EFFECT OF LONG TERM ROTATION, NITROGEN FERTILIZER AND TILLAGE ON SOIL QUALITY AND MAIZE YIELD IN THE NORTHERN GUINEA SAVANNA OF NIGERIA

BY

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MSc/Agric/24113/2012-2013 (P16AGSS8004)

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES,

AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD

OF MASTERS DEGREE IN SOIL SCIENCE.

DEPARTMENT OF SOIL SCIENCE,

FACULTY OF AGRICULTURE,

AHMADU BELLO UNIVERSITY, ZARIA.

NIGERIA

DECEMBER, 2017

Declaration

I declare that the work in this dissertation entitled effect of long term rotation, nitrogen fertilizer and tillage on soil quality and maize yield in the Northern guinea Savanna of Nigeria has been performed by me in the Department of Soil Science, Ahmadu Bello university, Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this project report/dissertation was previously presented for another degree or diploma at this or any other institution.

…… ……..

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Certification

This dissertation entitled "**Effect of long term rotation, nitrogen fertilizer and tillage on soil quality and maize yield in the northern Guinea savanna of Nigeria**" meets the regulation governing the award of the degree of Masters in Soil Science of Ahmadu Bello University Zaria, and is approved for its contribution to knowledge and literary presentation

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Acknowledgement

My sincere gratitude goes Almighty ALLAH (SWT) for seeing me through the period of my study.

I am greatly indebted to the Head of Department of Soil Science, who is also my Project supervisor, Prof. A. A. Yusuf for his valuable assistance and support, who worked tirelessly by offering constructive criticism and making corrections and adjustment were necessary. I remain grateful.

My heartfelt appreciation goes to my minor supervisor, Dr. A. Abdulkadir who was never tired of leading me to the right way. May ALLAH (SWT) give you more strength, courage and time to continue the good things you always do.

My immeasurable appreciation goes to my parents Alh I. A. Usman (May his soul rest in peace) and Haj. Asma'u Musa for their support and patience during my study period.

Worthy of acknowledgement is my wife, Hafsat Abubakar for her words of wisdom, patience, advices and lots more, words cannot express my gratitude to you.

Finally I say thank you to all my relatives, in-laws, classmates, my colleagues in College of Agriculture, Lafia, all the Academic, technical and non-academic staff of Soil Science Department A.B.U Zaria, my friends and well wishers.

Abstract

A long-term field experiment was established in 2003 at the Institute for Agricultural Research, (I.A.R) Samaru, northern Guinea savanna of Nigeria to evaluate the effect of N fertilizer on maize grown in rotation with maize, cowpea and soybean. The trial was modified to accommodate tillage as an additional experimental factor in 2009. Ten years later (in 2013), soil and crop data were collected to determine the influence of the experimental factors namely; crop rotation, tillage and N fertilization on soil quality, maize grain and stover yield. To achieve these objectives, data were taken from the maize phase of the rotation where maize was grown in rotation with maize, maize in rotation with soybean and maize in rotation with cowpea, under conventional and reduced tillage, with N fertilization of 0 kg N ha^{-1} and 90 kg N ha^{-1}. The trial was arranged in a split plot design, replicated three times, with the rotation and tillage in the main plot while N fertilization was in the sub-plot. Soil quality was determined using the procedure described by Parr *et al*. (1992). Soil quality indicators used were soil physical properties (bulk density, saturated hydraulic conductivity and moisture content), soil biological properties (urease, soil microbial biomass C and soil microbial biomass N) and soil chemical properties (total N. soil organic C). The study showed that the experimental soil was low in quality (SQ = 4) under continuous maize cultivation; however, crop rotation of soybean and cowpea improved the soil quality to moderate status (SQ = 3). Tillage had no effect on soil quality but N fertilization improved soil quality only in the rotation involving legumes (SQ = 3). To improve the soil quality in the northern Guinea savanna of Nigeria over a long period of time, farmers are recommended to practice crop rotation of maize in rotation with cowpea and maize in rotation with soybean at 90 kg N ha^{-1} under conventional tillage practices. Farmers are also recommended to practice crop rotation of maize in rotation with cowpea (2,791 kg ha^{-1}) and maize in rotation with soybean (3,262kg ha^{-1}) under conventional tillage (3,401 kg ha^{-1}) and the application of N fertilizer at 60 kg N ha^{-1} (3,564 kg ha^{-1}) for higher grain yield of maize in the northern Guinea savanna of Nigeria.

Table of Content

Tittle page……i

Declaration……..……ii

Certification……..……iii

Acknowledgement……...……...…iv

Abstract…….……v

Content……..…….…vi

List of Figures……..ix

List of Tables…….x

1.1 Introduction 1

1.2 Statement of the Problem 3

1.3 Justification 4

1.4 Objectives 5

CHAPTER TWO 6

2.0 LITERATURE REVIEW 6

2.1 Maize 6

2.1.1 Botanical description 6

2.1.2 Climatic and soil requirements of maize 6

2.1.3 Importance of maize 7

2.2 The Northern Guinea Savanna 7

2.2.1 Cropping systems and crops of the northern Guinea savanna. 7

2.2.2 Maize production in the northern Guinea savanna 8

2.2.3 Problems facing maize production in the northern Guinea savanna 8

2.3 Nitrogen Fertilization 9

2.4 Land Management 10

2.4.1 Tillage 10

2.4.2 Crop rotation 11

2.4.3 Effect of land management systems on some soil quality indicators 13

2.5 Concept of Soil Quality 16

2.5.1 Soil quality evaluation 16

2.5.2 Soil quality indicators 17

CHAPTER THREE 26
3.0 MATERIALS AND METHODS 26
3.1 Experimental Site 26
3.2 Treatment Structure and Experimental Design 26
3.3 Cultural Practices 28
3.3.1 Land preparation 28
3.3.2 Plot size 28
3.3.3 Sowing 28
3.3.4 Fertilizer application 28
3.3.5 Weeding and earthen up 29
3.4 Data Collection 29
3.4.1 Plant height (cm) 29
3.4.2 Number of leaves per plant 29
3.4.3 Leaf width 29
3.4.4 Leaf length 29
3.4.5 Leaf area (LA) cm^2 $plant^{-1}$ 30
3.4.6 Dry matter yield of maize 30
3.5 Harvesting 30
3.6 Grain Yield 30
3.6.1 100 grain weight (g) 30
3.6.2 Grain Yield (kg/ha) 31
3.7 Soil sampling 31
3.8 Physical and Chemical Characterization of the Soil 31
3.8.1 Measurement of soil physical properties 31
3.8.2 Measurement of soil chemical properties 33
3.8.3 Measurement of soil biological properties 35
3.9 Soil Quality Determination 37
3.9.1. Selection of minimum data set (Indicators) 37
3.9.2 Interpretation of indicators 37
3.9.3 Soil Quality Index 37
3.10 Statistical Analyses 39
CHAPTER FOUR 40
4.0 RESULTS AND DISCUSSION 40

