SOIL CONDITIONS UNDER DIFFERENT LAND USE TYPES IN A PART OF NIGERIA'S SEMI–ARID SAVANNA.

By

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DECLARATION

I, S.M. Abubakar do hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented in any previous application for a higher degree. All quotations are indicated and the sources of information used in the review or in support of my arguments are specifically acknowledged by means of references.

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CERTIFICATION

This is to certify that this thesis entitled "Soil Conditions under different land use types in a part of Nigeria's semi-arid Savanna" by Sani Mashi ABUBAKAR meets the regulation governing the award of Master of Science degree in Soil Geography, Post-graduate School, Ahmadu Bello University, Zaria and is hereby approved for its contribution to Knowledge and literary presentation.

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DEDICATION

This research work is dedicated to the entire inhabitants of Nigeria's Marginally Fragile Sudano - Sahelian Zone for their courageous fights with persistency of drought and increasing threats of desertification.

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Finally, as an African Scientist working and living in an Environment which is so fragile as ours, I certainly don't have the priviledge of being neutral especially at a time when our Environment is facing different forms of degradation. By very definition therefore, the orientation of this research work shows the level of my commitment towards solving some of the fundamental problems facing my people. I wish to therefore assure them that my Education will forever be a blessing to them.

ABSTRACT

This study examines the variations in Soil Conditions among different land use types in the Kabomo basin, Katsina State. Eight plots were selected, one was under natural vegetation cover, three were under legume grass, arableland and rangeland respectively and the remaining four were fallows ranging in age from 2 to 15 years. Systematic sampling technique was used to select soil samples from each plot at two standard depths: namely 0-15cm (topsoil) and 20-30cm (subsoil). Soil samples collected were analysed for some key physical and chemical properties: texture, bulk density, moisture content, water stable aggregates greater than 0.50 mm, organic matter, total nitrogen, available phosphorous, exchangeable bases, cation exchange capacity, P^H and base saturation. Analysis of variance and t-test were used to test for significant differences between and amongst the various land uses.

The results obtained vary considerably. In general however, it was found that the mean values of soil properties are in most cases significantly higher over the control than the three land use types, the only exceptions being soil bulk density and sand fractions which in most cases are significantly higher over the various land

uses. Similarly, it was observed that most of the soil properties were differently affected by the differences in land use practices. The properties are also differently affected by the differences in age of fallow. It was observed that there are general decreases in coarsening of soil texture and bulk density, and increases in organic matter, nutrient elements, cation exchange capacity, base saturation percentage, moisture content and water stable aggregates > 0.50 mm with increase in the length of fallow period. However, these changes were found to be less significant over the 2 and 5 years old fallow than over the 10 and 15 years old fallows.

It was concluded that human interference with the natural vegetation cover and the establishment of the various land use types in the study area have caused the degradation of soil properties, with the arable plot being the most degraded. On the other hand, the establishment of the fallow system in the area has produced some favourable changes in soil condition, though the changes were found to be more effective under the old fallow ages (10 and 15 years old). Some suggestions were offered towards tackling the problem of soil degradation, improving the efficiency of the fallows and ensuring the sustainability of agriculture in the area.

TABLE OF CONTENTS

ITEM	PAGE
TITLE	i
DECLARATION	ii
CERTIFICATION	iii
DEDICATION	iv
ACKNOWLEDGEMENT	v
ABSTRACT	viii
TABLE OF CONTENTS	x
LIST OF TABLES	xiv
LIST OF FIGURES	xv
LIST OF APPENDICES	xvi
CHAPTER ONE: INTRODUCTION	1
1.0 Background	1
1.1 Statement of Research Problem	4
1.2 Objectives of the Study	4
1.3 Justification of the Study	6
1.4 Organisation of the Thesis	7
1.5 Literature Review	8
1.5.1 Land Uses and Soil degradation	8
1.5.1.1 Continuous Cultivation	8
1.5.1.1.1 Tillage	8
1.5.1.1.2 Bush Burning	9

1.5.1.1.3 Crop growing and harvesting 10

1.5.1.2 Vegetation clearance/wood cutting 11

1.5.1.3 Rangeland 12

1.5.2 Fallowing and Soil regenerations 13

1.5.3 Concluding Remarks 15

CHAPTER TWO: PHYSICAL ENVIRONMENT 16

2.0 Introduction 16

2.1 Geology 16

2.2 Climate 18

2.2.1 Rainfall characteristics 20

2.2.2 Temperature 23

2.2.3 Humidity 25

2.3 Geomorphology 25

2.3.1 Geomorphic history 25

2.3.2 Landforms and Drainage 29

2.4 Soil characteristics 31

2.5 Vegetation and Land Use characteristics 34

2.5.1 Vegetation types 34

2.5.2 Land Use characteristics 35

CHAPTER THREE: METHODOLOGY 37

3.0 Introduction 37

3.1 Experimental Setting 37

3.2 Soil sampling 40

3.3 Laboratory analysis 41

3.4 Statistical analysis 42

CHAPTER FOUR: COMPARISON OF SOIL PROPERTIES BETWEEN DIFFERENT LAND USE TYPES. 44

4.1 Variation of Soil Properties over different land uses 44

4.1.1 Soil texture 44

4.1.2 Organic matter and nitrogen 53

4.1.3 Available Phosphorous 54

4.1.4 Exchangeable cations and cation Exchange capacity 55

4.1.5 P^H and base saturation 57

4.1.6 Moisture content 59

4.1.7 Bulk density and water stable aggregates greater than 0.50mm 60

CHAPTER FIVE: PATTERNS OF CHANGES IN SOIL PROPERTIES OVER FALLOWS OF DIFFERENT AGES 63

5.1 Introduction 63

5.2 Differences in Soil Properties of different fallows 63

5.2.1	Texture	63
5.2.2	Organic matter and Nitrogen	68
5.2.3	Available Phosphorous	72
5.2.4	Exchangeable bases and cation Exchange capacity	73
5.2.5	P^H and Base saturation	75
5.2.6	Soil moisture	76
5.2.7	Bulk density and water stable aggregates greater than 0.50mm	78
5.3	Comparison of Soil Properties under different fallows and natural vegetation.	79
CHAPTER SIX; DISCUSSION		86
CHAPTER SEVEN; SUMMARY AND CONCLUSION		96
7.1	Summary	96
7.2	Conclusion and Recommendations	103
REFERENCES		106
APPENDICES		120-134

LIST OF TABLES

TABLE		Page
4.1	Summary results of analysis of variances of soil properties between different land uses	50
4.2	Summary results of t-test of soil properties amongst land use types	51
5.1	Summary results of analysis of variance for soil properties between fallows of varying ages	69
5.2	Summary results of t-test of soil properties amongst varying age-grade fallows	70
5.3	Value of the soil properties of each of the fallow period expressed as a percentage of the value under natural vegetation	83

LIST OF FIGURES

FIGURE	PAGE
1.1: Actions, interactions, agents, catalyst and result - effects of soil degradation	3
1.2: Katsina State showing the location of Kabomo basin and some major towns	5
2.1: Kano Plains showing the position of Kabomo basin	17
2.2: Location and extent of the study area on the Kano plains	19
2.3: Detailed physiographic map of Kabomo basin	21
2.4: Variation of mean annual rainfall at Bakori (1962-1982)	22
2.5: Average monthly rainfall at Funtua (1962-1982)	24
2.6: Mean daily minimum and maximum temperatures at Funtua (1962-1982)	26
2.7: Mean monthly values of relative humidity over Funtua (1962-1982)	27
4.1: Mean values of soil properties for different land uses	45
5.1: The variations in mean values of soil properties over fallows of different ages	64

LIST OF APPENDICES

APPENDIX		PAGE
I:	Details of the laboratory methods used	117
II:	Mean and standard deviation values of the soil properties under the different land uses	128
III:	Mean and standard deviation values of the Soil properties under fallows of varying ages.	130

CHAPTER ONE

INTRODUCTION

1.0 Background

Soil results from biochemical weathering of rock minerals. It is a product of the interactions between the lithosphere and biosphere. It is an autonomous natural body of loose unconsolidated materials that occupy the upper portion of the lithosphere. It is a dynamic natural entity that interacts with the other spheres on the earth and shares characteristics of all of them. Soil behaves like a living body with self-regulating abilities to supply nutrients, buffer acid and base reactions, destroy and adsorb pathogens, detoxify and attenuate xenobiotic and inorganic compounds and also has a capacity for self restoration through the process of soil formation (Lal et al., 1989).

Soil degradation takes place when its self regulating ability is upset. It involves an unfavourable alteration in one or all of a soil's physical, chemical and biological properties and processes leading to loss of sustainable use. Processes that may lead to soil degradation include accelerated erosion, increasing wetness and poor drainage, lateritisation, salinisation, nutrient imbalance, decline in

organic matter level and reduction in activity and diversity of soil fauna and flora. Soil degradation is caused by both human and natural factors but emphasis has always been placed on human factors. Figure 1.1 gives a simplified account of the actions and interactions resulting into soil degradation.

In Nigeria, while natural factors can lead to soil degradation, human activities act as the major catalyst of soil degradation. This is because many of these activities (e.g grazing, wood cutting, agriculture) have deprived the soils of vegetative cover and have exposed them to the high erosive power of rainfall and wind. The extension of agricultural activities into the erstwhile climatically marginal areas has had tremendous negative effects on the quality of soils, particularly in the semi-arid areas of the country. Many areas of the northern part of Nigeria are now under the threat of severe land degradation as a result of unchecked human activities. This calls for a need to monitor the extent of soil degradation and in particular the effectiveness of fallowing in improving the soil productivity. To do this, one needs to understand the various changes that do take place in the soil system under different land use types. This forms the focus of the present study.

Fig.1.1: Actions, interactions, agents, catalysts and Results-effects of Soil degradation.

SOIL DEGRADATION

Actions and Interactions

Physical

(a) Deteriorations in soil structure leading to:
(i) Compaction
(ii) Crusting
(iii) Accelarated soil erosion
(iv) Hard setting

(b) Imbalance in water/air ratio:
(i) Wetness
(ii) Drought

(c) Extremes of temperature
(i) Perma frost
(ii) Super- optimal

Chemical

(a) Leaching
(b) Fertility depletion
(c) Sodification
(d) Laterisation
(e) Toxification.

Biological

(a) Decline in biomass
(b) Reduction in organic matter content
(c) Decrease in Species diversity of Soil fauna and flora

Agents and Catalysts

Agricultural Activities

(a) Deforestation
(b) Excessive and untimely Plowing
(c) Intensive row cropping and monoculture
(d) Indiscriminate and excessive use of chemicals
(e) Excessive grazing and high stocking rrate.
(f) Irrigation with poor sub-soil drainage and water with high salt content.

Industrial Activities

(a) Waste disposal
(b) Acid rain

Urbanisation

(a) Application of city waste
(b) Conversion of land to non-agricultural uses.

Results-effects

(a) Productivity loses
(b) Water quality depreciation
(c) Green house effect
(d) Political and Economic instability

Source: Lal et al (1989)

1.1 Statement of Research Problem

Soil fertility in the northern part of Nigeria has been maintained for a long time by the use of organic or farmyard manure and fallowing of different lengths. Under the impact of rapidly growing population and expansion of market, however, the system of fallowing is coming under increased strain. In recent years, most soils have had to be under continuous cultivation while farm machineries, fertilisers, pesticides and herbicides are being freely used, resulting in the expansion of agriculture even into the very marginal areas. The consequences of these new practices on soil productivity have not been adequately studied and their performance in conserving soil relative to the traditional method of fallowing is little known, especially in the semi-arid areas. One way to examine this is to compare soil characteristics under fallows and those under different land use types. This constitutes the problem of interest.

1.2 Objectives of the Study

The objective of the study is to examine changes in soil physical and chemical properties brought about by different land utilisation and management practices in the Kabomo River basin of Katsina State (Fig 1.2). The specific objectives are:

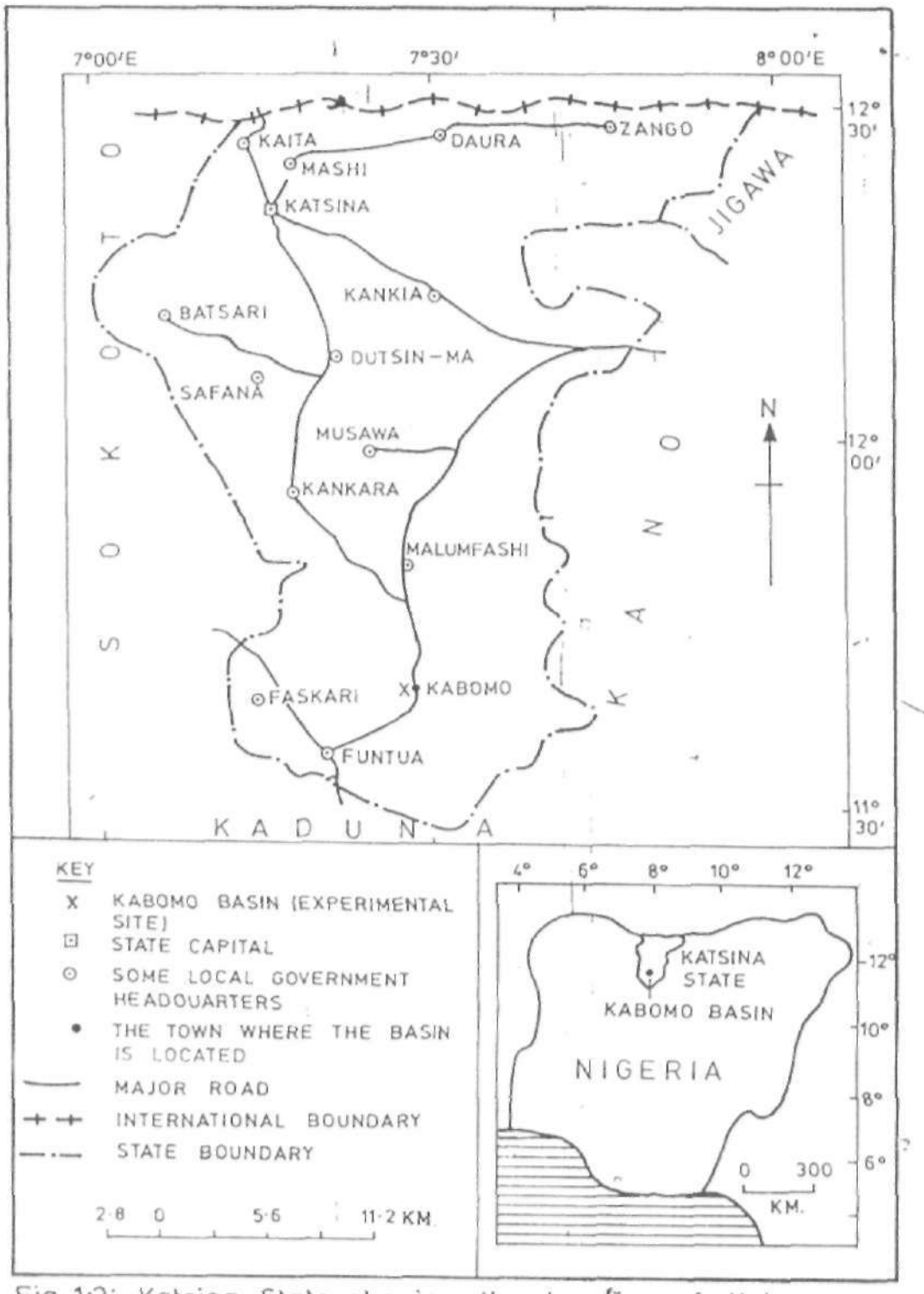


Fig. 1·2: Katsina State showing the locafion of Kabomo Basin and some Major Towns

i) to compare soil properties under rangeland, arableland and legume grass with one another and each with the soil properties under a long standidng fallow vegetation which was chosen to serve as the control.

ii) to compare soil properties of four plots under varying lengths of fallow with one another and each with those under the control.

Based on these objectives, two main hypotheses are formulated:-

a) changes in soil physical and chemical properties differ significantly between land use types in the study area.

b) changes in soil physical and chemical properties differ significantly between fallow plots of different ages in the study area.

1.3 Justification of the Study

Knowledge about changes in soil properties under specific land use types is important in land planning and management. Such knowledge is useful for the assessment of the extent to which a specific land use is jeopardising the agricultural productivity of a soil or otherwise. Unlike in many parts of Nigeria, the extent of information about changes in the soil properties under different land uses in the semi-arid areas of the country is very limited. Yet,

this region constitutes the most fragile ecosystem for agriculture. The need to study changes in soil properties under different land uses cannot therefore be over emphasised.

The information obtained from this study would, undoubtedly, be of some value to the management of the soils in the whole ecological zone that the area of study represents.

1.4 Organisation of the Thesis

This thesis is organised into seven Chapters. Chapter One introduces the study and presents the statement of research problem, objectives and justification of the study and also the review of relevant literature. In Chapter Two, the physical environment of the study area is discussed with particular emphasis on the geologic, climatic, geomorphic, edaphic, vegetational and land use characteristics of the study area. In Chapter Three, the methods used in the collection and analysis of the soil samples and the statistical techniques employed in data analysis are discussed. Chapter Four and Five contain the presentation and discussion of the results obtained for the land uses and fallow plots respectively and in Chapter Six, the results obtained are discussed extensively while in Chapter Seven

the major findings of the study and the conclusions that have justifiably been drawn from the findings of the study are presented. Recommendations that could be offered towards tackling the problem of soil degradation in the area are also presented in the Chapter.

1.5 Literature Review

1.5.1 Land Uses and Soil Degradation

Land use is the use or combination of uses to which a piece of land is put. It may be temporary or permanent. A number of studies have described land uses as being the primary causes of soil degradation (Jones and Wild, 1975; Greenland, 1986; Lal et.al 1989; Mortimore, 1989; Mulongoy et.al 1993). Several works have been carried out on the effects of different land uses on soil conditions. The ones that will be discussed include the effects of continuous cultivation, vegetation clearance and grazing.

1.5.1.1 Continuous Cultivation

Continuous cultivation often involves three major practices in the area which could lead to soil degradation, these are tillage, bush burning, and harvesting.

1.5.1.1.1 Tillage

Land is tilled to provide good seed bed, easy penetration of crops' roots and improved aeration and

water - nutrient conduct into the soil. A number of studies in Nigeria have however pointed out that continuous mechanised tillage practices may have some undesirable effects on soil conditions (see Sam, 1987 and Ohiri, 1988 for instance). Such studies have shown that lands that are mechanically tilled, using heavy machines, tend to be more compacted, contain less faunal population and are generally less stable and fertile than those that are tilled with hoes. The former lands were also found to be more acidic and sandy than the latter. Similar observations have been made in other countries (Balesdent et al 1990, Carter, 1991). Thus, a number of authorities have suggested the adoption of Zero, alternative or minimum tillage systems. Alternatively, Carter (1991) has suggested that direct drilling of crop residue into the soil can compensate for the loses of good soil conditions that may be occasioned by tillage operations.

1.5.1.1.2 Bush Burning

Fire is one of the most powerful tools in the hands of a Nigerian former. Jones and Wild (1975) have recognised two spheres of fire use, namely bush fires and crop residue burning. Bush fires may be started to stimulate growth of fresh grazing grasses and herbs or to flush out game for

hunters or they may be started accidentally. Because of their uncontrolled progress and the indiscriminate destruction that they cause to Nigerian environment, they have been the subject of much controversy, legislation and scientific study. Some researchers have frequently blamed fires for deteriorating fertility of some soils because they encourage the removal of floral and faunal components of the environment which play some important roles in soil nutrient cycling and also because fires accelerate soil erosion (see Hopkins, 1965; Ayuba, 1994). Some others however argue that fires ensure quick return of some nutrient elements, especially bases to the soil (Vine, 1963; Atolagbe, 1990). In a number of West African countries outside Nigeria, cases have been reported where soil fertility decline was noticed due to bush fires (see Jones and Wild, 1975) and outside West African sub-region, similar cases have been reported (Brockington, 1961; Araki, 1993).

1.5.1.1.3 Crop growing and harvesting

A number of studies in Nigeria have shown that continuous cropping causes decline in soil fertility because some important nutrient elements are exported out of a soil in grains and crops residues at harvest, which is especially so because most arable crops have high nutrient

immobilisation (Adepetu et.al, 1979; Obafemi, 1991; Mulongoy et.al, 1993). The decline however appear to be well marked where fertiliser is used in soil fertility maintenance (Aina, 1979). On the other hand, the decline was found to be less marked and often negligible where manure instead of fertiliser is used or where crop residue is retained on the soil as mulch or where cropping is carried out in alleys with leguminous species (Opara-Nadi, 1993; Owaiye, 1993).

1.5.1.2 Vegetation Clearance/Wood Cutting

Vegetation is the fundamental component of nutrient cycling that keeps the cycle functional. Obviously, therefore, its removal will distort such a cycle and can lead into soil degradation. Vegetation removal has been observed to have caused a decline in soil organic matter, nutrients and CEC levels by between 10-26% after about 7 years (Cunningham, 1963). In another study, Lal (1986) has observed that forest clearance in south western Nigeria has exposed the soil to direct impact of rainfall which erodes a substantial part of the productive upper soil layer and this has resulted in some serious ecological consequences including the extinction of certain plant types, accelerated growth of weeds and decline in soil fertility level. However, where the residue is returned to the soil after the

vegetation has been cleared or pruned, cases have been reported where positive changes in soil nutrient and CEC levels have occurred (Lal and Cummings, 1979; Obatolu and Agboola, 1993). Similar evidences are available in several other countries (Seubert et al 1993; Van Holm, 1993).

