OAc) and 1*M*KCl extractable acidity.

### 3.3.9 Base Saturation (BS)

Base saturation was calculated for both ECEC and CEC ($NH_4OAc$) from the formula:

$$\% \text{ Base Saturation} = \frac{\text{Total exchangeable bases}}{\text{ECEC or CEC}} \times 100$$

### 3.3.10 Organic Carbon (OC)

The acid-dichromate wet oxidation method of Walkey and Black as described by Nelson and Sommers (1982) was used in the determination of organic carbon. The soil organic matter was digested with potassium dichromate ($K_2Cr_2O_7$) using concentrated sulphuric acid to increase temperature and hasten the reaction. One gram each of the finely ground air-dried soil sample was weighed into 250ml Erlen Meyer flasks and 10mls of 1*M* $K_2Cr_2O_7$ added. Then 20mls concentrated sulphuric acid ($H_2SO_4$) was added and the content of each flask was allowed to stand for thirty minutes after which the mixture in it was diluted to 250ml with distilled water. Excess dichromate was back-titrated with ferrous ammonium sulphate using barium diphenylamine sulphate as indicator.

### 3.3.11 Available Phosphorus

Available phosphorus was determined by the Bray No -1 Method (Bray and Kurtz, 1945). Phosphorus extracting solution (7ml) was added to 1g of soil in a test-tube and shaken for about five minutes. The content of the test-tube was filtered into another test-tube. Then 1ml of solution made of 5ml of distilled water, 2ml of ammonium molybdate, concentrated stanuous chloride and 33ml water was added to the filtrate,

shaken and allowed to develop colour. Phosphorus in solution was determined calorimetrically by the ascorbic acid method (Murphy and Riley, 1962).

### 3.3.12 Total Nitrogen

Total nitrogen was determined by the regular Macro-Kjeldahl technique (Bremmer, and Mulvaney, 1982). One gram of soil was weighed into a digesting tube into which 20ml of concentrated sulphuric acid was added and digested for two hours. The content of the tube was then emptied into a 250ml volumetric flask and filled to mark. This was distilled after which 10ml of the distillate was titrated with 0.01m $H_2SO_4$ to the end point. Potassium sulphate ($K_2SO_4$) was used as the catalyst.

### 3.3.13 0.01*M* HCl Extractable Micronutrients (Cu, Zn, Mn, and Fe)

The 0.1 *M* HCl extraction method of Osiname *et al.,* (1973) was used in the determination of HCl extractable micronutrient. The micronutrient cations in solution was read on the AAS; Cu at 325nm, Zn at 214nm, Mn at 80nm and Fe at 373.9mm wavelengths.

## 3.4 STATISTICAL ANALYSIS

The data generated were analyzed statistically using analysis of variance (ANOVA) (One–way) to compare the means of each parameter. Correlation analyses by Statistical Analysis System (SAS) were used to relate the various soil parameters determined.

## 3.5 SOIL CLASSIFICATION

Soil classification was done according to the USDA Soil Taxonomy (Soil Survey Staff, 1999) and the FAO World Reference Base for Soil Resources (FAO – ISRIC – ISSS, 1998).

## 3.6 LAND SUITABILITY CLASSIFICATION

The approach adopted for developing suitability classes for rain-fed arable crops; cotton, cowpea, maize, and sorghum in this study was the principle of matching the land use requirements with land qualities (FAO, 1995). The land suitability evaluation of the soil was done using the additive and limiting procedures of Sys *et al.,* (1991).

The parameters used for the land quality calculation included rainfall, length of growing season, mean temperature, slope, wetness, drainage, texture and volume of coarse. Materials include soil depth, fertility, cation exchange, base saturation and organic carbon. The sums of these were divided by the number of the parameters considered to determine their values. The soil suitability classification consisted of assessing and grouping the land types in orders, classes and subclasses and units based on the crop requirements. The suitability classification was done separately for each soil unit identified in the survey area.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 TOPOGRAPHIC SURVEY

The topographical map is shown in Fig 4.1. The relief of the study area was gently sloping. The contour interval was 0.2meters. The highest elevation was at 686.2m and the lowest at 682m. Soil units A and B occupy the upper to middle slope positions while soil unit C occupy the lower slope position.

## 4.2 SOIL MORPHOLOGY

The soil map is shown in Fig 4.2. Three distinct soil units are scattered in the various landscape positions. Soil unit A occupies the upper slope position, soil unit B occupies the middle slope position and soil unit C occupies the lower slope. A greater extent of the land was under arable farming, except for the exposed iron pan surfaces that are under fallow.

Soil morphological properties studied are summarized in Table 4.1. The detailed profile descriptions are given in Appendix A. Morphological properties, some of which are quite important in the classification of the soils include soil depth, colour, texture, structure, consistence and horizon differentiation. They also indicate the degree of soil development.

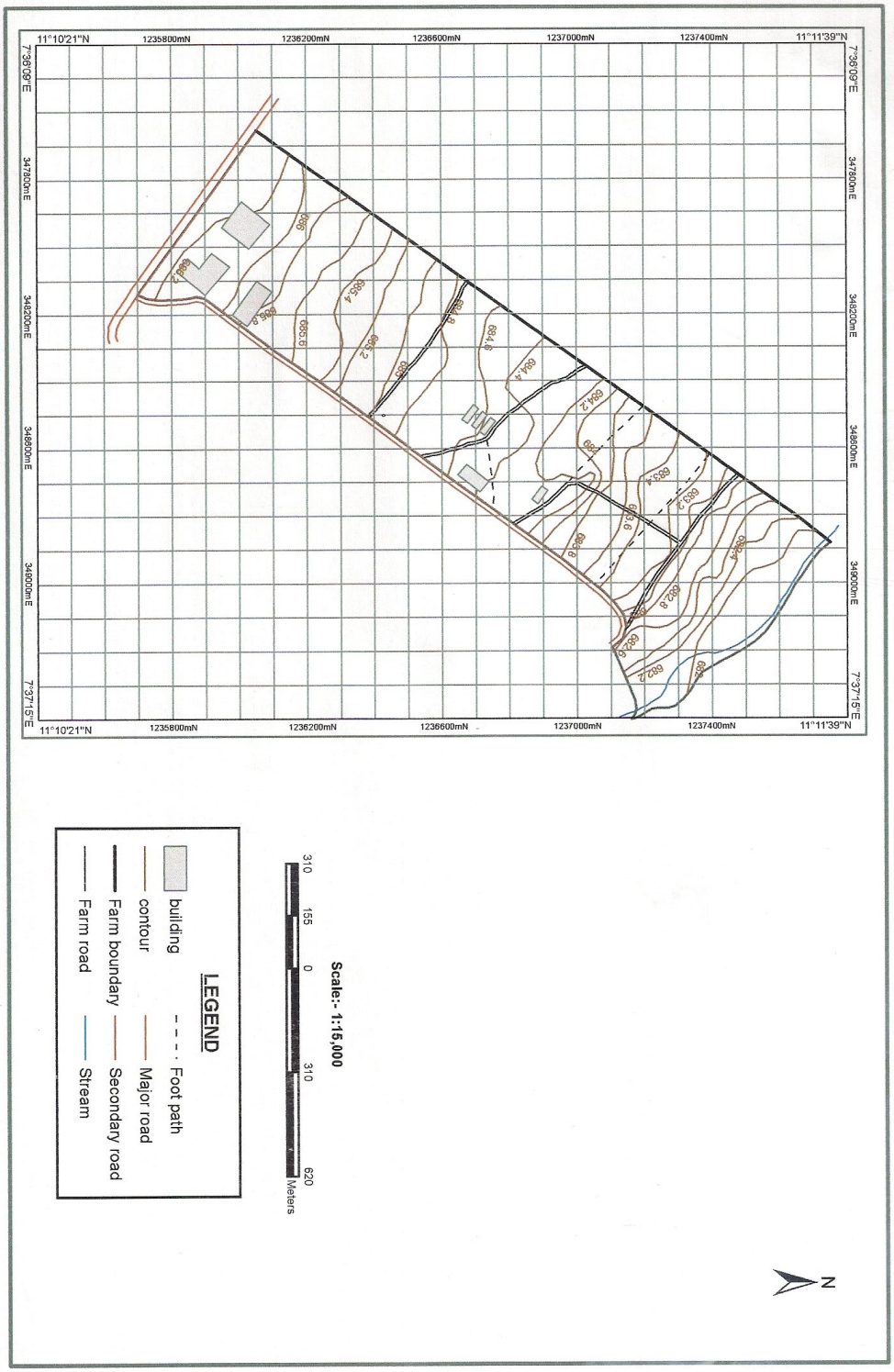



**Figure 4.1: Contour Map of IAR Research Farm**



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### 4.2.1 Soil Depth

Soil depth varied both within and among soil units. All the soils are deep to shallow, the deepest profile being 166cm deep, while the shallowest measured a depth of 4cm. The depth was restricted by the presence of parent rock at depth of 4cm. This is in agreement with the report of Mosugu (1989) that depths restrictions in soils of the basement complex were as a result of contact with underlying weathering rocks. The depths of all the soil profiles except pedon PA2 will permit crop root proliferation and elongation since the hard pan / lithic contact is deep enough not to constitute hindrance to root development.

**Table 4.1: Soil morphological properties of IAR Research farm.**

| Horizon | Depth (cm) | Munsell colour (moist) | Texture | Structure | Consistency | | | Boundary | Features |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Wet | moist | dry | | |
| **Soil Unit A** | | | | | | | | | |
| **Pedon A1** | | | | | | | | | |
| Ap | 0-27 | 10YR ¾ | Sl | msmsbk | Ssnp | fr | s | G | Common medium roots. |
| Btc | 27-63 | 2.5YR 4/8 | Gscl | wfcrsbk | Ss | l | s | C | Few fine roots. |
| C | 63-115 | 2.5YR 4/6 | Gcl | structureless | Ss | fm | sh | C | Many coarse gravels. |
| **Pedon A2** | | | | | | | | | |
| Apv | 0-4 | 10YR 3/2 | Gsl | msmsbk | Ns | vfr | l | A | Many medium roots, gravels. |
| **Soil Unit B** | | | | | | | | | |
| **Pedon B1** | | | | | | | | | |
| Ap | 0-23 | 10YR 3/3 | Sl | msmsbk | Ss | fr | s | C | Few fine roots,tubular micropores. |
| BE | 23-41 | 7.5YR 5/6 | Scl | msmsbk | S | fm | sh | C | Common fine roots, many micropores. |
| Bt1 | 41-81 | 5YR 5/8 | Cl | scsbk | S | vfm | h | A | Few fine roots, presence of macro-micropores. |
| Bt2 | 81-142 | 5YR 5/8 | Cl | scsbk | S | vfm | h | C | Few fine roots, few empty termite holes, few clay skins. |
| Bct | 142-166 | 10YR 7/6 | Sc | scsbk | S | vfm | h | A | Few medium roots, few gravels, few concretions. |
| **Pedon B2** | | | | | | | | | |
| Ap | 0-23 | 10YR 4/3 | Sl | msmsbk | S | vfr | s | C | Common medium roots, few micropores. |
| Bt | 23-97 | 7.5YR 4/6 | Cl | scsbk | S | fm | h | A | Few fine roots, few micropores/macropores, few empty termite holes. |
| Bctg | 97-150 | 7.5YR 5/6 | Cl | scsbk | S | fm | h | C | Common coarse roots,few micropores. |
| **Soil Unit C** | | | | | | | | | |
| **Pedon C1** | | | | | | | | | |
| Ap | 0-20 | 2.5YR 4/1 | Cl | wfcrsbk | Ss | fm | h | C | Many medium roots, few micropores. |
| Bt1 | 20-89 | 2.5YR 6/2 | Cl | wfcrsbk | S | fm | vh | A | Few coarse roots, few micropores. |
| Bctgv | 89-114 | 2.5Y 7/1 | Gc | structureless | Ss | fm | vh | A | Many coarse gravel, few fine roots, water table high. |
| **Pedon C2** | | | | | | | | | |
| Apg | 0-30 | 2.5Y 5/1 | C | msmsbk | Vs | fm | vh | C | Common fine roots, few micropores. |
| Bt1g | 30-90 | 2.5Y 6/1 | C | msmsbk | Vs | vfm | vh | A | Few fine roots, few micropores. |
| Bt2g | 90-145 | Gley2 ( 7/5) | C | msmsbk | Vs | vfm | vh | C | Common medium concretions, common micropores. |

* Symbols are defined in appendix B

### 4.2.2 Soil Colour

The kind, amount and distribution of organic matter, various mineral substances, mainly iron compounds, and/or stagnant water table cause soils to appear in different colour (Farshad, 1984). The unit A soils are well drained as evidenced by the absence of mottles within 100cm depth in the entire soil profile, the soils of unit B are moderately drained (Plate 2), while soils of unit C are poorly drained (Plates 3 and 4).

Soils developed on soil unit A had dark yellowish brown (10YR 3/4) surface horizons over red (2.5 YR 4/8) subsurface horizons. Pedon PA2 had a very dark grayish brown (10YR 3/2). Soil unit B had a range of dark brown (10YR 3/3) to brown (10YR 4/3) Ap horizon and a range of yellowish red (5 YR 5/8) to strong brown (7.5 YR 4/6) subsoil.

Soil unit C had a dark reddish gray (2.5Y 4/1) to gray (2.5Y5/1) while the subsoil had a range of pale red (2.5YR 6/2) to reddish gray (2.5Y 6/1) with a yellow (2.5Y7/6) Bt2g horizon. The reddish, brownish or yellowish colours indicate soils with oxidized iron content and the gray to light gray conditions indicate a reduced iron to ferrous state under wet aerobic condition.

### 4.2.3 Soil Texture

Soil texture is the relative proportions of the various size groups of individual soil grains in a mass of soil (Table 4.1). The table shows relative proportions of different separates namely gravel, sand, silt and clay and classes of the soil samples. The texture of the profiles ranged from gravelly loam to silty clay loam in the surface horizons.

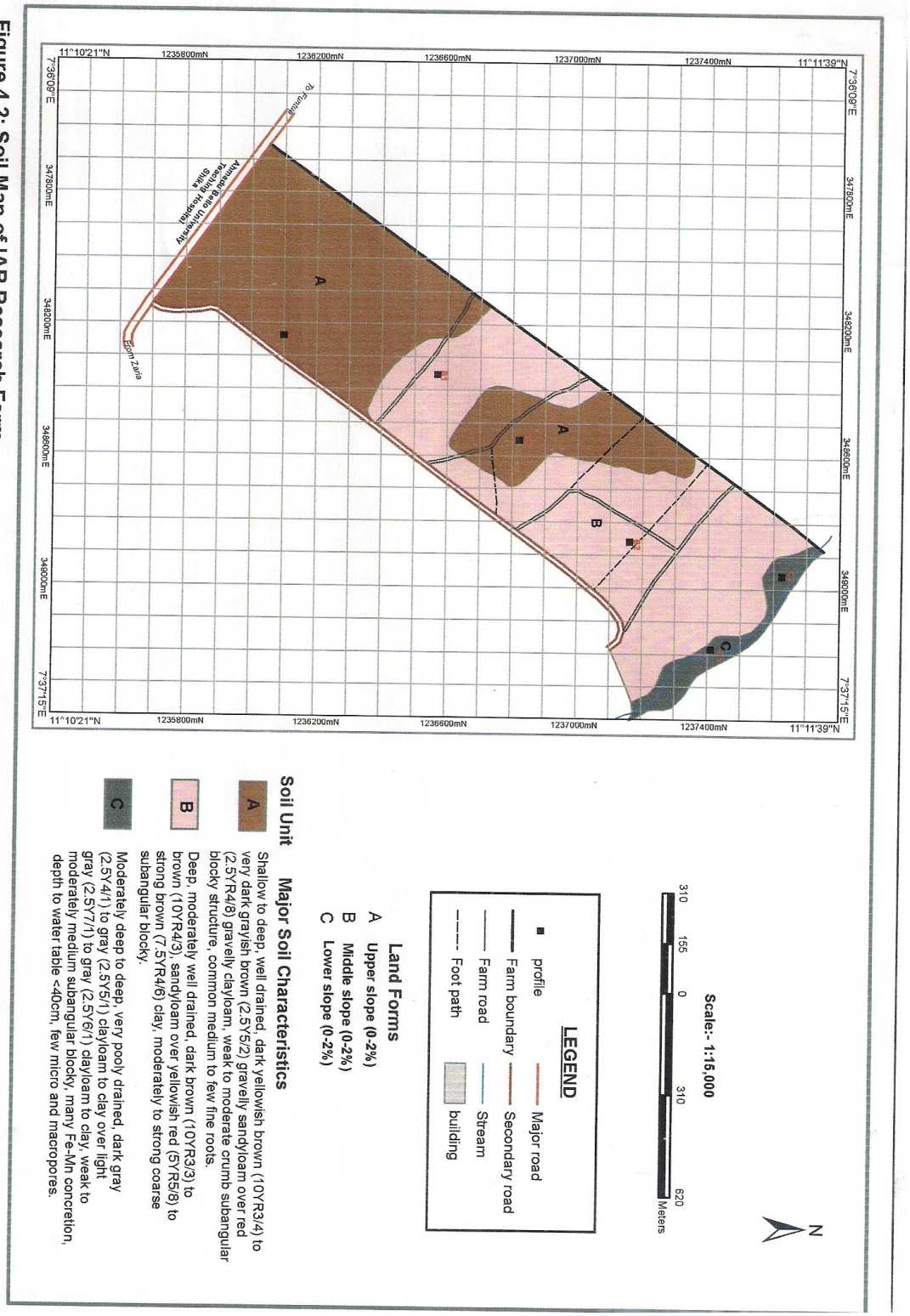



**Figure 4.2: Soil Map of IAR Research Farm**

Fig. 4.2: Soil map of the study area



Plate 4.1: Pedon A1 in soil unit A showing simple profile horizonation



Plate 4.2: Pedon B1 in soil unit B showing mottles at lower depth.