4.1 Growth Parameters 40
4.1.1 Plant height 40
4.1.2 Leaf area (LA) per plant 42
4.2 Yield Parameters 46
4.2.1 100 Grain weight (g) 46
4.2.2 Grain yield (kg/ha) 48
4.3 Soil Physical Properties 51
4.3.1 Effect on particle size distribution 51
4.3.2 Saturated hydraulic conductivity (Ks) 51
4.3.3 Bulk density 53
4.3.4 Moisture content 56
4.4 Soil Chemical Properties 56
4.4.1 Total nitrogen (g kg^{-1}) 56
4.4.2 Soil organic carbon (g/kg) 64
4.5 Soil Biological Properties 66
4.5.1 Urease Activity µg$mL^{-1}hr^{-1}$ 66
4.5.2 Soil microbial biomass carbon 68
4.5.3 Soil microbial biomass nitrogen (SMBN) 72
4.6 Soil Quality 74
4.6.1 Total soil quality assessment 74
4.6.2 Overall effect of crop Rotation, tillage and nitrogen rates on soil quality 74
4.6.3 Effect of continuous maize cultivation, tillage and nitrogen rate on soil quality in relation to soil depth 78
4.6.4 Effect of maize – cowpea rotation, tillage and nitrogen rates on soil quality in relation to soil depth 78
4.6.5 Effect of maize in rotation with soybean cultivation, tillage and nitrogen rates on soil quality in relation to soil depth 79
4.7 Correlation of Crop Rotation, Tillage and Nitrogen Rate on Soil Quality 86
4.7.1 Correlation of grain yield and soil properties at 0 – 5 cm soil depth 86
4.7.2 Correlation of grain yield and soil properties at 5 – 15 cm soil depth 89
4.7.3 Correlation of grain yield and soil properties at 15 – 25 cm soil depth 91
4.7.4 Correlation of grain yield and mean soil depth of soil properties 93
CHAPTER FIVE 96
5.0 SUMMARY AND CONCLUSION 96
5.1 Summary 96
REFERENCES 99

List of Figures

Figure 4.1: Interaction of tillage and crop rotation on maize grain yield…….50

Figure 4.2: Interaction of tillage and N rate on total nitrogen (g kg^{-1}) at 0 – 5 cm soil depth……..61

Figure 4.3: Interaction of crop rotation and N rate on total nitrogen (g kg^{-1}) at 0 – 5 cm soil depth… ..62

Figure 4.4: Interaction of rotation, tillage and N rate on total nitrogen (g kg^{-1}) at 0 – 5 cm soil depth....63

Figure 4.5: Interaction of tillage and crop rotation on soil microbial biomass carbon……..71

List of Tables

Table 2.1: Soil quality rating for soil microbial biomass C, soil microbial biomass N, urease and maize grain yield, moisture content, bulk density, Saturated hydraulic conductivity, total nitrogen and soil organic matter…….……..……..…….20

Table 3.1. The layout of the experimental site…….27

Table 4.1: Effect of Crop Rotation, Tillage and Nitrogen rate on maize Plant height (cm)……41

Table 4.2: Effect of Crop Rotation, Tillage and Nitrogen rate on maize Leaf Area (cm^2)…….43

Table 4.3: Effect of Crop Rotation, Tillage and Nitrogen rate on maize Total Dry Matter Yield (g).....45

Table 4.4: Long term Effect of Crop Rotation, Tillage and Nitrogen rate on Seed Weight of Maize……..47

Table 4.5: Effect of Tillage and N rate on Soil Particle Size Distribution at 0 – 5 cm depth……52

Table 4.6: Long term Effect of Crop Rotation, Tillage and Nitrogen rate on Saturated Hydraulic Conductivity Ks (cm hr^{-1})……54

Table 4.7: Long term Effect of Crop Rotation, Tillage and Nitrogen rate on Bulk density (Mg m^{-3})…55

Table 4.8: Long term Effect of Crop Rotation, Tillage and Nitrogen rate on Moisture Content (cm^3/cm^3) at Field Capacity…….....57

Table 4.9: Long term Effect of Crop Rotation, Tillage and Nitrogen rate on Total Nitrogen (g kg^{-1})...58

Table 4.10: Long term Effect of Crop Rotation, Tillage and Nitrogen rate on Soil Organic Carbon (g kg-1)……65

Table 4.11: Long term Effect of Crop Rotation, Tillage and Nitrogen rate on Urease (μg mL^{-1} hr^{-1})…67

Table 4.12: Long term Effect of Crop Rotation, Tillage and Nitrogen rate on Soil Microbial Biomass Carbon (mg C kg^{-1})……69

Table 4.13: Long term Effect of Crop Rotation, Tillage and Nitrogen rate on Soil Microbial Biomass Nitrogen (mg N kg^{-1})……..73

Table 4.14: Effect of Crop Rotation, Tillage and Nitrogen rate on Total Soil Quality in relation to soil depth …… ……..75

Table 4.15: Mean values of grain yield and soil properties as influenced by crop rotation,

tillage and nitrogen fertilizer…..…….……76
Table 4.16: Total soil quality rating as affected by crop rotation, tillage and nitrogen fertilizer.....77
Table 4.17 Mean values of grain yield and soil properties at varying soil depths
as influenced by continuous maize cultivation, tillage and nitrogen fertilizer…….....80
Table 4.18: Soil quality rating at varying depths as affected by continuous maize
cultivation, tillage and nitrogen fertilizer…….……81
Table 4.19 Mean values of grain yield and soil properties at varying soil depths as
influenced by maize after cowpea cultivation, tillage and nitrogen fertilizer…...…..….82
Table 4.20 Soil quality rating at varying depths as affected by maize in rotation with cowpea
cultivation, tillage and nitrogen fertilizer…….…..…83
Table 4.21 Mean values of grain yield and soil properties at varying soil depths
as influenced by maize after soybean cultivation, tillage and nitrogen fertilizer…..……84
Table 4.22: Soil quality rating at varying depths as affected by maize in rotation with
soybean cultivation, tillage and nitrogen fertilizer……...….……..85
Table 4.23: Correlation Matrix on grain yield and soil properties at 0 – 5 cm soil depth
of the study soils…….…….88
Table 4.24: Correlation Matrix of grain yield and soil properties at 5 – 15 cm soil depth
of the study soils……..…….90
Table 4.25: Correlation Matrix of grain yield and soil properties at 15 – 25 cm soil depth
of the study soils..…….92
Table 4.26: Correlation Matrix of grain yield and mean soil properties of the study soils……..95

CHAPTER ONE

1.1 Introduction

Long-term field experiments are expected to provide important information regarding soil properties as affected by cropping system and soil management practices. Legumes such as cowpea and soybean add both organic matter and nitrogen (N) to the soil (Omay *et al*., 1997; Sainju *et al*., 2003) and increase soil fertility. Maize is the second most essential cereal crop after sorghum in sub-Saharan Africa; it is grown much more intensively than it was estimated since 1985 (FAO, 1999). In Nigeria, maize yield averages about 1.4 tons per hectare and this is only about 20% of the average in Canada and other parts of the world where intensive cereal production is carried out (Afolami and Fawole, 1991; FAO, 1999). Studies have shown that legume-cereal rotation produce relatively higher grain yields than either crop grown alone (Rao and Mathuva, 2000; Olufemi *et al*., 2001; Mpairwe *et al*., 2002; Dapaah *et al*., 2003). Rotating maize with grain legumes is often targeted towards utilizing biologically fixed-nitrogen by legumes for the benefit of the maize (Yusuf *et al*., 2009). Nitrogen fertilizers are most effectively used as part of a balanced fertilization plan that aims to maximize economic return of a cereal–legume rotation system; Nitrogen fertilizer, apart from increasing the content of nitrate in soil that leads to its leaching (Porter *et al*., 1996), results in changes in soil pH and many other soil properties (Brady and Weil, 2002). Long-term field experiments with N fertilization can give valuable information about how those changes occur and indicate the trends of the changes (Dragan *et al.,* 2010).