1.5.1.3 Rangeland

Grazing by livestock removes vegetation cover and thus may lead to soil degradation. In Nigeria in particular, animals are forced to eat every available scarp of arable vegetation they find which they graze ruthlessly and destructively. One major consequence of this practice is reduction in the capacity of vegetation to recycle nutrients and gradually therefore soil fertility is depleted. Obafemi (1991) in Zaria area of Nigeria has observed that soils under rangelands have higher levels of sands and bulk density but lower levels of silt, clay, moisture water stable aggregates, organic matter and nitrogen than either of the soil under forestry or natural vegetation. This clearly shows that some negative changes in soil conditions occur where land is subjected to grazing. In some other countries, similar observations have been made (see Coleman et al 1959; Paul and Beauchamp, 1989).

1.5.2 Fallowing and Soil Regeneration

Evidences in the literature indicate that for quite a long period of time, shifting cultivation or bush fallowing is an important way to restore soil fertility in Nigeria (Nye and Greenland, 1960; Greenland, 1975; Ayinde-Tukur, 1990). This practice, which has been described as being one of the most efficient ways of soil fertility maintenance, involves the cultivation of a land for about three to four years and its subsequent abandonment so that it lies under fallow for a number of years. The length of fallow period varies with farmer's choice or the availability of an alternative land. During fallow, some important changes to restore fertility take place and a number of researches have been carried out on this in Nigeria (Jou and Lal, 1977; Areola, 1979; Aweto and Areola, 1979; Aweto, 1981; Areola et al 1982; Ayinde - Tukur, 1990; Mulongoy et al 1993).

Jou and Lal (1977) have carried out an experiment to examine changes in soil properties resulting from the establishment of three fallows namely Pigeon Pea, Leucena and guinea grass planted fallows, and bush regrowth in Ibadan area of Nigeria. After three years, it was observed that although these are some differences among the plots, all of them show some significant changes in organic Carbon, Nitrogen, CEC and base elements.

In another related study, Areola (1979) has carried out a comparative analysis of soils under Savanna fallows of different ages (5,10,15,25 and 30 years) and observed a general decrease in bulk density, fine sand and coarse sand values but some increases in silt, clay, total Phosphorous, Potassium, Calcium, CEC, Organic matter, Moisture and P^{H} with increase in the length of fallow period. These findings were again confirmed in another study by Aweto and Areola (1979) in another area in South Western Nigeria.

In Zaria area of Nigeria's Northern Guinea Savanna ecological Zone, Ayinde-Tukur (1990) has carried out an assessment of soil regeneration rate under fallow and observed that the increases in mean values of nutrient elements, moisture level, silt and clay fractions with increase in the length of fallow period were more progressive after the 5th year of fallow period so much that by the 9th fallow year, about 95% equilibrium in the buildups of the soil properties were attained. Several other studies in Nigeria have made similar observations (Areola et al 1982; Jaiyeoba, 1989; Kang, 1993; Mulongoy et al 1993). Similar results are available for many West African Countries and also some countries outside West African Sub-region (Bartholomew et al 1953; Morel and Quantin, 1964; Bebwa and Lejoly, 1993).

1.5.3 Concluding Remark

It follows from the review of literature above that land uses are perhaps the most important causes of soil degradation and that fallowing is one of the most important ways of restoring the fertility of a soil. In marginal areas such as the semi-arid region of Nigeria where land is subjected to a number of uses, the need to examine the impacts of land uses on soil degradation and the role fallowing can play in reversing such degradative trends need not be emphasised.

In conclusion, it should be understood from this survey of the literature that few works have been carried out in the semi-arid region of Nigeria on the subject matter despite the fragile nature of their ecosystems. It is thus obvious that more work is necessary towards the understanding of land use-soil relationships in the region. Again, the role of fallowing in soil fertility restoration in the region needs to be explored further. The primary objective of this study is to further advance such understanding using the Kabomo basin of Katsina State as a case study.

CHAPTER TWO

PHYSICAL ENVIRONMENT

2.0 Introduction

This Chapter discusses the Physical Environment of the study area, the Kabomo basin (longitude 7°26' -7°28' East and latitude 11°34' - 11°37' North). The basin is situated on the Jare Plains of central northern Nigeria (Fig 2.1). These plains are located on the extreme western edge of the Kano Plains as shown in Figure 2.1. The Jare Plains cover an area of about 352km^2 representing about 2.5% of the total land area covered by the Kano Plains. In the following sub-sections, the climatic, geologic, geomorphic, vegetation, edaphic and land use characteristics of the area are discussed.

2.1 Geology

The Jare Plains are underlain by two major geological formations, namely younger metasediments and differentiated Basement Complexes which mainly consist of gneiss and migmatite. The Kabomo experimental station is situated on the differentiated Basement Complexes formation. This formation, also referred to as Sensu stricto, includes all rocks older than the younger metasediments. The original rocks have been extensively modified by metamorphism and now

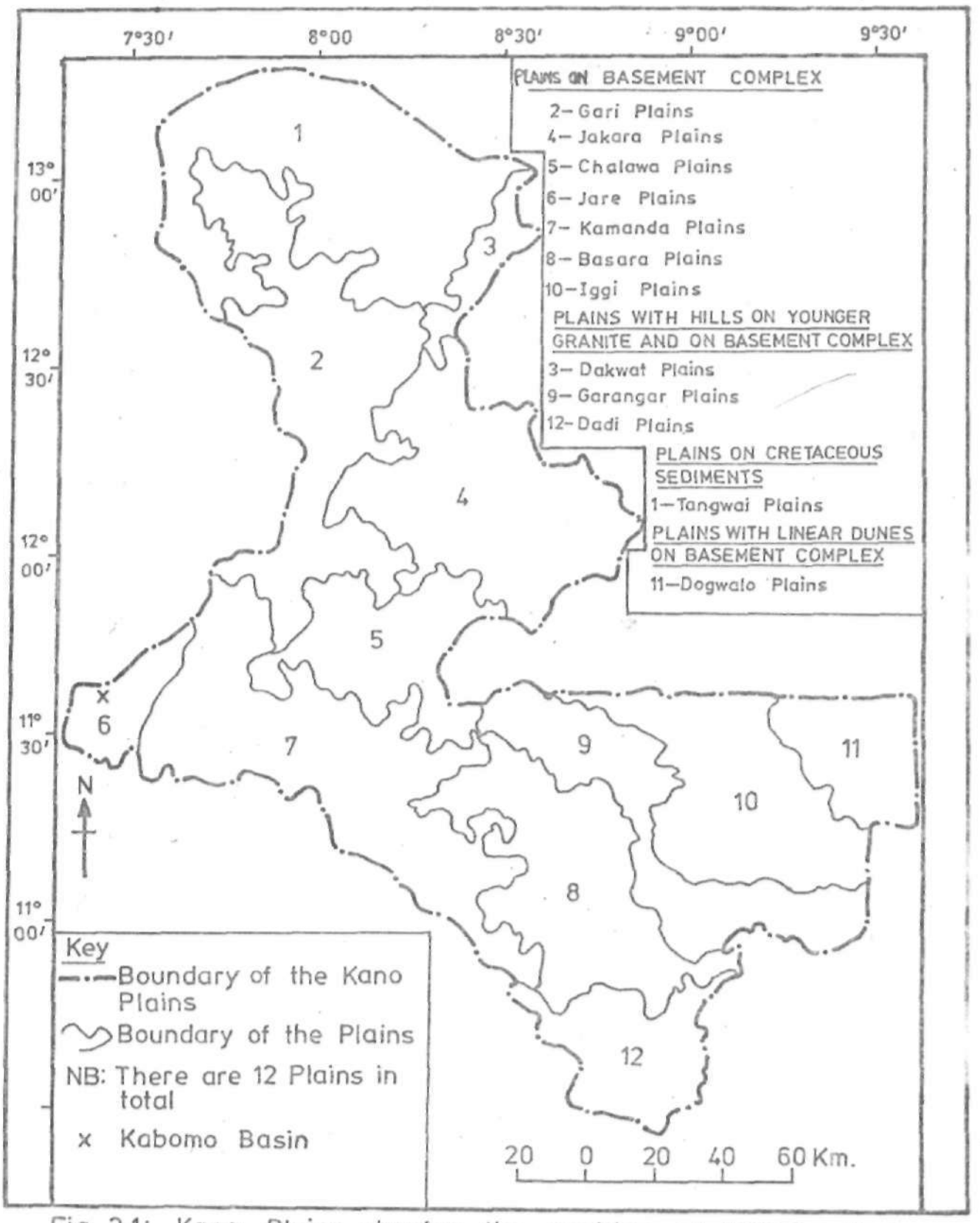


Fig 2·1: Kano Plains showing the position of Kabomo Basin

mainly occur as migmatite and granitic gneiss (McCury, 1976): Quartzite ridges, which are important features of the landscape in the area, belong to this group of rocks. The Sensu stricto consist mainly of quartz and Feldspar which on weathering give rise to relatively sandy and poor soils (Bennett et al 1978).

2.2 Climate

The area has a semi-arid climate with total annual rainfall usually below 700mm and which is concentrated in the months of May/June to September/October. Temperatures are however high for most times of the year with daily maximum temperature ranging from 27^0c to 40^0c and occurring during the months of March to May while daily minimum ranges from 12^0c to 25^0c and occur during the months of November to Friday (Bennett et al 1978).

The highest temperatures occur in April and the lowest in December to January. On the basis of temperature and rainfall, four main seasons have been recognised in the area and they are:

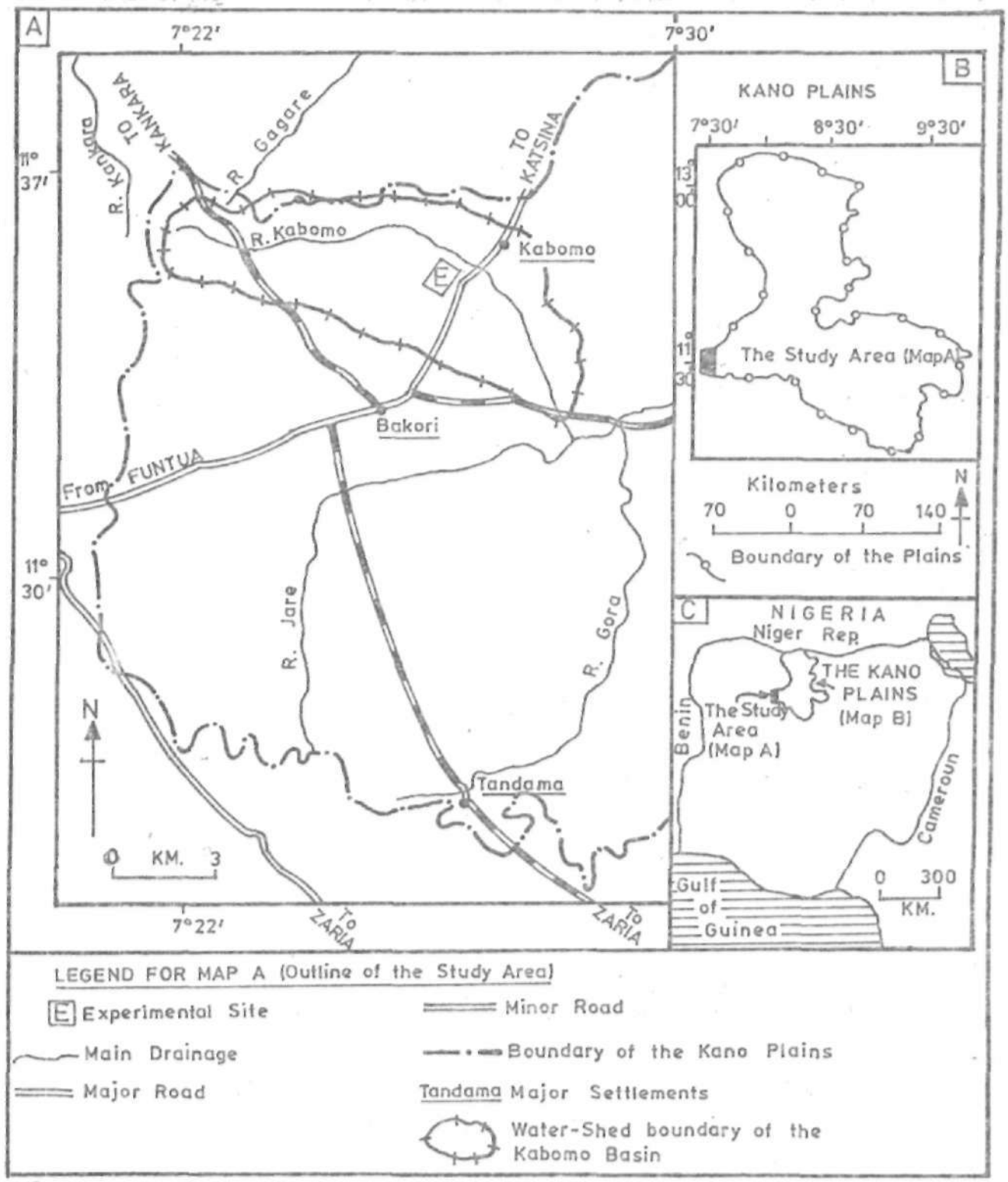
a) Cool dry season; from December to February

b) Hot dry season; from March to may

c) Warm wet season; from May/June to September

d) Season of decreasing rainfall and falling temperatures from September to November.

Fig. 2.2 : Location and extent of the study area on the kano plains



Source: Bennett R. G. et al (1978)

The seasonal pattern is determined largely by the movement of the Inter-Tropical Discontinuity (ITD), a transient discontinuous zone where tropical maritime and tropical continental air masses meet. The former is a warm, moist air which moves inland off the ocean in north-eastern direction and the latter is a warm and dry air which moves from the desert in an opposite direction to the maritime airmass. The winds of the tropical continental airmass are often dust laden and are locally known as Harmattan.

The ITD, which extends roughly east-west across West Africa migrates north and south of the study area. Over the whole of Kano Plains, it is situated at approximately 8^0N of latitude in January and at 20^0N of latitude in July. This means that the ITD crosses the Plains twice in a year, once on its north ward progress and again during its south ward progress (Mc Tainsh, 1982).

2.2.1 Rainfall Characteristics

The rainfall of the area is seasonal in character and highly variable from year to year. Rainfall records at Bakori, for instance, indicate that in 1974 the annual total was 590mm which dropped to 570mm in 1976 and then shot up to 650mm in 1976. Such a pattern of variation is shown in Figure 2.4. The rainfall is unimodal in nature and usually

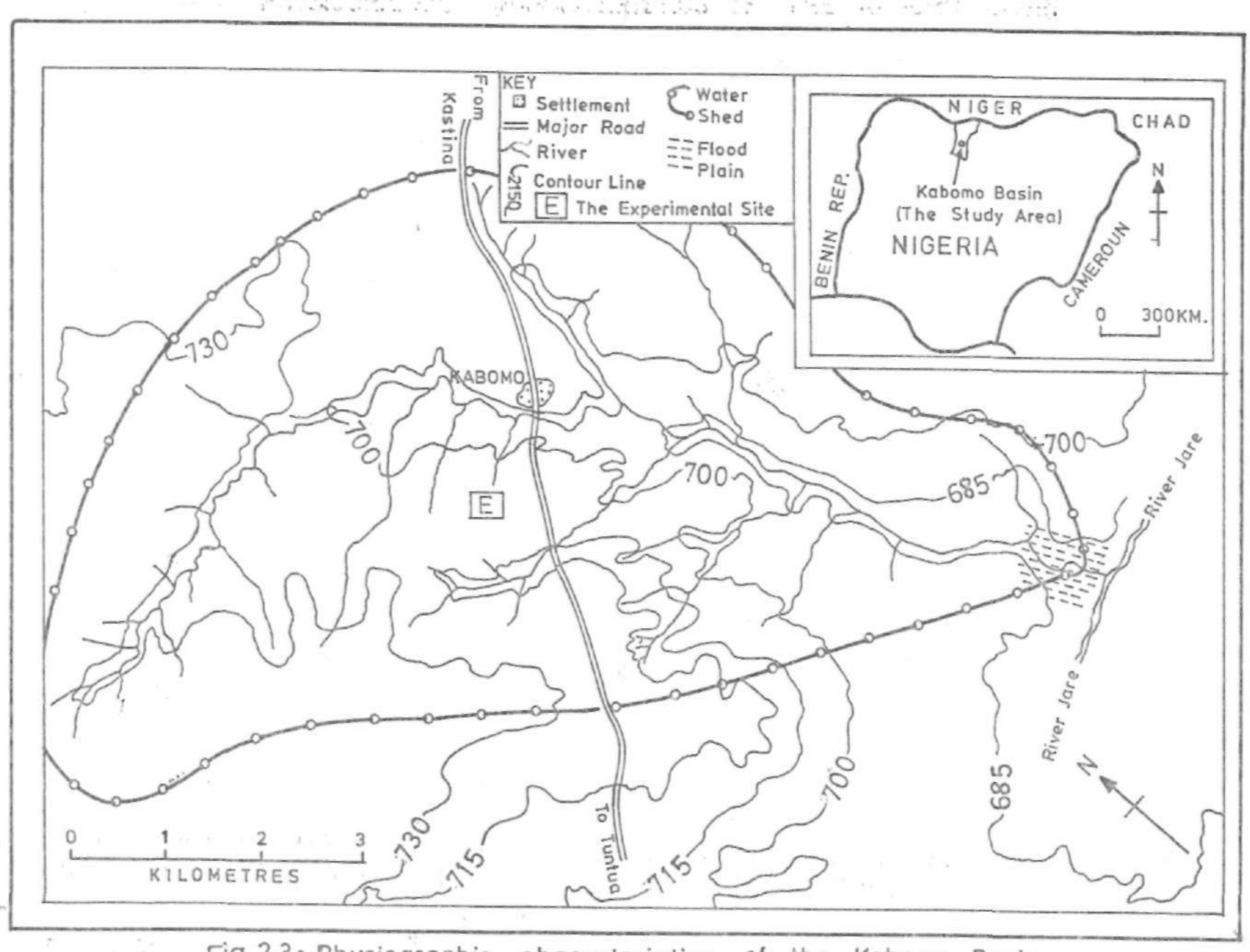


Fig. 2.3: Physiographic characteristics of the Kabomo Basin

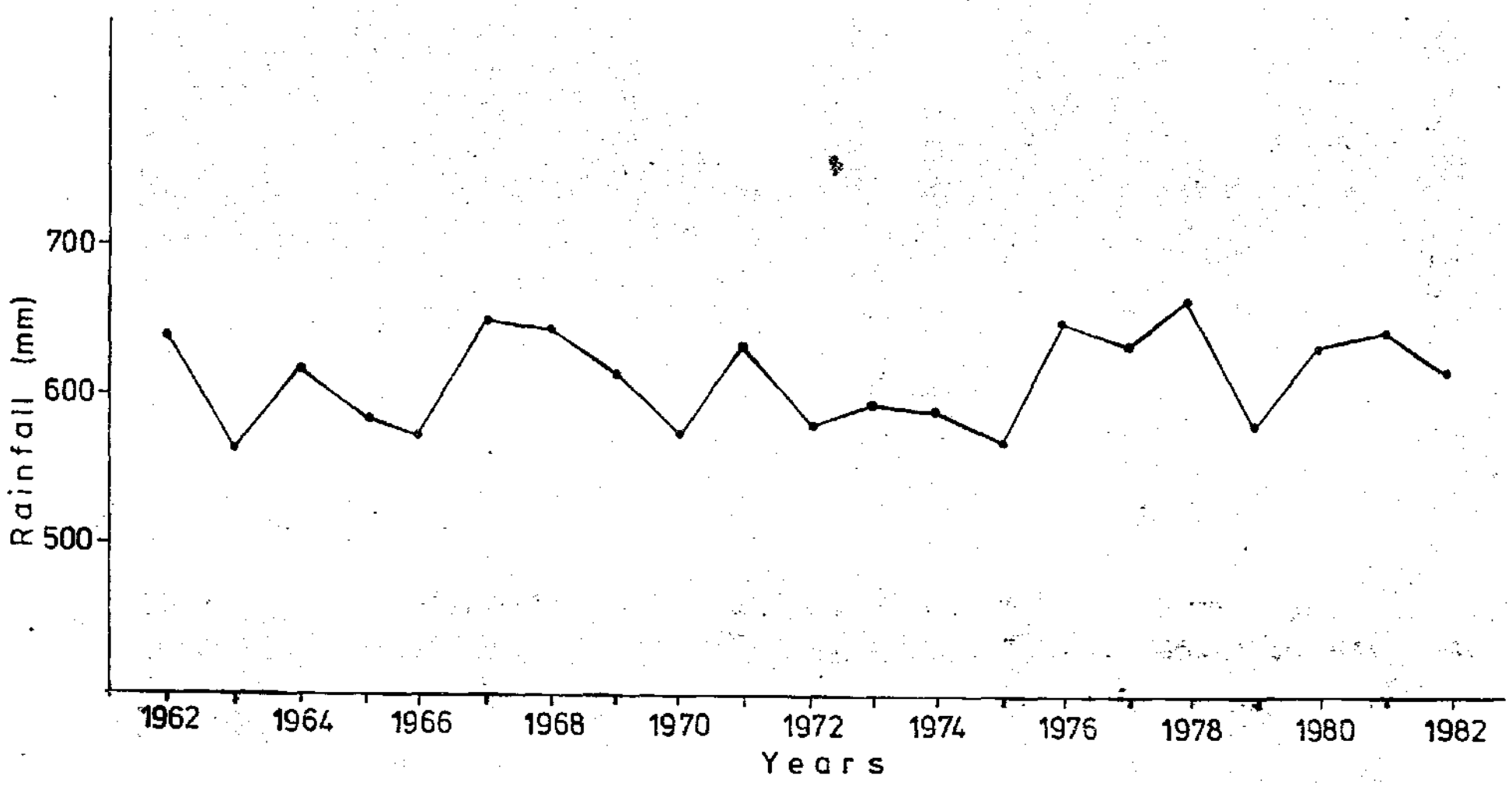


Fig. 2·4: Variation of mean Annual Rainfall at Bakori (1962–1982)

reaches its peak in July or August and then drops sharply in October. The three wettest months are July (with a range of 180 to 250mm), August (with a range of 230-245mm) and September (with a range of 125-175mm). The months of November to May constitute the dry season in which little or no rainfall is received. The inter annual variation of rainfall on monthly basis between 1962 to 1982 for Funtua, which is located very close to Kabomo is shown in Figure 2.5.