Plate 4.3: Pedon C1 in soil unit C showing evidence of gleization



Plate 4.4: Pedon C2 in soil unit C showing high water table level

Soil Unit A had a gravelly texture which increases throughout the horizons in which the mean gravel of 515gKg$^{-1}$ was obtained. There is insignificant quantity of gravel in soil units B and C, except in pedon PC1 where the Bctgv had gravel content of 300 gkg$^{-1}$. These gravels were mostly Fe or Fe and Mn concretions or nodules. Ferritization was, therefore an active soil forming process in the area.

The sand fraction decreased regularly with depth in soils of units A and B, ranging from 220gkg$^{-1}$ to 600gkg$^{-1}$. The soil unit C had irregular pattern of sand fraction ranging from 200gkg$^{-1}$ to 400gkg$^{-1}$ (mean 287gkg$^{-1}$).

The values of the clay content increased with depth in all the soils and ranged from 140gkg$^{-1}$ to 480gkg$^{-1}$. Increase in clay content with depth indicated clay migration and erosion from the soil surface layer into the subsurface horizon, giving rise to pronounced argillic horizons which characterized most of the Nigerian savanna soils as reported by Esu (1987), Maniyunda (1999).

The silt content generally decreased from the top soil to the subsoil throughout the study area. The silt content in the Ap horizons ranged from 360gkg$^{-1}$ to 460gkg$^{-1}$ and a range of 280gkg$^{-1}$ to 420gkg$^{-1}$ in the subsoils.

### 4.2.4 Soil Structure

Soil structures refers to clusters of primary particles, which are separated from adjoining aggregates by surfaces of weakness, that is, due to the contribution of physical processes (drying, cracking) and possible later modifications caused by biological activities.

Subangular blocky structures were dominant in soil units, A, B and C. This is due to greater pedogenic development (Yaro, 2005). Blocky structure is often found in B horizons (Singer and Munns, 1999).

### 4.2.5 Soil Consistence

Soil consistence comprises the attributes of soil minerals that are expressed by the degree and kind of cohesion and adhesion or by the degree of resistance to deformation or rupture. Soil units A and B had consistence ranging from slightly sticky and non-plastic to sticky to slightly plastic (wet); very friable to friable (moist) and soft in the Ap horizons. The sub horizons were generally slightly sticky and plastic to sticky (wet), very friable to very firm (moist) and soft to hard (dry).

The horizons of soil unit C, generally had slightly sticky, slightly plastic to very sticky and plastic (wet); firm to very firm (moist) and hard to very hard (dry). The increase in consistence down the profile and between soils might be attributed to the increase in clay content (Raji, 1995). It also buttresses the assertion made by Singer and Munns (1999) that more clay increases the hardness of dry soils.

### 4.2.6 Horizonation within Profiles

Horizon differentiation in soil units A and B is not quite pronounced. In each case, however, the Ap horizons were quite distinct from the B horizons and marked by clear boundaries due to melanization by organic matter in the Ap horizons. Soil unit C showed more distinct horizons within the profile. There was evidence of gleization within the profiles. The profiles are shown in Plate 1 and 2.

### 4.2.7 Other Morphological Features

The Ap horizons of all the soil units have common medium pores to common fine pores. Similarly, the subsoil horizons of all the soil units had common fine pores. There were few fine to common medium roots in the Ap horizons of all the soil units, while the subsoil horizons had few fine roots. Generally, the content of roots decreased with increase in soil depths. Many roots were found mostly in Ap horizons, which are the zones of root activities.

The iron nodules were almost absent in the Ap horizons of soil unit A and B, but were present up to the Ap Horizons of soil unit C. The sub-surface horizons of soil unit B and C had both iron and manganese nodules. Iron and manganese have been reported as constituent of plinthite (Sivarajesingham *et al.,* 1962). Few empty termite holes were common in all the soil units, indicating that termites also contributed significantly to fauna pedoturbation in the soils.

## 4.3 PHYSICAL PROPERTIES

### 4.3.1 Bulk Density

The bulk density of soil unit A ranged from 1.52Mgm$^{-3}$ to 1.65Mgm$^{-3}$ with a mean of 1.56Mgm$^{-3}$, that of soil unit B ranged from 1.59Mgm$^{-3}$ to 1.86Mgm$^{-3}$ with a mean of 1.68Mgm$^{-3}$. Soil unit C had a range of 1.50Mgm$^{-3}$ to 1.73Mgm$^{-3}$ with a mean of 1.59Mgm$^{-3}$. The Ap horizons were high in bulk density, followed by a decreasing pattern in the subsoils horizon, but further rise in the lowest horizons (Table 4.2). Such patterns were also observed by Esu (1988), Raji (1995) and Raji *et al.* (1996) and were attributed to surface compaction due to both mechanical or animal traction and better structural development in the subsoil horizons. The increase in the lowest parts of the

profiles may be attributed to the presence of parent material (Buol *et al.,* 1980) and low faunal and root activities.

The bulk density values were lower than 1.85Mgm$^{-3}$, a value considered by Veparaskas (1988) to impede root penetration. Therefore, bulk density will not be a retarding factor for crop cultivation in the study area.

Bulk density in the subsoil horizons of the soils unit A and B increased with depth (Table 4.2), this may be due to the high clay content in the subsoils, filling the part of the pore spaces (Anderson and Ingram*,* 1993).

### 4.3.2 Particle Size Distribution

The particle size distribution data for soils is presented in (Table 4.2). Soils of unit A generally had higher gravel content than those of Units B and C. Gravel content of the surface soils ranged from 210 to 520gkg$^{-1}$ in soil unit A and 0 to 10gkg$^{-1}$ in the soil unit B with corresponding means of 365 and 5gkg$^{-1}$ respectively. In the same order, subsoils values varied from 600 to 730gkg$^{-1}$ (unit A), 0 to 10gkg$^{-1}$ (unit B) and 0 to 300gkg$^{-1}$ (unit C) with corresponding means of 665kg$^{-1}$ 10gkg$^{-1}$ and 300gkg$^{-1}$ in that order. The gravel particles were mainly hardened Fe/Mn nodules. Comparing the means, soil Unit A had significantly ($p = 0.05$) higher gravel content than soil units B and C.

Clay content tends to increase with increase in depth in all the soil units (except pedon C2) indicating possible clay migration by eluviation –illuviation process within profile (Fig. 4.3). Clay content in the soil ranged from 140 to 160gkg$^{-1}$ (mean 150gkg$^{-1}$), 160gkg$^{-1}$, and from 220 to 380gkg$^{-1}$ (300gkg$^{-1}$) in the surface soils of units A, B and C respectively. Correspondingly, the clay content in the subsoil ranged from 240 to 340gkg$^{-1}$ (mean, 290gkg$^{-1}$), 240 to 480gkg$^{-1}$ (360gkg$^{-1}$) and 280 to 360 (320gkg$^{-1}$). The

high clay content in the B-horizons relative to the A-horizons confirms the presence of argillic horizon in pedons A1, A2, B1, B2 and C1. It is evident that clay content of the soils varied significantly ($p \leq 0.01$) between surface soils and subsoils.

The lower clay content of the surface soil is a characteristic that has been observed for most soils on Basement complex in Nigeria (Esu, 1987; Kparmwang, 1993; Zarafi, 1993, Abdullahi, 1997, Maniyunda, 1999). This characteristic has been attributed to biological (termite) sorting of soil material, downward eluviations of clay and erosion. All of these activities are common occurrence in the Northern Guinea Savanna. This finding is in line with the work of Mosugu (1989), which submitted that the lower clay content of the top soils relative to the sub soil could also mean a more intensive chemical weathering at the subsoils relative to the top soil. When the mean values of clay content of both soil unit A ($290gkg^{-1}$), soil unit B ($360gkg^{-1}$) and soil unit C ($320gkg^{-1}$) were compared statistically, the mean value of soil unit B was found to be higher but the difference was not statistically significant at 5% level of probability.

Total sand content ranged between $220gkg^{-1}$ and $600gkg^{-1}$ with a mean of $560gkg^{-1}$. Sand dominated particle size fraction of the fine earth (or less than 2mm fraction) portion of the soils developed on basement materials. Similar results have been reported by Mosugu (1989), Zarafi (1993), and Maniyunda (1999) in their works within the Zaria region. In all the soils, it is important to point out that sand fraction is highest at the surface horizons across the six pedons. Sand fraction ranged from 380 to 600 (mean, $487gkg^{-1}$), 280 to 400 ($336gkg^{-1}$), 220 to 400 ($240gkg^{-1}$), 280 to 400 ($333\ gkg^{-1}$), 200 to 300 ($240\ gkg^{-1}$) for pedons A1, B1, B2, C1 and C2 respectively. Pedon A2 had a mean of $500gkg^{-1}$. The means of pedon A1 is higher and Pedon C2 is lowest because they

occupy the higher and lower slopes respectively. The high total sand content of the soils reflect the granitic origin of the parent materials.

Silt content (Table 4.2) of the soils of the study area ranged between 160 to 360gkg$^{-1}$ (mean, 290gkg$^{-1}$), 280 to 440gkg$^{-1}$ (315gkg$^{-1}$) and 320 to 460gkg$^{-1}$ (397gkg$^{-1}$) for soil units A, B, and C respectively. In all the soils, surface soils generally had higher silt content than the subsurface soil and the difference was statistically significant. The mean of silt content in soil unit C was higher due to its 'Fadama' nature. This is in agreement with the report of Abdullahi (1997) on fadama soils at Zaria and Maniyunda (1999) on some loess soils in Funtua. The former being attributed to the fine sediments eroded from the aeolian deposits which form part of the upland soils, while the later could be partly attributed to loess being main source of silt (Raji, 1995, 1996).

**Table 4.2: Particle size distribution and Bulk density of IAR Research farm**

| Horizon | Depth (cm) | Gravel* ($gkg^{-1}$) | Sand ($gkg^{-1}$) | Silt ($gkg^{-1}$) | Clay ($gkg^{-1}$) | Textural class | Bulk density ($Mgm^{-3}$) |
|---|---|---|---|---|---|---|---|
| **Soil Unit A** | | | | | | | |
| **Pedon A1** | | | | | | | |
| Ap | 0-27 | 210 | 480 | 360 | 160 | Gravelly loam | 1.53 |
| Btc | 27-63 | 730 | 380 | 280 | 340 | Gravelly clay loam | 1.53 |
| C | 63-115 | 600 | 600 | 160 | 240 | Gravelly sandy clay loam | 1.52 |
| **Pedon A2** | | | | | | | |
| Apv | 0-4 | 520 | 500 | 360 | 140 | Gravelly Loam | 1.65 |
| **Soil Unit B** | | | | | | | |
| **Pedon B1** | | | | | | | |
| Ap | 0-23 | 0 | 400 | 440 | 160 | Loam | 1.63 |
| Bc | 23-41 | 0 | 380 | 380 | 240 | Loam | 1.59 |
| Bt1 | 41-81 | 0 | 280 | 320 | 400 | Clay loam | 1.62 |
| Bt2 | 81-142 | 0 | 280 | 300 | 420 | Clay | 1.73 |
| Bct | 142-166 | 0 | 340 | 280 | 380 | Clay loam | 1.59 |
| **Pedon B2** | | | | | | | |
| Ap | 0-23 | 10 | 400 | 440 | 160 | Loam | 1.68 |
| Bt | 23-97 | 0 | 220 | 300 | 480 | Clay | 1.70 |
| Bctg | 97-150 | 10 | 220 | 300 | 480 | Clay | 1.86 |
| **Soil Unit C** | | | | | | | |
| **Pedon C1** | | | | | | | |
| Ap | 0-20 | 0 | 320 | 460 | 220 | Loam | 1.62 |
| Bt1 | 20-89 | 0 | 280 | 400 | 320 | Clay loam | 1.59 |
| Bctgv | 89-114 | 300 | 400 | 320 | 280 | Gravelly clay loam | 1.73 |
| **Pedon C2** | | | | | | | |
| Apg | 0-30 | 0 | 200 | 420 | 380 | Silty clay loam | 1.60 |
| Bt1g | 30-90 | 0 | 220 | 420 | 360 | Clay loam | 1.50 |
| Bt2g | 90-145 | 0 | 300 | 360 | 340 | Clay loam | 1.51 |

*= Percent of whole soil.

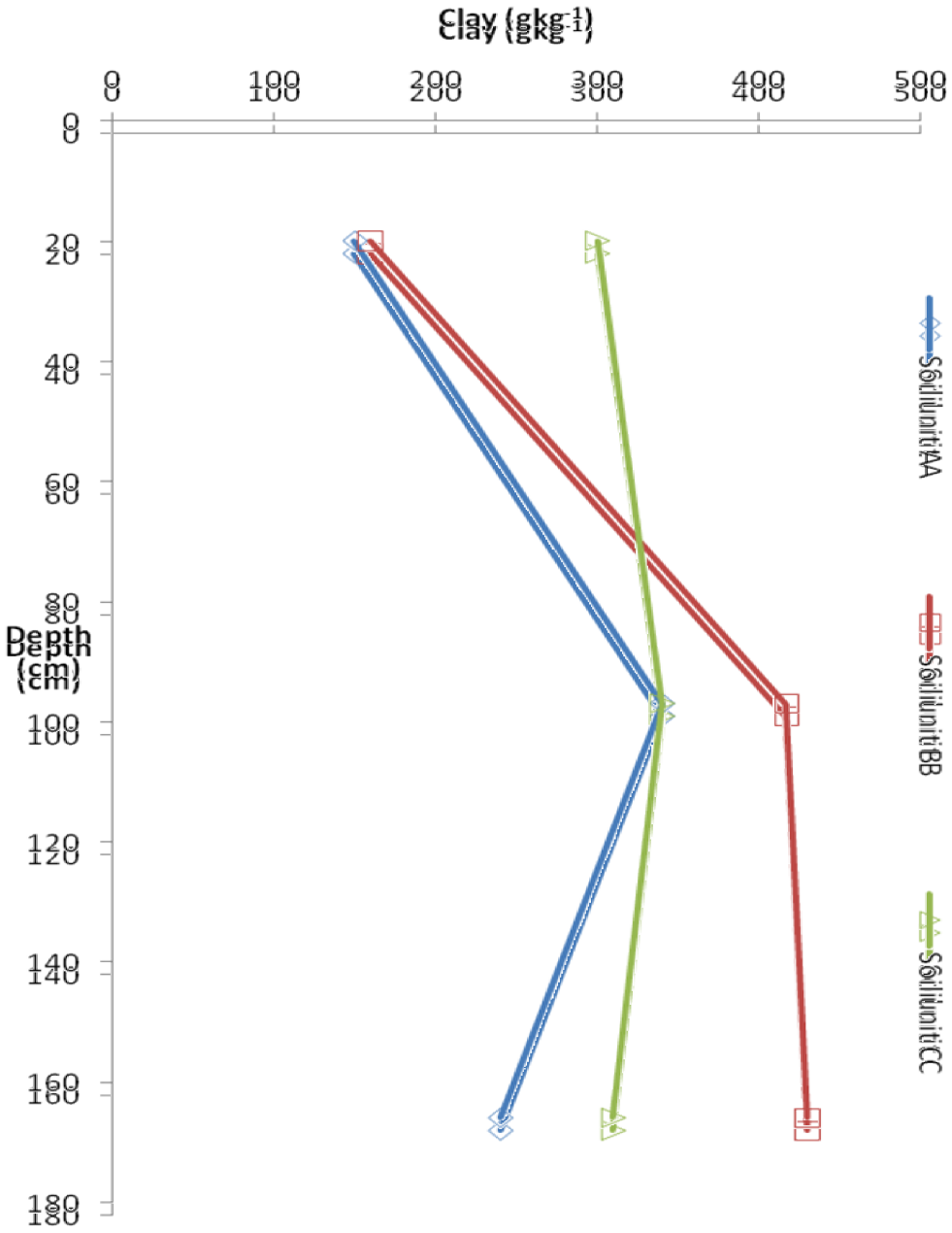



Fig. 4.3: Depth function of clay in the soils

## 4.4 CHEMICAL PROPERTIES

The parameters considered under chemical properties include; soil reaction, exchangeable acidity, cation exchange capacity, base saturation. Data on these properties are given in Tables 4.3 and 4.4. Ratings for soil chemical properties are presented in Appendix C.