Nitrogen (N) is most often the yield limiting nutrient with respect to crop production (Factsheet, 2014). Nitrogen contributes firstly to grain yield and forage biomass production, and at the same time to protein (Eche, 2011). Nitrogen is essential for seed formation and maturity. A steady supply is needed during the early growth stage and this steady supply can be provided by the action of soil microorganisms on the soil organic matter (SOM) or by application of inorganic fertilizers (Eche, 2011). Nitrogen stress

was observed to cause reduction in the number of grains per ear (Lemcoff and Loomis, 1994). However, nitrogen fertilizers can be permanently lost through ammonia volatilization, denitrification, leaching and run-off if not well managed. It could also result in changes in soil p^H which affects the availability of other plant nutrients. Nitrogen can be fixed in the soil through symbiotic association of some microorganism (e.g rhizobia) and leguminous plants (Brady and Weil, 2002). Therefore proper management of soil in terms of method of tillage practice and cropping system is very important in determining the amount of N in the soil (Veenstra *et al*., 2006).

Tillage is any physical, chemical or biological soil manipulation to optimize conditions for germination, seedling establishment and crop growth. Tillage practice is very important in relation to cereal – legume rotation; it could be divided into conventional, reduced and zero tillage. Conventional tillage refers to tillage operations considered standard for a specific location and crop; it tends to bury the crop residue, usually considered as a base for determining the cost effectiveness of erosion control practices (Jasper, 2005). Reduced tillage involves no ridging and less weeding compared to the conventional tillage; it also refers to any method of soil cultivation that leaves the previous year's crop residue on fields before and after planting the next crop to reduce soil erosion and runoff (MDA, 2014). Conventional tillage produces a reduction of organic matter content due to enhanced mineralization of crop residues, disruption of soil aggregates and increasing aeration (Sainju *et al*., 2006). Conservation (reduced or zero) tillage increases soil organic carbon in the surface layer (Six *et al*., 1998; Sainju *et al*., 2006; Melero *et al*., 2009; Lo´pez-Bellido *et al*., 2010), improves soil aggregation (Coulombe *et al*., 1996), and preserves soil resources better than conventional tillage practices (Six *et al*., 1998). Conventional tillage helps in loosening and aerating the top layer of the soil, in destroying weed mechanically and in mixing crop residue, organic matter (humus), and nutrients evenly into the soil (Ray, 2013). One goal of soil quality research is to learn how to manage soil in a way that improves soil function; therefore

soil tillage is among the important practices affecting soil quality and crop yield. It contributes up to 20% of all crop production factors (Khurshid *et al*., 2006).

Soil quality is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans (NRCS, 2014). Soil contains living organisms that provide the basic necessities of life. Healthy soil gives clean air and water, bountiful crops and forests, productive grazing lands, diverse wildlife, and beautiful landscapes. Soil does all these by performing five essential functions: regulating water, sustaining plant and animal life, filtering and buffering potential pollutants and cycling nutrients. Soils respond differently to management depending on the inherent properties of the soil and the surrounding landscape. Understanding soil health means assessing and managing soil so that it functions optimally and is not degraded for future use (NRCS, 2011). Soil quality indicators are used to evaluate how well soil functions since soil function often cannot be directly measured. Measuring soil quality is an exercise in identifying soil properties that are responsive to management, affect or correlate with environmental outcomes, and are capable of being precisely measured within certain technical and economic constraints (Doran and Parkin, 1996). Dynamic soil quality is how soil changes depending on how it is managed. Management choices affect the amount of soil organic matter, soil structure, soil depth, and water and nutrient holding capacity (NRCS, 2011).

1.2 Statement of the Problem

In Africa, three quarter of farmland is severely degraded due to poor soil quality (Eswaran, 1997). Agricultural production in Nigeria is mainly constrained by low levels of soil organic matter, low nutrient status and water holding capacity. Due to the fragile nature of the soils, they degrade rapidly under continuous and intensive cultivation (Abu and Abubakar 2013). It is, however, a known phenomenon that savanna soils in Nigeria have low inherent fertility status, low organic matter, low

total nitrogen and phosphorus, low water infiltration capacity, poor internal drainage due to poor structure (Lombin *et al.,* 1991). As a result of the low fertility level in the soil, farmers apply fertilizer to make up for the deficient nutrient. Recent studies have shown that biologically fixed-N from cowpea or soybean is not enough to meet all the N demand of subsequent maize crop. Supplementary fertilizer N is necessary for optimum maize yield under crop rotation, though the quantity required is lower than that under continuous maize cultivation (Yusuf *et al*., 2009). However, these fertilizers are not applied at recommended rates. Hence, crop productivity declines gradually due to poor soil quality.

1.3 Justification

Crop rotation with grain legumes helps to improve soil fertility, through biological nitrogen fixation while tillage helps in soil aeration and soil aggregation thereby improving the soil physical properties (soil texture and soil structure). Tillage practices also affect soil organic matter in surface soils (Paustian *et al*., 1997). Studies have also shown the effects of different tillage management systems on soil quality under different climatic conditions and fertilization (Kandeler *et al*., 1999; Rolda´n *et al.*, 2005; Melero *et al*., 2009). Soil quality helps to indicate the productivity potential of soils. Perhaps, long-term continuous mono-cropping may contribute to rapid decline in soil productivity as these biological, physical and chemical properties continue to degrade (Tarawali *et al.*, 2001). However, information on changes produced by the interaction of tillage system, crop rotation, rate of N fertilisation and soil quality over a long time is very scarce (Melero *et al*., 2009; Melero *et al*., 2011). Therefore in an effort to reduce land degradation and soil nutrient depletion problems in the northern Guinea savanna of Nigeria, the contributions of crop rotation under conventional and reduced tillage practices in improving soil quality and yield of maize using different N fertilizer rates were investigated.

1.4 Objectives

The main objective of this research was to determine the effect of long term rotation, nitrogen fertilizer and tillage on soil quality and maize yield in the northern Guinea savanna of Nigeria.

The specific objectives of this research were:

1. To determine the influence of long-term crop rotation, tillage and N fertilization on soil quality in the northern Guinea savanna of Nigeria.

2. To determine the influence of long-term crop rotation, tillage and N fertilization on maize grain and stover yield.

3. To determine the relationship between soil quality indicators and maize grain yield as affected by crop rotation, tillage and N fertilizer.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Maize

2.1.1 Botanical description

Maize (*Zea mays* L.) is an annual plant of the grass Graminiaceae family. It is an open-pollinated plant which matures usually within 100 - 120 days. Although some variations exists, the male flower, called tassel emerge 50-60 days after planting at the apex of the plant. At about the same time, the female flowers are formed in the auxils of the lower leave. But the stigmatic surfaces of the female flower called silk only emerge from the axils shortly after tasseling (Ebireri, 2013).