2.2.2 Temperature

The temperature of the area is high for most times of the year. The mean maximum increases from 27^0c in February onwards reaching a peak of 40^0c in April. The mean minimum is lowest in December to January during which a temperature of as low as 6^0c is recorded. During this well-known Harmattan period, nights tend to be cloudless and there is considerable radiation of heat from the ground. Figure 2.6 shows the mean daily minimum and maximum temperatures at Funtua between 1962 to 1982. The high temperature of the area coupled with the sparseness of vegetation cover is expected to cause high levels of soil temperature. This can consequently keep the soil moisture content low for most parts of the year.

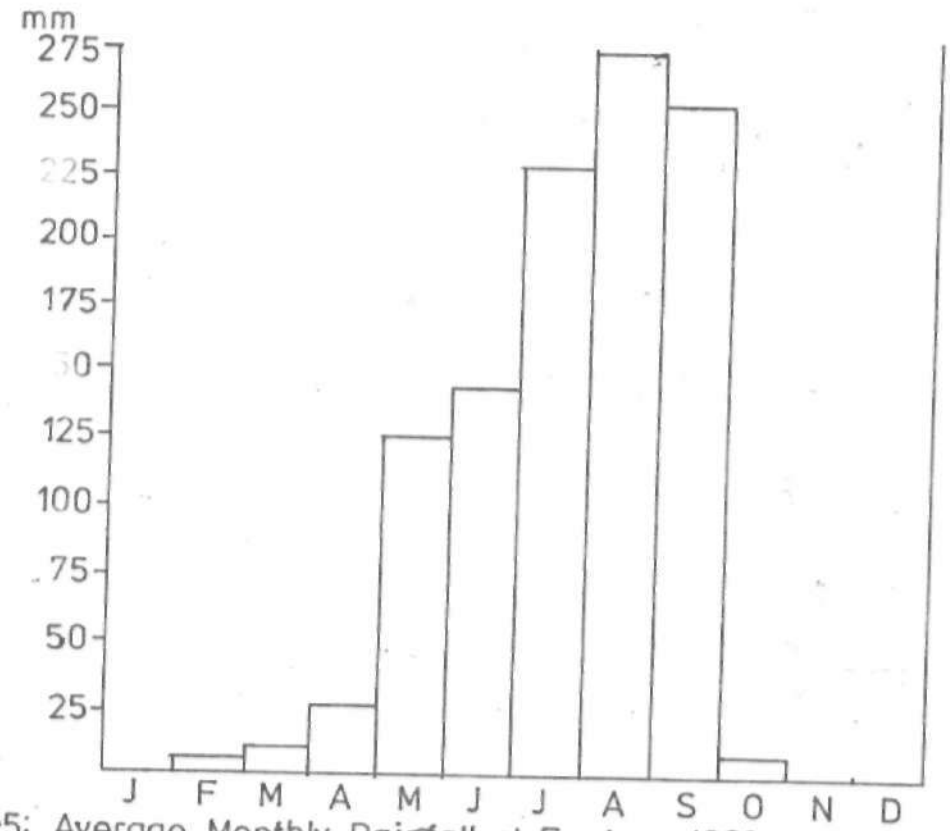


Fig. 2-5: Average Monthly Rainfall at Funtua 1962–1982

2.2.3 Humidity

Figure 2.7 shows the mean monthly values of relative humidity over Funtua between the years 1962-1982. From the Figure, it could be seen that the relative humidity of the area reaches its peak of about 70% in August and becomes as low as 27% around December to January. During the rainy season, there are many hot humid days but during the Harmattan period, the humidity level may drop to as low as 20%. The humidity pattern of the area greatly influences the life cycle of vegetation because the increase in Humidity level before the onset of the wet season and the first showers in the period between April to May use to cause many trees to turn green. This invariably means that humidity pattern indirectly influences soil development processes in the area.

2.3 Geomorphology

2.3.1 Geomorphic History

The area has a complex geomorphic history beginning in the Jurassic period with formation of the oldest known erosion surface, commonly referred to as the Gondwana peneplain (Buckle, 1976). During the cretaceous period, a general subsidence occurred and the Gondwana surface was covered by lacustrine and fluviatile formations. It is

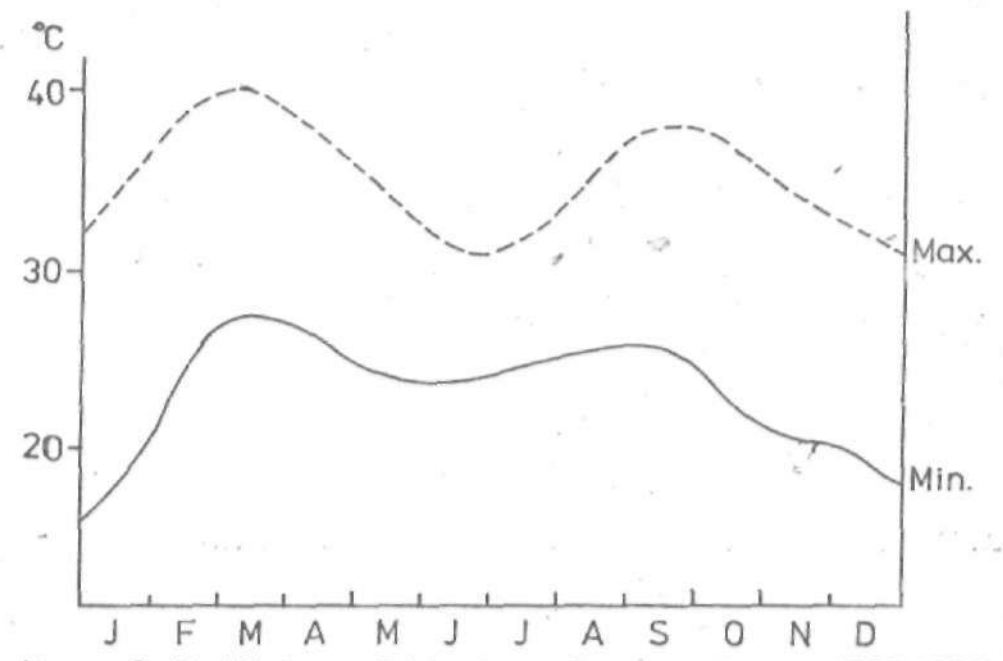


Fig. 2·6: Mean Daily Minimum & Maximum Temp. at Funtua 1962–1982

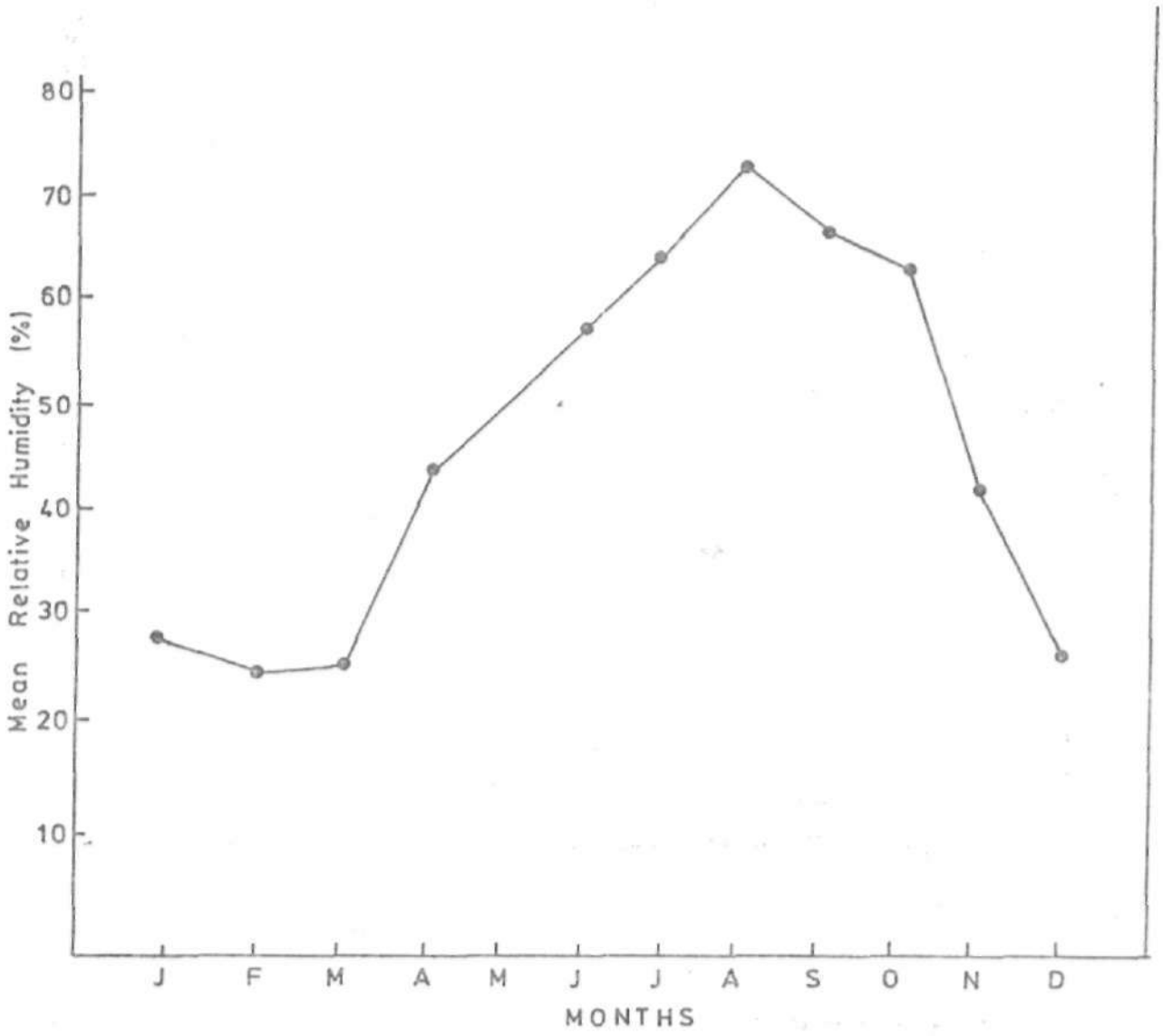


Fig. 2·7: Mean Monthly values of Relative Humidity over Funtua (1962–1982)

likely that the subsidence stopped after the deposition of these formations and a general uplift followed afterwards in the late lacustrine period (FAO/UNDP, 1969). The Post Gondwana process of pediplanation in the late cretaceous caused the removal of thinner parts of these formations. More depositions were reported to have taken place during the early tertiary period after the general subsidence (Thomas, 1974).

During the miocene period, another uplift also occurred and resulted in a pediplanation cycle which is represented by what is commonly referred to as the African surface. This surface is marked by the presence of extensive sheets of massive and indurated laterite and broad river meanders.

During the pliocene, another uplift took place and caused the rejuvenation of the drainage system in the area to result in the formation of V-shaped valleys cutting across the old sediments (FAO/UNDP, 1969). During the pleistocene and holocene, techtonically-stable conditions prevailed although there may have been some relative uplift. The geomorphic processes that were operative then and up to the present time, were controlled by several changes of the climate from arid to moist to wet and vice versa (FAO/UNDP,

1969). The evidence for such changes is the presence of several river sedimentation patterns alternating with various deposits of loess and cover sands (McTainsh, 1982). Since the late pleistocene, at least five major drainage patterns have developed in the area (FAO/UNDP, 1969) and these include:

a) Older braiding and locally meandering river system

b) Younger braiding river system

c) Sub-recent meandering river system

d) Lacustrine meandering system

e) Recent meandering system

2.3.2 Landforms and Drainage

Five major landforms could be identified in the study area and a brief description of each is given below:

a) Areas with very high relief which consist of the following: sharp ridges, scarps and rock outcrops.

b) Areas with high relief intensity, which comprise of hilly landscape, talus slopes and isolated ridges.

c) Areas with medium relief intensity including badland, valleys excluding flood plains and dissected pediplains.

d) Areas with low relief intensity which are overlain by deposits of aeolian and fluvial origin and consist of

the following: almost flat aeolian deposits, sandy wash plains, upland river terraces, flat remnants of pediplain, denudating sedimentary plains, structural plateaux, headwater regions, low terrace flood plains, dissected floe terrace, intersected levees and spills, back swamps, gullies of sub-recent braiding system, present day channels of meandering system, partly silted-in gullies and ponds, and undifferentiated minor flood plains.

The study area has medium to coarse textured undulating plains of moderate relief. It has a mean altitude of about 1.5° (Bennett et al 1978). There are few rock outcrops with small to medium cappings. Few ridges, some standing up to 100m above the adjacent plains are also found in the area. The drainage pattern is mainly dendritic and has a density of about 1.1km/km^2. Three main drainage basins are found in the Jare Plains and they include: Kabomo, Gora and Bakori basins. All these basins drain into the Jare river system which also drains into Lake Chad through the Kano-Hadejia river system. Physiographically, the Niger-Chad watershed forms the Western edge of the study are (Fig.2.2). Detailed physiographic features of the Kabomo basin (the study site) is given in Figure 2.3. The Jare Plains are generally

overlain by aeolian deposits which are sometimes referred to as drifts or loess.

2.4 Soil Characteristics

The soil resources of the area have been studied using reconnaissance survey method by FAO/UNDP (1969). Using identified morphological, physical and bio-chemical properties, the soils have been classified as Entisols (using USDA, 1975 system) and Xerosols (using FAO/UNESCO, 1974 system). These soils have been described as fine sands, slightly acidic with P^H of 5.5 to 6.5, and less-leached soils with very high base saturation, that have been derived from Basement Complex rocks and aeolian drifts. Their organic matter content is low and total nitrogen content rarely exceeds 0.2%, while available phosphorous is generally below 10 ppm. The inherently low organic matter content of the soils is being aggravated by loses of potential humus material in the form of leaf and litter oxidation and /or burning, erosion, continuous cultivation and grazing in the area.

The dominant clay mineral of these droughty soils is kaolinite. Results of soil analyses carried out by FAO/UNDP (1969) have, however, revealed that the soils located on the floodplains have fairly high cation adsorption capacity

values which suggests that in such soils, colloidal materials other than kaolinite may be present. They have also observed some montimorillonitic clay minerals occurring in some dark coloured and cracking fadama soils in the presence of varying proportions of kaolinite. The dominance of kaolinite in the area has been attributed to the nature of underlying geology which is largely quartz. The soils are also characterised by vertical eluviation of clay fractions from the A to B horizon which is sometimes referred to as argillic horizon. Such a horizon may restrict movement of water down the profile and by doing so can reduce the amount of water made available to plant roots.

Under intensive irrigation without subsoil drainage the slowly permeable argillic horizon of the soils of the study area may give rise to perched water tables thereby causing waterlogging and uneven distribution of the irrigation water. Perhaps much more serious than this is the tendency that evaporation from such slowly subsiding water table will, in time, cause progressive accumulation of injurious salts within the root zone of crops. Continuous irrigation of such soils can therefore aggravate the problem of degradation in the area.

The soils are generally low in exchangeable bases and CEC and tend to have poor buffering capacities (Lombin and Chude, 1988). They therefore have low resistance to changes in P^H which tend to decline as the soils are subjected to cultivation with fertiliser application. Any application of acidic or alkaline materials such as fertilisers may thus worsen the soils' chemical status.

According to Bennett et al (1978), the present day soils of the area have been developed within present parent materials formed through several cycles of alternating wet and dry conditions. During wet phases, deep chemical weathering occurred with downwasting of the land surface and removal of soil components in solution and by surface wash. During dry phases, weathered material was exposed to wind action and high intensity rainfall brought about mass movement of loose, unconsolidated surfaces. A site in the area may therefore have been acted upon during several periods by wind or water, erosional or depositional processes, or any combination of the four. While colluviation processes tend to result in only local reworking of the regolith, wind action can bring about addition or removal of materials over greater distances, as well as local movement (Bennett et al 1978).

2.5 Vegetation and Land Use Characteristics

2.5.1 Vegetation Types

The physiognomic communities or vegetation types in the area are largely an expression of overall climatic and anthropogenic controls. The component species and structure of such species have changed from place to place and time to time in response to human activities or the influence of fire or soil, separately or in combination. The main vegetation communities are: (i) tree savanna (ii) shrub vegetation (iii) riparian vegetation and (iv) Fadama grass savanna. The tree savanna is of two types namely the Parkland (Man-made) and fire controlled. All but the tree savanna are seasonal in character and thus provide cover to the soils of the area for only short period of the year. On the other hand, the parkland savanna covers approximately 75% of the vegetation community of the study area and is by far the most important. It consists of a few trees of economic value standing over cultivated lands or other lands that may be reserved for the growth of such trees. Such trees include Acacia albida, Afzella africana, Adansonia digitica, Butyrosperum paradoxum, Danielli olivera, Ficus sycomorous, Khaya senegalensis, Parkia clappertoniana, Pterocarpus erinaceous, Tamarindus indica and Vitex doniana.

Through fires, grazing, agriculture and wood cutting, substantially large proportions of the remaining vegetation types beside the Parkland have been greatly modified in the area.

2.5.2 Land Use Characteristics

In the study area, as in most other areas in rural Nigeria, agriculture is the dominant occupation. Agriculture in the area involves both crop production and livestock management. A variety of crops are produced under upland rainfed farming conditions including millet (Pennisetum americanum), guinea corn (Sorghum bicolor), Cowpeas (Vigna sinensis), groundnuts (Arachis hypogaea), cassava (Manihot esculenta) Maize (Zea mays L), cotton (Gossypium spp) and Beans. In the dry season, Onions (Allium capa), tomatoes (Solanum lycopersicum), cocoyam (Colocasia esculenta) and sugar cane (Saccharum officinarium) are often planted on the lowland fadamas.

The area also supports large numbers of cattle, sheep and goats which are owned by both the Fulani rearers and settled or semi-nomadic rearers. The Fulani rearers trek southward with their herds during the dry season and on their way force the herds to eat every available stalk, grass patches or pruned leaves from trees. Other movements

of herds within the area also occur and involve both the Fulani rearers and settled herders both of who allow their herds to ruthlessly destroy the few vegetative cover as much as they could. Evidences also abound of roofing timber and firewood collection which also help greatly in modifying the character of vegetation communities in the area. It is thus quite clear that land use practices in the area contribute greatly to aggravating the problem of soil degradation.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter describes the methods of soil samples collection, laboratory analysis and the statistical tests that were used in the study. Emphasis is on the experimental setting, laboratory techniques (physical and chemical) and the test statistics.

3.1 Experimental Setting

An inferential approach involving side-by-side comparison of soil under different land use types and fallows of different duration was employed in this study, For the purpose of assessing the effect of different land uses on soil, four adjacent plots were selected. They are (i) arableland (ii) rangeland (iii) legume grass (Stylonsanthes guianensis) farming and (iv) long standing fallow plot serving as the control. All the plots lie on a single catchment area within an experimental station in the study area. The station was established in 1972 for the purpose of improving beef supply through intensive production of livestock feeds by means of legume grass, arable maize crop (Zea mays L.) farming and intensive livestock ranching.

The control plot represents a plant community which is well over 80 years of age. In this respect it is taken to represent the natural vegetation plot. The plot under legume grass farming has since its establishment been under continuous cultivation of Stylosanthes guianensis (Schofield Stylo) grass. The grass is a perennial specie with branching upright stem and has hairy stems with pinnately trifoliate leaves. Although it has low protein content, its phosphorous requirements are very low and as such require little or no fertiliser to do well. The grass is planted at the beginning of the rainy season and harvested by the end of the season after which the ground is prepared for the next planting. Both planting and harvesting are done manually. Its cultivation is without pesticides or chemical applications.

The rangeland plot has similarly been under continuous Gamba grass (Andropogon gayamus) farming since the establishment of the experimental station. Gamba grass is a non-leguminous grass widely grown in Nigeria's semi-arid savanna. It is an erect tufted perennial that can tolerate long dry season. The grass is usually planted at the beginning of a rainy season but rather than harvesting it like the

schofield style grass, it is simply open up for grazing by livestock during the dry season. Here also no pesticides and chemicals are used and the planting is done manually.