### 4.4.1 Soil Reaction (pH)

The soil pH values range from 6.30 and 7.20 (mean 6.75), 5.40 and 6.20 (mean 5.80) and 4.70 and 5.50 (mean 5.1) in water in the surface horizons of soil units A, B, and C profiles respectively. The soil reaction in water is therefore neutral in soil unit A, moderately acid in soil unit B and strongly acid in soil unit C. Corresponding values in the subsoils varied from 6.60 to 6.70 with a mean of 6.65 for soil unit A, 5.00 to 6.10 with a mean of 5.55 for soil unit B and 4.90 to 5.80 with a mean of 5.35 in soil unit C.

Soil reaction in the subsoils was slightly acid to neutral in soil unit A, strongly acid to slightly acid in soil unit B and very strongly acid to moderately acid in soil unit C. The low pH of these soils tend to indicate leaching of bases out of the solum (Kparmwang, 1993; Raji, 1995) and the acidic nature of the soils corroborates the results of earlier workers (Ipimidun, 1972; Esu, 1987; Zarafi, 1993; Abdullahi 1997). Raji and Mohammed (2000) investigated the nature of acidity in Nigerian savanna soils and reported that the savanna soils are largely strongly to slightly acidic. They submitted that the Northern Guinea Savanna has the highest total potential acidity (mean 5.67cmolkg$^{-1}$) in comparison to other savannah ecological zones. The surface soils had higher pH than the subsoils. This may be attributed to the influence of organic matter through biogenetic cycling of bases, a process which reduces the acidification of soils (Jones and Wild, 1975; Mosugu, 1989).

Soil pH measured in 0.01M $CaCl_2$ was in all cases lower than pH measured in water. The values of delta pH (pH [$CaCl_2$] – pH [$H_2O$]) were therefore negative in all the soils and the mean values of the entire profile were -1.2, - 0.6 and – 0.5 for soil unit A, B, and C respectively.

Similar findings were reported by other researchers (Kparmwang, 1993; Raji, 1995; Maniyunda, 1999). This implies that the soils had net negative charge (Partiff, 1980; Uehara, and Gillman, 1981). Uehara and Gillman (1981) reported that delta pH of values < -0.5 indicates a dominance of the exchange sites of clay by variable charge minerals. As the soils in the present study had delta pH value greater than -0.5, it is believed that they contain significant amounts of independent charge minerals or 2:1 clay.

### 4.4.2 Exchange Acidity

The exchange acidity comprises exchangeable hydrogen and exchangeable aluminium. The values were classified as generally low (<1.0cmolkg$^{-1}$) which suggests that the soils have little or no acidity problems, except for incipient acidity in some horizons. However, the low pH values (Table 4.3) would suggest that liming and/or use of farmyard manure incorporated into the soils would restore pH values to the range of pH 5.0 to 6.0 at which most nutrients are readily available to crop roots (Odunze, 2006).

In the surface horizons, the values were in the order 0.20 to 0.62 (mean, 0.41), 0.40 to 0.84 (mean, 0.62) and 0.96 to 1.80 (mean 1.38) in soil units A, B, and C respectively. There was a general trend of increasing exchange acidity values with depth followed by a slight decrease in some horizons in the subsoils which is attributed to the influence of soil texture. Buol, *et al.,* (1980) reported that increase in exchange acidity with depth is

attributed to weathering and leaching intensity in the tropics. The subsoil values range from 0.40 to 0.46 (0.43), 0.48 to 1.20 (0.84) and 0.68 to 2.40 (1.54) for soil units A, B, and C respectively.

### 4.4.3 Exchangeable Bases

The exchangeable bases comprises of exchangeable calcium, magnesium, potassium and sodium (Table 4.3). Calcium dominated the exchangeable bases. This is similar to several reports of wok done in the Nigerian savannah (Esu, 1987; Mosugu, 1989; Kparmwang, 1993; Raji, 1995; Yaro, 2005). The values in the surface horizon were 2.17 and 4.33 (mean 3.25), 3.17 and 4.00 (3.59) and 3.17 and 4.83 (mean 4.00) in soils of unit A, B, and C respectively. Correspondingly, the subsoil horizon values varied from 3.00 to 3.17 (3.09), 3.00 to 4.00 (3.50) and 2.17 to 4.83 (3.50) $cmol^{+}kg^{-1}$.

The values in surface horizons are rated as medium for soil units A, B, and C (Appendix C). In the sub horizons they are also rated medium for all the soil units. The low values obtained in some horizons may be due to cation removal by plant uptake of the calcium, low organic matter decomposition, erosion or leaching.

There was no significant difference between the surface and subsurface soils of unit A at 5% level of probability, and when the top soils of the three soil units and their subsoil were compared statistically, the differences were also not significant.

Exchangeable magnesium ranked next to calcium on the exchangeable site. Mg values were generally in the high range (Appendix C). The values of magnesium were 1.18 and 2.15 (mean, 1.67), 1.52 and 2.83 (2.18) and 1.32 and 1.93 (1.63) $cmol^{+}kg^{-1}$ in the Ap horizons of soil units A, B and C respectively. In the same order, the subsoil horizon values varied from 1.50 to 1.78 (1.64), 1.48 to 2.28 (1.88) and 1.33 to 2.18 (1.76) cmol

$Kg^{-1}$. However, results showed that Mg content generally increased with depth. The rating for the surface and subsurface horizons is high for all the soil units. The observed trend of distribution in the profiles is similar to that of calcium, except that magnesium was lower than calcium in all the soil.

The potassium (K) content was in the order 0.27 and 0.28 (mean, 0.28), 0.21 and 0.30 (0.26) and 0.10 and 0.14 (0.12) $cmol^{+}kg^{-1}$ for the Ap horizons in soil units A, B, and C respectively. Similarly in the subsoils, the values varied between 0.29 and 0.42 (0.36), 0.18 and 0.29 (0.24) and 0.14 and 0.16 (0.15) $cmol^{+}kg^{-1}$. The values in the surface horizons are rated as medium for soil units A and B, and low for soil unit C. In the subsoil horizons, the values are rated as medium to high in soil unit A, medium in soil unit B and low to medium in soil unit C. The trend in profile distribution is similar to those of calcium and magnesium.

Exchangeable Na was irregularly distributed; the ranges in values for exchangeable Na of surface soils were 0.20 to 0.25 (mean 0.23), 0.18 to 0.28 (0.23) and 0.27 to 0.39 (0.33) $cmol^{+}kg^{-1}$ in soil units A, B and C respectively. In the same order, the subsoil horizon values for soil unit A was 0.23, the values range from 0.21 to 0.27 (0.24) and 0.26 to 0.46 (0.36) $cmol^{+}kg^{-1}$ for units B and C. Values in the surface horizon of soil units A and B are medium, and medium to high in soil unit C. In the subsoil horizons, the values are rated as medium for soil units A and B, and medium to high for soil unit C. There is no clear trend in the profile distribution, but generally, the subsoils had higher exchangeable sodium than the surface horizons. This trend is similar to the report of Kparmwang (1993) on basaltic soils of Northern guinea savanna of Nigeria and Raji (1995) on ancient dune soils of Northern Nigeria.

Generally, the exchangeable bases occurred in the order Ca>Mg>K>Na in soil units A and B, this corroborates earlier reports on soils of the Nigerian savannah (Raji, 1995). Calcium was the dominant exchangeable basic cation in soil unit C followed by Mg, then Na, while K was the least dominant. The distribution patterns were in agreement with what was reported in the review by Kparmwang and Esu, 1990; Abdullahi, 1997.

### 4.4.4 Cation Exchangeable Capacity

The cation exchangeable capacity (CEC) of the soils fall into two distinct ratings of low and moderates. Low to moderate CEC values have been reported to be an indication of dominance of kaolinitic clays in the fine earth fractions (Ojanuga and Awujoola, 1981). Both surface and subsurface values of CEC were rated as low to medium in the soils; this might be a reflection of the intensity of weathering that produced the soil. The increasing trend in CEC with depth (Fig. 5) with increases in clay content might be an indication of argilluviation. The exchange sites were dominated by Ca, followed by Mg, probably because of soils' affinity for these cations. Similar findings were reported by Mosugu (1989), Zarafi (1993), Abdullahi (1997), Maniyunda (1999), and Yaro (2005).

The values of CEC - $NH_4OAc$ in the surface horizons are 5.00 and 7.10 (mean, 6.05), 6.40 and 8.50 (7.45) and 8.00 and 11.8 (9.90) $cmol^{+}kg^{-1}$ in soil units A, B, and C respectively. The corresponding values in the subsoil horizons were 6.80 to 6.90 (6.85), 6.70 to 11.80 (9.25) and 6.80 to 8.10 (7.45) $cmol^{+}kg^{-1}$ soils. The values in surface horizons are rated as medium for all the horizons. The subsoil horizons are also rated medium for all the soils in units A, B, and C. The CEC correlated positively with clay ($r = 0.9830$, $p = 0.001$) indicating that clay is a major contributor to the CEC of the soils (Sombroek and Zonneveld, 1971).

The low to moderate values of CEC suggests that the soils are formed from highly weathered materials of granitic origin, which are low in basic cations. When the means were compared between the soil units, no statistical difference was observed at 5% level of probability.

The values of effective cation exchange capacity (ECEC) were 4.07 and 7.58 (mean, 5.83), 6.11 and 8.16 (7.14) and 5.86 and 9.05 (7.46) $cmol^{+}kg^{-1}$ soils in the surface horizon developed in soil units A, B, and C respectively. In the same order, the subsoil values varied from 5.61 to 5.87 (5.74), 5.89 to 7.03 (6.46) and 6.30 to 7.39 (6.85). The values in the surface and subsurface horizons are rated as medium.

The ECEC values were all lower than CEC ($NH_4OAc$). This trend has been attributed to the fact that the CEC of tropical soils are highly pH dependent (Balasubramanian *et.al.,* 1980). This might also be attributed to the pH of the soils ( < 7), since ECEC measures the charge at the soil pH, whereas the CEC - $NH_4OAc$ measures the charges on the soil colloids at pH 7.

The values of CEC of clay indicate the chemical activity of their surfaces. The values in the Ap horizons were in the order 11.21 and 18.13 (mean, 14.67), 18.38 and 30.38 (24.38) and 22.58 and 26.82 (24.70) $cmol^{+}kg^{-1}$ clay in soil units A, B and C respectively. Similarly, the subsoil horizon values varied from 13.91 to 25.13 (19.52), 18.00 to 24.00 (21.00) and 18.86 to 22.58 (20.72) $cmol^{+}kg^{-1}$ clay. The means for all the profiles indicate that the mean for soil unit A (17.1 $cmol^{+}kg^{-1}$) was less than the mean for soil unit B (21.8 $cmol^{+}kg^{-1}$) which was less than that of soil unit C (22.1 $cmol^{+}kg^{-1}$). The CEC of clay in these soils were within the 15-40 $cmol^{+}kg^{-1}$ range, suggesting their clay minerals contains some illite, chlorite or montmorillonite in mixture with dominant kaolinite (Sombroek and Zonneveld, 1971; Buol, *et al.,* 1980). The values of CEC clay

indicate that all the pedons are dominated by low activity clay (LAC). Juo (1980) gave the boundary limit between high activity clay (HAC) and LAC to be 24 $cmol^{+}kg^{-1}$ clay.

**Table 4.3: Soil chemical properties: Soil pH, exchangeable bases and exchange acidity**

| Horizon | Depth (cm) | pH 1:2.5 | | | Exchangeable bases [cmol(+)$kg^{-1}$] | | | | | EA [$H^+$+$Al^{3+}$] [cmol(+)$kg^{-1}$] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $H_20$ | $CaCl_2$ | dpH | Ca | Mg | Na | K | Total | |
| **Soil Unit A** | | | | | | | | | | |
| **Pedon A1** | | | | | | | | | | |
| Ap | 0-27 | 7.20 | 5.40 | -1.8 | 2.17 | 1.18 | 0.25 | 0.27 | 3.87 | 0.20 |
| Btc | 27-63 | 6.70 | 5.50 | -1.2 | 3.17 | 1.78 | 0.23 | 0.29 | 5.47 | 0.40 |
| C | 63-115 | 6.60 | 5.60 | -1.0 | 3.00 | 1.50 | 0.23 | 0.42 | 5.15 | 0.46 |
| **Pedon A2** | | | | | | | | | | |
| Apv | 0-4 | 6.30 | 5.50 | -0.8 | 4.33 | 2.15 | 0.20 | 0.28 | 6.96 | 0.62 |
| **Soil Unit B** | | | | | | | | | | |
| **Pedon B1** | | | | | | | | | | |
| Ap | 0-23 | 6.20 | 5.50 | -0.7 | 3.17 | 1.52 | 0.18 | 0.30 | 5.17 | 0.40 |
| Bc | 23-41 | 6.10 | 5.60 | -0.5 | 3.50 | 1.93 | 0.21 | 0.20 | 5.84 | 0.48 |
| Bt1 | 41-81 | 5.60 | 4.70 | -0.9 | 3.50 | 2.28 | 0.22 | 0.23 | 6.23 | 0.80 |
| Bt2 | 81-142 | 5.10 | 4.50 | -0.6 | 3.00 | 2.12 | 0.25 | 0.28 | 5.65 | 1.20 |
| Bct | 142-166 | 5.20 | 4.70 | -0.5 | 3.00 | 1.78 | 0.25 | 0.18 | 5.21 | 0.68 |
| **Pedon B2** | | | | | | | | | | |
| Ap | 0-23 | 5.40 | 4.80 | -0.6 | 4.00 | 2.83 | 0.28 | 0.21 | 7.32 | 0.84 |
| Bt | 23-97 | 5.00 | 4.80 | -0.2 | 3.50 | 1.78 | 0.27 | 0.23 | 5.78 | 0.96 |
| Bctg | 97-150 | 5.60 | 5.00 | -0.6 | 4.00 | 1.48 | 0.27 | 0.29 | 6.04 | 0.86 |
| **Soil Unit C** | | | | | | | | | | |
| **Pedon C1** | | | | | | | | | | |
| Ap | 0-20 | 5.50 | 4.90 | -0.6 | 3.17 | 1.32 | 0.27 | 0.14 | 4.90 | 0.96 |
| Bt1 | 20-89 | 4.90 | 4.70 | -0.2 | 2.17 | 1.33 | 0.26 | 0.14 | 3.90 | 2.40 |
| Bctgv | 89-114 | 5.30 | 4.90 | -0.4 | 4.33 | 1.83 | 0.27 | 0.14 | 6.57 | 0.82 |
| **Pedon C2** | | | | | | | | | | |
| Apg | 0-30 | 4.70 | 4.40 | -0.3 | 4.83 | 1.93 | 0.39 | 0.10 | 7.25 | 1.80 |
| Bt1g | 30-90 | 5.60 | 5.00 | -0.6 | 3.17 | 1.93 | 0.36 | 0.14 | 5.60 | 0.94 |
| Bt2g | 90-145 | 5.80 | 5.10 | -0.7 | 3.50 | 2.18 | 0.46 | 0.16 | 6.30 | 0.68 |

EA=Exchange acidity

**Table 4.4: Soil chemical properties: Cation exchange capacities (CEC) and Base saturations (BS)**

| Horizon | Depth (cm) | Cation Exchange Capacity [cmol(+)$kg^{-1}$] | | | Base Saturation (%) | |
|---|---|---|---|---|---|---|
| | | ECEC | $NH_4OAc$ | Clay | ECEC | $NH_4OAc$ |
| **Soil Unit A** | | | | | | |
| **Pedon A1** | | | | | | |
| Ap | 0-27 | 4.07 | 5.00 | 18.13 | 95 | 77 |
| Btc | 27-63 | 5.87 | 6.90 | 13.91 | 93 | 79 |
| C | 63-115 | 5.61 | 6.80 | 25.13 | 92 | 76 |
| **Pedon A2** | | | | | | |
| Apv | 0-4 | 7.58 | 7.10 | 11.21 | 92 | 98 |
| **Soil Unit B** | | | | | | |
| **Pedon B1** | | | | | | |
| Ap | 0-23 | 6.11 | 6.40 | 18.38 | 85 | 81 |
| Bc | 23-41 | 6.32 | 6.70 | 23.25 | 92 | 87 |
| Bt1 | 41-81 | 7.03 | 8.60 | 18.00 | 89 | 72 |
| Bt2 | 81-142 | 6.85 | 9.20 | 20.07 | 83 | 61 |
| Bct | 142-166 | 5.89 | 7.40 | 18.37 | 89 | 70 |
| **Pedon B2** | | | | | | |
| Ap | 0-23 | 8.16 | 8.50 | 30.38 | 90 | 86 |
| Bt | 23-97 | 6.74 | 11.00 | 21.75 | 86 | 53 |
| Bctg | 97-150 | 6.90 | 11.80 | 24.00 | 88 | 51 |
| **Soil Unit C** | | | | | | |
| **Pedon C1** | | | | | | |
| Ap | 0-20 | 5.86 | 8.00 | 26.82 | 84 | 61 |
| Bt1 | 20-89 | 6.30 | 7.40 | 20.06 | 62 | 53 |
| Bctgv | 89-114 | 7.39 | 6.80 | 22.29 | 89 | 97 |
| **Pedon C2** | | | | | | |
| Apg | 0-30 | 9.05 | 11.8 | 22.58 | 80 | 61 |
| Bt1g | 30-90 | 6.54 | 7.70 | 18.86 | 86 | 73 |
| Bt2g | 90-145 | 6.98 | 8.10 | 21.97 | 90 | 78 |