2.1.2 Climatic and soil requirements of maize

Maize is grown over a wide range of climatic conditions. In Nigeria, maize is grown in areas where annual rainfall ranges from 500 mm to 3500 mm covering from the Sudan/Sahel savanna to the Mangrove forest. Solar radiation of maize growing zones in Nigeria ranges from 350 to 400 cal^{-2} day^{-1} in the north and averages about 250 cal cm^{-2} day^{-1} in the south, while the corresponding mean daily temperature is 27^{o}C at tasseling (FAO, 1997). Maize is grown on a wide range of soils, but it is grown best in deep, well drained, medium to moderately heavy-textured soil, with adequate organic matter. It yields poorly on shallow, sandy soils because of higher susceptibility to moisture and nutrient stress. Maize does best on soils with pH of 5.5 – 7.0, and strongly acid soils with pH < 5.0 are unsuitable except when limed. It can also be grown in alkali soils but deficiencies of iron and manganese must be corrected (Ebireri, 2013).

2.1.3 Importance of maize

Maize is the most important cereal crop in sub-Saharan Africa. It is an important staple food for more than 1.2 billion people in sub-saharan Africa and Latin America (IITA, 2009). Maize is one of the most important cereal crops grown in Nigeria, it serves as a major food and cash crop of the savanna. In the last decade through the introduction of fertilizers, maize cropping has dramatically transformed agriculture in the northern Guinea savanna (NGS) from subsistence to cash oriented system (Jabbar, 1995). The crop is being utilized as a staple food; feed for livestock and in brewery and confectionary industries in Nigeria (Winrock, 1992). Maize has high yield potential and occupies about 40% of the area under arable crops in the savanna zones, especially northern Guinea savanna (Badu-Apraku *et al.*, 1997).

2.2 The Northern Guinea Savanna

The Northern Guinea savanna (NGS), which is the region in which this experiment was carried out, covers a land area of about 5.6 million km^2 of the total crop land of sub-saharan Africa. About 42% of the resident human population are said to contribute towards improved crop and livestock production in this region (Winrock, 1992; Jabbar, 1995). The region has a unimodal pattern of rainfall. Annual precipitation ranges between 900 mm to 1300 mm with a growing period of 150–180 days (June – October). The vegetation is dominated by fire tender and tolerant trees with shrubs and grasses. The tree cover varies from open woodland to light forest which has been reduced to bare land due to uncontrolled tree felling for fuel wood and farming activities (Carsky *et al*., 1998).

2.2.1 Cropping systems and crops of the northern Guinea savanna.

In the Northern Guinea savanna region, sorghum, maize and millet-based cropping systems are predominant, and legume-cereal cropping systems also exist and are commonly practiced (Jabbar,

1995). The major staple food crops are millet, sorghum and maize. The main cash crops are groundnut, cotton, maize and vegetables. Other crops that supplement diet and provide some income are cowpea, tomatoes, pepper, okra, sugarcane and rice which are grown in well-watered areas (Elemo *et al.,* 1990).

2.2.2 Maize production in the northern Guinea savanna

Maize, though the second most essential cereal crop after sorghum has now become more important and is grown much more intensively than estimated since 1985 (FAO, 1999). In Nigeria, maize yield averages about 1.4 tons per hectare and this is only about 20 % of the average in Canada and other parts of the world where intensive cereal production is carried out (FAO, 1999). Maize is produced by both small and large scale farmers in the Northern Guinea savanna of Nigeria, where it is widely consumed as a staple food by poor rural and urban households. Maize is also processed industrially for flour, animal feeds, biscuits, beverages and beer and in these forms is consumed widely across Nigeria. The ban on importation of cereals by the Federal Government of Nigeria since 1986 has greatly expanded these latter uses and thus overall demand for maize (Benjamin and Laraba , 2005).

2.2.3 Problems facing maize production in the northern Guinea savanna

The major problems facing maize production in the region are weed infestation, erratic rainfall, and poor soil fertility. The high rate of evaporation especially in the early part of the growing season is the major factor causing water loss in the savanna region (Vanlauwe *et al.,* 2001). Unstable rainfall early in the growing season has been reported to cause drought for crops. Water is shown to be the main limiting factor for maize growth (rather than N) in treatments with sole application of urea, while N availability is the limiting factor with organic treatments (Vanlauwe *et al.*, 2001). This resulted to large number of plants being barren cobs, which is a common feature of severely stressed maize.

2.3 Nitrogen Fertilization

Nitrogen (N) in soil is the most important element for plant development. It is required in large amounts and must be added to the soil to avoid its deficiency in crop production. Nitrogen is a major component of chlorophyll of plants and is responsible for lush, vigorous growth and development of a dense, attractive lawn (Veenstra *et al*., 2006). Although nitrogen is the most abundant element in our atmosphere, plants cannot use it until it is naturally processed in the soil, or added as fertilizer. Sawyer (2008) reported that if no N is applied for many years (fertilizer and manure), the soil's ability to supply plant available N becomes depleted. Sawyer (2008) also reported that apart from N fertilization, N could also come from fixed ammonia as well as mineralization caused by microbial activities on crop residues and soil organic matter. Soil nitrogen is an important nutrient for plants and microbes; large amounts of N are needed to form amino acids, proteins and enzymes (Veenstra *et al.*, 2006). Nitrogen fertilization is the most influential in terms of increasing crop production. Mineral nitrogen, in addition to increasing the content of nitrate in soil, leads to changes in soil pH and many other soil properties. Long-term mineral nitrogen addition experiments (over 40-years) can give us valuable information about how those changes occur and point out the trends of the changes. There is general agreement, that of all the nutrient amendments made to soil, N fertilizer application has had and still has by far the most important effects in terms of increasing crop production such as maize. Under intensified agricultural production the soil receives ever more nitrogen (Freney, 2005; Erisman *et al.*, 2005). Good land management such as tillage, crop rotation, residue management etc are soil related action necessary for increasing yield in crop production (Antapa and Angen, 1990).

2.4 Land Management

2.4.1 Tillage

Tillage is any physical loosening of the soil carried out in a range of cultivation operations, either by hand or mechanized. Tillage includes all mechanical meaures / operation to loosen, turn or mix the soil such as ploughing, digging, hoeing, harrowing etc. therefore tillage is a soil related action necessary for crop production (Ahn and Hintze, 1990). Tillage systems can be categorized into two major systems;

1. Conservation tillage (Reduced)
2. Conventional tillage

Conservation tillage, which could also be called cover cropping, is defined by Philips *et al*. (1980) as a system in which the crop is planted either entirely without tillage or with just sufficient tillage to allow crop seed to germinate and emerge. It alters the physical and chemical properties of the soil. In conservation tillage systems, bulk density is decreased and available concentrations of nitrate and phosphorus are increased because of the presence of soil organic matter. Soil manipulation can change fertility status markedly and the changes may be manifested in good or poor performance of crop (Ohiri and Ezumah, 1990). In addition, tillage operations loosen, granulate, crush or compact soil structure, changing soil properties such as bulk density, pore size distribution and the composition of the soil atmosphere that affect plant growth.

Conventional tillage is perceived to be less sustainable compared to conservation tillage, since it greatly perturbs the soil. This is caused by the use of mouldboard plough, which results in soil inversion to a depth approximately 25cm, the soil surface remain bare and unprotected.