The arableland has on the other hand been under continuous arable rainfed cultivation with maize (Zea mays L.) as the main crop. Harrowing is done using tractor while subsequent ploughing is done using bullock powered plough. Clearing of land to prepare for cultivation is done manually. Both weeding and harvesting are also done manually. There is crop residue removal while the soil fertility is maintained by the use of compound (NPK) fertiliser. The rate of application of the fertilisers is 60 Kg/N per ha, 60 Kg/P_2O_5 per ha and 30 Kg/K_2O per ha.

For the purpose of assessing soil fertility under fallow, four plots were also selected for consideration. These are 2,5,10 and 15 years old fallow plots. The plots lie outside the beef improvement station at Kabomo but are in the same catchment area. The selection of these four plots was governed by three main factors. Firstly, they must be such that their agronomic characteristics and land use history are similar and the only difference between them is the length of fallow

period. Secondly, the plots must be from the same slope segment of the catena in the catchment and this eliminates the differences that may arise due to slope angle variations. Finally, these four plots are those whose ages were certified by the farmers in the area. The control plot is also the one under vegetation community of well over 80 years of age.

The validity of the inferential method adopted in this study in respect of an assessment of soil changes under different land uses depends entirely upon the assumption that the different land uses plots selected differ only in land use history and management practices, and in the case of soil regeneration under fallow the plots differ only in age under fallow (Jou and Lal, 1977; Aweto, 1979; Ayinde-Tukur, 1990). To minimise the likelihood of errors due to original soil variability, the plots selected are those located at the upper slope segment of the catena and are under lain by identical geological material, mainly granitic gneiss. The agronomic history of the plots under fallow is also similar.

3.2 Soil Sampling

For the purpose of soil sampling, each of the eight plots selected was partitioned into 12 equal grid squares. At mid-point of every grid square, soil samples were taken at two standard depths namely 0-15cm (top soil) and 20-30cm (subsoil)

depths. The depths were chosen based upon the understanding that 0 - 15cm represents the average plough layer while 20 - 30cm represents the layer where the clay particles leached from the topsoil gets accumulated. Two categories of soil samples were taken from each sampling point and depth. The first was an undisturbed sample, using bulk density ring while the other was a disturbed soil sample using soil auger. The following procedure was used for taking the undisturbed samples: a cylindrical ring of 15cm height and 7cm diameter was driven into the soil. A piece of wood was used as a buffer and a hammer for driving the ring into the soil. After driving the ring to a required depth, it was dug out and the soil level in it trimmed and place in its case immediately. The undisturbed soil samples were used to determine bulk density and moisture content while the fairly disturbed samples were used to determine the remaining soil properties. Details on how each of the soil properties was determined are given in Appendix I.

3.3 Laboratory Analysis

The collected soil samples were analysed using standard procedures, which include: Pippete method for particle size analysis; *Core method for bulk density and moisture content*; Wet sieving method for water stable aggregates; p^H meter (1:2.5

soil to water ratio) for soil pH; Walkey-Black digestion method for organic matter; ammonium acetate extraction method for Cation Exchange Capacity (CEC) and using the extracts obtained by extracting the base elements from the soil samples using 1N ammonium acetate, the concentrations of calcium and magnisium in the soils where determined using atomic absorption spectrophotometer while those of potassium and sodium were determined using flame emission method; regular macro-kjeldahl method for total nitrogen; Bray No.1 method for available phosphorous while base saturation was determined by adding up the base elements content which was then divided by the CEC value and then multiplied by 100. Details on each of this methods are given in Appendix I.

3.4 Statistical Analysis

Two main statistical tests were used to examine the significance of variations in the soil properties selected and these are: analysis of variance and students' t-test.

The analysis of variance is a parametric test for significant difference amongst three or more variables. In this study, it has been used to test for the significance of differences in the selected soil properties between the four land uses and between the four fallow plots. Students' t-test is a parametric test of significant difference between two

samples and in this study it has been used to test for significance of the differences in the selected soil properties amongst the four fallow plots and the four land uses. In both cases, three probability levels have been chosen in order to assess the levels at which the differences are significant and they include 0.05, 0.01 and 0.001 respectively.

The use of the analysis of variance and t-test in this study has been informed by the need to identify the differences in the soil properties both between and amongst the plots selected. Though the analysis of variance can effectively be used in investigating the significance of differences amongst the four land uses and the four fallow plots, it cannot simultaneously be used to identify which of the plots differ most significantly from the other plots. In the other words, it cannot be used to identify the source of variation between the plots. The use of students' t-test as a supplement therefore becomes necessary since this test helps one to do exactly this.

CHAPTER FOUR

COMPARISON OF SOIL PROPERTIES BETWEEN DIFFERENT LAND USE TYPES

This chapter presents and discusses the results of the analyses of soil properties under different land uses. Emphasis is on significant differences as determined by the analysis of variance and the t-test statistics.

4.1 Variation of Soil properties over different land uses

Figure 4.1 shows the histograms of the mean and standard error of mean of each of the soil properties for the different land use types. Summary results of the laboratory analysis of the soil samples showing the mean values and standard deviation of the soil properties are presented in Appendix I. Table 4.1 gives the summary results of the analysis of variance comparing the mean values of soil properties for the land uses, while Table 4.2 summaries the results of student's t-test comparing the mean of soil properties among pairs of land use types.

4.1.1 Soil Texture

In the surface horizon, the sand content is highest over the arableland and lowest over the natural vegetation. The values for the rangeland and legume grass farming plot

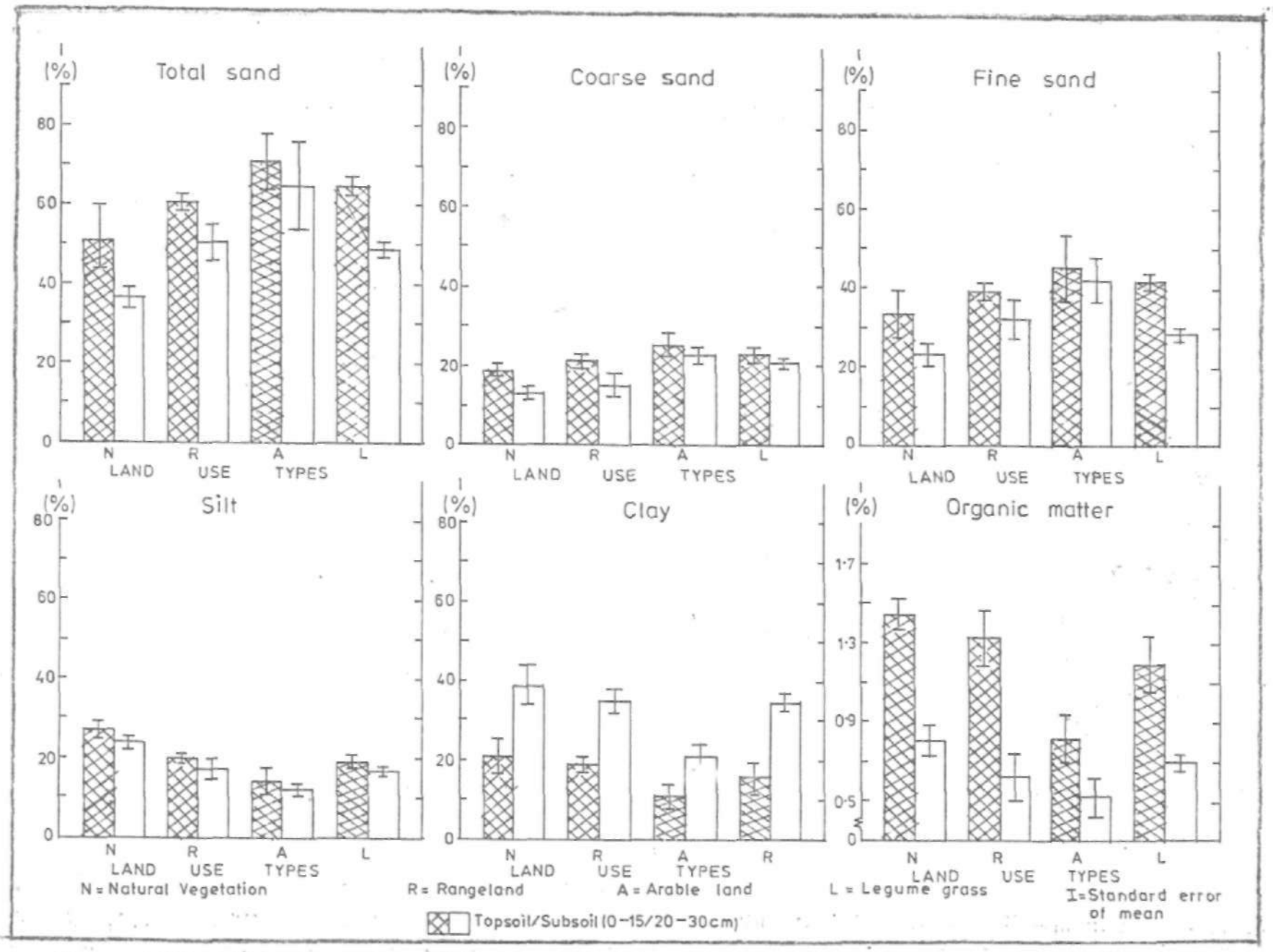


Figure 4·1: Mean values of soil properties for different land uses

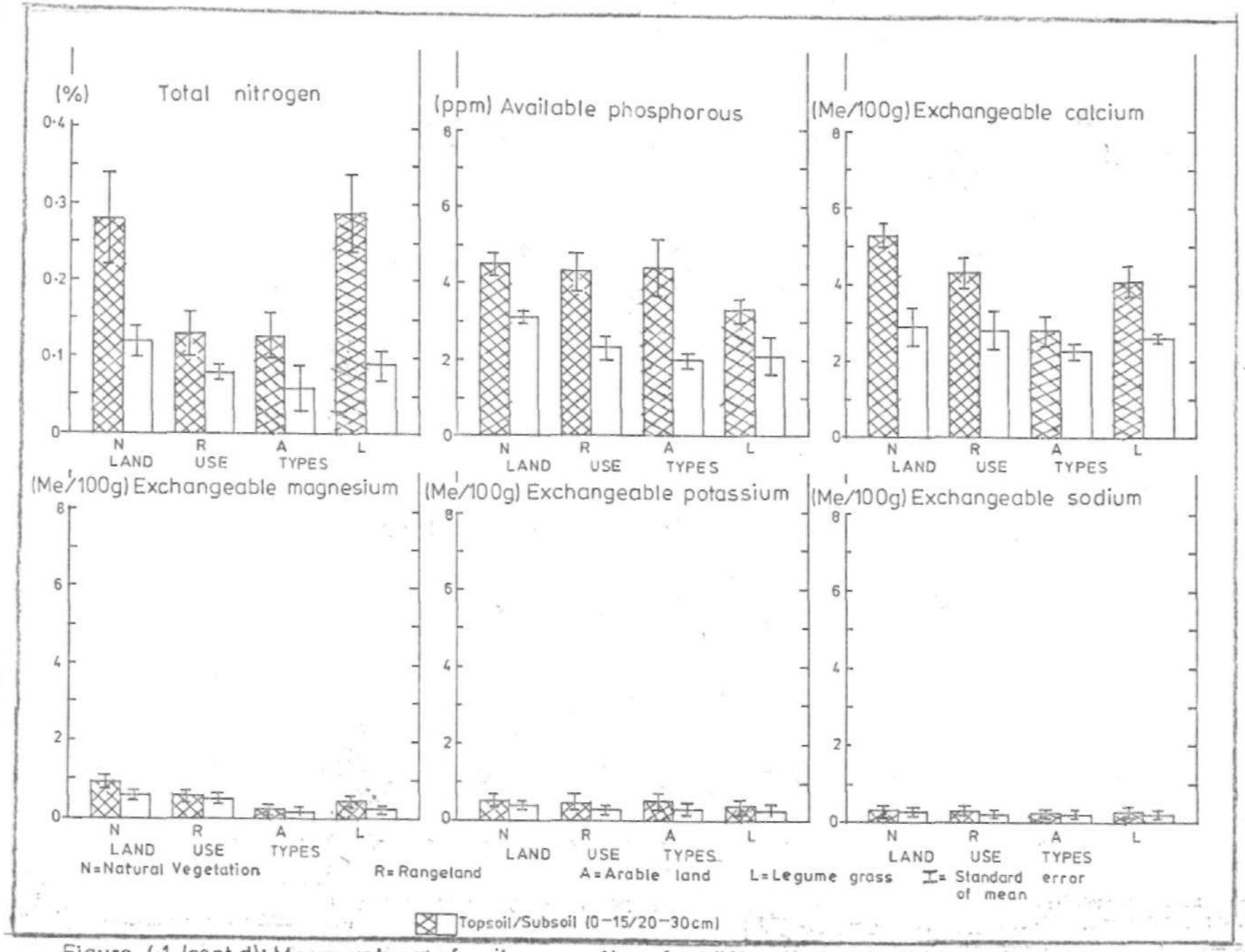


Figure 4·1 (cont.d): Mean values of soil properties for different land uses

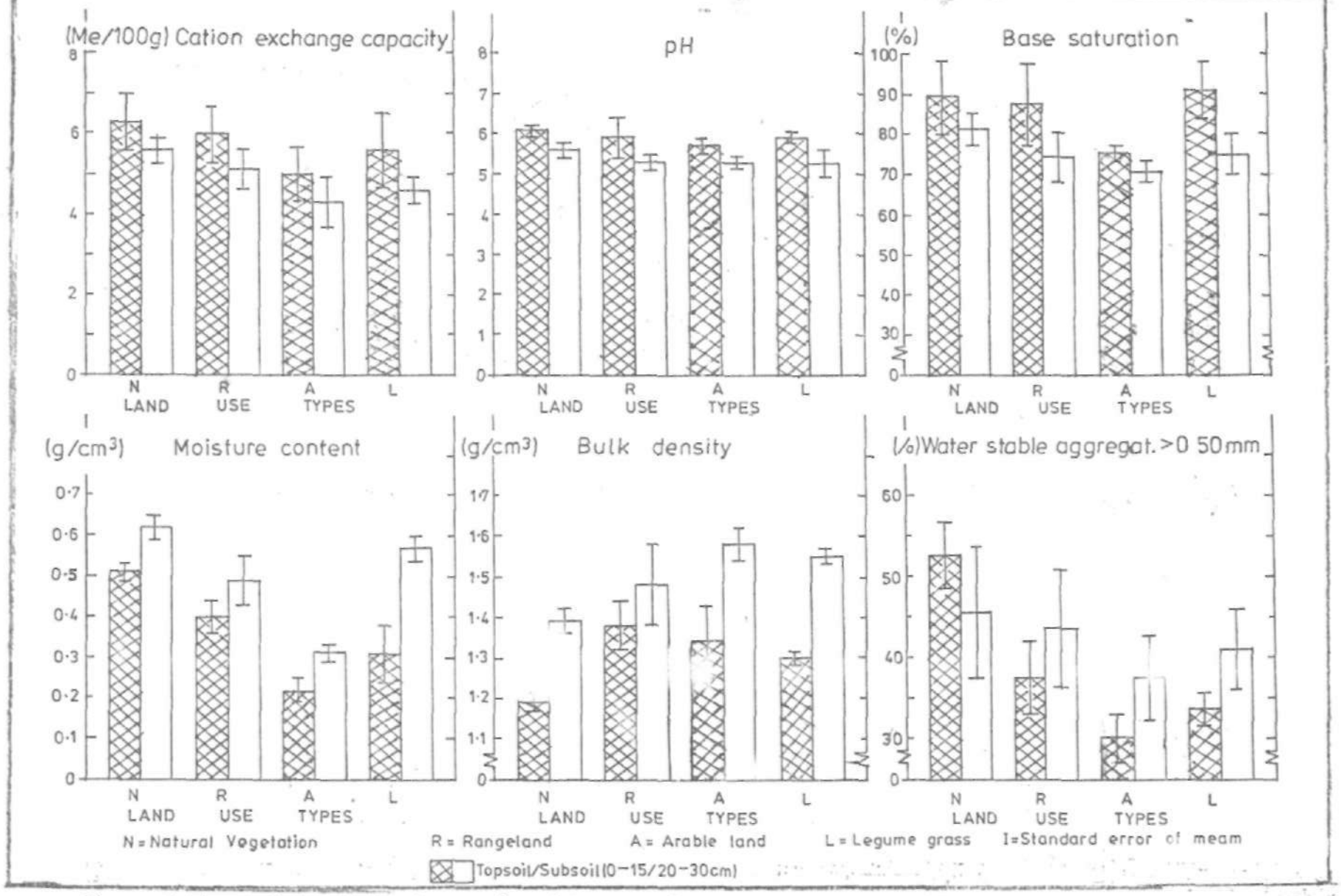


Figure 4·1 (cont.d): Mean values of soil properties for different land uses

are intermediate. The differences amongst the different land uses are significant at 0.05 probability level by analysis of variance (Table 4.1). The result of t-test shows that the differences between pairs of land use categories are generally significant, at least at 0.05 probability level (Table 4.2). In the lower horizon, the sand content follows similar trend as in the surface horizon and both the analysis of variance and t-test results show that the plots are, in general, significantly different from each other. The results obtained for coarse sand (2.00 - 0.50mm) and fine sand (0.50 - 0.05 mm) are quite similar to that of total sand, except that differences between the land use types by analysis of variance are not significant in the topsoil.

In the surface horizon, the silt content varies from being about 28% under the natural vegetation, 20% under the rangeland and 19% under legume grass to about 16% for the arableland. The t-test results show highly significant differences between the natural vegetation on one hand and each of the other land uses on the other hand. The variation in silt content of the lower horizon parallels that of the top layer.

Analysis of variance reveals significant differences in clay content between the different land uses. The value is

highest in the control plot (21%) followed by the rangeland (19%), the legume grass plot (16%) and lastly the arableland (12%). In the lower horizon, the highest value of 37% was obtained for the control while lower values of 28% and 21% were obtained for the legume grass plot and arableland. Results of t-test indicate that in both soil layers, differences in clay contents of the soils between pairs of land use types are not significant, except that between the arableland and each of rangeland and natural vegetation.

Thus in general, the nature of textural variation among the land use types is that of lower sand values and higher silt and clay fractions under the natural vegetation cover, compared to the arableland, while values for the rangeland and legume grass plot are intermediate. The more sandy texture of the respective land use types than the natural vegetation may be attributed to the loss of fine fractions (silt and clay) during one part of the year or another through colluviation, vertical eluviation and lateral eluviation. The exceptionally higher sands and lower silt and clay contents of the arableland may be due to disturbances by tillage operations which pulverize the soils and render the finer particles susceptible to removal (Lal, 1987).

Table 4.1: Summary results of analysis of variance of soil properties amongst different land uses.

Soil Property	TOPSOIL F-Ratio	Sig. Diff	SUBSOIL F-Ratio	Sig.Diff
Total Sand (%)	3.20	*	4.26	***
Coarse Sand (%)	2.18		2.84	*
Fine Sand (%)	1.76		4.60	**
Silt (%)	2.45		2.76	
Clay (%)	2.68		3.01	*
Organic Matter (%)	5.03	**	3.12	*
Total Nitrogen (%)	4.94	**	2.65	
Available Phosphorous (PPM)	1.45		2.12	
Exchangeable Calcium (Me/100g)	6.13	**	2.20	
" Magnesium "	10.64	***	5.62	**
" Potassium "	3.01	*	3.36	*
" Sodium "	2.56		2.68	
Cation Exchange Capacity "	3.52	*	2.52	
pH	2.24		0.72	
Base Sation (%)	3.96	*	2.72	
Moisture Content (g/cm3)	2.86	*	2.22	
Bulk density (g/cm3)	3.02	*	2.45	
Water stable aggregates >0.50mm (%)	2.52		1.89	

Level of Significance: * = 0.05(5%); ** = 0.01(1%) and *** = 0.001(0.1%).