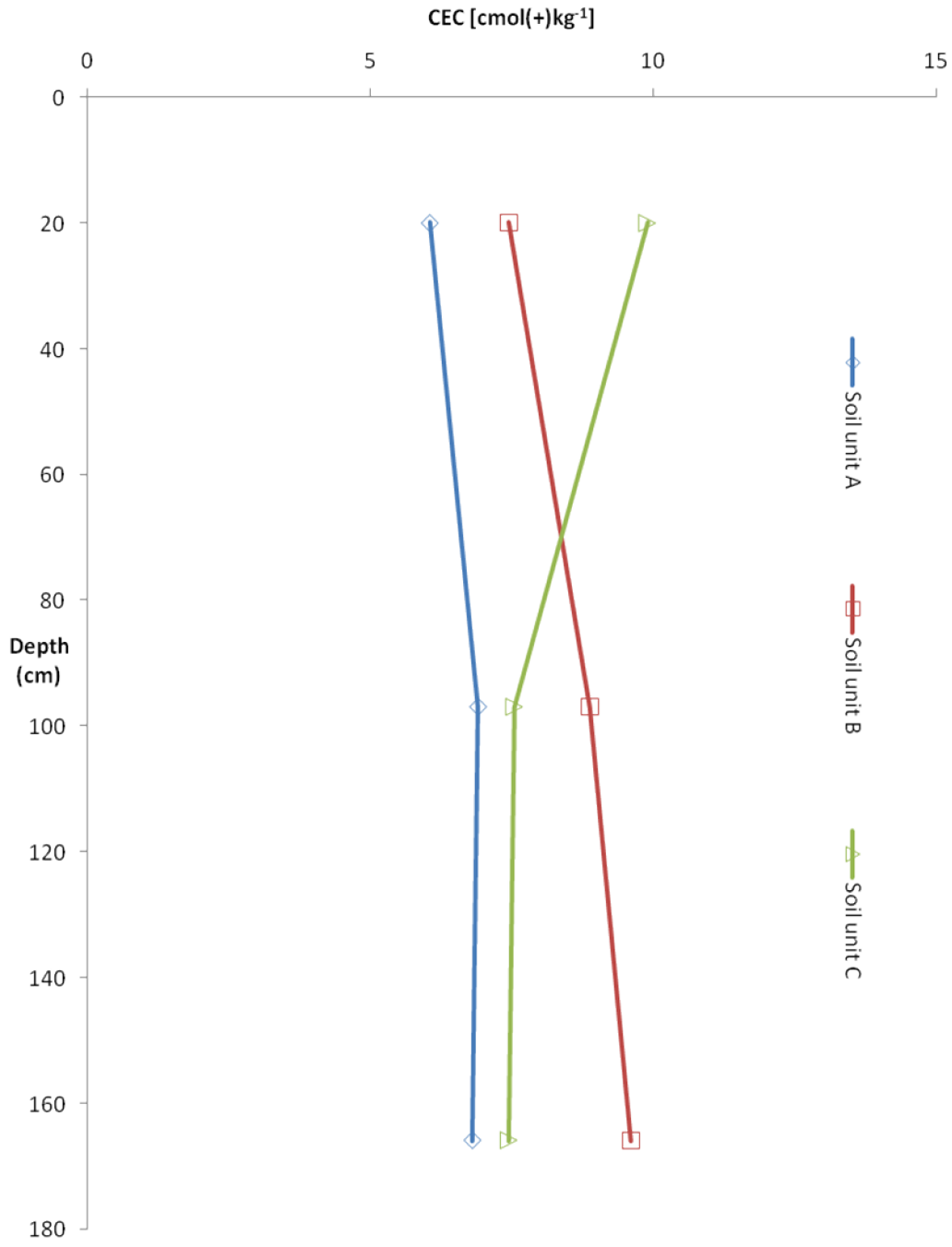



Fig. 4.4: Depth function of CEC ($NH_4OAc$) in the soils

**Table 4.5: Correlation matrix for physico-chemical properties**

| | Gravel | Sand | Silt | Clay | O.C | Tot.N | C/N | Av.P | pH $H_20$ | pH $CaCl_2$ | TEB | Exc. Acid. | BS_ ECEC | BS_$NH_4$ OAc | CEC_ ECEC | CEC_ $NH_4$ OAc | CEC_ Clay | BD | Cu | Zn | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sand** | .6283 | | | | | | | | | | | | | | | | | | | | |
| **Silt** | -.4628 | .2723 | * | | | | | | | | | | | | | | | | | | |
| **Clay** | -.3951 | .3043 | .9088 | | | | | | | | | | | | | | | | | | |
| **O.C** | .2494 | -.1891 ** | -.7279 | -.5345 | | | | | | | | | | | | | | | | | |
| **Tot. N** | .6947 | .9708 | .1249 * | .1658 *** | .0297 | | | | | | | | | | | | | | | | |
| **C/N** | -.4878 ** | .1612 | .8720 | .9860 | -.4573 | .0362 | | | | | | | | | | | | | | | |
| **Av. P** | -.9256 | -.5015 * | .5195 | -.4464 | .0879 | -.5070 | .5402 | | | | | | | | | | | | | | |
| **pH $H_20$** | .2496 | .8525 | .6742 | .7441 * | -.3724 | .7752 | .6436 | -.0971 | *** | | | | | | | | | | | | |
| **pH $CaCl_2$** | .0757 | .7654 | .7959 * | .8390 *** | -.4922 | .6595 | .7465 *** | .0475 | .9817 | * | | | | | | | | | | | |
| **TEB** | -.3961 | .2882 | .9078 * | .9991 | -.5225 * | .1542 | .9892 | .4562 | .7372 | .8309 | | | | | | | | | | | |
| **Exc. Acid.** | -.5487 | -.0594 | .8627 | .6620 * | -.8907 | -.2395 | .6427 | .4795 | .3017 ** | .4550 *** | .6639 * | | | | | | | | | | |
| **BS_ECEC** | .0186 | .7102 | .7932 | .8837 | -.4368 | .6073 | .8085 | .1036 | .9682 ** | .9905 *** | .8770 | .4301 | ** | | | | | | | | |
| **BS_$NH_4$OAc** | .0762 | .7690 | .7943 ** | .7767 *** | -.4441 | .6942 | .6820 ** | .1035 | .9642 | .9776 | .7717 *** | .4469 | .9537 * | | | | | | | | |
| **CEC_ECEC** | -.4714 | .2271 | .9610 * | .9830 *** | -.6390 | .0759 | .9694 *** | .5087 | .6821 | .7977 | .9836 *** | .7853 | .8289 | .7512 | ** | | | | | | |
| **CEC_$NH_4$OAc** | -.4536 | .1916 | .8703 * | .9830 ** | -.5708 | .0314 | .9818 * | .4424 | .6457 | .7543 * | .9810 ** | .6841 | .8089 * | .6628 | .9699 ** | ** | | | | | |
| **CEC_Clay** | -.2372 | .4667 | .9061 * | .9410 ** | -.7325 | .2846 | .8793 * | .2214 | .8027 * | .8918 ** | .9311 * | .7181 | .9009 ** | .8160 * | .9384 * | .9302 * | ** | | | | |
| **Bulk Density** | -.2331 | .5545 | .8833 | .9287 | -.6111 | .4027 | .8598 | .2619 | .8539 | .9317 | .9146 | .6016 | .9424 | .8769 | .9046 | .8898 | .9688 | | | | |
| **Cu** | -.7141 | -.1937 * | .5489 | .7176 | .0291 | -.2164 | .8011 | .8001 | .2556 * | .3556 | .7227 | .2879 | .4593 | .3243 * | .6758 | .7182 | .4698 | .5344 | | | |
| **Zn** | .5003 | .8328 | .4998 | .4301 | -.3423 | .8036 | .3158 | -.2914 | .8539 | .7949 | .4345 | .2628 | .7309 | .8461 | .4185 | .3026 | .5334 | .5407 | -.1432 * | | |
| **Mn** | -.5802 | -.2620 | .5600 ** | .6231 * | .0350 | -.2394 | .7191 | .7818 | .2188 * | .2943 | .6497 | .3902 * | .3707 | .3314 | .6324 * | .5880 | .3439 * | .3412 * | .8210 | .0900 | |
| **Fe** | -.4895 | .2978 | .9554 | .8118 | -.7858 | .1366 | .7524 | .4915 | .6113 | .7446 | .8000 | .8466 | .7231 | .7475 | .8744 | .7773 | .8683 | .8749 | .4571 | .4148 | .3606 |

Level of Significance * = P 0.05, ** = P 0.01, *** = P 0.001

### 4.4.5 Base Saturation (BS)

Base saturation (BS) was calculated by two methods, namely $NH_4OAc$ and ECEC method (Table 4.4). In all soils, the BS by ECEC gave higher values than the corresponding values obtained by $NH_4OAc$ method. The values were rated moderate being generally between 50 and 80% (Appendix C) by $NH_4OAc$ method. Sanchez (1976) submitted that base saturation (by ECEC) gives a more realistic picture of the acidity level of variable charged soils than base saturation ($NH_4OAc$) which tends to overestimate. The values of base saturation ($NH_4OAc$) for surface horizons were 77 and 98 (mean, 87.5), 81 and 86 (83.5) and 61% for soil units A, B and C respectively. The subsoil horizon values for soil unit A ranged from 76 to 79 with a mean of 77.5, those of soil unit B ranged from 51 to 87 with a mean of 69 and those of soil unit C, ranged from 53 to 97 with a mean of 75 percent. The values for all the surface horizons are rated as moderate to high. The subsoil values are rated moderate. There is no clear trend in profile distribution of base saturation ($NH_4OAc$).

The base saturation (ECEC) values for soil unit A were 92 and 95 with a mean of 93.5, for soil unit B, 85 to 90 with a mean of 87.5 and for soil unit C, the values were 80 to 84 with a mean of 82 percent in the Ap horizons. The values in subsoil horizons ranged between 92 and 93 (92.5), 83 and 92 (87.5) and 62 and 90 (76) percent for soil units A, B, and C respectively. The surface horizon values are rated as high for soil unit A, medium to high for soil unit B and medium for soil unit C. The values in the subsoil horizons are rated as high, medium to high and low to medium for soil units A, B, and C respectively. When the means of both the top soil and subsoils of each unit were compared, differences observed in BS ($NH_4OAc$ and ECEC) were not statistically significant at 5% level of probability.

### 4.4.6 Organic Carbon

The organic carbon values for surface horizons were 6.00 and 15.80 (mean 10.9), 9.90 and 10.40 (10.15) and 6.00 and 9.20 (7.6) $gkg^{-1}$for soil unit A, B, and C respectively. The corresponding subsoil horizon values were 2.20 and 6.20 (4.20), 0.80 and 4.00 (2.40) and 1.60 and 2.80 (2.20) gkg-1 (Table 4.6). The values in the surface horizons are rated low to moderate for soil units A and B, and low for soil unit C. The subsoil values are all rated as low (Appendix C). The values in surface horizon were much higher than those in subsoil horizons and there is a consistent decrease with increase in depth in the profiles (Fig. 4.5). This is similar to the report of Ogunwale (1973) on soils derived from sandstones.

The sharp decrease in organic carbon with depth from the Ap horizon to the subsoil horizon may be attributed to immobilization of organic matter by clay in the Ap horizons in forms of organo-clay-complexes (Mortland, 1970; Ogunwale, 1973; Maniyunda, 1999). This is supported by the negative correlation with clay (r = - 0.5345, Table 4.5). Organic matter is observed to correlate with several properties, thus, indicating its association or relationship, usually as a source of such parameter (Jones and Wild, 1975). In line with this, Goh (1980) had reported that in soils with variable charges, organic matter serves as a reservoir for macronutrients such as nitrogen and phosphorus which are released during its decomposition.

The low to moderate values of CEC suggests that the soils are formed from highly weathered materials of granitic origin, which are low in basic cations. When the means were compared between the soil units, no statistical difference was observed at 5% level of probability.

The values of effective cation exchange capacity (ECEC) were 4.07 and 7.58 (mean, 5.83), 6.11 and 8.16 (7.14) and 5.86 and 9.05 (7.46) $cmol^{+}kg^{-1}$ soils in the surface horizon developed in soil units A, B, and C respectively. In the same order, the subsoil values varied from 5.61 to 5.87 (5.74), 5.89 to 7.03 (6.46) and 6.30 to 7.39 (6.85). The values in the surface and subsurface horizons are rated as medium.

The ECEC values were all lower than CEC ($NH_4OAc$). This trend has been attributed to the fact that the CEC of tropical soils are highly pH dependent (Balasubramanian *et.al.,* 1980). This might also be attributed to the pH of the soils ( < 7), since ECEC measures the charge at the soil pH, whereas the CEC - $NH_4OAc$ measures the charges on the soil colloids at pH 7.

The values of CEC of clay indicate the chemical activity of their surfaces. The values in the Ap horizons were in the order 11.21 and 18.13 (mean, 14.67), 18.38 and 30.38 (24.38) and 22.58 and 26.82 (24.70) $cmol^{+}kg^{-1}$ clay in soil units A, B and C respectively. Similarly, the subsoil horizon values varied from 13.91 to 25.13 (19.52), 18.00 to 24.00 (21.00) and 18.86 to 22.58 (20.72) $cmol^{+}kg^{-1}$ clay. The means for all the profiles indicate that the mean for soil unit A (17.1 $cmol^{+}kg^{-1}$) was less than the mean for soil unit B (21.8 $cmol^{+}kg^{-1}$) which was less than that of soil unit C (22.1 $cmol^{+}kg^{-1}$). The CEC of clay in these soils were within the 15-40 $cmol^{+}kg^{-1}$ range, suggesting their clay minerals contains some illite, chlorite or montmorillonite in mixture with dominant kaolinite (Sombroek and Zonneveld, 1971; Buol, *et al.,* 1980). The values of CEC clay indicate that all the pedons are dominated by low activity clay (LAC). Juo (1980) gave the boundary limit between high activity clay (HAC) and LAC to be 24 $cmol^{+}kg^{-1}$ clay.

**Table 4.6: Organic carbon, total nitrogen and available phosphorus.**

| Horizon | Depth (cm) | O.C ($gkg^{-1}$) | Total N ($gkg^{-1}$) | Av. P ($mgkg^{-1}$) |
|---|---|---|---|---|
| **Soil Unit A** | | | | |
| **Pedon A1** | | | | |
| Ap | 0-27 | 6.00 | 0.70 | 2.63 |
| Btc | 27-63 | 6.20 | 1.05 | 1.75 |
| C | 63-115 | 2.20 | 0.53 | 2.63 |
| **Pedon A2** | | | | |
| Apv | 0-4 | 15.80 | 1.23 | 2.63 |
| **Soil Unit B** | | | | |
| **Pedon B1** | | | | |
| Ap | 0-23 | 9.90 | 0.88 | 1.75 |
| Bc | 23-41 | 3.20 | 0.35 | 1.75 |
| Bt1 | 41-81 | 4.00 | 0.53 | 1.75 |
| Bt2 | 81-142 | 2.20 | 0.35 | 1.75 |
| Bct | 142-166 | 1.40 | 0.53 | 1.75 |
| **Pedon B2** | | | | |
| Ap | 0-23 | 10.40 | 0.53 | 1.75 |
| Bt | 23-97 | 1.60 | 0.53 | 5.25 |
| Bctg | 97-150 | 0.80 | 0.35 | 1.75 |
| **Soil Unit C** | | | | |
| **Pedon C1** | | | | |
| Ap | 0-20 | 6.00 | 0.70 | 1.75 |
| Bt1 | 20-89 | 2.80 | 0.35 | 2.63 |
| Bctgv | 89-114 | 1.60 | 0.53 | 3.50 |
| **Pedon C2** | | | | |
| Apg | 0-30 | 9.20 | 0.70 | 1.75 |
| Bt1g | 30-90 | 2.60 | 0.35 | 3.50 |
| Bt2g | 90-145 | 1.80 | 0.35 | 5.25 |