Conservation tillage is seldom practiced in Nigeria, thus the impact of different land management practices on soil quality and crop production such as zero tillahge, reduced tillage, conventional tillage and cover cropping are studied in the northern Guinea avanna Alfisol of Nigeria. Conventional tillage operations consume considerable energy, equipment and labor need, so there may be an economic benefit for reverting to conservation tillage. Conservation tillage crop production practices may help reduce the environmental impacts and production cost of farming (Majiyebo, 2014).

2.4.2 Crop rotation

Crop rotation is the growing of a series of dissimilar or different types of crops in the same area in a sequential seasons, it has been shown to provide various nutrients to the soil. A traditional element of crop rotation is the replenishment of nitrogen through the use of green manure in sequence with cereals and other crops. Crop rotation also mitigates the build-up of pathogens and pest that occurs when one species is continuously cropped, and can improve soil structure and fertility by alternating deep-rooted and shallow-rooted plants. Crop rotation is one component of polyculture (Daxl *et al*., 1994).

Growing the same crop in the same place for many years in a row disproportionately depletes the soil of certain nutrients. With crop rotation, a crop that depletes the soil of one kind of nutrient is followed during the next growing season by a dissimilar crop that returns that nutrient to the soil or draws a different ratio of nutrients: for example, rice followed by cotton (Brooklyn, 1999).

2.4.2.1 Choice of crops

The choice and sequence of rotation crops depends on the nature of the soil, climate, and precipitation which together determine the type of plants that may be cultivated. Other important aspects of farming such as crop marketing and economic variables must also be considered when deciding crop rotations.

Crop rotations may include two to six or more crop rotations over numerous seasons. A two crop rotation such as corn and soybean in cash grains or corn and alfalfa in forage system use legume to help fix nitrogen in the soil for utilization over the long term (Ebirere, 2013). Multiple cropping systems, such as intercropping or companion planting, offer more diversity and complexity within the same season or rotation. Carrots can be shaded by tomatoes and loosen soil below them. Double cropping is common where two crops, typically of different species, are grown sequentially in the same growing season. Winter rye and barley can be sown after oats or rice and harvested before the next crop goes in of oats or rice (Elemo *et al.*, 1990). These systems can maximize benefits of the rotation as well as available land resources. More complex rotations commonly utilize people for greater use of on-farm nutrient management and additional farm products. A soil-feeding crop of winter grains after potatoes. Soil building and pest population management benefits can be further utilized with different complexities of crop rotation. In general the complexity of a field's rotation is limited by what soil, climate, and other environmental conditions permit. This also includes the current or desired management tools and goals of the farmer (Teetes and Pendleton, 1999).

2.4.2.2 Benefits of crop rotation

Using some form of crop rotation, farmers can keep their fields under continuous production, instead of letting them lie fallow, as well as reducing the need for artificial fertilizers, both of which can be expensive. A general effect of crop rotation is that there is a geographic mixing of crops, which can slow the spread of pest and diseases during the growing season (Majiyebo, 2015). The different crops can also reduce the effects of adverse weather for the individual farmer and, by requiring planting and harvest at different times, allow more land to be farmed with the same amount of machinery and labour. Agronomist describe the benefits to yield in rotated crops as "The Rotation Effect". There are many

found benefits of rotation systems: however, there is no specific scientific basis for the sometimes 10 – 25 % yield increase in a crop in rotation versus monoculture (Daxl *et al*., 1994). The factors related to the increase are simply described as alleviation of the negative factors of monoculture cropping systems. Explanations due to improved nutrition; pest, pathogen, and weed stress reduction; and improved soil structure have been found in some cases to be correlated, but causation has not been determined for the majority of cropping systems (Brooklyn, 1999). Crop rotation prevents soil depletion, helps to maintains soil fertility, reduces soil erosion, controls insect pests. Crop rotation as a means to control insect pests is most effective when the pests are present before the crop is planted. Crop rotation reduces reliance on synthetic chemicals, it reduces the pests' build-up, prevents diseases and helps control weeds (Daxl *et al*., 1994).

2.4.2.3 Disadvantages of crop rotation

Some crops are picky in the type of soil they need for maximum profitability. Crop rotation is centered around the need of the soil and not of the crop. Planting picky crops on not-preferred soil will lead to a lower yield in a specific growing season (Teetes and Pendleton, 1999).

2.4.3 Effect of land management systems on some soil quality indicators

Land management systems also have effect on soil physical, soil chemical and soil biological property, ortherwise referred as soil quality. Below is some effect of tillage on some soil quality indicators:

2.4.3.1 Effect of land management systems on bulk density

Bulk density is a measure of soil’s weight or mass per unit volume; soil with lower bulk density has more pore space and allows for more water infiltration and space for roots to grow than soil with higher bulk density. In a research conducted by Veenstra *et al.* (2006), they found that after 4 years of

conservation tillage and cover cropping, soil bulk density was lowest with conservation and highest with conventional tillage.

2.4.3.2 Effect of land management systems on total nitrogen

Proper management of soil in terms of method of tillage adopted is very important in determining amount of N in the soil. For instance, Veenstra *et al*. (2006) showed increased total N for conservation and conventional tillage. According to them, the increase in total nitrogen in both the conservation and conventional tillage were linked to increased input of organic matter associated with cover crop. Celik *et al*. (2011) observed total N to be higher only at surface 0 – 10 cm depth under no tillage with and lowest for conventional tillage with cover cropping. However, conventional tillage was reported not to have any effect on total N at 10 – 30 cm depth for 3 years. They concluded that higher total organic carbon content caused high total N content in reduced and no tillage plots compared to conventional tillage. Also there was no significant effect of different tillage methods on total N at 10-30 cm and no difference in total nitrogen concentration between tillage methods on total Nat 10 – 30 cm and no difference in total N concentration between tillage methods in the first year of treatment (Mc Carty *et al.,* 1998), but had significant difference after 3 years (Aon *et al.*, 2001).

2.4.3.3 Effect of land management systems on soil organic matter (SOM)

Soil organic matter is a reservoir of nutrients for plants and microorganisms. It helps improve soil structure, which gives the soil its porosity and allows more space for water and air, benefitting plant growth.

Frequent tillage can reduce the amount of organic matter in the soil, an important component of its quality. Tillage results in loss of SOM primarily through three mechanisms:

- Mineralization of organic matter due to breakdown of soil aggregates and changes in temperature and moisture regimes.

- Leaching of organic carbon

- Accelerated rates of erosion (Lal, 2002).

2.4.3.3 Effect of land management systems on soil microbial biomass

Soil microbial biomass is a living active part of soil organic matter, an agent of mineral nutrient transformations for added and native organic matter and acts as a labile reservoir for plant available N, P and S (Fauci and Dick 1994; Wick *et al*., 1998; Kanchikerimath and Singh, 2001). The activity of the microbial biomass is commonly used to characterize the microbiological status of a soil (Nanniperi *et al*., 1990) and to determine the effects of cultivation (Anderson and Domsch, 1993), field management (Perott *et al.,* 1992) or contamination (Chander and Brookes, 1993) on soil microorganisms. Soil microbial biomass (SMB) is often used as an indicator of changes in soil chemical and physical properties resulting from soil management and environmental stresses in agricultural systems (Trasar-Cepedar *et al.,* 1998).