Table 4.2: Summary Results of t-test of Soil Properties Amongst Land Use Types

Soil Property	Soil Layer	N/R		N/L		N/A		R/L		R/A		L/A	
		t-value	Sig. Dif.	t-value	Sig. Dif.	t-value	Sig. Dif.	t-value	Sig. Dif.	t-value	Sig. Dif.	t-value	Sig. Dif
Total Sand	Top	2.13	*	2.26	*	4.76	***	1.88		1.87		2.08	*
	Sub	2.83	**	2.76	*	4.36	***	1.73		1.94		1.86	
Coarse Sand	Top	1.03		1.73		2.06	*	0.92		1.86		1.95	
	Sub	0.73		2.00		3.94	***	1.05		1.95		1.74	
Fine Sand	Top	1.79		2.26	*	2.64	*	0.97		2.04		1.76	
	Sub	2.26	*	1.85		2.86	**	0.73		1.89		1.90	
Silt	Top	1.92		2.54	*	2.96	**	0.45		1.03		2.06	
	Sub	2.31	*	2.83	**	2.95	**	0.84		1.64		1.76	
Clay	Top	1.32		1.82		3.05	**	1.76		2.08	*	2.15	*
	Sub	1.70		1.94		2.61	*	1.79		1.82		2.01	
Organic Matter	Top	1.73		1.76		2.87	**	1.35		2.24	*	2.18	*
	Sub	1.86		1.86		2.52	*	1.42		1.69		0.73	
Total Nitrogen	Top	2.01		0.64		2.30	*	1.54		1.76		2.02	
	Sub	2.02		1.78		3.09	**	0.18		0.95		0.80	
Avail. Phos.	Top	1.25		2.62	*	1.26		1.80	*	1.03		1.85	
	Sub	1.70		1.32		2.97	**	1.04		2.80	*	1.75	
Exch. Calcium	Top	2.31	*	3.16	**	4.98	***	1.12		2.09		2.02	
	Sub	1.90		2.56	*	3.32	**	0.76		0.75		0.19	
Exch. Magnesium	Top	2.09	*	3.09	**	5.66	***	1.79	*	2.81	*	1.88	
	Sub	2.81	*	3.05	**	4.52	***	2.03	*	2.06		2.02	
	Top	2.03		2.72	*	1.10		0.32		0.80		0.96	

Soil Property	Soil Layer	N/R t-value	N/R Sig. Dif.	N/L t-value	N/L Sig. Dif.	N/A t-value	N/A Sig. Dif.	R/L t-value	R/L Sig. Dif.	R/A t-value	R/A Sig. Dif.	L/A t-value	L/A Sig. Dif.
Exch. Potassium	Sub	1.60		1.40		3.72	**	1.00		1.39		0.91	
	Top	1.62		2.05		2.20	*	0.40		1.75		1.73	
Exch. Sodium	Sub	0.95		2.09	**	2.90	**	0.50		2.20	*	0.32	
	Top	1.73		2.18	*	2.94	**	2.42	*	1.87		1.75	
CEC	Sub	2.12	*	2.19	*	3.12	**	1.80		1.73		1.83	
	Top	1.03		1.42		1.82		1.00		1.32		0.91	
P[illegible]	Sub	1.63		0.67		0.98		0.67		1.09		0.82	
	Top	1.01		0.69		3.29	**	1.59		1.80		2.46	*
Base Saturation	Sub	1.66		0.93		2.40	*	0.25		2.02		1.73	
	Top	2.71	*	2.96	**	4.06	***	2.50	*	2.62	*	2.16	*
Moisture Content	Sub	1.03		1.81		4.51	***	0.96		2.76	*	3.01	**
	Top	1.63		0.81		1.54		0.24		0.70		1.03	
Bulk Density	Sub	1.18		1.77		1.80		1.05		1.51		1.05	
	Top	1.08		3.04	**	5.23	***	0.25		3.21	**	2.54	*
Water Stable-Agg.	Sub	0.77		1.21		2.38	*	1.08		2.91	**	1.79	

Top/Sub refers to: 0-15/20-30 soil depth

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

Land Uses: N = Natural vegetation; R = Rangeland; A = Arable land; L = legume grass

Level of Significance:* = 0.05 ** = 0.01 and *** = 0.001

4.1.2. Organic matter and Nitrogen

The organic matter of the surface horizon ranges from a mean of about 1.5% over the control plot, 1.3% in both the rangeland to legume grass plots and 0.9% in the arableland. The analysis of variance result reveals significant differences amongst different land uses. The differences between pairs of land use categories are however significant only between the arableland on one hand and each of natural vegetation and rangeland on the other hand. The organic matter variation in the lower horizon is slightly different from that of the surface horizon becauses value for the legume grass plot is higher than that of the rangeland. Unlike the topsoil, however, only the difference between the natural vegetation and arableland is statistically significant. The differences in organic matter content between the different land use types no doubt reflect differences in vegetation cover. Under natural vegetation, the normal cycle of growth, litter fall and decomposition is in place. This contrasts with those of other plots where the vegetation cover is intermittently harvested or grazed by livestock. Similarly the lower value of the arable plot reflects more persistent soil disturbance by tillage and harvesting operations (Agboola and Corey, 1973; Agboola and Obatolu, 1993).

The variation in nitrogen content of the two soil layers is similar to that of organic matter. The only major discrepancy is in the top layer where the value for the legume grass plot is slightly higher than that of the natural vegetation. Results of t-test show that the differences between all pairs of land use categories, except for arableland grass plot and natural vegetation in the top layer, are not significant. The comparatively higher nitrogen value of the legume grass plot is expected because of the leguminous nature of the grass (Schofield Stylo). The values of both the organic matter and nitrogen are higher in the topsoil than in the subsoil. These again are expected because the topsoil is in direct contact with the biosphere where most organic activities are concentrated.

4.1.3 Available Phosphorous

In the topsoil, available phosphorous content is approximately the same under the natural vegetation and arableland (4.7 ppm). This is followed by the rangeland (4.1 ppm), and finally, the legume grass (3.4 ppm). Only the difference between legume grass and natural vegetation is statistically significant. In the subsoil, the values of the element are 3.2 ppm, 2.5 ppm, 2.3 ppm and 2.0 ppm for the natural vegetation, rangeland, legume grass and

arableland, respectively. The t-test result indicates significant differences between the arableland on the one hand and each of the rangeland and natural vegetation on the other hand. The use of fertiliser or animal manure may account for higher phosphorous content over the arable plot (Heathcote, 1970; Mulongoy et al. 1993).

4.1.4 Exchangeable Cations and Cation Exchange Capacity

Variations in mean values of exchangeable calcium, magnesium and sodium in the topsoil parallel that of organic matter. That is, each shows the greatest value over natural vegetation, followed by rangeland and legume grass, and least over the arableland. In general, the differences amongst the various land use types show statistical significance by analysis of variance. The differences between the various land use types are also significant, between the natural vegetation and each of rangeland, arableland and legume ley plots. The pattern of exchangeable sodium and magnesium in the lower layer is the same as in the top layer, but that of exchangeable calcium is slightly different in that values for the different land uses are nearly the same. Exchangeable Potassium in the topsoil is highest over the natural vegetation (0.56 me/100g) followed by the arableland (0.52 me/100g), the

rangeland (0.43 me/100g) and lowest over the legume grass plot (0.39 me/100g). The differences amongst the various land use categories are significant by analysis of variance but differences between them are not significant except for natural vegetation and rangeland, and legume grass plots. In the subsoil, the element is highest under natural vegetation and lowest in the arableland, but only the differences between these extreme values are statistically significant.

We may summarise that in general, with the exception of potassium, the exchangeable bases are higher under natural vegetation than under any other land use type, the comparatively lower values for the rangeland, legume grass and arableland may be a reflection of losses through cultivation or harvesting (Wilson and Kang, 1983). The reasons for the relatively high potassium over the arableland is not clear, but again, it could be a result of fertiliser application.

A close look at the results reveals that the values of the exchangeable cations are only slightly higher in the upper layer. Given the greater biological activities in the upper layer, one would expect that each of them should be significantly greater in the layer than in the lower layer.

Possible explanations for these include greater immobilisation by plants and animals in the top horizon, eluviation of the materials from top horizon and deposition in the lower horizon, or greater weathering and release of the elements in the lower horizon (Fitzpatrick, 1980).

The pattern of cation exchange capacity (CEC) over the different land uses is similar to those of organic matter and clay, and differences between all pairs of land use types are significant. The similarity in pattern of CEC with organic matter and clay is not surprising given that the two substances (organic matter and clay) are the principal soil colloidal materials upon which rests the phenomena of cation exchange process (Buckman and Brady, 1969; Brady, 1974; Fitzpatrick, 1980; Esu et al, 1987; Parton et al; 1989). The comparatively high CEC values of the subsoil possibly reflects the higher clay content of the horizon or it may be that the clay mineralogy is more of active montimorillonite-illite types and less of the chemically sterile kaolinite type (Fitzpatrick, 1980).

4.1.5 P^H and Base Saturation.

The P^H value is highest over the natural vegetation, while the values under the different land uses are approximately the same. Result of analysis of variance

reveals significant differences amongst the different land uses in the surface horizon, while result of t-test shows no any significant difference between the landuse pairs. The lack of significant differences between the different land uses is unexpected given the patterns of organic matters and exchangeable cations. A possible explanation for this is the similarity of the underlying geological material, being biotite granitic gneiss type. The same factor might also explain, at least in part, the generally acidic nature of all groups of soils of the area (Lombin and Chude, 1988).

The percentage base saturation in the surface horizon is highest under the control and legume grass plots (about 90%) and lowest over the arableland (75%) while the value for rangeland is 87%. The trend of base saturation in the lower layer is similar to that of the surface layer. The result of the analysis of variance shows that in the top layer, the differences amongst the different landuses are significant while the result of the t-test indicates that in the top layer, the differences between the arableland and each of the natural vegetation and legume grass are significant while in the lower layer only the difference between the arableland and natural vegetation is

statistically significant. The comparatively high base saturation of all groups of soils conforms with the result obtained by Lombin and Chude (1988) in north western Nigeria, but contradicts that of Esu, et al., 1987 in Keffi area of central Nigeria. The high values obtained in this study may indicate less leaching of base elements (Brady, 1974).

4.1.6 Moisture Content

The soil moisture content shows similar trend with the clay and organic matter, in that the natural vegetation has the highest value (0.51 g/cm^3), followed by rangeland (0.40 g/cm^3), then the legume grass (0.31 g/cm^3) and the least value over the arableland (0.22 g/cm^3) in the upper soil layer. The differences are significant both between and amongst the various land use types (Tables 4.1 and 4.2).

The trend of the properly in the lower layer is similar to that of the upper layer but the differences are generally not significant, except between the arableland on one hand and each of the natural vegetation, rangeland, and legume ley on the other hand. The comparatively lower moisture content of the different land uses compared to the control plot could be attributed to lower clay and organic matter contents, and greater rate of evaporation due to scanty

vegetation cover. Under all the plots, soil moisture content is higher at the subsoil than topsoil, presumably because of higher subsoil clay content and less evaporation. Cultivation and livestock movement (traffic) on the topsoil also do break-up soil structure thereby reducing its potential for water retention (Brussard et al, 1993; swift and Woomer, 1993).

4.1.7 Bulk density and water stable aggregates greater than 0.50mm

Bulk density value is lowest under the natural vegetation (1.20 g/cm^3) and highest over the rangeland (1.40 g/cm^3) while values for the arableland and legume grass plot are about the same (1.30 g/cm^3) in the top layer. The result of analysis of variance reveals significant difference amongst the different land uses in the top layer but the result of t-test reveals no significant difference between the various plots pairs. In the subsoil, the property has the highest value over the arableland and legume grass plot (about 1.6 g/cm^3) and the lowest over the natural vegetation (1.40 g/cm^3), while the value for the rangeland is intermediate (1.48 g/cm^3). The analysis of variance result shows no significant difference amongst the different land uses so also the t-test results. The comparatively higher bulk density value over the rangeland

at the topsoil may be a reflection of trampling effects of browsing livestock, while the lower value for the natural vegetation reflects higher biological activities (Brady, 1974; Saibu, 1991).

In general, the bulk density values are lower at the topsoil than the subsoil over all land use types. This is expected because of higher biological activities of the top layer which besides creating a fluffy porous condition also adds more organic matter to the layer. Organic matter usually has a lower density (less than 0.4 g/cm^3) than most soil mineral particles (2.6 - 2.7 g/cm^3) (Briggs, 1977). These therefore mean higher organic matter content will promote a lower bulk density value while a lower content will promote a higher bulk density value.

The value of water stable aggregates (WSA) greater than 0.50 mm is highest over the natural vegetation, followed by the rangeland and legume grass and lowest over the arableland, in both the topsoil and subsoil. The analysis of variance result shows that the differences amongst the land uses are not significant in both soil layers while the t-test reveals that in the top soil the differences are all significant except between the rangeland on the one hand and each of the natural vegetation and legume grass plots on the

other, while in the top soil only the differences between the arableland and each of the rangeland and natural vegetation are significant. The greater WSA content of the natural vegetation is expected and can be attributed to higher organic matter and clay contents, and generally greater biological activities. The buffering effect of leaf canopy and litter for example reduces the otherwise shattering effects of raindrops on soil aggregates.

Except over the natural vegetation, the WSA values are higher at the lower layer than at the top layer for all groups of soils. The higher value at the topsoil for the natural vegetation could be attributed to higher leaf canopy which helps to reduce the shattering effects of raindrops while the lower values of the other land uses may be due to disturbances of the soil by cultivation, grazing or livestock traffic.

CHAPTER FIVE

PATTERNS OF CHANGES IN SOIL PROPERTIES OVER FALLOWS OF DIFFERENT AGES

5.1 Introduction:

This chapter presents and discusses the results of the laboratory analyses of the soil samples collected from fallows of different ages. Emphases are on significant differences between and amongst the different fallows and control plot. The first section compares soil properties for different age grade fallows and the second part compares the fallows plots with the control plot.

5.2 Differences in Soil Properties of Different Fallows

Figure 5.1 summarises the relationships between the soil properties and varying age-grade fallows. Tables 5.1 and 5.2 present the results of the analysis of variance and the t-test performed amongst and between the various age grade fallows respectively. Detail statistics of the soil properties themselves are presented in Appendix II.

5.2.1 Texture

The sand content shows a general decrease in value with increase in age of fallow in the topsoil (0-15 cm depth). The analysis of variance result shows no significant differences amongst the fallow periods, so also

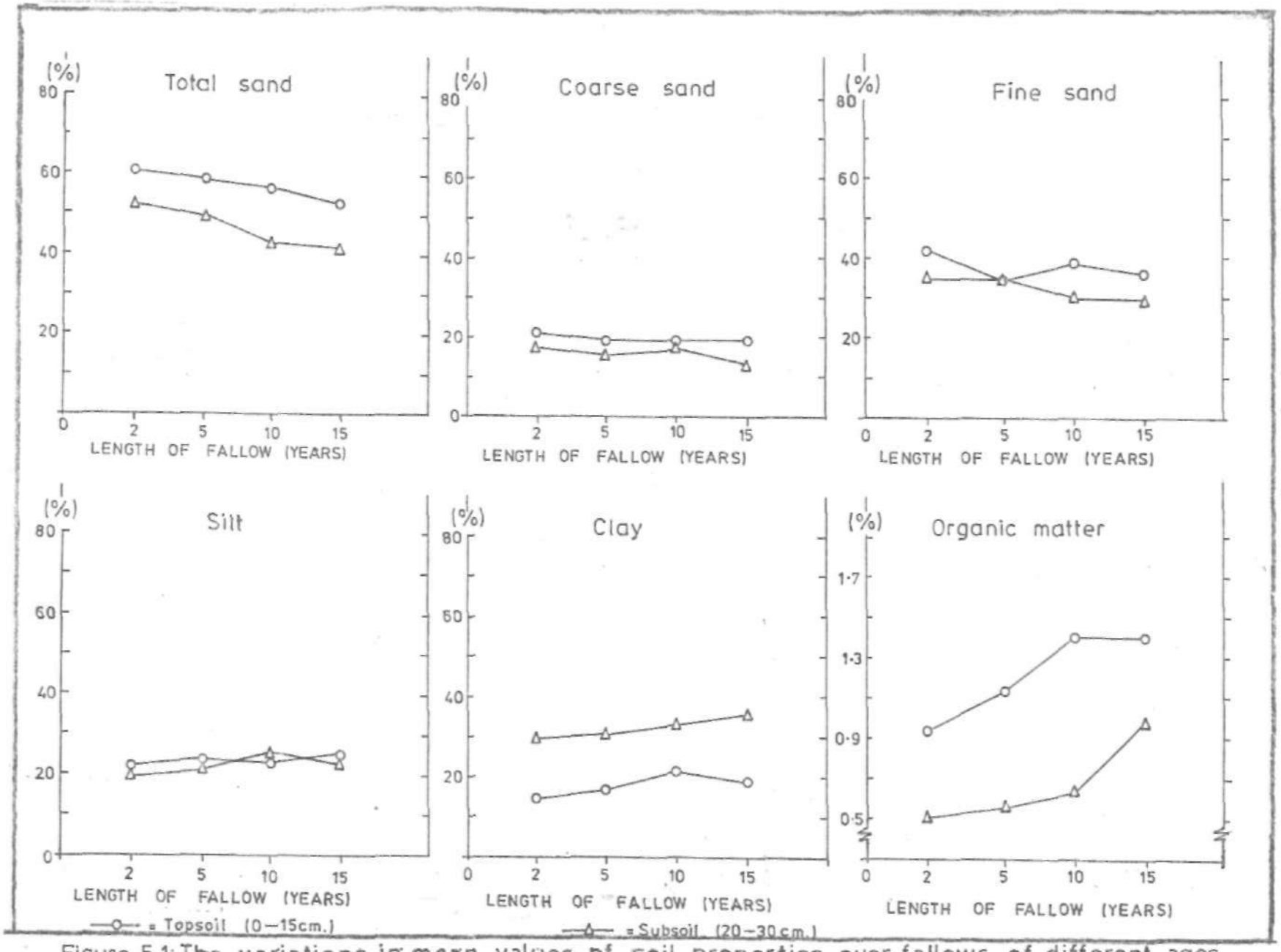


Figure 5·1: The variations in mean values of soil properties over fallows of different ages.

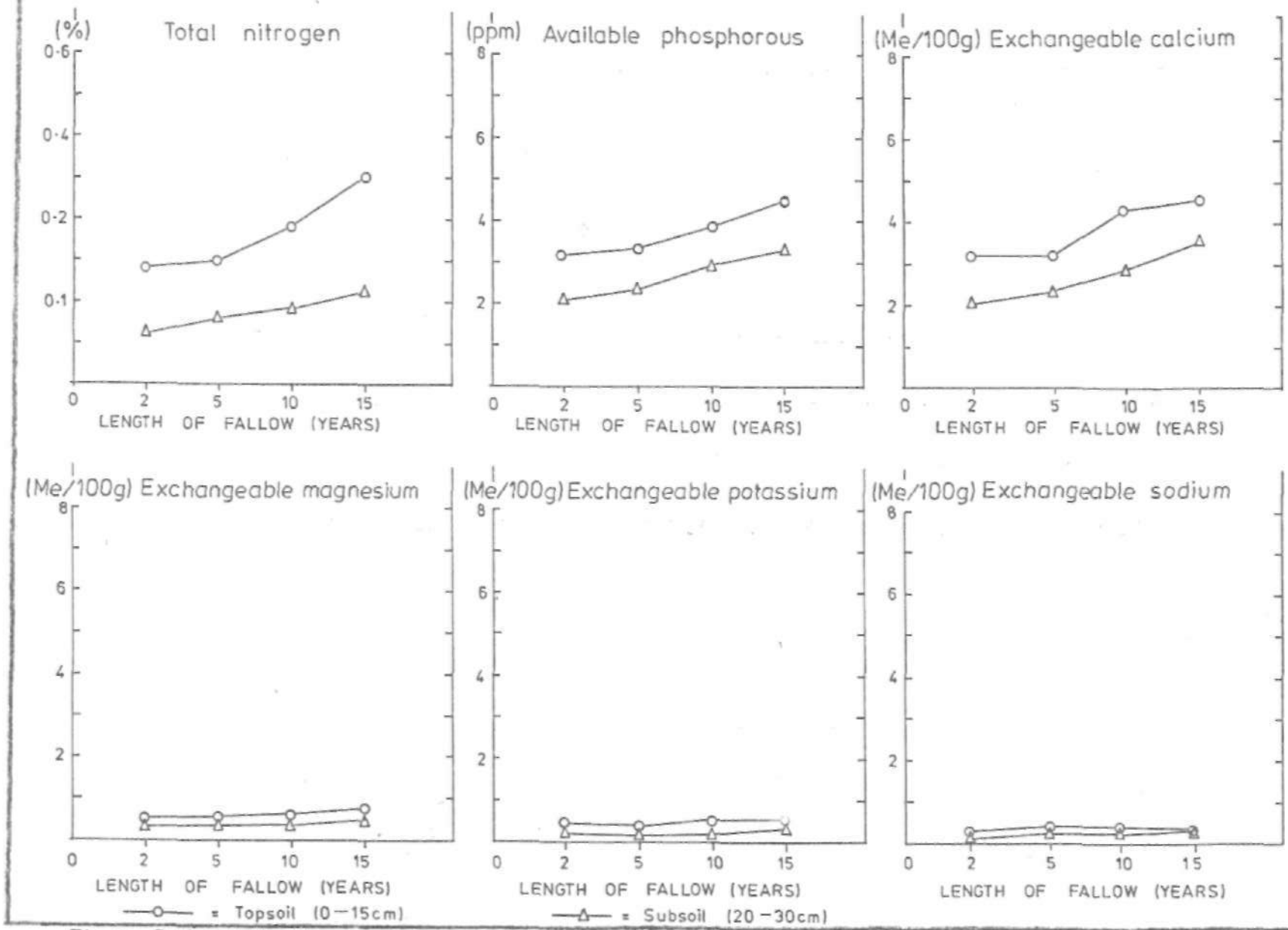


Figure 5·1(cont.d); The variations in mean values of soil properties over fallows of different ages.