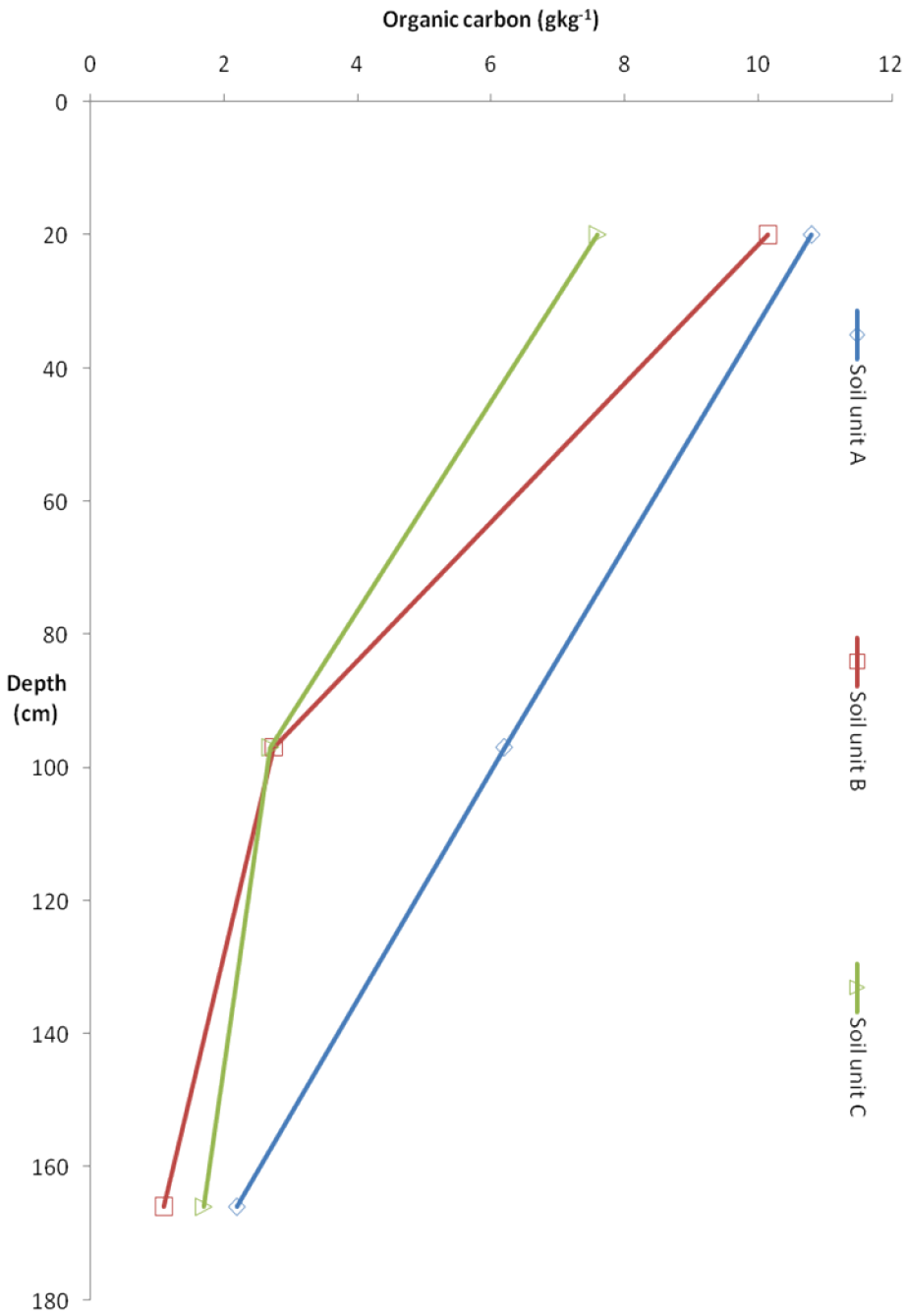



Fig. 4.5: Depth function of organic carbon in the soils

### 4.4.7 Total Nitrogen (TN)

The total nitrogen values in the surface horizon varied between 0.70 and 1.23 (mean, 0.96), 0.53 and 0.88 (0.71) and 0.70gkg$^{-1}$ in soil units A, B, and C respectively (Table 4.6). Similarly, the values in the subsoil horizons ranged from 0.53 to 1.05 (0.79), 0.35 to 0.53(0.44), 0.35 to 0.53 (0.44) gkg$^{-1}$. The values are all rated as low (Appendix C). The total nitrogen content decreased with increase in depth of the profiles and had a positive correlation with organic carbon (r = 0.0297, Table 4.5), Jones and Wild, 1975; Kparmwang, 1993). This shows that total nitrogen is largely in organic form.

### 4.4.8 Available Phosphorus

The available phosphorus content varied from 2.63 to 10.9 (mean, 6.77), 5.53 to 11.75 (8.64) and 5.51 to 6.75 (6.13) mgkg$^{-1}$ in the surface horizons of the profiles in soil unit A, B, and C respectively (Table 8). In the subsoil horizon and in the same order, the values ranged from 1.75 to 2.63 (2.19), 1.75 to 5.25 (3.50) and 2.63 to 5.25 (3.94) mgkg$^{-1}$. The values are rated as low for Ap horizons in profiles of soil unit A, B, and C (Appendix C). The profile distribution trend was the same in all the soil units. The values were highest in the Ap horizons and decreased drastically in the B horizons of the profiles. Similar findings were reported by Mosugu, 1989; Kparmwang, 1993; Maniyunda, 1999 and Yaro, 2005. This may be due to some anthropogenic influences such as addition of phosphorus fertilizers to crops. The trend also supports the fact that available phosphorus is largely sourced from organic matter, a fact which is buttressed by the positive correlation between available phosphorus and organic carbon (r = 0.0879, Table 4.5), such positive correlations were also reported by Kparmwang (1993). Negative correlation with clay was recorded (r = 0.4464), which means that the higher

the clay content, the lower the available phosphorus, probably due to fixation of phosphorus by the clays and sesquioxides.

## 4.5 MICRONUTRIENT LEVELS IN THE SOILS

The values of micronutrients determined in the six pedons are presented in Table 4.7. The micronutrients considered include copper, zinc, manganese, and iron. Of the four available micronutrient elements determined, available iron (Fe) content was highest in the soils, available manganese (Mn) ranked next, followed by available zinc (Zn), while available copper (Cu) was found to be present in the lowest amount in the soils. The nutrients were found to occur in the order: Fe>Mn>Zn>Cu in the soils.

### 4.5.1 Copper

Available copper (extractable by 0.1*M* HCl) content in virtually all the soils was in trace quantity. Available copper content in the Ap horizons of soils in soil units A, B and C were zero, except pedon B2 (0.28mgkg$^{-1}$) (Table 4.7). Similarly, the copper content in the subsoil horizons were trace, except Bct horizon of pedon B1 (0.28mg kg$^{-1}$) and Bt1g (pedon C2) (0.28mgkg$^{-1}$).

### 4.5.2 Zinc

The 0.1*M* HCl extractable zinc in surface soils, ranged from 3.64 to 8.64 (mean, 6.14), 4.55 to 5.45 (5.00), and 9.55 to 10.40 (9.98) mgkg$^{-1}$ in soil units A, B, and C respectively. In the same order, subsoils values varied from 5.91 to 19.10 (12.51), 3.64 to 8.64 (6.14) and 4.10 to 7.73 (5.92) mgkg$^{-1}$. The values of extractable zinc in the soils in most cases varied irregularly down the profile and could be attributed to leaching

effect on micronutrient. Generally, the values were above critical level of 0.6mgkg$^{-1}$ soil for Zn (Katyal, 1985). It was observed that extractable zinc content was higher in soil unit C, which varied insignificantly between the soil units. There was no significant difference when the means of both surface soils and subsoils of soil units A and B were compared. The values of the HCl extractable zinc were generally higher than those reported by Yaro *et al.*, (2006) on a plinthitic landscape at Zaria.

### 4.5.3 Manganese

Manganese exists in soils as insoluble oxides of trivalent and tetravalent manganese, exchangeable and water soluble divalent Mn, as originally bound Mn and reducible Mn, all in a state of equilibrium (Halvin *et al,* 2003). The ranges in values for extractable Mn of surface soils were from 6.94 to 14.99 (mean, 10.97), 14.99 21.39 (18.19), and 9.44 to 33.33 (21.39) mgkg$^{-1}$, in the soils of soil units A, B, and C respectively. In the same order, subsoil values ranged from 2.49 to 6.67 (4.58), 3.61 to 14.17 (8.89) and 3.06 to 33.33 (18.20) mgkg$^{-1}$ in the soil units A, B, and C.

The soils are rated high in Mn content, being generally greater than 2.0mgkg$^{-1}$ (Appendix C) and higher than the critical level given by Lindsay and Norvell (1978). The means of values obtained for the surface soils were found to be higher than those of the subsoils, and were statistically significant at 5% level of probability. The trend in Mn content distribution in the soils indicates that its distribution was not controlled by a single pedogenic process. The HCl extractable Mn generally decreased with increase in soil depth.

The pattern of distribution though irregular, but still correlated positively with organic matter. This is confirmed by the positive correlation (r = 0.0350, Table 4.5) between

HCl extractable Mn and organic carbon. Kparmwang *et.al.,* (1995) observed positive correlation between HCl extractable Mn and organic carbon.

### 4.5.4 Iron

The 0.1*M* HCl extractable iron (Fe) content in the soils followed an irregular pattern down the soil profile (Table 9). The range in values for extractable iron (Fe) of the surface were 16.67 to 25.56 (mean, 21.12), 32.22 to 54.44 (43.33) and 33.33 to 45.10 (39.22) $mgkg^{-1}$ for soils developed in soil unit A, B, and C respectively. In the same order, subsoils values ranged from 20.08 to 24.44 (22.26), 18.89 to 30 (24.08) and 25.56 to 41.11 (30.56) $mgkg^{-1}$. The means obtained between the surface soil and subsoil of each soil unit was statistically similar. Though, geological formation of the study sites is of basement complex origin; the high Fe content obtained is probably largely neo-formed from the transformation product of biotite mica. The values obtained were far above the critical levels of 4.5$mgkg^{-1}$ (Lindsay and Norvell, 1978).

**Table 4.7: Extractable micronutrients level in the soils**

| Horizon | Depth (cm) | Copper ($mgkg^{-1}$) | Zinc ($mgkg^{-1}$) | Manganese ($mgkg^{-1}$) | Iron ($mgkg^{-1}$) |
|---|---|---|---|---|---|
| **Soil Unit A** | | | | | |
| **Pedon A1** | | | | | |
| Ap | 0-27 | Trace | 3.64 | 6.94 | 16.67 |
| Btc | 27-63 | Trace | 19.10 | 6.67 | 24.44 |
| C | 63-115 | Trace | 5.91 | 2.49 | 20.08 |
| **Pedon A2** | | | | | |
| Apv | 0-4 | Trace | 8.64 | 14.99 | 25.56 |
| **Soil Unit B** | | | | | |
| **Pedon B1** | | | | | |
| Ap | 0-23 | Trace | 4.55 | 21.39 | 54.44 |
| Bc | 23-41 | Trace | 3.64 | 9.44 | 25.56 |
| Bt1 | 41-81 | Trace | 4.55 | 14.17 | 21.11 |
| Bt2 | 81-142 | Trace | 7.73 | 7.50 | 18.89 |
| Bct | 142-166 | 0.28 | 8.64 | 3.61 | 22.22 |
| **Pedon B2** | | | | | |
| Ap | 0-23 | 0.28 | 5.45 | 14.99 | 32.22 |
| Bt | 23-97 | Trace | 4.10 | 8.06 | 26.67 |
| Bctg | 97-150 | Trace | 4.10 | 6.94 | 30.00 |
| **Soil Unit C** | | | | | |
| **Pedon C1** | | | | | |
| Ap | 0-20 | Trace | 10.40 | 9.44 | 45.10 |
| Bt1 | 20-89 | Trace | 7.73 | 3.06 | 41.11 |
| Bctgv | 89-114 | Trace | 4.10 | 3.06 | 25.56 |
| **Pedon C2** | | | | | |
| Apg | 0-30 | Trace | 9.55 | 33.33 | 33.33 |
| Bt1g | 30-90 | 0.28 | 4.55 | 16.94 | 30.00 |
| Bt2g | 90-145 | Trace | 7.73 | 9.17 | 25.56 |

## 4.6 SOIL CLASSIFICATION

### 4.6.1 Criteria for Classification

a) *Soil Moisture regime:*- The mean annual rainfall in the study area average about 1033.27mm. This amount is concentrated within 5-6 months (Table 3.1). The moisture regime within the study area is, therefore Ustic. This implies a limited moisture situation, but the moisture is present when conditions are suitable for plant growth (Soil Survey Staff, 1998, 1999). All the pedons were well drained, except pedon C1 and C2 (fadama), which were poorly drained. Pedons A1, A2, B1 and B2 had predominantly ustic moisture regime, while pedons C1 and C2 had aquic moisture regime.

b) *Soil temperature regime*:- The mean annual temperature in the study area is $33^0$C or higher. The mean summer and winter soil temperature do not differ by more than $5^0$C at a depth of 30cm (Table 3.2). The soil temperature regime prevalent here is, therefore, the isohyperthermic type (Soil Survey Staff, 1998, 1999).

c) *Diagnostic surface horizons (Epipedons)*:- All the soil units had ochric epipedons because they were too thin, poor in humus, had colours with values and/ or chromas greater than 2, poor in bivalent cations and low in P, to qualify either as mollic, anthropic, umbric, histic, melanic or plaggen epipedons.

d) *Diagnostic sub-surface horizons:*- All pedons in soil units A,B, and C had significant accumulation of illuviated layer – lattice silicate clays formed below eluvial horizons. The argillic horizons were confirmed to be present by the clay ratio of the illuvial to the eluvial horizon of 1.2 or greater (Soil Survey Staff, 1998, 1999). The subsurface horizons are therefore argillic B-horizons because they had:

i) 1.2 times more clay than the eluvial horizons, which contained between 15-40% total clay in the fine earth fraction.

ii) a total thickness that was more than 15cm in all the pedons where they occurred.

### 4.6.2 Classification according to USDA Soil Taxonomy System

At the order level, all pedons (except pedons A2 and C2) in soil units A,B, and C had argillic horizons, with base saturation of greater than 50% (by $NH_4OAc$) and therefore classified as *Alfisols*. Pedon A2 on the other hand, was classified as *Entisols*. This is because the soil is weakly developed without any other diagnostic horizon apart from an ochric epipedon. Pedon C2 was classified as *Inceptisols*, because they had few diagnostic horizons and a cambic B horizon.

At the suborder level, pedons A1, B1 and B2 were classified as *Ustalfs*, because they had ustic soil moisture regime. Pedon A2 was classified as *Psamment* because the soil had 50% sand within the section on particle size. Pedons C1 and C2 were classified as *Aqualfs* and *Aquepts* respectively, because the soils were saturated with water long enough to exhibit grey colours of chroma 2 or less and presence of reddish or brownish Fe - mottles.

At the great group level, pedons A1, B1 and B2 were further classified as *Haplustalf*, while pedon A2 was classified as *Ustipsamment* because the soils were dry for more than 90 cumulative days but less than 180 cumulative days. Pedons C1 and C2 were classified as *Endoaqualfs and Endoaquepts*.

At the subgroup level, pedons A1, B1 an B2 had a clay distribution in which the percentage of clay did not decrease from its maximum amount by as much as 20% within a depth of 150cm from the mineral soil surface and were therefore classified as *Typic Haplustalf*, while pedon A2 was classified as *Lithic Ustipsamment* because of lithic contact within 5 cm of the mineral soil surface. Pedons C1 and C2 were classified

as *Typic Endoaqualfs and Typic Endoaquepts respectively*, because they had redox depletions with chroma of 2 or less in layers that also have *aquic* conditions in normal years.

### 4.6.3 Classification according to FAO World Reference Base for Soil Resources

Using the FAO World Reference Base for Soil Resources (1974, 1998, and 2001), Pedons A1 in soil unit A, B1 and B2 in soil unit B were classified as Lixisols. These are soils with argic B horizons with high base saturation and low activity clays at certain depths. The argic B horizon is a new terminology in the 1989 legend which replaces the argillic horizon in the 1974 legend (FAO-UNESCO, 1974, 1989). It is similar to the argillic horizon, but had modification of definition to permit easier field identification. At the second level, pedons A1, B1 and B2 were classified as Haplic Lixisols, because they had simple profiles, i.e. with no special features. Pedon A2 was classified as Leptosol and Lithic Leptosol at the second level, because the soils are very shallow over continuous rock, and had a high base saturation respectively.

Pedons C1 and C2 in soil unit C were classified Gleysols, because the soils were water saturated for long enough periods to develop a characteristics gleyic colour pattern. Pedons C1 and C2 are also classified in the second level as Haplic Gleysols because they had simple profiles.

**Table 4.8: Summary of classification of soils of part of IAR (ABU) farm, Zaria.**

| Soil Unit | Pedon | USDA System | WRB System |
|---|---|---|---|
| A | A1 | Typic, Haplustalf, fine loamy-skeletal, isohyperthermic | Haplic Lixisols |
| | A2 | Lithic, Ustipsamment, coarse loamy-skeletal, isohyperthermic | Lithic Leptosols |
| B | B1 | Typic, Haplustalf, fine loamy, isohyperthermic | Haplic Lixisols |
| | B2 | Typic, Haplustalf, fine clayey, isohyperthermic | Haplic Lixisols |
| C | C1 | Typic, Endoaqualf, fine loamy, isohyperthermic | Haplic Gleysols |
| | C2 | Typic, Endoaquept, fine loamy, isohyperthermic | Haplic Gleysols |

## 4.7 LAND SUITABILITY CLASSIFICATION FOR RAINFED CULTIVATION

The suitability classes obtained from the matching of the land use requirement and land qualities are presented in Table 4.9 to 4.14 and summarized in Table 4.15.

Land units 1 and 2 were moderately suitable for cotton (Table 4.11). This is due to their low cation exchange capacity and organic carbon status respectively. LU3 was classified as not suitable, indicating difficult working condition, poor drainage, high acidity, and low inherent fertility status. None of the land units presently fits into the highly suitable class for cotton.