Soil microbial biomass is influenced by biological, chemical and physical properties of the plant-soil system (Ndakidemi, 2006). Soil microbial biomass C, N, and P and the most labile and play a key role in soil C, N, and P cycles. This gives an indication of the constant available pool of the nutrients in the soil. The productivity of agricultural systems and availability of nutrients depend therefore, on the activity of the microbial biomass (Friedel *et al.,* 1996).

Measurement of SMB is essential in soil nutrient cycling studies and has been used as an indicator of soil quality under long-term management trials (Wick *et al*., 1998), and will be of importance in the

development of new management strategies to reverse declining organic matter content and soil fertility status of agricultural soils which may result in yield decline (Collins *et al*., 1992).

Whether the management practices in mixed cultures involving legumes and cereals favor the stimulation of biological soil activity and result in higher turnover of organic substrates in the soil that are utilized by micro-organisms, it is a good subject to be investigated. There is a lot of information that show the relationship between soil management and soil microbial activity, but little is known about these effects under mixed cropping such as in this study and those practiced by farmers in the tropical and subtropical environments (Ndakidemi, 2006). The measurement of microbial biomass activities could provide useful information concerning soil health and also serve as a good index of biological status in various crop management systems (Eche, 2011).

2.5 Concept of Soil Quality

Soil quality has been defined in different ways by different authors / or researchers. According to the United States Department of Agriculture (USDA) and national Remote Sensing Center (NRSC), soil quality refers to soil health. It is how well soil does over what we want to do. More specifically, soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, support human and healthy and habitation (Anikwe, 2006).

2.5.1 Soil quality evaluation

Soil quality is evaluated to learn about the effects of management practices on soil function. Reasons for evaluating soil quality fall into three categories: Awareness and education, Evaluation of practice effects and trouble-shooting and evaluation of alternative practices. The objectives of soil quality are

similar to the monitoring and maintenance of human health. Doctors monitor health indicators and watch for irregularities or declines in status. The same thing also happens to the soil, the set of soil quality indicators measured during a check-up is important in relation to tillage, crop rotation and N fertilization. These parameters affect the soil quality either positively or negatively (NRCS, 2011).

2.5.2 Soil quality indicators

Scientists use soil quality indicators to evaluate how well soil functions since soil function often cannot be directly measured. Measuring soil quality is an exercise in identifying soil properties that are responsive to management, affect or correlate with environmental outcomes, and are capable of being precisely measured within certain technical and economic constraints. Soil quality indicators may be qualitative (e.g. drainage is fast) or quantitative (infiltration= 2.5 in/hr) (Doran and Parkin, 1996).

Ideal indicators according to Doran and Parkin. (1996) should:

- Correlate well with ecosystem processes
- Integrate soil physical, chemical, and biological properties & processes
- Be accessible to many users
- Be sensitive to management and climate
- Be components of existing databases
- Be interpretable

There are three main categories of soil indicators: chemical, physical and biological. Typical soil tests only look at chemical indicators. Soil quality attempts to integrate all three types of indicators. The categories do not neatly align with the various soil functions, so integration is necessary (Doran and Parkin, 1996).

Organic matter, or more specifically soil carbon, transcends all three indicator categories and has the most widely recognized influence on soil quality (NRCS 2011). Organic matter is tied to all soil functions. It affects other indicators, such as aggregate stability (physical), nutrient retention and availability (chemical), and nutrient cycling (biological); and is itself an indicator of soil quality (Doran and Parkin, 1996). Some indicators are descriptive and can be used in the field as part of a health card. Others must be measured using laboratory analyses. Some examples of indicators that fall into the three broad categories of chemical, physical and biological are provided below (Anikwe, 2006).

2.5.2.1 Chemical indicators

Chemical indicators can give you information about the equilibrium between soil solution (soil water and nutrients) and exchange sites (clay particles, organic matter); plant health; the nutritional requirements of plant and soil animal communities; and levels of soil contaminants and their availability for uptake by animals and plants. Indicators include measures of:

- Total Nitrogen
- Soil organic matter
- Soil organic carbon (NRCS, 2011).

➢ Total nitrogen

Nitrogen occurs in the soil in several forms, only some of which are available to plants. Generally nitrogen has to be in a mineralized form (nitrate or ammonium) to be readily available to plants. A discussion of the nitrogen cycle and availability in soils is presented in Strong and Mason (1999). Various pools of nitrogen occur in the soil. The nitrogen in the soil organic matter pool is mineralized

to form nitrate (NO_3^-) and ammonium (NH_4^+) that are the forms most available to plants. Nitrate can be readily leached in waterlogging conditions or can be subject to denitrification to nitrous oxide (N_2O) and nitrogen gas (N_2) (Ebirere, 2013). Nitrous oxide is a significant greenhouse gas that can add to global warming, especially as it is 296 times more effective as a greenhouse gas than carbon dioxide and it has been estimated to contribute up to 6% of the greenhouse gas warming effect (Dalal *et al.* 2003*a*, 2003*b*). Estimating critical values for nitrogen requires local knowledge of soils and climatic conditions. Therefore local advisors need to be consulted to obtain recommendations on the addition of nitrogen fertilizers. Total nitrogen measures the total amount of nitrogen present in the soil, much of which is held in organic matter and is not immediately available to plants as seen in Table 2.1. It may be mineralized to available forms. Total nitrogen cannot be used as a measure of the mineralized forms of nitrogen (NH_4^+, NO_3^-, NO_2^-), as much of it is held in the organic matter in the soil.

- Soil organic matter (OM) and soil organic carbon (OC)

  Organic matter is the material in soil that is directly derived from plants and animals, and it supports most important microfauna and microflora in the soil. Through OM breakdown and interaction with other soil constituents, it is largely responsible for much of the physical and chemical fertility of a soil (Charman and Roper, 2007). Soil organic matter is a term that is usually used in the broadest sense to describe a wide range of organic components in the soil including living and non-living organic materials. The non-living organic matter can be broken down into dissolved organic matter, particulate organic matter, humus and inert organic matter (charcoal and charred materials). A detailed discussion of organic matter in Australian soils is given in Baldock and Skjemstad (1999), who also give a range of critical values for soil carbon. Organic matter and organic carbon are usually expressed as a percentage of the soil by weight. When results are presented and interpreted, care should be taken to note whether organic matter or organic carbon levels are indicated.

Table 2.1: Soil quality rating for soil microbial biomass C, soil microbial biomass N, urease and maize grain yield, moisture content, bulk density, Saturated hydraulic conductivity, total nitrogen and soil organic matter.

Soil Quality Rating	Soil microbial biomass C (mg kg^{-1})	Soil microbial biomass N (mg kg^{-1})	Urease ($\mu g\ mL^{-1}\ hr^{-1}$)	Grain yield of Sammaz 14 (t ha^{-1})[3]	Moisture content (mm water / m soil)[4]	Bulk density (Mgm^{-3})[5]	Saturated hydraulic Conductivity (cm h^{-1})[6]	Total nitrogen (g/kg)[7]	Soil organic Matter (g/kg)[8]
1 (Very high)	> 400 [1, 2]	>100 [1, 2]	>12.00 [9]	6.8 – 5.4 [3]	<100	<1.0	<0.05	<0.05	<0.70
2 (High)	300 – 400	91 – 100	9.0 – 12.0	5.3 – 3.9	100–130	1.0–1.3	1–2	0.05–0.15	1.00–1.70
3 (Moderate)	200 – 300	80 – 90	6.0 – 9.0	3.8 – 2.4	130–160	1.3–1.6	2–6	0.15–0.25	1.70–3.00
4 (Low)	100 – 200	51 – 79	3.0 – 6.0	2.3 – 0.9	160–200	1.6–1.9	6–12	0.25–0.50	3.00–5.15
5(Very Low)	< 100 [0, 1]	< 50 [1, 2]	< 3.00 [9]	0.8 – 0 [3]	>200	>1.9	>12	>0.5	>5.15

Note: Soil quality ratings from 2 – 4 (high to low) were estimated using a constant difference between the lowest ratings and the highest ratings for all soil biological properties and grain yield of sammaz 14.