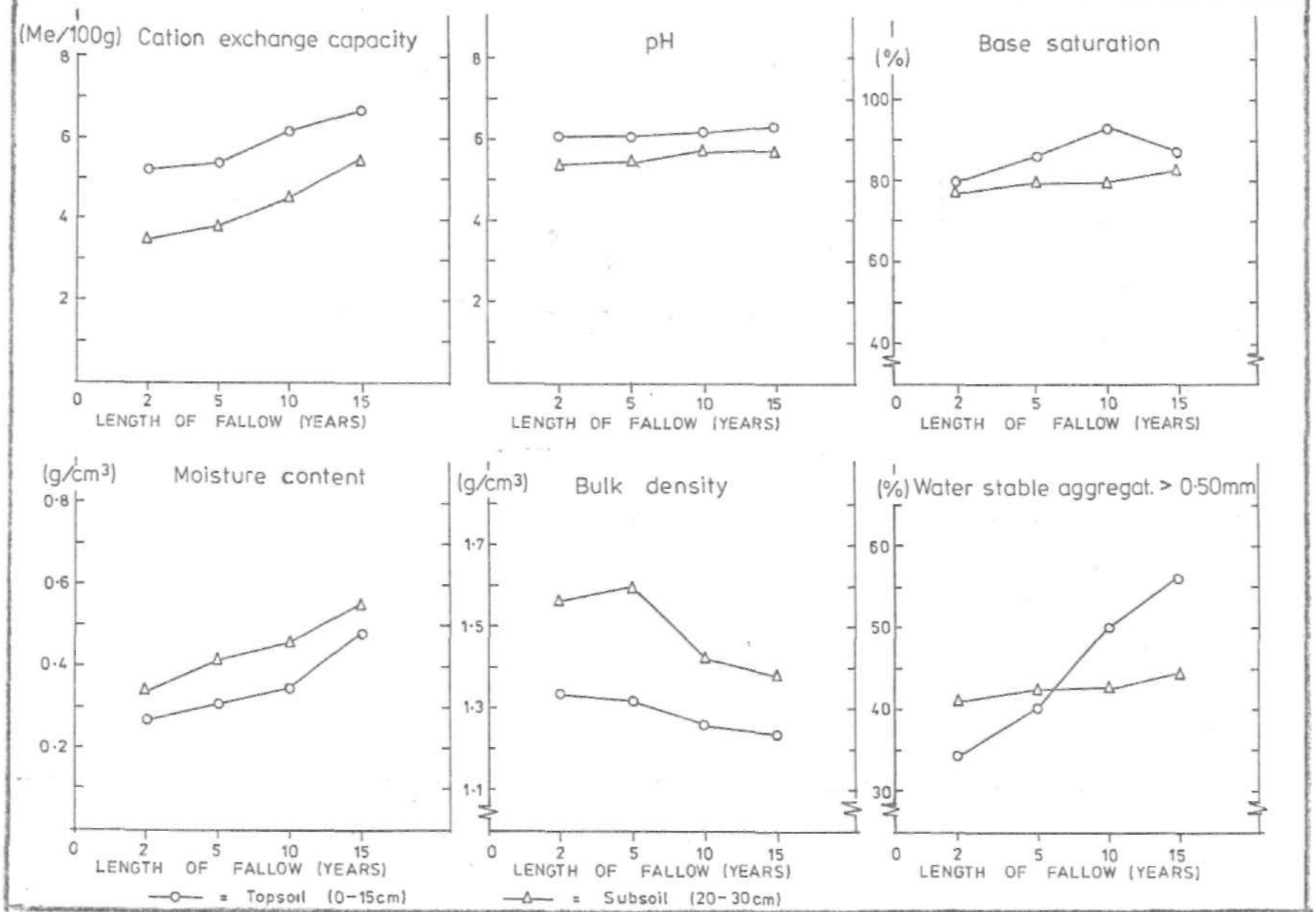


Figure 5·1 (cont.d): The variations in mean values of soil properties over fallows of different ages.

the t-test results (Tables 5.1 and 5.2). In the subsoil (20-30 cm depth), the sand fraction also shows a general decrease with increase in age of fallow, with no significant differences amongst the different age-grade fallows. The differences between the various fallow plots are also not significant. The coarse sand (2.00 - 0.5mm) and fine sand (0.50 - 0.05mm) fractions show the same pattern as total sand and the analysis of variance results reveal no significant differences between the different fallow periods.

The silt fraction shows an opposite trend to the sand content, varying from about 23% and 19% for topsoil and subsoil, respectively, over the two years old fallow, to 28% and 23% for the 15 years old fallow plot. Neither analysis of variance nor t-test reveals significant differences between or amongst the fallow periods.

The clay fraction also shows an increase in value with increase in age of fallow, combined with significant differences between the fallow periods (Table 5.1). In both the topsoil and subsoil, both the differences amongst and between the fallow plots are not statistically significant (Table 5.2).

On the whole, there is a tendency for the soils to become less sandy but more clayey and silty as the length of fallow period increases. This feature could be ascribed to an increase in vegetation cover with an increase in length of fallow. As vegetation cover increases, the rate of removal of fine soil particles in runoff or soil wash decreases.

5.2.2 Organic Matter and Nitrogen

There is a significant increase in the organic matter content with increase in the length of fallow period. This range from about 0.94% over 2-year fallow plot to about 1.44% over 15-year fallow plot. The result of the analysis of variance shows that there are significant differences amongst the fallow periods, but the t-test result indicates that the differences are not significant only between the 2-year fallow on one hand and each of the 10 the 15-year fallows on the other hand. The variation in soil organic matter of the lower horizon parallels that of the top horizon. The differences amongst the different age-grade fallows are also significant and only the difference between the 2-year fallow and that of the 15-year age grades are significant by t-test (Tables 5.1 and 5.2). The increases in soil organic matter with increase in age of fallow is

Table 5.1: Summary results of analysis of variance for soil properties amongst fallows of varying age.

Soil Property	Topsoil F-Ratio	Sig. Dif.	Subsoil F-Ratio	Sig. Dif.
Total sand (%)	2.40		2.20	
Coarse sand (%)	1.50		1.73	
Fine Sand (%)	1.44		2.26	
Silt (%)	2.02		1.46	
Clay (%)	2.19		2.50	
Organic Matter (%)	11.65	***	4.26	*
Total Nitrogen (%)	4.94		2.65	
Available Phosphorous (ppm)	1.45	**	2.12	
Exchangeable Calcium (Mc/100g)	6.13	**	2.20	
" Magnesium "	10.64	**	5.62	**
" Potassium "	3.01	*	3.36	*
" Sodium "	2.56	*	2.68	
Cation Exchange Capacity "	3.54		2.52	
pH	2.24	*	0.72	
Base Saturation (%)	3.96	*	2.72	
Moisture Content (g/cm^3)	2.86	*	2.22	
Bulk density (g/cm^3)	3.02		2.45	
Water stable aggregates > 0.50 mm %	2.52		1.89	

Level of Significance : * = 0.05(5%); ** = 0.01(1%) and *** = 0.001(0.1%).

Table 5.2: Summary Results of t-test of Soil Properties Amongst Varying Age - grade Fallows

Soil Property	Soil depth	AGE OF FALLOWS (YEARS) 2 Vs 5 t-value	Sig. Dif.	2 Vs 10 t-value	Sig. Dif.	2 Vs 15 t-value	Sig. Dif.	5 Vs 10 t-value	Sig. Dif.	5 Vs 15 t-value	Sig. Dif.	10 Vs 15 t-value	Sig. Dif
ctal Sand	Top	1.06		1.04		2.03		1.75		1.74		0.30	
	Sub	0.13		2.03		2.00		1.81		1.86		0.74	
barse sand	Top	0.28		0.16		0.96		0.70		1.22		0.56	
	Sub	0.03		0.76		1.76		0.87		1.01		0.84	
ine Sand	Top	1.64		1.57		2.00		0.11		0.72		0.80	
	Sub	1.06		0.83		1.79		0.36		0.93		0.05	
ilt	Top	0.61		1.84		2.07		1.01		0.60		0.16	
	Sub	0.16		0.54		2.01		0.59		1.76		0.67	
Clay	Top	1.86		1.93		2.01		1.02		1.24		1.02	
	Sub	0.76		1.05		1.80		0.71		0.82		0.70	
rganic matter	Top	1.00		2.08	*	2.54	**	1.80		2.01		1.22	
	Sub	1.04		1.07		2.80	**	1.70		1.67		1.20	
otal Nitrogen	Top	0.20		1.74		2.03		1.82		19.6		0.25	
	Sub	0.24		0.43		0.56		0.39		0.79		1.00	
vail. Phosphorous	Top	0.34		1.82		2.04		1.96		1.76		1.84	
	Sub	0.40		1.74		2.04		1.80		1.90		2.16	*
xch. Calcium	Top	2.04		2.45	*	3.25	**	1.75		2.01		1.95	
	Sub	1.35		2.30	*	2.82	*	2.04		2.09	*	2.01	
xch. Magnesium	Top	0.33		0.83		2.08	*	0.37		2.03		1.73	
	Sub	0.17		0.86		1.80		0.08		1.67		0.50	
xch. Potassium	Top	0.50		2.33	*	2.05		2.08	*	1.96		0.22	
	Sub	1.04		2.22	*	1.80		0.20		1.75		0.40	

Property	Depth	AGE OF FALLOWS (YEARS) 2 Vs 5 t-value	Sig. Dif.	2 Vs 10 t-value	Sig. Dif.	2 Vs 15 t-value	Sig. Dif.	5 Vs 10 t-value	Sig. Dif.	5 Vs 15 t-value	Sig. Dif.	10 Vs 15 t-value	Sig. Di
Exch. Sodium	Top	0.83		1.25		2.01		0.11		0.33		0.27	
	Sub	1.22		1.80		1.87		0.25		1.28		0.17	
CEC	Top	0.50		1.88		2.09	*	1.84		2.76		1.23	
	Sub	0.36		1.76		2.76	*	2.78	*	3.02	**	1.89	
pH	Top	0.10		0.70		1.04		0.95		0.83		0.38	
	Sub	1.03		0.80		1.74		1.00		0.82		0.47	
Base Saturation	Top	1.62		2.42	*	2.92	**	0.70		0.76		0.76	
	Sub	0.76		0.81		1.74		0.38		0.84		1.06	
Moisure Content	Top	1.62		1.90		2.56	*	1.09		2.39	*	1.82	
	Sub	1.54		2.09	*	3.06	**	1.96		3.45	**	2.00	
Bulk Density	Top	1.00		1.76		2.04		1.05		2.00		0.80	
	Sub	0.38		2.70	*	2.83	**	1.85		2.25	*	1.35	
Water Stable Agg.	Top	1.80		2.08	*	3.83	**	2.43	*	2.79	*	1.85	
	Sub	1.05		0.80		3.09	**	1.19		1.38		0.91	

Level of Significance: * =0.05; ;** = 0.01 *** = 0.001

Top/Sub = refers to 0.15/20-30 cm soil depth

Level of Significance: * = P0.05 (5%); ** = P0.01 (1%) and *** = P0.001 (0.1%)

expected because of an increase in vegetation cover which tends to lead into greater turn over of organic material (Nye and Greenland, 1960).

Similar pattern of a general increase with length of fallow was observed for the nitrogen content in both soil layers. The differences amongst the fallow periods in the top horizon are also highly significant but the differences between the pairs of fallow periods are not significant. The analysis of variance results however, reveals no significant differences between the fallow periods in the lower layer, so also that of the t-test between the fallow periods (Tables, 5.1 and 5.2). These results suggest that the longer the fallow length, the greater the activities of the nitrogen oxidising bacterial (Ayinde-Tukur 1990). As the fallow length increases, vegetation cover becomes more continuous to enhance improved micro-climate activities in the soil (Nye and Greenland, 1960).

5.2.3 Available Phosphorous

The available phosphorous in the topsoil increases from a mean of 3.2 ppm over the 2 years old fallow to 3.32 over the 5 years old fallow, 3.9 ppm over the 10 years fallow and 4.3 ppm over the 15 years old fallow. The analysis of variance reveals significant differences between the

different age - grade fallows while t-test result indicates none in both soil horizons (Table 5.2).

The increases in the amount of available phosphorous with increase in the length of fallow period could be attributed to the increase in vegetation cover. Vegetation cover influences the degree of rock and soil weathering and hence the release, to the soil system, of phosphorous held in inorganic combination. Similarly, increase in vegetation cover tends to favour the increase in organic matter content of a soil and since organic matter stores important amounts of phosphorous, increase in organic matter might lead into higher available phosphorous level of a soil.

5.2.4 Exchangeable bases and Cation Exchange Capacity

The exchangeable bases show a general increase with increase in the length of fallow period. However, only magnesium and potassium show significant differences between the fallow periods in both the soil layers (Table 5.1). The rest show significant differences only in respect of one horizon. Calcium shows significant difference between the 2-year fallow on one hand and each of the 10 and 15-year fallows on the other hand in the top soil and between the 2 and 10, 2 and 15, and 5 and 15-year fallows in the subsoil. Magnesium shows significant difference between the 2 and 15-

year fallows only in both soil layers. In the case of Potassium, the differences are all significant in the topsoil between the 2-year fallow on one hand and each of 5 and 10-year old fallows on the other hand but in the subsoil only the difference between 2 and 10-year fallows is significant. Sodium on the another hand shows no significant differences between all pairs of fallow plots in both soil horizons (Table 5.2).

The increases, although often insignificant trend, of the exchangeable bases with increase in the length of fallow period could be attributed to vegetation effect on the supply of the nutrient elements. As the vegetation cover increases, soil conditions become more favourable for the supply of the elements by humification and biochemical weathering processes and their retention in the soil (Areola and Faniran, 1978).

The CEC of the topsoil increases in mean value from 5.24 me/100g over the 2 years fallow plot, to 5.42 me/100g over the 5 years plot, 6.24 over the 10 years plot and 6.74 me/100g over the plot with 15 years fallow. The result of analysis of variance indicates that the differences amongst the age grade fallows are not significant (Table 5.1). Results of t-test indicate however that the differences

between the 2 and 15-year fallows are statistically significant (Table 5.2). The trend of the property in the subsoil is similar to that of the topsoil except that the differences between the fallow periods are not significant only for the 2 and 5, 2 and 10, and 10 and 15-year fallows respectively. The observed increases in CEC with increase in the fallow period is expected because of increases in clay and organic matter contents of the soils.

5.2.5 P_H and Base Saturation

The P_H value shows only slight increase with increase in the length of fallow period in both the soil layers. In the topsoil, the value varies between 5.86 over the 2 years old fallow to 6.06 over the 15 years old fallow and in the subsoil, between 5.25 over the 2 years old fallow to 5.62 over the 15 years old fallow. The analysis of variance results thus show no significant difference between the fallow periods, and the t-test result also showed none between pairs of fallows. All groups of soils are acidic. This result is in agreement with the work of Lombin and Chude (1988) which shows that most soils of the savanna zone are generally slightly acidic in reaction and do not under go rapid changes in P_H unless acidifying fertilizers such as urea or lime are excessively applied.

In the surface horizon, base saturation percentage shows an increase in value from about 80% over the 2-year fallow plot through 88% over the 5-year fallow plot and 90% over the 10-year fallow plot and then decreases to 88% over the 15-year fallow. The analysis of variance result shows that there are significant differences between the fallow periods (Table 5.1) while t-test results indicate that the differences are significant only between the 2-year fallow on one hand and each of the 10 and 15-year fallows on the other hand (Table 5.2). In the subsoil, the value increases from 78% over the 2-year fallow plot to 79% over the 5 and 10-year fallows plot and 82% over the 15-year fallow plot. The analysis of variance result indicates that the differences are not significant so also the t-test result between the various pairs of fallow plots. The increases in base saturation values with increase in the length of fallow period, though largely not significant, could be attributed to the increases in the exchangeable base contents of the soils.

5.2.6 Soil Moisture

Soil moisture content increases from 0.27 g/cm^3 over the 2-year fallow through 0.31 g/cm^3 and 0.35 g/cm^3 over the 5 and 10-year fallows respectively to 0.42 g/cm^3 over

the 15-year fallow in the top layer. The result of the t-test indicates that the differences between most pairs of fallows are significant (Table 5.2). The analysis of variance result also reveals significant differences amongst the different age grade fallows (Table 5.1). In the lower layer, the soil moisture content increases from 0.45 g/cm^3 over the 5-year fallow to 0.62 g/cm^3 over the 15-year fallow. The result of the analysis of variance shows that the differences amongst the fallow age-grades are not significant while the t-test result indicates that the differences between the plot pairs are all significant, except those between the 2 and 5, 5 and 10, and 10 and 15-year fallows respectively.

The increase of the soil moisture content with increase in length of fallow period might be a reflection of the reduction in the rate of evaporation from soil surfaces as the vegetation cover becomes dense. Another possible reason is the increase in clay and organic matter content with the increase in the length of fallow period, since these two materials constitute the soil colloids that have high water retention potentials (Brady, 1974).

5.2.7 Bulk Density and Water Stable Aggregates greater than 0.50mm

In both soil layers, the bulk density value shows an opposite trend to that of organic matter, in that values decrease with increase in the length of fallow period. The analysis of variance result reveals no significant differences amongst the various age-grade fallows, but the t-test calculated between pairs of fallow age-grades reveals that the differences are significant only on the subsoil between 2 and 10, 2 and 15, and 5 and 15-year fallows respectively (Table 5.1 and 5.2). The decrease in bulk density with increase in the length of fallow period might be a reflection of an increase in the organic matter content with increase in the length of fallow. Besides the effects of organic matter in lowering the value of the bulk density, the loosening of the topsoil by roots of shrubs, grasses and short trees could also contribute to the lowering of the bulk density (Ayinde - Tukur, 1990).

The pattern of water stable aggregates greater than 0.50 mm is the same as that of the organic matter. That is, the property shows an increase with increase in the length of fallow period. In the top layer, the differences amongst and the different fallow age-grades are significant while those between 2 and 5, and 10 and 15-year fallows are not

(Tables 5.1 and 5.2). In the lower layer, the differences amongst the various fallow age-grades are also not significant and only the difference between the 2 and 15-year fallows is significant. The similarity in pattern of organic matter and water stable aggregates is expected for at least four main reasons. Firstly, organic matter is the major agency that encourages the development of granular-type aggregates in soils (Lal 1977; Mulongoy et al, 1993). Secondly, the electromagnetic properties of humus, as well as that of clay are known to be effective in the organisation and subsequent stabilisation of soil aggregates. Thirdly, products of microbial and other organism in a soil (such as casts of earthworms) do encourage crumbs development in a soil and exert some significant influences in the formation and stabilisation of soil aggregates. Fourthly, as vegetation cover develops with the increase in fallow period, there would be an increase in the buffering effects of leaf canopy and litter cover on the soil and this would help in reducing the shattering effects of raindrops on soil surfaces.

5.3 Comparison of soil properties Under Different Fallows and natural Vegetation.

Table 5.3 gives the value of the soil properties for each of the fallow period expressed as a percentage of the

value under natural vegetation (i.e assumed equilibrium level) and also summarizes the results of the t-test between the control plot and each of the fallow plots.

The natural vegetation cover shows higher silt and clay contents and lower sand contents than the respective fallow plots. The results of t-test show, however, that only the 2-year fallow has, in general, significantly different values of the size factions from those of the natural vegetation in the topsoil while in the subsoil, both the 2 and 5-year fallows show significantly different values (Table 5.3). These results indicate that the changes that occur in soil textural properties after being left to fallow are relatively insignificant in the first 5 years. This may be because during this early period, the vegetation cover is low and this encourages active removal of fine materials in wash process.

The natural vegetation cover shows significantly higher organic matter value than those of the 2 and 5-year fallows in the topsoil and the 2,5 and 10-year fallows in the subsoil. These results mean that the build-up in organic matter in the soils becomes significant at about the 10th year under fallow for the topsoil and the 15th year for the subsoil. In the Zaria area, Ayinde - Tukur (1990) observed

that the organic matter content of the soils under fallow have by the 9th year of fallow period reached 95% of the equilibrium level. In the present study, the percentage by the 10th year under fallow is 98.61% in the topsoil which more or less agrees with the observation made by Ayinde-Tukur (1990). In a related study, Aweto and Areola (1979) have in the south-western Nigeria observed that organic build-up in soils under secondary succession approaches the equilibrium level at about the 10th year of fallow. The build-ups in soil nutrients were, however, found to be confined to the first seven years after which declines in total nutrient levels were observed (Aweto and Areola 1979; 247). They attributed such declines to the high demands of the nutrients by the re-established woody vegetation which result into high nutrient immobilisation in the tissues of the re-developed woody vegetation. In both soil layers, only nitrogen content of the 15 years old fallow is not significantly lower than that of the natural vegetation. The value for the rest of the fallows are significantly lower. This suggests a rather lower rate of build-up of nitrogen in the soils under fallow in the study area. Such a slow rate could be attributed to high rate of nitrogen immobilisation by the standing fallow vegetation (Ayinde-

Tukur, 1990). Another probable reason for this is high rate of nitrogen losses through leaching and volatilization. Like nitrogen, the phosphorous content of the control plot and respective fallow plots are, in general, significantly different except for the 15-year age-grade fallow.

In general, all the fallow plots show significantly lower exchangeable cations than the natural vegetation. This means, leaving a land to fallow for only 15 years in the study area may not in any way produce significant result in the soil base status. This picture is contrary to Areola et al, (1982) observation in the rainforest zone of south western Nigeria where the nutrient elements are said to be approaching the equilibrium level by the 8th - 10th year under fallow. The probable reason for this is the low net primary productivity of the savanna biome as a whole. Ahn (1970) has pointed out that while the total weight of vegetation of the savanna may be only about 1-5 tons dry weight per hactre, about 150 tons dry weight per hactre is recorded for forest vegetation.

Table 5.3: Value of the soil properties of each of the fallow period expressed as a percentage of the value under natural vegetation.