Cowpea had wide range of adaptation cutting across the Nigerian agro-ecological zone with wide range of soils, temperature, rainfall, etc. There are very few demands on soil fertility. It is sensitive to water logging, but tolerant to drought stress than most cereal and other legume. This therefore resulted in raising the classes to highly suitable (S1) for LU1 and LU2 (Table 4.12). However, LU3 was lowered to moderately suitable (S2ag) due to poor drainage, which reduces oxygen availability and high acidity.

Generally, maize desire good climatic conditions, good supply of nutrients during growth, well aerated, deep loamy soils, and rich in organic matter. This resulted in land units LU1 and LU2 to be classified as moderately suitable (S2), while LU3 as not suitable (N). LUI is further lowered to S2 by rooting condition and inherent soil fertility. LU2 is lowered to S2 by high acidity and low organic matter content (Table 4.13).

On the other hand, sorghum need high temperature for good growth, grow on a wide range of soil; sand, loam, sandy loam, well drained and poorly drained, pH of 4-8.5 and salt and alkaline soils. This, therefore, resulted in raising the classes to highly suitable (S1) for LU1 and LU2 (Table 4.14). However, LU3 was lowered to moderately suitable

(S2mg) due to poor drainage which reduces oxygen availability and low organic matter content.

Contrastingly, the limitation method approach gave lower suitability classification for all the land units (Table 4.15). The results showed that LU1 and LU2 were lowered to marginally suitable (S3) for the production of cotton and maize. This is due to the low CEC and organic carbon. For the production of cowpea, Land unit one and two were lowered to moderately suitable (S2) based on their low CEC and nutrient availability. In addition to this, based on rooting condition LU1 was classified as moderately suitable (S2), while LU2 and LU3 were lowered to marginally suitable (S3) due to low organic carbon.

The summary of the qualitative suitability classes (additive and limiting conditions) of the various crops are shown in Table 4.15. Land units LU1 and LU2 were moderately suitable (S2) for cotton and maize, and highly suitable (S1) for cowpea and sorghum. Land unit 3 (LU3) was moderately suitable (S2) for cowpea and sorghum, and not suitable (N) for cotton and maize. Conversely, the limiting condition lowered the classes for LU1 and LU2 to marginally suitable (S3) for cotton and maize and moderately suitable (S2) for cowpea, and LU3 was not suitable for cotton and maize, but marginally suitable for cowpea. For sorghum LU1 was lowered to moderately suitable, while LU2 and LU3 were classified as marginally suitable.

Quantitative suitability evaluation was done on the basis of the observed yield retrospectively as a check on suitability assessments based on soil qualities (FAO 1976). Grain yields (GY) collected from the farmers' field (2008-2009 cropping seasons) and the potential yield for cotton, cowpea, maize and sorghum is shown on Table 18.

The result showed that LU1 and LU2 were lowered to marginally suitable for cotton. This is due to low yield caused by late planting, lack of fertilizer and insecticide application and poor weed control.

LU1 and LU2 were lowered from highly suitable (S1) and moderately suitable (S2) to marginally suitable (S3) for Cowpea and maize respectively, this is due to the abysmal low actual yield compared to their potential yields (Table 4.16). The low yield is due to poor cultural practices, prevalence of diseases and insect pests, and low yield crop varieties.

The yield for sorghum, on the other hand, is above average. Therefore, LU1 and LU2 remained highly suitable.

The summary of the quantitative suitability classes of the various crops are shown in Table 19. Land units LU1 and LU2 were marginally suitable (S3) for cotton, cowpea and maize, and highly suitable (S1) for sorghum.

Generally, it can be seen in the study area that physical and chemical factors affect soil suitability greatly for sustainable production of cotton, cowpea, maize and sorghum. The soils of land units 1, 2 and3 are characterized by low levels of organic matter, total nitrogen, cation exchange capacity and poor buffering capacity. The soils should be monitored for nutrient balance, since the majority of the nutrient elements are close to critical levels. Proper soil management of all the land units, such as effective tillage, application of organic amendments and other soil and water conservation practices will improve crop yields and soil productivity along with the present inorganic fertilization programme. It is recommended that controlled fallow and landuse should be introduced which involves crops like sunnhemp and centrocema be ploughed into the soil to

improve soil nutrients. This is similar to the report by Kumar et.al. (2010). The use of fortified organic manure may also be employed, which could improve soil structure and nutrient level (Ayoola et.al., 2008). The valley bottom soils of land unit three (LU3) can be used for seasonal farming such as sugarcane and rice, but should not be considered for the selected crop types because of its high water table which cause root rot as well as its capacity to hold nutrients.

**Table 4.9: Land unit characteristics and qualities in the profile studied**

| Land quality | Diagnostic factor | Unit | Land units | | |
|---|---|---|---|---|---|
| | | | LU1 (Soil Unit A) | LU2 (Soil Unit B) | LU3 (Soil Unit C) |
| **Climate** | | | | | |
| Annual rainfall (i) | Rainfall | mm | 1,033 | 1,033 | 1,033 |
| Mean annual temp (t) | Temp. | $^0$C | ≥ 29 | ≥29 | ≥ 29 |
| **Topography** | | | | | |
| Erosion hazard(e) | Slope | % | 0-2 | 0-2 | 0-2 |
| **Wetness** | | | | | |
| Oxygen avail. (g) | Drainage cond. | Class | Good | Good | Poor |
| Flooding (f) | Flood | Class | Fo | Fo | F2 |
| **Soil physical properties** | | | | | |
| Soil workability (w) | Soil texture | class | SL/GSCL, CL | SL/SCL,CL | CL,C/CL, C |
| Soil workability (k) | Soil structure | class | Sbk | Sbk | Sbk |
| Rooting cond. (r) | Depth | cm | ≥ 115 | ≥166 | ≥145 |
| **Nutrients (Chem. Prop.)** | | | | | |
| Nutr. retention capacity (n) | Base saturation | % | 83* | 70 | 71 |
| Nutr. retention capacity (c) | Cation exch. cap. | cmol/kg | 6.45 | 8.70 | 8.30 |
| Nutrient availability (a) | Soil reaction | pH | 6.8/ 6.5 | 5.8/5.4 | 5.1/5.4 |
| Organic matter (m) | Organic carbon | $gkg^{-1}$ | 7.55 | 4.19 | 4.00 |

*.? = denote mean values of surface horizons over subsoil horizons.

**Table 4.10: Rating of land use requirement**

| Land quality | Diagnostic factor | Unit | Factor rating | | | |
|---|---|---|---|---|---|---|
| | | | S1 | S2 | S3 | N |
| **A) Cotton** | | | | | | |
| **Climate** | | | | | | |
| Annual rainfall (i) | Rainfall | mm | > 600 | 500 – 600 | 300 – 400 | <300 > 1500 |
| Mean annual temp (t) | Temp. | $^0$C | 25 – 35 | 18 – 25 | 12-17 | < 12 |
| **Topography** | | | | | | |
| Erosion hazard(e) | Slope | % | 0-3 | 3 – 5 | 5-7 | > 7 |
| **Wetness** | | | | | | |
| Oxygen available (g) | Drainage cond. | class | Good | Fair | Poor | Very poor |
| Flooding (f) | Flood | class | Fo | Fo | F2 | F3 |
| **Soil physical properties** | | | | | | |
| Soil workability (w) | Soil texture | class | SL,L | SCL, CL | SL, LS | C, S |
| Soil workability (k) | Soil structure | class | Mod.well dev. struc. | Moderately dev. struc. | Fairlydev. Structure | Structureless |
| Rooting condition (r) | Depth | cm | > 130 | 100 – 130 | 50 – 100 | < 50 |
| **Nutrient ( Chem. prop.)** | | | | | | |
| Nutr. retention capacity (n) | Base saturation | % | > 60 | 45 – 60 | 30- 40 | < 30 |
| Nutr. retention capacity (c) | Cation exch. cap. | cmol/kg$^{-1}$ | > 12 | 8 – 11 | 4 – 7 | < 4 |
| Nutrient availability (a) | Soil reaction | pH | 6.0 – 6.8 | 5.7 – 7.2 | 5.0 – 8.0 | <5, > 8 |
| Organic matter (m) | Organic carbon | gkg$^{-1}$ | > 10 | 7 – 9 | 2-6 | < 2 |

**Table 4.10 contd.: Rating of land use requirement**

| Land quality | Diagnostic factor | Unit | Factor rating | | | |
|---|---|---|---|---|---|---|
| | | | S1 | S2 | S3 | N |
| **B) Cowpea** | | | | | | |
| **Climate** | | | | | | |
| Annual rainfall (i) | Rainfall | Mm | 900 – 1200 | 700 – 900 | 500 – 700 | >500 |
| Mean annual temp (t) | Temp. | $^0$C | 24 – 30 | 20 – 24 | 15 – 20 | > 15 |
| **Topography** | | | | | | |
| Erosion hazard(e) | Slope | % | 0 – 4 | 4 – 6 | 6 – 8 | >8 |
| **Wetness** | | | | | | |
| Oxygen available (g) | Drainage cond. | Class | Good | Fair | Poor | Very poor |
| Flooding (f) | Flood | Class | Fo | Fo | F2 | F3 |
| **Soil physical properties** | | | | | | |
| Soil workability (w) | Soil texture | Class | LS, SL, CL | SC, SCL | SCL | S |
| Soil workability (k) | Soil structure | Class | Crumb | SBK | SBK | Columnar |
| Rooting condition (r) | Depth | Cm | > 100 | 50 – 90 | 25 – 50 | < 25 |
| **Nutrient (chem. prop.)** | | | | | | |
| Nutrient retention capacity (n) | Base saturation | % | > 60 | 40 – 60 | 10 - 40 | < 10 |
| Nutrient retention capacity (c) | Cation exch. cap. | cmol/kg-1 | 10 – 8 | 5 – 7 | 3 – 4 | < 3 |
| Nutrient availability (a) | Soil reaction | pH | 6.0 – 7.0 | 5.5 – 8.0 | 4.5 – 8.5 | < 4.5 > 8.5 |
| Organic matter (o) | Organic carbon | gkg-1 | 1.5 – 2.5 | 1.25 – 1.5 | 1.0 – 1.25 | <10 |

**Table 4.10 contd.: Rating of land use requirement**

| Land quality | Diagnostic factor | Unit | Factor rating | | | |
|---|---|---|---|---|---|---|
| | | | S1 | S2 | S3 | N |
| **C) Maize** | | | | | | |
| **Climate** | | | | | | |
| Annual rainfall (i) | Rainfall | Mm | > 500 | 300 – 400 | 150-250 | <150 > 1400 |
| Mean annual temp (t) | Temp. | $^0$C | >20 | 15-20 | 10 -14 | <10, > 30 |
| **Topography** | | | | | | |
| Erosion hazard(e) | Slope | % | 0-2 | 2-4 | 4-6 | > 6 |
| **Wetness** | | | | | | |
| Oxygen available (g) | Drainage condition | Class | Good | Fair | Poor | Very poor |
| Flooding (f) | Flood | Class | Fo | Fo | F2 | F3 |
| **Soil physical properties** | | | | | | |
| Soil workability (w) | Soil texture | Class | SL, L | SCL, SiL | LS, CL | S, SC, C |
| Soil workability (k) | Soil structure | Class | Mod. well dev. struc. | Moderately dev. Struc. | Weakly dev. struc. | Structureless |
| Rooting condition (r) | Depth | Cm | >120 | 50 - 120 | 30-50 | < 30 |
| **Nutrient (chem. prop.)** | | | | | | |
| Nutr. retention capacity (n) | Base saturation | % | > 70 | 50 – 70 | 30 – 50 | < 30 |
| Nutr. retention capacity (c) | Cation exch. cap. | cmol/kg$^{-1}$ | > 12 | 7 – 12 | 4 – 6 | < 4 |
| Nutrient availability (a) | Soil reaction | pH | 6-7 | 5.5 – 7.5 | 5 – 8 | <5, > 8 |
| Organic matter (m) | Organic carbon | gkg$^{-1}$ | > 15 | 10 – 15 | 4 – 9 | < 6 |

**Table 4.10 contd: Rating of land use requirement**

| Land quality | Diagnostic factor | Unit | Factor rating | | | |
|---|---|---|---|---|---|---|
| | | | S1 | S2 | S3 | N |
| **D) Sorghum** | | | | | | |
| **Climate** | | | | | | |
| Annual rainfall (i) | Rainfall | Mm | > 400 | 150 – 400 | 100 – 150 | < 100 |
| Mean annual temp (t) | Temp. | $^0$C | > 25 | 20 – 25 | 15 – 20 | <15 |
| **Topography** | | | | | | |
| Erosion hazard (e) | Slope | % | 0 – 4 | 4 – 8 | 8 – 12 | > 12 |
| **Wetness** | | | | | | |
| Oxygen available (g) | Drainage condition | Class | Good | Fair | Poor | Very poor |
| Flooding (f) | Flood | Class | Fo | Fo | F2 | F3 |
| **Soil physical properties** | | | | | | |
| Soil workability (w) | Soil texture | Class | SL -, L, S | CL – SCL | SC, LS | C |
| Soil workability (k) | Soil structure | Class | Mod. well dev. struc. | Mod. dev. struc. | Weakly dev. struc. | Structure less |
| Rooting condition (r) | Depth | Cm | > 120 | 50 – 120 | 30 – 50 | < 30 |
| **Nutrient (chem. prop.)** | | | | | | |
| Nutr. retention capacity (n) | Base saturation | % | > 40 | 30 – 40 | 20 - 30 | < 20 |
| Nutr. retention capacity (c) | Cation exch. cap. | cmol/kg$^{-1}$ | 10 – 7 | 4 – 6 | 2 – 3 | < 2 |
| Nutrient availability (a) | Soil reaction | pH | 5.5 – 7.5 | 4.8 – 8.0 | 4.5 – 8.3 | < 4.5 > 8.5 |
| Organic matter (m) | Organic carbon | gkg$^{-1}$ | > 10 | 6 – 9 | 2 – 5 | <2 |

**Table 4.11: Matching land use requirement with land qualities for cotton**

| Land use requirement/ land quality | Symbols | Suitability rating of land units | | |
|---|---|---|---|---|
| | | LU1 | LU2 | LU3 |
| **Climate** | | | | |
| Annual rainfall | (i) | S1 | S1 | S1 |
| Mean Annual Temperature | (t) | S1 | S1 | S1 |
| **Topography** | | | | |
| Erosion hazard (slope) | (e) | S1 | S1 | S1 |
| **Wetness** | | | | |
| Oxygen available (drainage) | (g) | S1 | S1 | S3 |
| Flooding | (f) | S1 | S1 | S3 |
| **Soil physical properties** | | | | |
| Soil texture | (w) | S2 | S2 | N |
| Soil structure | (k) | S1 | S1 | S2 |
| Rooting condition | (r ) | S2 | S1 | S1 |
| **Nutrient ( chem. properties)** | | | | |
| Base saturation | (n) | S1 | S1 | S1 |
| Cation exchange capacity | (c) | S3 | S2 | S2 |
| Nutrient available (soil reaction) | (a) | S1 | S2 | S3 |
| Organic carbon | (m) | S2 | S3 | S3 |
| **Overall suitability (Additive method)** | | S2(c) | S2(m) | N |
| **(Limiting condition)** | | S3 | S3 | N |

**Table 4.12: Matching land use requirement with land qualities for cowpea**

| Land use requirement/ land quality | Symbols | Suitability rating of land units | | |
|---|---|---|---|---|
| | | LU1 | LU2 | LU3 |
| **Climate** | | | | |
| Annual rainfall | (i) | S1 | S1 | S1 |
| Mean Annual Temperature | (t) | S1 | S1 | S1 |
| **Topography** | | | | |
| Erosion hazard(slope) | (e) | S1 | S1 | S1 |
| **Wetness** | | | | |
| Oxygen available(drainage) | (g) | S1 | S1 | S3 |
| Flooding | (f) | S1 | S1 | S3 |
| **Soil physical properties** | | | | |
| Soil texture | (w) | S1 | S1 | S1 |
| Soil structure | (k) | S2 | S2 | S2 |
| Rooting condition | (a) | S1 | S1 | S1 |
| **Nutrient ( chem. properties)** | | | | |
| Base saturation | (n) | S1 | S1 | S1 |
| Cation exchange capacity | (c) | S2 | S1 | S1 |
| Nutrient available (soil reaction) | (a) | S1 | S2 | S1 |
| Organic carbon | (m) | S1 | S1 | S3 |
| **Overall suitability (Additive method)** | | S1 | S1 | S3(fg) |
| **(Limiting method)** | | S2 | S2 | S3 |

**Table 4.13: Matching land use requirement with land qualities for maize**

| Land use requirement/ land quality | Symbols | Suitability rating of land units | | |
|---|---|---|---|---|
| | | LU1 | LU2 | LU3 |
| **Climate** | | | | |
| Annual rainfall | (i) | S1 | S1 | S1 |
| Mean Annual Temperature | (t) | S1 | S1 | S1 |
| **Topography** | | | | |
| Erosion hazard (slope) | (e) | S1 | S1 | S1 |
| **Wetness** | | | | |
| Oxygen available (drainage) | (g) | S1 | S1 | S3 |
| Flooding | (f) | S1 | S1 | S3 |
| **Soil physical properties** | | | | |
| Soil texture | (w) | S2 | S2 | N |
| Soil structure | (k) | S1 | S1 | S1 |
| Rooting condition | (a) | S2 | S1 | S1 |
| **Nutrient ( chem. properties)** | | | | |
| Base saturation | (n) | S1 | S1 | S1 |
| Cation exchange capacity | (c) | S2 | S2 | S2 |
| Nutrient available (soil reaction) | (a) | S1 | S2 | S3 |
| Organic carbon | (m) | S3 | S3 | S3 |
| **Overall suitability (Additive method)** | | S2(rcm) | S2(am) | N |
| **(Limiting method)** | | S3 | S3 | N |