Source:[0] = Eche (2011). [1] = Lawal (2015) ; Arifin *et al.*, (2012)[2]. [3] = IAR (2015) ; [4] = McIntyre (1974) ; [5] = Cresswell and Hamilton (2002). [6] = Geeves *et al.*, (2007*a*). [7] = Bruce and Rayment (1982). [8] = Charman and Roper (2007). [9] = Bandick and Dick (1999).

Organic matter is calculated from the levels of organic carbon in the soil by multiplying by 1.72. This factor is based on the assumption that the organic matter in the soil has a constant carbon composition of approximately 57 %. However, Nelson and Sommers (1996) have pointed out that the actual conversion factors of organic carbon to organic matter vary from 1.72 – 2.00, and they recommend that only organic carbon values be reported.

The method of determining soil carbon can influence the results. A LECO (Laboratory Equipment Corporation) furnace is often used to determine soil carbon by combustion and has tended to replace the older, more labor intensive Walkley-Black method, which uses chemical oxidation. Tests have shown these are generally equivalent, or can be converted, provided the exact methodology for the Walkley-Black method has been recorded (Skjemstad *et al.*, 2000).

The general ranking of soil organic matter levels (see Table 2.1) has been based on soils that are light-textured (sand loams, loams) and weakly structured. These soils broadly coincide with hard-setting soils.

2.5.2.1 Physical indicators

Physical indicators provide information about soil hydrologic characteristics, such as water entry and retention that influences its availability to plants. Some indicators are related to nutrient availability by their influence on rooting volume and aeration status. Other measures gives information about erosional status. Some soil physical indicators are:

- Saturated hydraulic conductivity
- Aggregate Stability
- Bulk Density
- Water Holding property (NRCS, 2011).

- Saturated hydraulic Conductivity

Hydraulic conductivity is the flow of water through soil per unit of energy gradient. For practical purposes, it is a measure of the rate at which water moves into and through the soil. It is useful for predicting runoff from rainfall, soil drainage, irrigation rates, leaking from dams and deep drainage that contributes to salinity (Cass, 1999).

The knowledge of water movement in field soil is essential with respect to plant nutrient transport. The measure of the soil's ability to transmit water called hydraulic conductivity (Table 2.1) does not remain constant due to the various chemical, physical and biological processes going on in the soil. Therefore, hydraulic conductivity may change as water permeates and flows through the soil (Abdulkadir, 2006). Hydraulic conductivity is influenced by total porosity of the soil, which in turn is affected by the bulk density and available water content and other factors (Mbagwu, 1995; Rawls *et al*., 1998; Abdulkadir, 2006).

- Bulk Density

Bulk density (Pb) is the oven dry weight of soil per unit volume. It may be expressed in g/cm^3 or t/m^3 (1 g/cm^3 = 1000 kg/m^3 = 1 t/m^3). It affects porosity and soil strength. Bulk density is a measure of the density of a porous material that takes into account the density of the solid material (e_s) and the amount of porosity (*f*). The rating of bulk density is presented in Table 2.1by Cresswell and Hamilton (2002).

- Water-holding property (Moisture content)

a. Gravimetric moisture content

Moisture is expressed as weight of water per weight of oven dry soil, usually as g/g or as g water per 100 g of oven dry soil (%).

b. Volumetric moisture content

Moisture is expressed as the volume of water per volume of soil, usually as cm^3/cm^3. This converts to depth of water per depth of soil for a unit area. It can be expressed as centimeter of water per centimeter of soil, or, more conveniently, millimeters of water per centimeter of soil, or millimeters of water per meter of soil. Volumetric moisture is derived from gravimetric moisture by using bulk density and the density of water in the following equation:

Volumetric moisture = (gravimetric moisture x density of water) / (bulk density)

Volumetric moisture can be measured directly using neutron probes and Time Domain Reflectometry (TDR) (Zegelin *et al.*, 1990). Table 2.1 shows the rating of soil moisture content.

2.5.2.1 Biological Indicators

Biological indicators can tell us about the organisms that form the soil food web that are responsible for decomposition of organic matter and nutrient cycling. Information about the numbers of organisms, both individuals and species, that perform similar jobs or niches, can indicate a soil's ability to function or bounce back after disturbance (resistance and resilience). Indicators include measures of:

- Soil Microbial Biomass
- Soil Enzymes (e.g Urease)
- Earthworms
- Particulate Organic Matter
- Potentially Mineraliable Nitrogen (NRCS, 2011).

a. Ureases

Soil enzymes are a group of enzymes whose usual inhabitants are the soils and are continuously playing an important role in maintaining soil ecology, physical and chemical properties, fertility, and soil health

(Richmond, 1991). Urease is a nitrogen cycling enzyme that is responsible for the hydrolysis of urea fertilizers applied to the soil into ammonia (NH_3) and carbondioxide with the concomitant rise in soil pH. This, in turn, results in a rapid N loss to the atmosphere through NH_3 volatilization (Simpson *et al.*, 1984; Simpson and Freney, 1988). Due to this role, urease activities in soils have received a lot of attention since it was first reported by Rotini (1935), a process considered vital in the regulation of N supply to plants after urea fertilization. Soil urease originates mainly from plants (Polacco, 1977) and microorganisms found as both intra- and extra-cellular enzymes (Burns, 1986). On the other hand, urease extracted from plants or microorganisms is rapidly degraded in soil by proteolytic enzymes. This suggests that a significant fraction of ureolytic activity in the soil is carried out by extracellular urease, which is stabilized by immobilization on organic and mineral soil colloids (Zantua and Bremner, 1977). Urease activity in soils is influenced by many factors. These include cropping history, organic matter content of the soil, soil depth, soil amendments, heavy metals, and environmental factors such as temperatures. For example, studies have shown that urease was very sensitive to toxic concentrations of heavy metals. Generally, urease activity increases with increasing temperature. It is suggested that higher temperatures increase the activity coefficient of this enzyme (Simpson and Freney, 1988). Therefore, it is recommended that urea be applied at times of the day when temperatures are low. Since urease plays a vital role in the hydrolysis of urea fertilizer, important to uncover other unknown factors that may reduce the efficiency of this enzyme in the ecosystem (Yang *et al*., 2006). Table 2.1 shows the laboratory ratings for urease.

b. Soil Microbial Biomass Carbon (SMBC)