Soil Property	Soil Depth	Fallow Period (Years) 2	5	10	15
Total Sand	Top	120*	115	108	104
	Sub	144*	136*	120*	109
Coarse Sand	Top	118	104	109	101
	Sub	122	113	131*	98
Fine Sand	Top	126*	103	108	108
	Sub	156*	151*	131	124
Silt	Top	83	90	84	95
	Sub	77	113	131*	98
Clay	Top	70*	81	109	93
	Sub	74*	76	83	92
Organic Matter	Top	65**	78*	99	100
	Sub	60**	68**	76*	93
Total Nitrogen	Top	50***	54***	68**	95
	Sub	54***	67**	75*	95
Avail. Phos.	Top	68**	70*	81*	93
	Sub	64**	71*	88	100
Exch. Calcium	Top	60**	60**	82	85
	Sub	61**	69**	85	105
Exch. Magnesium	Top	64**	66*	70*	83*
	Sub	52**	56*	64**	73*
Exch. Potassium	Top	57**	63**	82	80*
	Sub	58**	45***	53**	63**
Exch. Sodium	Top	70*	90	96	96
	Sub	63**	92	83	96
CEC	Top	83*	85	90	106
	Sub	63**	68**	81	96
pH	Top	96	96	98	99
	Sub	94	96	101	100
Base Saturation	Top	90	96	101	100
	Sub	95	97	101	98
Moisture Content	Top	53***	61**	69**	82*
	Sub	55**	66**	73*	92
Bulk Density	Top	109	109	106	104
	Sub	129	129	102	99
Water Sta. Agg. >0.50mm	Top	66**	76*	95	108
	Sub	86*	90	93	92

Top/Sub = Refers to 0-15/20-30 cm Soil Depth
level of significance for t-test = * = 0.05(5%); ** = 0.01(1%) and*** =0.001(0.1%).

These imply that lower amounts of plant nutrients are stored in the savanna fallow vegetation and upon decay and mineralisation, in the savanna soil compared to what will be stored in forest fallow vegetation and soil. The CEC of the fallow soils also remained significantly lower than the equilibrium except the 15 years fallow (Table 5.3).

None of the fallow age-grades shows significantly different P_H value from the natural vegetation. This may be because of the acidic nature of the soils' parent rock or the intensive leaching in the more pluvial period in the past (Grove, 1956).

There is lower moisture content in the soils of the respective fallow plots than those of the control plot. The results of t-test indicate that there are significant differences between the control plot, and respective fallow plots, except for the subsoil of the 15-year fallow plot. The higher moisture content of the control plot could be attributed to higher clay and moisture contents, and a greater leaf canopy and litter cover.

The bulk density values of the different fallow plots are higher than that of the control in both soil layers, but none of the fallow age-grades has significantly different bulk density value with the control (Table 5.3). The

comparatively lower bulk density value of the control relative to the fallow plots could be attributed to greater biological activities which favour organic matter accumulation and, probably, greater activities of soil organisms that help in creating a fluffy porous condition. The water stable aggregates greater than 0.50 mm on the other hand is higher over the control plot than the respective different fallow plots. The differences between the control plot and each of the 2 and 5 years old fallow are significant while the rest are not.

researchers (e.g. Nye and Greenland, 1960; Juo and Lal, 1977; Areola, 1979; Aweto and Areola, 1979; Aweto, 1981; Areola, et al., 1982; Mulongoy, et al., 1993), also reveal that most of the soil properties considered are significantly differentiated over the fallow plots either in both or in one of the two soil layers and these could be attributed to the variation in the amount and character of vegetation cover over the different fallow age grades.

The effects of vegetation cover on soil properties are manyfold, it influences the rate of biochemical weathering processes of soil and rock minerals and by so doing influences the rate of release to the soil of the nutrient elements held up in inorganic combination. It also protects the soil from surface wash and erosion. This means that the clearance of vegetation cover would lead to some reduction in the amount of nutrient elements and fine soil fractions in a soil. Vegetation cover is also the main source of organic matter to a soil and hence its removal can cause some reductions in not only the organic matter content, but also nutrient elements of the soil since organic mater is the major source of most soil nutrients. As has been explained by Nye and Greenland (1960) and Brady (1974), organic matter is the sole source of nitrogen in a soil and

also stores important amounts of phosphorous. Through roots development, vegetation cover also influences the conduct of water and nutrients in a soil and this helps not only in water and nutrients conservation but also in accelerating the rate of biochemical weathering in a soil. Vegetation cover also provides leaf and litter canopy cover on soil surfaces which improves soil moisture retention in a soil, reduces the rate of clay and organic matter removal from soils and increases the stability of soil aggregates. Similarly, through the rooting system and its role in promoting biological activities in a soil, vegetation cover helps in lowering soil bulk density. These relationships no doubt means that the clearance of vegetation cover will clause a soil to become sandy and compacted and also to undergo declines in organic matter, nutrients moisture content and water stable aggregates contents. In Ibadan Nigeria, Juo and Lal (1977)d have for instance observed that after 3 years of forest clearance, soil organic matter declined from about 1.74 to 1.2%, clay from about 18.4 to 11.6%, calcium from about 4.79 to 4.10 me/100g, magnesium from about 1.29 to 0.92 me/100g, nitrogen from about 0.16 to 0.12% while potassium was raised from 0.39 to 0.46 me/100g. In British Isles, Strutt (1970) has observed that forest

clearance has not only accelerated soil compaction, it has also exposed the soil to the impact of rain, caused accelerated litter losses and declines in nutrient levels. Though no attempt has been made in this study to quantity the amount of vegetation cover over the different land uses studied, it is nonetheless reasonable to assumed that the cover indeed varies in character, type and between the different land uses. For instance, maize (Zea Mays L.) is the dominant plant cover over the arableland while over the rangeland and legume grass plots, Andropogon gayamus and Stylonsanthes guianensis respectively are the dominant plant covers. In the natural vegetation plot, a plant community of trees, shrubs and annual grasses dominate. No doubt therefore, differences in soil properties are expected among these four land uses. This also explains, at least in part, why soil of the arableland, where there is more persistent vegetation removal, is the most degraded of all. It then follows that where an area is left to lie in fallow, the nature and character of vegetation cover which redevelops on it through the process of secondary succession can often be considered as the most important factor that determines the fertility of soils of such an area.

Ecological successions are, in general, usually characterised by increasing trends in the features of certain attributes as they progress from younger or earlier stages to mature or later stages. These attributes include species diversity, size of individuals, biomass of individuals, gross production within the community, life cycle of species, community structure and ecosystem stability (Fatubarin, 1993). Irrespective of the stage of a fallow vegetation, four important pedogenic processes take place which help greatly in improving the fertility level of a soil under fallow. These processes include those of (a) capture of energy and substances through photosynthesis (b) decomposition of plant residues (c) cation exchange and (d) formation of organomineral complexes (Boul, et al., 1976). Though a substantially large part of the substances captured by plants are used up in the growing processes of the plants themselves, some important proportions of such substances are finally released to the soil at every successional stage either through direct fixation, leaf or litter fall, or when finally the plants die and get decomposed. It should however be expected that the longer the fallow period, the more effective will such pedogenic processes tend to be. This relationship therefore, can partly explain why the

changes in most of the properties studied were found to be less marked under the younger fallow ages than the older ones sin the study area. It should be understood here that the ability of a fallow vegetation to cause significant changes in soil's condition vary considerably from a bio-climatic environment to another. Thus, while it was observed in the are under present study that the changes in most of the properties were found to be effective only at about the 15th fallow year with the exchangeable bases found not to have undergone significant changes even at about the 15th fallow year, Areola, et al., (1982) have observed that in south-western Nigeria, the build-ups in most of the nutrient elements in some fallow soils have by the 8th fallow year been close to equilibrium. It appears therefore, that in areas of low rainfall and low biological productivity, like the dry savanna region of Nigeria, fallow ages have to be quite long before significant build-ups in most soil nutrients can be achieved. This can be attributed to the predominance in a dry savanna fallow vegetation community of herbaceous flora and a general lack of dense cover of woody species which could otherwise have encouraged more effective litter and leaf supplies to the soil system.

Tillage operation tends to promote increased granulations, accelerate the degree of soil compaction and destroy soil organic matter. The durability of such changes however can be quite variable. For example and as observed by Charreau and Nicoul (1971) and quoted by Jaiyeoba (1983), the residual effect of plowing in promoting good tilth with the incorporation of organic matter in some soils of Senegal often lasts about 4 years. In Ibadan area, however, Salau, et al., (1992) observed that the use of heavy farm machinery in tillage over 5 years period has caused some significant declines in soil faunal density, the rate of organic matter mineralisation and total porosity of the soils. In the present study, because of the sandy texture and low organic matter, the positive modifying effects of tillage on soil condition are less marked in soils under arable farming in the study area which are not only sandy but are more acidic, less moist and contain lower levels of nutrients and water stable aggregates than the soils of the other land uses. Akogun (1986) has also explained that subjecting a virgin soil to tillage operation would entail the loosening of the soil, the breaking down of its aggregates and the making of the soil materials more susceptible to removal by running water or wind.

Cropping causes decline in soil fertility levels because of nutrient immobilisation by crops. When crops are planted, a number of nutrients are needed in varying proportions in their various stages of development (Russel, 1961). For instance, maize (Zea Mays L.) requires adequate supply of potassium before it develops long straws or else it will resort to premature dropping or drying up of leaves (Hesse, 1971). When it is approaching maturity, it requires adequate supply of magnesium or else it will develop chlorosis and witness retardation in chlorophyll and enzyme reactions. Thus, as nutrients elements are immobilised in plant tissues of growing crops, the nutrient reserves of soils are being gradually depleted. Moreover, as crops are harvested, some important amounts of nutrients are lost (Mulongoy, et al., 1993). Similarly, except where crop residues are being returned on cultivated fields, harvesting leads to decline in organic matter which accelerates soil compaction and decline in the amounts of water stable aggregates and soil nutrients. It is thus not surprising that the arableland is the most acidic, the lowest in organic matter, nutrients and moisture contents and in the amount of water stable aggregates.

The residual effect of chemical fertiliser application on soil conditions seems to be a controversial one. For instance, Wali (1986) doubt whether it will have a major effect on soil structure and "even if it does, it seems in general and on theoretical consideration that the commonly used fertilisers like $NaNO_3$ and NH_4SO_4 should increase soil acidity and reduce the stability of aggregates and hasten the deterioration of soil granules (Wali, 1986 27)". However, Mulongoy, et al. (1993) observed that the use of an NPK fertiliser for maize (Zea mays L) in some parts of South Western Nigeria has raised the levels of soil phosphorous but increased the acidity level. Similarly, Lombin and Chude (1988) have explained that the use of acidifying fertilisers such as UREA causes more acidic condition in savanna soils. The comparatively high phosphorous and potassium level of the arableland observed in the present study can be linked to the use of fertiliser (NPK). Theoretical ideas on the effects of chemical fertiliser application on savanna soils (Heathcote, 1973; Lombin and Chude, 1988) emphasize that the phosphorous and potassium components of NPK fertiliser are not easily lost from soils when applied, compared to the nitrogen component which is easily lost to leaching, volatalisation or uptake by crops, especially cereals. These means that effective

application of NPK fertiliser can help improve the status of native phosphorous and potassium in a soil. However, since soil fertility is not dependent on these two elements alone, it then suggests that the use of NPK fertiliser alone cannot significantly improve the fertility of soils of the area.

The impact of grazing on soil properties is somewhat straight forward. Grazing by livestock removes vegetation cover, often ruthlessly and destructively, and may thus lead to soil deterioration. In Zaria area, Obafemi (1991) has for instance, observed that the soil under rangeland is more sandy and higher in bulk density but is lower in nitrogen than soils under either forestry or natural vegetation. Where animals are concentrated in a given area, there is the tendency that soil compaction will be accelerated because the trampling effects of livestock tend to destroy the soil structure. This, perhaps, explains why the soil of the rangeland was found to have a higher bulk density value than the soil of the arableland even though a tractor is used in plowing the arable plot.

CHAPTER SEVEN

SUMMARY AND CONCLUSION

7.1 Summary

This study examined changes in soil properties resulting from the establishment of land uses and fallowing in a part of Nigeria's Semi-arid Savanna. The land uses to which considerations were given include arableland rangeland, legume grass and natural vegetation. The fallow plots studied are of 2,5,10 and 15 years of age. The study area is the Kabomo basin of Katsina State.

The results obtained in respect of the land uses show that the soils of all land use types are more sandy than soil of natural vegetation. The particle size fractions are, in general, significantly differentiated over the land uses either in both or in one of the two soil layers. The more sandy nature of the various land uses than the control was thought to be a reflection of loses of fine soil particles. The more sandy texture of the arableland than the rest of the plots has been attributed to more persistent soil disturbance by tillage operations. The organic matter of the surface horizon varies between about 1.5% over the natural vegetation and 0.9% over the arableland. The differences amongst the land uses are significant so also

most of the differences between them. In the lower layer, value for the legume grass is higher than that of the rangeland but only the natural vegetation shows significantly different value with the other land uses. The comparatively higher organic matter content of the natural vegetation than the different land uses has been attributed to greater vegetation cover and soil fauna. The nitrogen content shows a similar pattern with organic matter except that the value for the legume grass is slightly higher than that of the natural vegetation in the top layer. Available phosphorous in the topsoil is highest over arableland and natural vegetation and lowest over the legume grass. The differences between and amongst the land uses are mostly insignificant.

With the exception of potassium, the exchangeable bases are significantly higher over the natural vegetation than the other land uses. The differences between and amongst the land uses are mostly significant. The comparatively lower exchangeable base contents of the different land uses has been thought to be a reflection of loses through cultivation or harvesting. The potassium content is comparatively higher over the arableland than the remainder plots. The differences in the content of the element is

significant amongst the different land uses but the differences between them are mostly not significant. The comparatively high potassium content of the arable land than the remaining land uses has been attributed to the residual effects of fertilizer application in raising the potassium level of a soil. The CEC shows the same pattern with organic matter and clay in that the value is highest over the natural vegetation and lowest over the arableland while values for the rangeland and legume grass are intermediate.

The pH is highest over the natural vegetation but the values for the other land uses are approximately the same. Both the differences amongst and between the land uses are not significant. Base saturation value is highest over the control and legume grass and lowest over the arableland while value for the rangeland is intermediate. The analysis of variance result revealed significant differences amongst the land uses in the surface horizon but the t-test result indicated that only the differences between the arableland and each of the natural vegetation and legume grass are significant.

The moisture content is highest over the control, followed by the rangeland, then the legume grass and least over the arableland. The differences between and amongst

the various land uses are mostly significant. The comparatively lower moisture value of the land uses than the control was thought to be due to lower organic matter and clay contents and the breaking-up of soil structure by cultivation, tillage and grazing.

The bulk density value of the soils in the surface horizon is lowest over the natural vegetation and highest over the rangeland while values for the arableland and legume are about the same. In the subsoil, however, the property is highest over the arableland and legume grass and lowest over natural vegetation. The differences in soil bulk density are significant amongst the land uses by analysis of variance in the topsoil. The comparatively higher bulk density value of the rangeland at the topsoil has been thought to be a reflection of trampling effects of browsing livestock while the lower value for the natural vegetation was said to be a reflection of higher biological activities. Water stable aggregates greater than 0.50mm show the same pattern with organic matter in both soil layers with significant differences between most pairs of land uses. The comparatively higher water stable aggregate value of the control than the different land uses has been attributed to greater canopy and litter cover and of biological activities, and higher clay content.

The results obtained also show that there are general increases in the coarsening of soil texture with increase in the length of fallow period. The analysis of variance result shows that with the exception of the silt fractions, all the particles sizes are significantly differentiated amongst the land uses in both or either of the two soil layers. The t-test result however indicated that the differences between the fallow periods are generally not significant. The decrease in the coarsening of soil texture with increase in the length of fallow period has been attributed to the roles of vegetation cover in reducing the rates of removal of finer soil fractions.

Organic matter, total nitrogen and available phosphorous contents increase in value from the youngest to old fallows. The analysis of variance results revealed significant differences amongst the fallow periods in the top soil and the t-test results show that there are generally no significant differences between most of the pairs of fallow periods. The increases in organic matter, nitrogen and available phosphorous contents with increase in the length of fallow period has been attributed to increases in vegetation cover.

The exchangeable bases show the same trend with the organic matter. However, only magnesium and potassium show significant differences amongst the fallow periods in both soil layers. The rest show significant differences only in respect of one horizon. The t-test results vary considerably, but differences between most pairs of fallow periods are not significant. These trends have been attributed to the greater release of the base elements from both organic and inorganic sources. The CEC of the soils also show the same trend with the organic matter and the differences amongst the fallow age grades are highly significant. The t-test results show that the differences between the fallow age-grades are mostly not significant.

The P^H also shows a general increase with increase in the length of fallow period but the differences both between and amongst the different fallow age-grades are not significant and all groups of soils are acidic. The generally acidic nature of the soils has been attributed to the acidic nature of the underlying parent rock. The result of the analysis of variance shows significant differences in base saturation percentage amongst the fallow age-grades in the top soil but the t-test result indicated that the

differences between the fallow periods are mostly insignificant. On the whole however, there is a general increase in base saturation with increase in length of fallow.

In both soil layers, the soil moisture content increase in value with increase in the length of fallow period. The differences amongst and between the fallow age-grades are mostly significant by the analysis of variance and t-test respectively. The bulk density value on the other hand shows a decrease with increase in the length of fallow period. The result of the analysis of variance revealed no significant difference amongst the age-grade fallows so also that of the t-test between pairs of fallow plots.

Water stable aggregates greater than 0.50mm also shows the same pattern with the organic matter. In both soil layers, the differences between and amongst the fallow age-grades are mostly not significant. The increases in clay and organic matter, and of canopy and litter covers have been taken to be the reasons for the observed increase in water stable aggregates with increase in the length of fallow period.

On the whole, the natural vegetation cover shows significantly higher silt and clay contents and lower sand contents than the respective fallow plots. Similarly, the natural vegetation shows significantly higher organic matter, total nitrogen, exchangeable cations and CEC than the respective fallow periods. On the other hand, none of the fallow plots show significantly different P^H value and base saturation percentage than the natural vegetation except the 2 years old fallow.

There are lower soil moisture content in the respective fallow plots than the natural vegetation and only the subsoil of 15 years old fallow shows insignificantly different value from the natural vegetation. The bulk density value of the different fallow plots are higher than that of the control in both soil layers. The water stable aggregates greater than 0.50 mm on the other hand are higher over the natural vegetation than the respective fallows and only the 2 and 5 years old fallows show significantly different values from the control.

7.2 *Conclusion And Recommendations*

It is clear from this study that the opening-up of natural vegetation cover and the establishment of land uses have lead to soil degradation. In this study, it appears

that the magnitude of the degradation of the soil properties studied vary clearly between the different land uses, with the arableland being the most degraded of all the land uses considered, the annual dressing of the plot with fertilizers not with-standing. This result particularly calls for continuous monitoring of soil conditions under every land use type so as to determine whether or not such a land use is jeopardising the potentials of the soil.

The result also suggests that the use of chemical fertilizers alone cannot reverse the problem of soil degradation in the study area. In fact, based on the observation made in respect of the Pн level of the arable plot, it may be concluded that the use of chemical fertilizer on most sandy soils of low rainfall areas will aggravate the problem of soil degradation. Specifically, it is suggested here that all available alternative measures of soil fertility maintenance, such as the use of manure, compost or intercropping with leguminous species should be incorporated. One other practice that might help in reducing the extent of soil degradation on the arable plot is that of crop residue retention on the soil after harvest. It is hoped that retaining the plant residue on cultivated fields can help off-set the decline in organic matter level

and return to the soil much of the nutrients taken up from it by the crops.

Similarly, it is obvious from the results obtained here that short fallows are less effective than long fallows in restoring soil fertility in the area. Even at about the 15th fallow year, no significant changes in base elements were observed. However, it is reasonable to assume that as the high pressure of population on land intensifies, long fallows will increasingly become a less prominent feature of agriculture in not only the study area, but in Nigeria as a whole. At the very best therefore, short fallows may be accommodated. Therefore, in order to achieve maximum benefits on soil regeneration from such short fallows, it will be necessary for man to seek for ways of improving the restorative capacity of the short fallow. This is especially so for soils of Nigeria's marginally fragile ecosystems whose inherent restorative capacities are low. The management strategies currently being employed in soil fertility maintenance including the introduction of planted fallows e.g of leguminous or fast growing tree species and the application of manures or moderate use of fertilizers to promote the growth of fallows should be vigorously pursued.

From the foregone analysis, it should be very clear that to a very large extent, the nature of soils would determine the success or otherwise of any management strategy aimed at ensuring effective soil conservation. Any attempt to solve the problem of improving soil fertility or of the efficacy of dry savanna fallows must therefore be framed around given sets of soil conditions. For instance, the search for suitable plants to form stable fallow association is likely to be more successful where it is aimed at specific soil types within given environmental setting.

It is being recommended here that the all-too-common tendency to reduce the problem of agricultural productivity of Nigeria's semi-arid savanna to a simple proposition, such as the campaign for an intensive use of fertilizers or to seek to administer universal solutions, should be handled with caution. Solutions or propositions should be adequately tested to determine whether or not they suit the given sets of soil conditions in the region. There is simply the need to always consider each soil group on its own in order to discover those peculiar characteristics that may affect the performance of crops or planted fallows on it.