**Table 4.14: Matching land use requirement with land qualities for sorghum.**

| Land use requirement/ land quality | Symbols | Suitability rating of land units | | |
|---|---|---|---|---|
| | | LU1 | LU2 | LU3 |
| **Climate** | | | | |
| Annual rainfall | (i) | S1 | S1 | S1 |
| Mean Annual Temperature | (t) | S1 | S1 | S1 |
| **Topography** | | | | |
| Erosion hazard(slope) | (e) | S1 | S1 | S1 |
| **Wetness** | | | | |
| Oxygen available (drainage) | (g) | S1 | S1 | S3 |
| Flooding | (f) | S1 | S1 | S3 |
| **Soil physical properties** | | | | |
| Soil texture | (w) | S1 | S1 | S2 |
| Soil structure | (k) | S1 | S1 | S1 |
| Rooting condition | (a) | S2 | S1 | S1 |
| **Nutrient ( chem. properties)** | | | | |
| Base saturation | (n) | S1 | S1 | S1 |
| Cation exchange capacity | (c) | S1 | S1 | S1 |
| Nutrient available (soil reaction) | (a) | S1 | S1 | S2 |
| Organic carbon | (m) | S2 | S3 | S3 |
| **Overall suitability (Additive method)** | | S1 | S1 | S2(mg) |
| **(Limiting method)** | | S2 | S3 | S3 |

**Table 4.15: Land suitability classes for the selected crops.**

| | Land suitability classes | | | | | |
|---|---|---|---|---|---|---|
| Crops | LU1 | | LU2 | | LU3 | |
| | Additive method | Limiting method | Additive method | Limiting method | Additive method | Limiting method |
| Cotton | S2(c) | S3 | S2(m) | S3 | N | N |
| Cowpea | S1 | S2 | S1 | S2 | S3(fg) | S3 |
| Maize | S2(rcm) | S3 | S2(am) | S3 | N | N |
| Sorghum | S1 | S2 | S1 | S3 | S2(mg) | S3 |

**Table 4.16: Actual and potential yield of some selected crops**

| Crop Type | | Potential yield | Actual yield |
|---|---|---|---|
| **Land unit 1** | | | |
| | Cotton | 1t $ha^{-1}$ | 420kg$ha^{-1}$ |
| | Cowpea | 1-1.5t $ha^{-1}$ | 300kg$ha^{-1}$ |
| | Maize | 3t $ha^{-1}$ | 692kg$ha^{-1}$ |
| | Sorghum | 1.5-2.5t $ha^{-1}$ | 1.2t $ha^{-1}$ |
| **Land unit 2** | | | |
| | Cotton | 1t $ha^{-1}$ | 420kg$ha^{-1}$ |
| | Cowpea | 1-1.5t $ha^{-1}$ | 300kg$ha^{-1}$ |
| | Maize | 3t $ha^{-1}$ | 692kg$ha^{-1}$ |
| | Sorghum | 1.5-2.5t $ha^{-1}$ | 1.2t $ha^{-1}$ |
| **Land unit 3** | | | |
| | Cotton | Nil | Nil |
| | Cowpea | Nil | Nil |
| | Maize | Nil | Nil |
| | Sorghum | Nil | Nil |

Source: IAR, Samaru, Zaria.

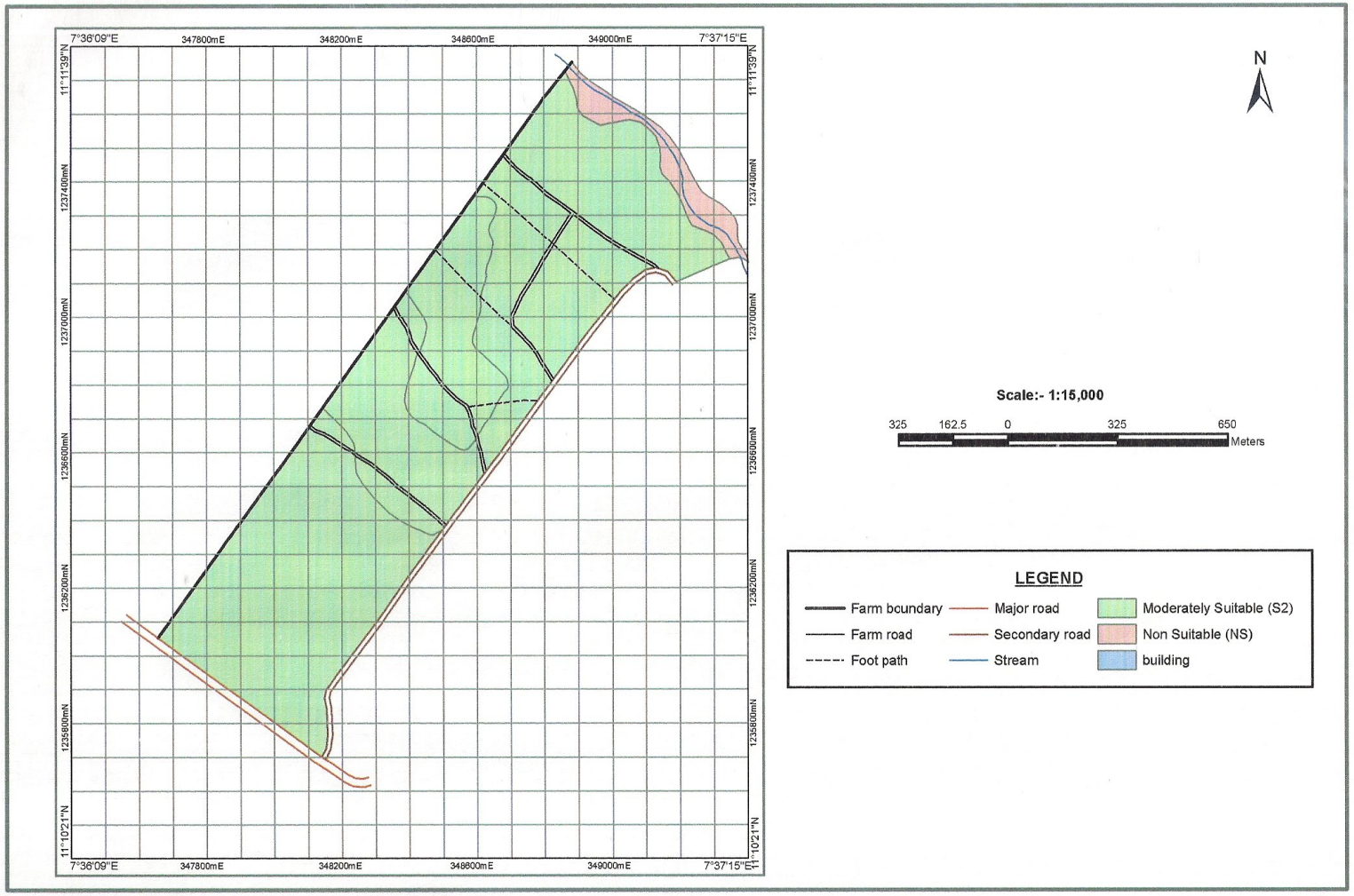



**Figure 4.6: Suitability Map of Soils in IAR Research Farm for Cotton**

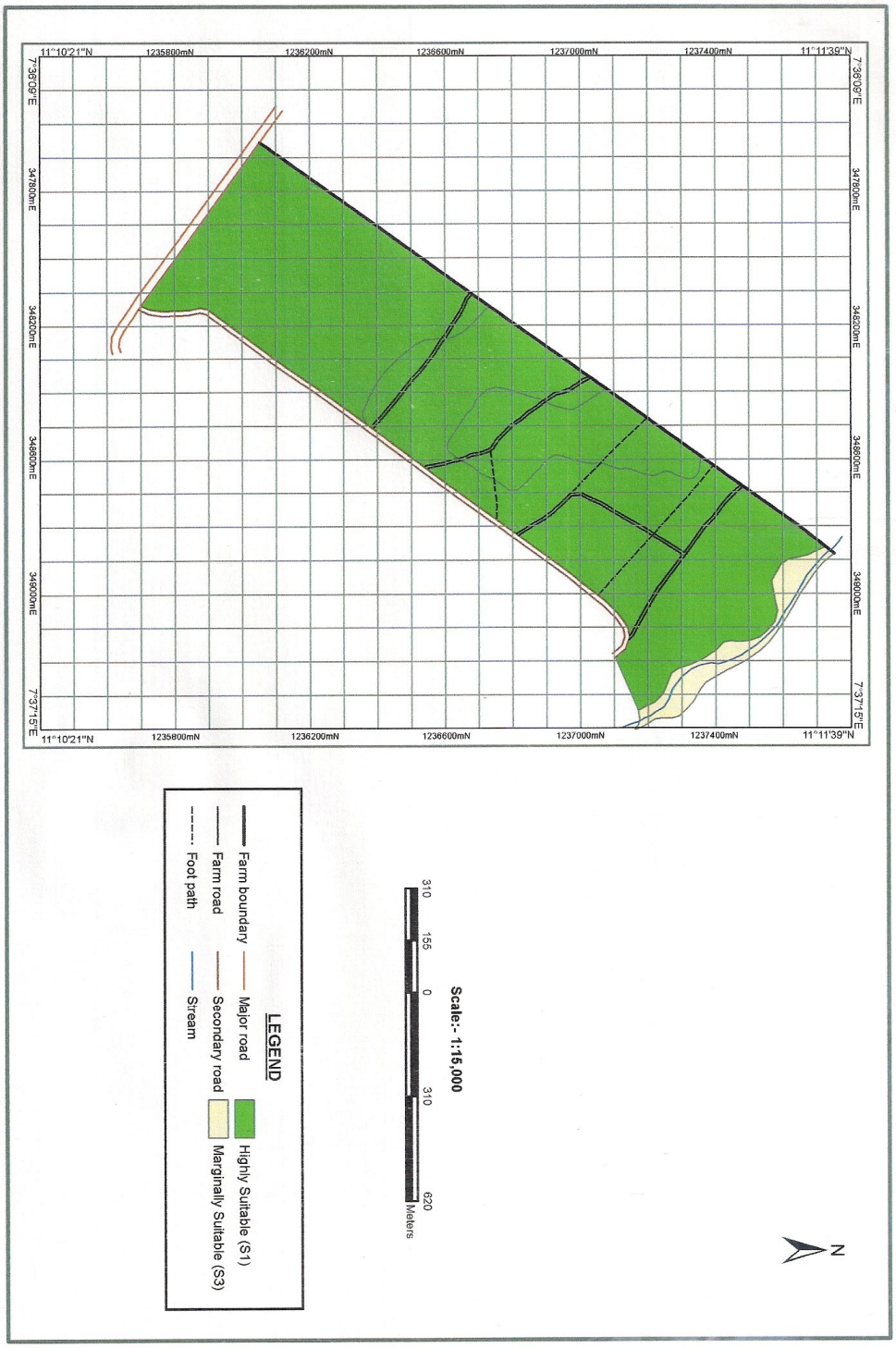



**Figure 4.7: Suitability Map of Soils in IAR Research Farm for Cowpea**




**Figure 4.8: Suitability Map of Soils in IAR Research Farm for Maize**

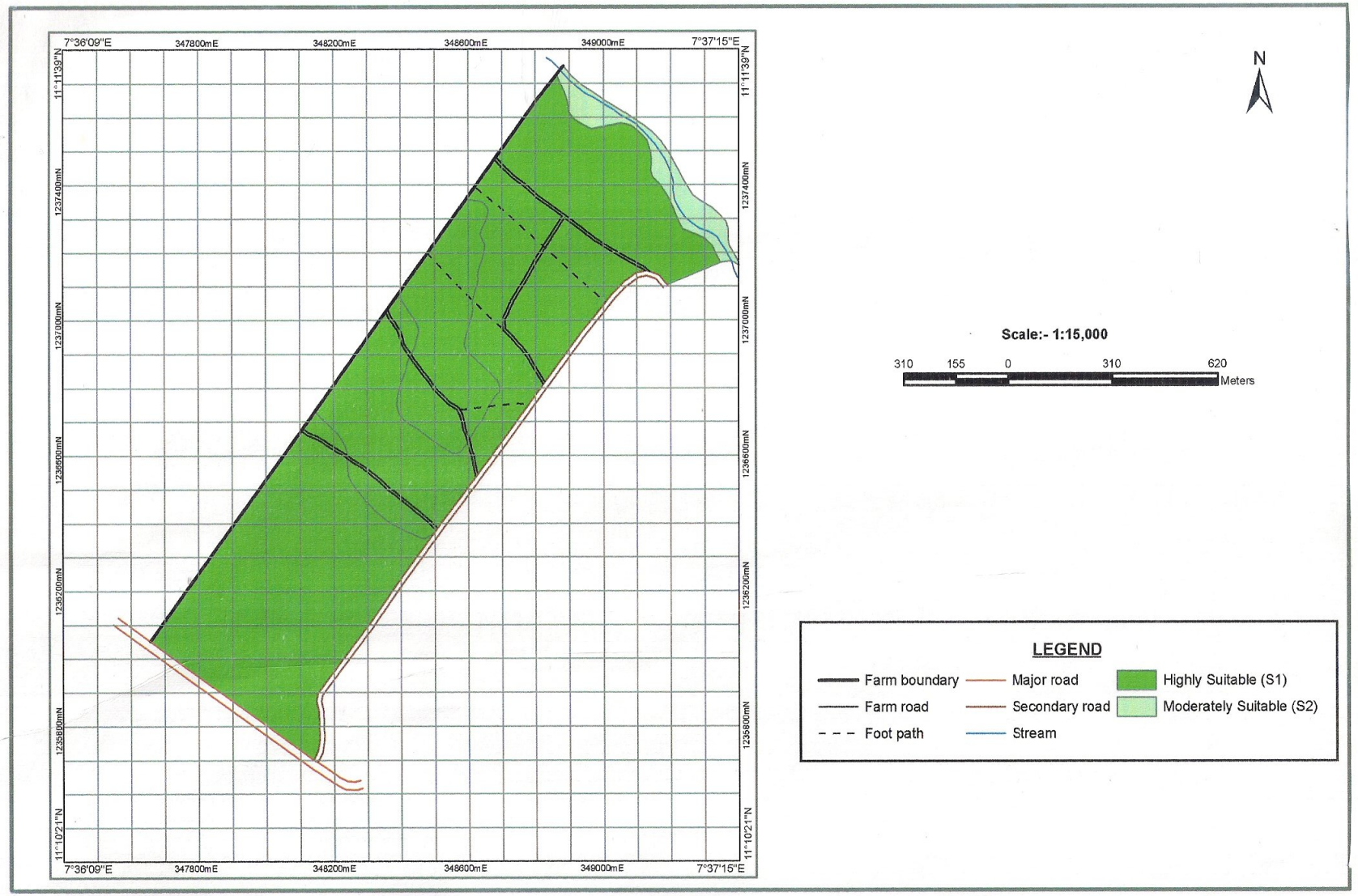



**Figure 4.9: Suitability Map of Soils in IAR Reseach Farm for Sorghum**

# CHAPTER 5

## SUMMARY AND CONCLUSION

This study was carried out at the Institute for Agricultural Research Farm, Ahmadu Bello University along Zaria-Sokoto road, north of the Ahmadu Bello University Teaching Hospital, Zaria. The objectives were to map (conventionally) and characterize the soils and discuss the soil forming processes. The soils were classified using the USDA Soil Taxonomy (Soil Survey Staff, 1999) and FAO World Reference Base for Soil Resources (FAO-ISRIC-ISSS, 1998). Suitability of the soil for rainfed cultivation of some major crops was evaluated. To achieve these objectives, the morphological and physico-chemical properties were determined.

From the results obtained, the soil showed more variation in morphological and physical properties than in chemical properties. The soils were shallow to very deep (4 to 166cm depth), depth increased down slope. The depth reflected influence of parent material and topography. The soils were predominantly medium textured with blocky structures dominating.

Drainage condition was very poor in the profiles in the depressions (Soil Unit C), but the other soil units were moderate to well drained. This was attributed to the topographical influence and increase in clay content. Soil Unit B was higher in clay than the other units. Horizonation was more pronounced between surface horizons and subsoil horizons than within B horizons.

Silt dominated the particle size fraction of the fine earth (< 2mm) portion of the soils. The bulk density was higher in surface soils, but decreased in the upper parts and again

increased in the lower parts of the subsoils, which may be attributed to crust formation (Kowal and Knabe, 1972) in the surface horizon.

The chemical properties indicate low to medium pH (4.7 to 7.2), high exchangeable bases and high base saturation, thereby necessitating their classification as Alfisols. The CEC ($NH_4OAc$, ECEC) and CEC (Clay) did not differ significantly among the soil units. The organic carbon of the surface soils was generally rated low. The total nitrogen and available phosphorus followed the same trend as the organic carbon, suggesting that these nutrients could be derived in the soil from the organic matter.