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APPENDIX I Details of the laboratory methods used

A. Particle sizes

This was determined using pipette method. In this method, the collected samples were air-dried and from each, 50g sub-sample was taken which was then crushed gently in a mortar. Using a 2mm sieve, the gravel fractions were removed from the crushed soil sample and from that a 25g sub-sample was again taken. It is this 25g sub-sample that was used for the particle size analysis.

To ensure that the various particle sizes are in separate form, each of the 25g sub-sample was treated with sodium hexametaphosphate (calgon) and left for some hours to react completely with the soil samples. The suspension was then poured into a measuring 1000ml cylinder and some distilled water added to make it to 1000ml mark. This was then stirred for 30 seconds to ensure proper and thorough dispersion. it was then allowed to settle for 3 minutes 30 seconds. With the aid of a pipette, representative fractions of clay and silt were taken at different depths and time using stoke's law. The sucked mixtures were then poured into an evaporating dish and then ovendried at 105^{0}C after which the weight of silt and clay fraction and their percentages were determined as follows:

% silt (0.05-0.002mm) + % clay (<0.002)=

$$\frac{W^{z}e}{25} \times \frac{1000}{W^{a}} \times \frac{100}{} = \frac{40W^{z}e}{W^{a}} \times \frac{100}{} =$$

$$\frac{4000\ W^{z}e}{W^{a}}$$

$$\% \text{ clay} = \frac{W^{c}}{25} + \frac{1000}{W^{a}} \times \frac{100}{} = \frac{4000\ W^{c}}{W^{a}}$$

% silt = (% silt + % clay) - % clay

Where:

$W^z e$ = weight of silt and clay

W^a = weight of air-dried sub-sample (25g)

W^c = weight of clay

The remaining suspension in the measuring cylinders were then carefully poured into an evaporating dish and then ovendried. Using appropriate sieve, the fraction of sand was then separated into coarse and fine sand. The fractions of each of the sub-fraction (coarse and fine sand) was then estimated as follows:

$$\% \text{ fine sand } (0.50\text{-}0.05\text{mm}) = \frac{W^f s}{W^a} \times 100$$

$$\% \text{ Coarse sand } (2.00\text{-}0.50\text{mm}) = \frac{W^c s}{W^a} \times 100$$

Where:

$W^f s$ = weight of fine sand

$W^c s$ = weight of coarse sand

B. Bulk Density and moisture content (g/cm3)

The bulk density (BD) ring containing the collected soil sample was weighed and then oven-dried at 105^0c for 24 hours after which it was re-weighed. Bulk density value was then determine as follows:

$$BD(g/cm^3) = \frac{\text{Weight of the Soil}}{\text{Volume of the Soil}}$$

Where:

Weight of the Soil (g) = Weight of the ring plus the bulk sample after ovendrying Minus weight of the ring

Volume of the soil (cm^3) = Volume of the ring.

Volumetric water (moisture) content was determined as:

$$VWC = \frac{Ws_1 - Ws_2}{D_w - Vs_1}$$

Where:

VWC = Volumetric water content (g/cm^3)
Ws_1 = weight of the soil before oven drying
Ws_2 = weight of the soil after oven drying
Vs_1 = volume of the soil
DW = Density of the water in the sample

C. Water Stable Aggregates (>0.50 mm) (%)

To determine water stable aggregates greater than 0.50mm, water stable aggregates were prepared by crushing a moist condition bulk sample on a 8.00mm sieve. From then, an air dried sub-sample of 50g was taken from the amount retained on the sieve. The sub-sample was then spread evenly over a 0.50mm sieve and the sieve was then immersed in water for one minute. After that, the sieve was raised and lowered through 3cm at the rate of 30 times in 2 minutes to ensure that all the aggregates which are less

than 0.50mm were sieved. Then, the proportion retained on the 0.50mm sieve was oven-dried and weighed. After this, the percentage of water stable aggregates (> 0.50mm) was calculated using the formula:

$$\text{WSA (\%)} = \frac{W^{x}}{\text{Weight of the sub-sample (50g)}} \times \frac{100}{1}$$

Where:

WSA = Water stable aggregates

W^{x} = Weight of the retained soil aggregates on 0.50mm sieve

D. Soil P^{H} (1:2.5)

To determine soil P^{H}, 20g of air-dried soil sample was taken in a 50ml beaker to which 20ml of distilled water was added. The suspension was then stirred several times for 30 minutes with a glass rod after which it was allowed to stand for 30 minutes in order to allow most of the suspended clay to settle down. Electrodes of P^{H} meter were then inserted into the partly settled suspension and the P^{H} was then measured. While taking the measurement, the suspension was not stirred and the electrodes were not allowed to touch the bottom of the beaker, to avoid errors in measurement.

E. Soil Organic Matter (%)

This was determined using Walkey - Black digestion method. A representative sample was taken, grinded and passed through a 0.50mm sieve. 10g sub-sample was then taken in a 250ml conical flask and 10ml of Potassium dichromate ($K^2 Cr^2 0^7$) solution was then pipetted accurately into 200ml and 500ml conical flasks and swirled gently to disperse the soil. Then 20ml concentrated sulphuric acid was rapidly added from a measuring cylinder. The flasks were then immediately swirled gently until the soil and the reagents were mixed. Next, the mixtures were swirled more vigorously for one minute. Each flask was then rotated gently again and then allowed to stand on a sheet of asbestos for 30 minutes with a view to cooling the mixture.

Then, 100ml of distilled water was added after the cooling and then the mixture was allowed to cool again. Following this, four drops of indicator were added onto the mixture and titrated with 0.5N ferrous sulphate ($FeSO_4$) solution on a white background. After this was done, a blank determination was then made in the same way but without the soil with a view to standardising the dichromate. The percent carbon (PC) was then calculated using the formula:

$$PC = \frac{\text{Blank titre - actual titre} \times 0.3 \times m \times f}{\text{Weight of air - dried soil used}} \times \frac{100}{1}$$

Where:

PC = percent carbon

F = correction factor 1.33

m = concentration of $FeSO_4$

Organic matter (%) was then calculated using the formula

= % carbon x 1.729

F. Cation Exchange Capacity (CEC) (Me/100g)

The CEC was determined using ammonium acetate extraction method. 10g of air-dried 2mm sieved soil sample was weighed into a 500ml Erlenmeyer flask and 40ml of neutral 1N ammonium acetate (NH_4OAC) was added. The flask was then shaken thoroughly and allowed to stand over night. The soil was then filtered with light sunction using a 55mm buckner funnel. Then the soil was leached with the neutral 1N NH4OAC reagent until no evidence for calcium can be obtained in the affluent solution. The leacheate was then preserved for the determination of exchangeable bases.

Next, the soil was again leached four times with 250ml each of 1N ammonium chloride (NH4CL) and once with 250ml of 0.25N NH4cl. The electrolyte was then washed out with 200ml of 99 N ethyl Alcohol. When the chloride in the leachate (which was tested using 0.10 N Silver nitrate) became negligible, the soil was allowed to drain thoroughly.

The soil was then transferred and filtered into 50ml Kjeldahl flask and 250ml of distilled water was added. Then, few drops of liquid paraffin, pumice beads (to prevent fuming and bumping) and 10ml of 1N sodium hydroxide were added. About 60ml of the solution was then distilled into 50ml of 2% boric acid solution which was measured into a 250ml Erlenmeyer flask. 10 drops of bromocresol green-methyl-red mixed indicator were added and ammonium borate was titrated which was produced with standard 0.02 N sulphuric acid solution. Following this, blanks were run on the reagents and the titre results was corrected with the blank result. The CEC in me/100g of soil was then calculated using the formula.

$$\text{CEC (me/100g)} = \frac{(T-B) \times N \times 100}{W}$$

Where:

N = Normality of the acid used

W = Weight of the sub-sample

T = Titre volume of the acid used in titration

B = Blank titre Volume used.

G. Total Nitrogen (%)

This was determined using regular macro Kjeldahl method. To do this, 20g of soil was weighed into Kjeldahl flask and 20ml of distilled water was added and the flask was swirled for 5 minutes and allowed to stand for 30 minutes. Then 3g of catalyst and 20ml of concentrated sulphuric acid (H_2SO_4) were added. The mixture was then continuously heated slowly until the water was removed and frothing has ceased. The mixture was then boiled for 5 hours during which the heat was regulated so that the H_2SO_4 condensed half way up the neck of the flask. The flask was then allowed to cool. The digest was carefully transferred into another clean flask. The sand particles were retained in the original digestion so as to prevent the particles from causing bumping during distillation.

Next, the sand residue was washed with 50ml of distilled water for about four times and made to mark with distilled water. 10ml of boric acid solution was then added into a 500ml

Erlenmeyer flask which was then placed under the condenser of the distillation apparatus with the end of the condenser placed 4cm above the surface of the boric acid solution. 10ml of 4% sodium hydroxide (NaoH) was slowly added into 10ml of the digest which was attached to the distillation apparatus. The mixture was then heated until it boiled.

Sufficient water was allowed to flow through the condenser to allow it to cool (to below 30°c). When about 50% of the distillate was collected, the distillation was stopped. Ammonia, which was liberated from the H_2SO_4, was titrated and 3 drops of indicator was added until the color changed from green to pink. A blank determination was then run without the soil sample. The percent Nitrogen (PN) was then calculated using the formula:

$$PN = \frac{0.014 \times N \times 100 \times TV}{\text{Weight of soil uses} \times AD}$$

Where:

PN = Percent Nitrogen

VD = Volume of digest

N = Normality of acid

TV = Titre value

AD = Aliquot of digest

H. Exchangeable bases (me/100g)

The leachate which has been preserved during the CEC determination was used to determine the exchangeable bases (namely calcium, magnesium, potassium and sodium). Standard readings were used for different concentrations of each cation to plot a graph of adsorbance Vs concentration (ppm) of each base. Calcium and magnesium were determined using atomic absorption spectro-photometer while potassium and sodium were determined using flame emission method. The me/100g of each base was then calculated using the formula:

$$\text{Me/100g} = \frac{\text{PPm graph} \times \text{VE} \times \text{DF} \times 100}{1000 \times \text{W} \times \text{Equivalent weight of the element}}$$

Where:

VE = Volume of extractant

DF = Dilution factor

W = Weight of soil sample used

I. Available Phosphorous (PPm)

This was determined using Bray No 1 method. To do this, 1g of air-dried soil was weighed into a 15ml centrifuge tube and 7ml of extracting solution was added and the mixture was shaken for 1 minute on a mechanical shaker. The suspension was then centrifuged at 2,000 rounds per minute for 15 minutes and

was then decanted into an acid washed volumetric flask. The phosphorous in the extract was then determined using ascorbic molybdate blue method. This was done by pipetting 3ml of the soil extract into a 25ml volumetric flask and about 10ml of distilled water was then added to it.

Next, a 4ml of 0.5N hydrochloric acid was added and the mixture was then allowed to stand for 15 minutes for the color to develop. The P content was then determined in the extract on a spectrophotometer using spectronic 70,50,20 at 882 muo by percent transmittance. A set of standard P solutions containing 0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 ppm respectively were prepared and used for blank determination to aid in reading off the ppm of P for the soil solution prepared.

J. Base Saturation (%)

This was derived through the addition of the exchangeable cation values determined which was then divided by the CEC value and multiplied by 100.

Appendix II: Mean and standard deviation values of the soil Properties under the different land uses.

Soil Property	Soil depth		Control	Range land	Arable land	Legume Grass
	Top	Mean	51.3	60.6	71.6	65.2
Total Sand		Std.Dev.	30.9	39.8	23.2	5.1
(%)	Sub	Mean	36.4	50.3	64.9	48.9
		Std.Dev.	12.3	9.6	37.2	7.3
	Top	Mean	18.8	21.1	25.7	23.1
Coarse Sand		Std.Dev	3.4	3.7	10.2	5.8
(%)	Sub	Mean	13.5	15.5	22.6	20.4
		Std.Dev.	7.4	11.6	4.5	1.8
	Top	Mean	33.5	39.5	45.9	42.2
Fine Sand		Std.Dev.	20.6	5.2	23.9	2.7
(%)	Sub	Mean	22.9	31.9	42.3	28.5
		Std.Dev.	8.3	15.8	19.8	2.7
	Top	Mean	26.7	20.4	16.0	18.8
Silt		Std.Dev.	7.9	2.2	9.2	3.2
(%)	Sub	Mean	24.6	17.2	14.0	16.6
		Std.Dev.	4.8	8.0	6.2	2.3
	Top	Mean	21.0	19.0	12.4	16.0
Clay		Std.Dev.	15.3	5.1	7.2	7.2
(%)	Sub	Mean	39.0	35.4	21.1	34.5
		Std.Dev.	16.4	11.2	9.4	5.8
	Top	Mean	1.44	1.32	0.86	1.18
Org. Matter		Std.Dev.	0.56	0.62	0.40	0.57
(%)	Sub	Mean	0.82	0.63	0.52	0.70
		Std.Dev.	0.39	0.45	0.36	0.10
	Top	Mean	0.28	0.18	0.13	0.29
Total Nit.		Std.Dev.	0.20	0.10	0.10	0.17
(%)	Sub	Mean	0.12	0.08	0.06	0.10
		Std.Dev.	0.06	0.05	0.01	0.08
	Top	Mean	4.74	4.31	4.60	3.43
Avai.Phos.		Std.Dev.	1.04	1.70	2.55	1.33
(PPm)	Sub	Mean	3.24	2.50	2.01	2.32
		Std.Dev.	0.73	1.18	0.73	1.75
	Top	Mean	5.31	4.24	2.80	4.08
Exch. cal		Std.Dev.	1.32	1.57	1.45	1.57
(Me/100g)	Sub	Mean	3.32	2.76	2.43	2.61
		Std.Dev.	2.01	1.61	0.77	0.50

APPENDIX II (Contd.)

Soil Property	Soil Depth		Control	Range land	Arable land	Legume grass
	Top	Mean	0.86	0.60	0.24	0.45
Exch.Mag.		Std.Dev	0.37	0.37	0.10	0.26
(Me./100g)	Sub	Mean	0.62	0.48	0.18	0.32
		Std.Dev	0.44	0.35	0.14	0.10
	Top	Mean	0.56	0.43	0.52	0.39
Exch. Potas.		Std.Dev	0.20	0.28	0.24	0.14
(Me/100g)	Sub	Mean	0.40	0.33	0.27	0.36
		Std.Dev	0.14	0.10	0.10	0.16
	Top	Mean	0.27	0.28	0.20	0.22
Exch. Sodium		Std.Dev	0.14	0.14	0.10	0.14
(Me/100g)	Sub	Mean	0.24	0.23	0.16	0.18
		Std.Dev	0.09	0.14	0.10	0.10
	Top	Mean	6.34	6.07	5.01	5.62
CEC		Std.Dev	3.87	2.67	2.24	2.92
(Me/100g)	Sub	Mean	5.60	5.10	4.34	4.61
		Std.Dev	1.29	2.46	2.12	1.08
	Top	Mean	6.11	5.94	5.70	5.91
p^H (1:2.5)		Std.Dev	0.33	0.76	0.74	0.35
	Sub	Mean	5.60	5.29	5.35	5.31
		Std.Dev	0.69	0.62	0.45	0.16
	Top	Mean	89.30	87.13	75.05	91.30
Base Sat.(%)		Std.Dev	18.34	17.66	8.41	24.76
	Sub	Mean	81.79	74.51	70.05	75.27
		Std.Dev	13.94	26.20	13.20	18.83
	Top	Mean	0.51	0.40	0.22	0.31
Moist.Cont.		Std.Dev	0.14	0.09	0.10	0.14
(g/cm3)	Sub	Mean	0.62	0.49	0.31	0.47
		Std.Dev	0.09	0.08	0.15	0.18
	Top	Mean	1.19	1.38	1.34	1.30
Bulk Density		Std.Dev	0.08	0.22	0.30	0.51
(g/cm3)	Sub	Mean	1.39	1.48	1.58	1.55
		Std.Dev	0.10	0.34	0.14	0.39
	Top	Mean	52.81	37.90	30.20	33.70
Wat.Sta.Aggr		Std.Dev	13.68	15.31	18.15	4.06
(%)	Sub	Mean	45.50	43.72	37.90	41.00
		Std.Dev	27.93	24.96	17.41	17.84

Top/Sub = refers to 0-15 cm/ 20-30 cm Soil depth

APPENDIX III: Mean and Standard Deviation values of the Soil properties under the Fallows of varying ages.

Soil Property	Soil depth		2 YEARS FALLOW	5 YEARS FALLOW	10 YEARS FALLOW	15 YEARS FALLOW
	Top	Mean	61.6	59.0	56.4	53.1
Total Sand		Std.Dev.	25.7	9.7	16.6	20.1
(%)	Sub	Mean	52.3	49.7	43.8	41.7
		Std.Dev.	11.5	11.0	25.2	9.8
	Top	Mean	21.0	19.6	18.8	19.0
Coarse Sand		Std.Dev	5.8	9.2	5.5	6.8
(%)	Sub	Mean	16.5	15.2	17.7	13.2
		Std.Dev.	5.9	6.3	7.8	3.7
	Top	Mean	42.1	34.4	38.4	36.1
Fine Sand		Std.Dev.	29.7	12.1	11.1	8.8
(%)	Sub	Mean	35.8	34.5	30.1	28.5
		Std.Dev.	12.9	10.6	9.0	12.0
	Top	Mean	22.2	24.0	22.4	25.4
Silt (%)		Std.Dev.	8.0	10.1	11.4	10.1
	Sub	Mean	19.0	20.5	23.7	22.5
		Std.Dev.	7.7	9.3	8.0	5.43
	Top	Mean	14.7	17.0	21.4	19.5
Clay (%)		Std.Dev.	9.7	9.4	11.7	5.5
	Sub	Mean	28.7	29.8	32.5	35.8
		Std.Dev.	6.4	11.2	12.2	11.4
	Top	Mean	0.94	1.13	1.42	1.44
Org. Matter		Std.Dev.	0.32	0.67	0.71	0.30
(%)	Sub	Mean	0.49	0.56	0.62	0.76
		Std.Dev.	0.20	0.24	0.26	0.17
	Top	Mean	0.14	0.15	0.19	0.25
Total Nitr.		Std.Dev.	0.10	0.10	0.10	0.14
(%)	Sub	Mean	0.06	0.08	0.09	0.11
		Std.Dev.	0.04	0.04	0.03	0.07
	Top	Mean	3.20	3.32	3.85	4.50
Avai. Phosp		Std.Dev.	1.31	1.06	1.46	0.62
(PPm)	Sub	Mean	2.06	1.30	2.86	3.23
		Std.Dev.	0.53	0.24	0.37	1.82
	Top	Mean	3.21	3.20	4.34	4.50
		Std.Dev.	0.67	2.05	1.33	1.48
Exch. cal	Sub	Mean	2.01	2.30	2.81	3.50
(Me/100g)		Std.Dev.	1.71	0.28	1.11	2.75
	Top	Mean	0.55	0.57	0.60	0.71

APPENDIX III: (Contd)

Soil Property	Soil Depth		2 YEARS FALLOW	5 YEARS FALLOW	10 YEARS FALLOW	15 YEARS FALLOW
Exch. Mag.		Std.Dev	0.33	0.14	0.32	0.37
(me/100g)	Sub	Mean	0.34	0.33	0.40	0.45
		Std.Dev	0.17	0.22	0.28	0.10
	Top	Mean	0.32	0.35	0.46	0.45
Exch. Potass		Std.Dev	0.20	0.22	0.20	0.28
(Me/100g)	Sub	Mean	0.23	0.18	0.21	0.25
		Std.Dev	0.14	0.14	0.17	0.12
	Top	Mean	0.19	0.24	0.25	0.26
Exch. Sodium		Std.Dev	0.14	0.17	0.10	0.07
(Me/100g)	Sub	Mean	0.15	0.22	0.20	0.23
		Std.Dev	0.10	0.17	0.14	0.10
	Top	Mean	5.24	5.42	6.42	6.74
CEC		Std.Dev	1.67	1.44	1.16	2.14
(Me/100g)	Sub	Mean	3.52	3.82	4.53	5.40
		Std.Dev	1.84	0.56	1.53	0.58
	Top	Mean	5.86	5.89	6.00	6.06
pH (1:2.5)		Std.Dev	0.56	0.55	0.77	0.94
	Sub	Mean	5.25	5.40	5.67	5.62
		Std.Dev	0.39	0.35	1.00	1.15
	Top	Mean	80.15	86.44	90.54	87.83
Base Sat.(%)		Std.Dev	16.19	15.56	3.53	14.24
	Sub	Mean	77.76	79.32	79.91	82.04
		Std.Dev	17.47	5.71	14.50	8.27
	Top	Mean	0.27	0.31	0.35	0.48
Mois. Cont.		Std.Dev	0.03	0.04	0.05	0.10
(g/cm3)	Sub	Mean	0.34	0.41	0.45	0.54
		Std.Dev	0.12	0.07	0.13	0.18
	Top	Mean	1.34	1.30	1.26	1.24
Bulk Density		Std.Dev	0.30	0.48	0.22	0.17
(g/cm3)	Sub	Mean	1.56	1.59	1.42	1.38
		Std.Dev	0.26	0.24	0.32	0.35
	Top	Mean	34.32	40.62	50.20	56.30
Wat.Sta.Agg		Std.Dev	23.28	15.90	16.80	4.75
(%)	Sub	Mean	40.53	42.03	42.34	44.60
		Std.Dev	18.45	18.83	19.19	9.13

Top/Sub = refers to 0-15/20-30 cm Soil depth.