Parent material, topography and drainage had the most pronounced effect on the soil properties, thereby influencing their pedogenesis. The main pedogenetic process occurring in the soils are organic matter mineralization, argillation, eluviation, illuviation, leaching, textural and structural differentiation, horizonation and partial migration of clay.

According to the USDA system of classification at the great group levels pedons A1, B1 and B2 are classified as *Haplustalf*, Pedon A2 as Ustipsamment, while pedons C1 and C2 were classified as *Endoaqualfs* and *Endoaquepts* respectively. All the soils are classified as *Typic Haplustalf* because the percentage of clay (in clay distribution) does not decrease from its maximum amount by as much as 20% within a depth of 150cm from the mineral soil surface, but pedons A2 which was classified as *Lithic Ustipsamment*, and pedons C1 and C2 which were classified as *Typic Endoaqualfs* and *Typic Endoaquepts* respectively, because they have redox depletions with chroma of 2 or less in layers that also have aquic conditions in normal years. In the FAO/UNESCO system, all the soils were classified as *Haplic Lixisols*, but pedons A2 was classified as *Lithic Leptosols* and pedons C1 and C2 were classified as *Haplic Gleysols*.

The common constraints to agricultural productivity were low values of organic matter, low total N, available phosphorus and poor drainage. Thus, for optimum agricultural productivity, the soils would need full recommended rates of N and P from inorganic fertilizers. Incorporation of crop residues and application of organic manure will also help improve soil physical and chemical properties, which will invariably increase the productivity of the soil.

Land units LU1 and LU2 were moderately suitable (S2) for cotton and maize, and highly suitable (S1) for cowpea and sorghum. LU3 was marginally suitable (S3) for cowpea and sorghum and not suitable (N) for cotton and maize.

Quantitatively, Land units LU1 and LU2 were marginally suitable (S3) for cotton, cowpea and maize, and highly suitable (S1) for sorghum.

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## APPENDIX A: PROFILE DESCRIPTIONS
## PEDON 1 (PROFILE PA1)

**General Site Information**

| | |
|---|---|
| Location: | IAR Farm |
| Date of examination: | 08-08-09 |
| Weather prior to Description: | Sunny |
| Taxonomic classification: | Typic Haplustalf (USDA)<br>Haplic Lixisols (FAO) |
| Soil parent: | Basement complex |
| Local relief: | Upper slope |
| Slope: | 0-2% |
| Co-ordinate | $11^0$10'43''N<br>$7^0$36'36''E |
| Soil erosion/description: | Sheet |
| Rock outcrop: | No bedrock exposed |
| Drainage: | Well drained |
| Surface characteristics: | Gravelly |
| Dept to water table: | None |
| Depth to any impenetrable layer: | 115cm |
| Land use/vegetation: | Maize |
| Human influence: | Periodic harrowing/ploughing |
| Described by: | Hussaini G.M and Malgwi W.B. |

**Horizon Descriptions**

| Horizon | Depth (cm) | Descriptions |
|---|---|---|
| Ap | 0-27 | Dark yellowish brown (10YR3/4 moist), sandy loam; moderate medium subangular blocky, non plastic slightly sticky wet friable soft, common medium roots, common medium tubular pores, gradual smooth boundary. |
| Btc | 27-63 | Red (2.5YR4/8 moist), gravelly clay loam, structureless, slightly sticky wet, loose, few fine roots, clear smooth boundary. |
| C | 63-115 | Red (2.5YR4/6 moist), gravelly clay, many coarse prominent mottles, , structureless, slightly sticky wet, firm, hard, many coarse gravel, presence of pan materials, empty termite holes, few tubular pores, clear smooth boundary. |

## PEDON 2 (PROFILE PA2)

**General Site Information**

| | |
|---|---|
| Location: | IAR Farm |
| Date of examination: | 08-08-09 |
| Weather prior to Description: | Sunny |
| Taxonomic classification: | Lithic Ustipsamment(USDA)<br>Eutric Leptosol(FAO) |
| Soil parent: | Basement complex |
| Local relief: | Middle slope |
| Slope: | 0-2% |
| Co-ordinate | $11^0$11'07''N<br>$7^0$36'46''E |
| Soil erosion/description: | Sheet |
| Rock outcrop: | Very rocky |
| Drainage: | Well drained |
| Surface characteristics: | Gravelly |
| Dept to water table: | None |
| Depth to any impenetrable layer: | 4cm |
| Land use/vegetation: | Maize |
| Human influence: | Periodic harrowing/ploughing |
| Described by: | Hussaini G.M and Shobayo A.B. |

**Horizon Descriptions**

| Horizon | Depth (cm) | Descriptions |
|---|---|---|
| Ap | 0-4 | Very dark greyish brown (10YR3/2 moist), gravelly sandy loam grayish brown (2.5YR5/2 dry), moderate medium subangular blocky, non plastic non sticky, very friable moist, loose (dry), many medium roots, many medium gravels, presence of pan materials, abrupt smooth boundary. |

## PEDON 3 (PROFILE PB1)

**General Site Information**

| | |
|---|---|
| Location: | IAR Farm |
| Date of examination: | 08-08-09 |
| Weather prior to Description: | Rising sun |
| Taxonomic classification: | Typic Haplustalf (USDA)<br>Haplic Lixisols (FAO) |
| Soil parent: | Basement complex |
| Local relief: | Middle slope |
| Slope: | 0-2% |
| Co-ordinate | $11^0$10'59''N<br>$7^0$36'40''E |
| Soil erosion/description: | Sheet |
| Rock outcrop: | No bedrock exposed |
| Drainage: | Imperfectly drained |
| Surface characteristics: | None gravelly, none stony, none boulder |
| Dept to water table: | None |
| Depth to any impenetrable layer: | Bellow 150cm |
| Land use/vegetation: | Soya bean |
| Human influence: | Periodic harrowing/ploughing |
| Described by: | Hussaini G.M. |

**Horizon Descriptions**

| Horizon | Depth (cm) | Descriptions |
|---|---|---|
| Ap | 0-23 | Dark brown (10YR3/3 moist), sandy loam; moderate medium subangular blocky; slightly sticky wet, friable moist; few fine roots, empty termite holes, common medium tubular micropores, clear smooth boundary. |
| BE | 23-41 | Strong brown (7.5YR5/6 moist), sandy clay loam; moderate medium subangular blocky, sticky and plastic wet, firm, hard, common fine roots, few micropores, clear smooth boundary. |
| Bt1 | 41-81 | Yellow red (5YR5/8) moist, none mottled, clay loam, strong fine subangular blocky, very sticky, very plastic, very firm (moist), hard (dry), few medium roots, some micro and macropores, abrupt smooth boundary. |
| Bt2 | 81-142 | Yellow red (5YR5/8 moist), many medium prominent mottles, clay loam, strong medium subangular blocky, very sticky, very plastic, very firm (moist), hard (dry), few fine roots, presence of clay skin and empty termite holes, clear smooth boundary. |
| Bct | 142-166 | Yellow (10YR7/6) moist, common medium distinct mottles, sandy clay, strong medium subangular blocky, very sticky, very plastic, very firm (moist), hard (dry), few medium roots, few medium gravels, some concretions, presence of empty termite holes and macropores, abrupt smooth boundary. |

## PEDON 4 (PROFILE PB2)

**General Site Information**

| | |
|---|---|
| Location: | IAR Farm |
| Date of examination: | 08-08-09 |
| Weather prior to Description: | Sunny |
| Taxonomic classification: | Typic Haplustalf (USDA)<br>Haplic Lixisols (FAO) |
| Soil parent: | Basement complex |
| Local relief: | Middle slope |
| Slope: | 0-2% |
| Co-ordinate | $11^0$11'18''N<br>$7^0$36'57''E |
| Soil erosion/description: | Sheet |
| Rock outcrop: | No bedrock exposed |
| Drainage: | Poorly drained |
| Surface characteristics: | None gravelly, none stony |
| Dept to water table: | None |
| Depth to any impenetrable layer: | None |
| Land use/vegetation: | Jatropha |
| Human influence: | Periodic harrowing/ploughing |
| Described by: | Hussaini G.M. |

**Horizon Descriptions**

| Horizon | Depth (cm) | Descriptions |
|---|---|---|
| Ap | 0-23 | Light olive brown (2.5YR5/3 dry), brown (10YR4/3 moist), sandyloam, moderate medium subangular blocky, slightly plastic slightly sticky wet, friable moist, common fine to medium roots, few tubular micropores, clear smooth boundary. |
| Bt | 23-97 | Strong brown (7.5YR4/6 moist), clay loam; strong medium subangular blocky, sticky and very plastic wet, firm moist, hard dry, few fine roots; few micro/macro tubular pores; some empty termite holes, abrupt smooth boundary. |
| Bctg | 97-150 | Strong brown (7.5YR5/6) moist, clay loam; many medium distinct mottles, strong fine subangular blocky, very sticky and very plastic, firm moist, hard dry, common coarse roots, some micro/macro pores, clear smooth boundary. |

## PEDON 5 (PROFILE PC1)

**General Site Information**

| | |
|---|---|
| Location: | IAR Farm |
| Date of examination: | 08-08-09 |
| Weather prior to Description: | Sunny |
| Taxonomic classification: | Aquic Hapludalf (USDA)<br>Haplic Gleysols (FAO) |
| Soil parent: | Basement complex |
| Local relief: | Lower slope |
| Slope: | 0-2% |
| Co-ordinate | $11^0$11'26''N<br>$7^0$37'07''E |
| Soil erosion/description: | Severe sheet |
| Rock outcrop: | No bedrock exposed |
| Drainage: | Very poorly drained |
| Surface characteristics: | None gravelly, none stony, none boulder |
| Dept to water table: | 40cm |
| Depth to any impenetrable layer: | Below 114cm |
| Land use/vegetation: | Cane sugar |
| Human influence: | Periodic harrowing |
| Described by: | Hussaini G.M and Shobayo A.B. |

**Horizon Descriptions**

| Horizon | Depth (cm) | Descriptions |
|---|---|---|
| Ap | 0-20 | Dark gray (2.5YR4/1 wet) common medium prominent mottles, clay loam, weak fine crumb, plastic and slightly sticky wet, firm moist, hard dry, many medium roots, few micropores, clear smooth boundary. |
| Btg | 20-89 | Light brown gray (2.5YR6/2 wet)clay loam, many mottles, weak fine Subangular blocky, very sticky and very plastic, firm moist, very hard dry, few medium roots, some micro-macropores, abrupt smooth boundary. |
| Bctgv | 89-114 | Light gray (2.5Y7/1 wet) gravelly clay, many coarse prominent mottles, , structureless, slightly sticky, many coarse gravels, abrupt smooth boundary. |

## PEDON 6 (PROFILE PC2)

**General Site Information**

| | |
|---|---|
| Location: | IAR Farm |
| Date of examination: | 08-08-09 |
| Weather prior to Description: | Sunny |
| Taxonomic classification: | Aquic Hapludalf (USDA)<br>Haplic Gleysols (FAO) |
| Soil parent: | Basement complex |
| Local relief: | Fadama |
| Slope: | 0-2% |
| Co-ordinate | $11^0$11'33''N<br>$7^0$37'00''E |
| Soil erosion/description: | Very severe sheet |
| Rock outcrop: | No bedrock exposed |
| Drainage: | Very poorly drained |
| Surface characteristics: | Marshy |
| Dept to water table: | <40cm |
| Depth to any impenetrable layer: | Below 145cm |
| Land use/vegetation: | Cane sugar |
| Human influence: | Periodic harrowing |
| Described by: | Hussaini G.M and Shobayo A.B. |

**Horizon Descriptions**

| Horizon | Depth (cm) | Descriptions |
|---|---|---|
| Apg | 0-30 | Gray (2.5Y5/1, wet) Clay, many coarse prominent reddish brown mottles, moderate medium subangular blocky; very plastic and very sticky, firm moist, very hard dry, common fine roots, few micro-macropores, clear smooth boundary. |
| Bt1g | 30-90 | Gray (2.5Y6/1, wet) Clay, many coarse prominent reddish brown mottles, moderate fine subangular blocky, very sticky and very plastic, very firm moist, very hard dry, few fine roots, presence of empty termite holes and some micro-macropores, abrupt smooth boundary. |
| Bt2gv | 90-145 | Pale brown (gley2(7/5) wet) Clay, many coarse prominent reddish brown mottles, strong fine subangular blocky, very sticky and very plastic wet, very firm moist, very hard dry, presence of concretions and micro-macropores, clear smooth boundary. |

## APPENDIX B:
## LEGEND FOR SYMBOLS USED IN SOIL MORPHOLOGICAL DESCRIPTIONS

### Texture

Fsl - fine sandy loam
Sl - sandy loam
Gscl – gravelly sand clay loam
Scl – sandy clay loam
Ls – loamy sand
Vgsl – very gravelly sandy loam
Vgsc – very gravelly sandy clay
C – clay
Cl – clay loam

### Structure

Wfcrsbk - weak, fine, crumb, subangular blocky
Msmsbk – moderately strong medium subangular blocky
Scsbk – strong, coarse subangular blocky.
Wfcrsbk – weak, fine, crumb, subangular blocky
Scabk – strong coarse angular blocky
Wfcr – weak fine crumb
Wmcrsbk – weak, moderate, crumb subangular blocky

### Consistence

| | | |
|---|---|---|
| Wet (Stickiness): | NS | - Non sticky |
| | SS | - Slightly sticky |
| | S | - Sticky |
| | VS | - Very sticky |
| Wet (plasticity): | NP | - Non plastic |
| | SP | - Slightly plastic |
| | P | - Plastic |
| | VP | - very plastic |
| Moist: | fr | – friable |
| | Vfr | – very friable |
| | Fm | – firm |
| | Vfm | – very firm |
| | L | – loose |
| Dry: | S | – soft |
| | Sh | – slightly hard |
| | H | – hard |
| | Vh | – very hard |

**Boundary:**

Distinctness (thickness): a – abrupt (< 2cm)
c – clear (2-5cm)
g – gradual (5-15cm)
d – diffuse (>15cm)

Topography: s – smooth
w – wavy
i – irregular
b - broken

## APPENDIX C: RATING FOR SOIL DATA INTERPRETATION

| | | | | |
|---|---|---|---|---|
| **1. Soil Depth (cm)** | | | | |
| Very shallow | | | < 25 | |
| Shallow | | | 25 – 50 | |
| Moderately shallow | | | 50 – 100 | |
| Deep | | | 100 – 150 | |
| Very deep | | | > 150 | |
| **2. Soil Reaction** | | | | |
| Extremely acid | | | < 4.5 | |
| Very strongly acid | | | 4.5 - 5.0 | |
| Strongly acid | | | 5.1 - 5.5 | |
| Moderately acid | | | 5.6 - 6.0 | |
| Slightly acid | | | 6.1 - 6.5 | |
| Neutral | | | 6.6 - 7.3 | |
| Slightly alkaline | | | 7.4 - 7.8 | |
| Moderately alkaline | | | 7.9 - 8.4 | |
| Strongly alkaline | | | 8.5 - 9.0 | |
| Very strongly alkaline | | | > 9.0 | |
| **3. Organic Carbon ($gkg^{-1}$)** | | | | |
| Low | | | < 10 | |
| Medium | | | 10 – 15 | |
| High | | | > 15 | |
| **4. Total Nitrogen ($gkg^{-1}$)** | | | | |
| Low | | | < 1.5 | |
| Medium | | | 1.5 – 2.0 | |
| High | | | > 2.0 | |
| **5. Available Phosphorus (Bray 1) ($mgkg^{-1}$)** | | | | |
| Low | | | < 10 | |
| Medium | | | 10 – 20 | |
| High | | | > 20 | |
| **6. Exchangeable Cation ($cmol.kg^{-1}$)** | **Ca** | **Mg** | **K** | **Na** |
| Low | 0 – 2 | 0 – 0.3 | 0 – 0.15 | 0 – 0.1 |
| Medium | 2 – 5 | 0.3 – 1.0 | 0.15 – 0.30 | 0.1 – 0.3 |
| High | > 5 | > 1.0 | > 0.30 | > 0.3 |
| **7. Cation Exchange Capacity ($cmol.kg^{-1}$)** | | | **$NH_4OAc$** | **ECEC** |
| Low | | | < 6 | < 4 |
| Medium | | | 6 – 12 | 4 – 10 |
| High | | | > 12 | > 10 |

Source: Soil Survey Manual, U.S Dept. of Agriculture. 1993.

## APPENDIX C: RATING FOR SOIL DATA INTERPRETATION

Contd.

| **8. Base Saturation (%)** | | | **$NH_4OAc$** | **ECEC** |
|---|---|---|---|---|
| Low | | | < 50 | <70 |
| Medium | | | 50 – 80 | 70-90 |
| High | | | > 80 | >90 |
| **9. Micronutrients (mgkg-1)** | **Zn** | **Cu** | **Mn** | **Fe** |
| Low | < 1 | < 0.2 | < 1 | < 4.5 |
| Medium | 1 – 2 | 0.2 – 1.0 | 1 – 5 | - |
| High | > 2 | >1.0 | 2 – 5 | > 4.5 |

Source: Soil Survey Manual, U.S Dept. of Agriculture. 1993.