Soil microbial biomass carbon make up 1 - 4 % of the total soil organic carbon and ranges from 100-600mg kg^{-1} under cereals and can exceed 1500 mg kg^{-1} under grassland (Eche, 2011). Differences in

values within this range depends on the quantity and quality of organic matter inputs to the soil (Wardle, 1992). The amount of SMBC in soil organic carbon gives an index for monitoring soil development, changes under different cropping systems and land uses (Insam *et al*., 1991), and soil degradation or recovery. It reflects macro- and micro-climatic variation. The soil and plant management practices generally have greater effect on the level of soil microbial carbon (Dick, 1997; Alvey *et al.,* 2003). Soil microbial carbon shows the highest values in crop land and grassland and lowest in bare cultivated soils. Studies have shown that legumes accumulate greater amounts of SMBC in the soil than cereals (Walker *et al.,* 2003). This was attributed to lower C:N ratio of legume than that of cereal. Under conditions of adequate P-nutrient supply, the microbial biomass C increased due to improved plant growth and increased turnover of organic matter in soil (Brady, 1990). Table 2.1 shows the laboratory rating for soil microbial biomass carbon.

c. Soil Microbial Biomass Nitrogen (SMBN)

Soil microbial biomass is a key site for mineralization of organic N and P in soils. The soil microorganisms produce a variety of proteases capable of mineralizing organic N (Moore *et al*., 2000; Walker, *et al.*, 2003). Soil microbial biomass nitrogen make up about 5 % of the total soil N. The measurement of SMBN to essentials for quantifying N dynamics in agricultural ecosystems because it controls the loss and availability of soil inorganic N especially in high input systems (Moore *et al.*, 2000). Soil microbial biomass nitrogen is small but the rapid turn-over makes an important contribution to mineralization. Changes in size of microbial N pool reflects net rates of change with no net change in pool size though there may be a considerable turnover of N within the microbial biomass (Patra *et al*., 1990). Table 2.1 above shows the ratings for soil microbial biomass nitrogen. Therefore, this study will assess the effect of long term rotation, N fertilization and tillage on soil quality and maize yield in the northern Guinea savanna of Nigeria.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site

The study was carried out at the Institute for Agricultural Research (IAR) farm in Samaru, with coordinates 11^{o} 09, 943N', 007^{o} 37. 956E' and 686 m above the sea level in the northern Guinea savanna (NGS) of Nigeria. The soil type is an Alfisol derived from Pre-Cambrian Crystalline basement complex rocks with some quaternary Aeolian deposits (Yusuf, 2007). The main sub-group is Typic Haplustalf (Awujoola, 1979). The experimental field was relatively flat with a mono modal rainfall pattern and a mean annual rainfall of 1011 ± 161 mm concentrated almost entirely from May to October. Samaru has minimum and maximum temperatures of 21^{o}C and 33.5 ^{o}C, with a mean daily temperature of 24 ^{o}C and relative humidity of 55.23 %. This study was carried out in the wet season of 2013.

3.1.1 History of the site

A long-term field experiment begun in 2002 at the Institute for Agricultural Research, (I.A.R) farm in Samaru, to evaluate the effect of long term N fertilization on crop rotation, the site was later modified to accommodate tillage as an additional experimental factor in 2009. Now the experimental field has N fertilization, crop rotation and tillage practices.

3.2 Treatment Structure and Experimental Design

The treatments were factorial combination of three crop rotations (Maize - Maize, Maize – Cowpea and Maize – Soybean), two tillage practices (Reduced and Conventional) and four N levels (0 kg N ha^{-1}, 30 kg N ha^{-1}, 60 kg N ha^{-1} and 90 kg N ha^{-1}), arranged in split plot design replicated three times. The main plot consisted of combinations of crop rotation and tillage, while the sub-plot consisted of N rate (Table 3.1). Maize was sown on all the plots during this experiment.

Table 3.1. The layout of the experimental site

Rep I					Rep II					Rep III			
Soybean Conventional tillage 60 kg N ha^{-1}	Soybean Conventional tillage 0 kg N ha^{-1}	Soybean Conventional tillage 30 kg N ha^{-1}	Soybean Conventional tillage 90 kg N ha^{-1}		Cowpea Conventional tillage 90 kg N ha^{-1}	Cowpea Conventional tillage 0 kg N ha^{-1}	Cowpea Conventional tillage 30 kg N ha^{-1}	Cowpea Conventional tillage 60 kg N ha^{-1}		**Cowpea Reduced tillage 30 kg N ha^{-1}**	**Cowpea Reduced tillage 0 kg N ha^{-1}**	**Cowpea Reduced tillage 90 kg N ha^{-1}**	**Cowpea Reduced tillage 60 kg N ha^{-1}**
Cowpea Reduced tillage 0 kg N ha^{-1}	**Cowpea Reduced tillage 90 kg N ha^{-1}**	**Cowpea Reduced tillage 30 kg N ha^{-1}**	**Cowpea Reduced tillage 60 kg N ha^{-1}**		**Maize Reduced tillage 60 kg N ha^{-1}**	**Maize Reduced tillage 0 kg N ha^{-1}**	**Maize Reduced tillage 90 kg N ha^{-1}**	**Maize Reduced tillage 30 kg N ha^{-1}**		Soybean Conventional tillage 60 kg N ha^{-1}	Soybean Conventional tillage 90 kg N ha^{-1}	Soybean Conventional tillage 0 kg N ha^{-1}	Soybean Conventional tillage 30 kg N ha^{-1}
Maize Reduced tillage 90 kg N ha^{-1}	**Maize Reduced tillage 30 kg N ha^{-1}**	**Maize Reduced tillage 60 kg N ha^{-1}**	**Maize Reduced tillage 0 kg N ha^{-1}**		**Cowpea Reduced tillage 90 kg N ha^{-1}**	**Cowpea Reduced tillage 60 kg N ha^{-1}**	**Cowpea Reduced tillage 0 kg N ha^{-1}**	**Cowpea Reduced tillage 30 kg N ha^{-1}**		Maize Conventional tillage 0 kg N ha^{-1}	Maize Conventional tillage 90 kg N ha^{-1}	Maize Conventional tillage 60 kg N ha^{-1}	Maize Conventional tillage 30 kg N ha^{-1}
Soybean Reduced tillage 0 kg N ha^{-1}	**Soybean Reduced tillage 90 kg N ha^{-1}**	**Soybean Reduced tillage 30 kg N ha^{-1}**	**Soybean Reduced tillage 60 kg N ha^{-1}**		**Soybean Reduced tillage 90 kg N ha^{-1}**	**Soybean Reduced tillage 0 kg N ha^{-1}**	**Soybean Reduced tillage 60 kg N ha^{-1}**	**Soybean Reduced tillage 30 kg N ha^{-1}**		**Maize Reduced tillage 60 kg N ha^{-1}**	**Maize Reduced tillage 90 kg N ha^{-1}**	**Maize Reduced tillage 0 kg N ha^{-1}**	**Maize Reduced tillage 30 kg N ha^{-1}**
Maize Conventional tillage 0 kg N ha^{-1}	Maize Conventional tillage 90 kg N ha^{-1}	Maize Conventional tillage 30 kg N ha^{-1}	Maize Conventional tillage 60 kg N ha^{-1}		Maize Conventional tillage 60 kg N ha^{-1}	Maize Conventional tillage 30 kg N ha^{-1}	Maize Conventional tillage 0 kg N ha^{-1}	Maize Conventional tillage 90 kg N ha^{-1}		Cowpea Conventional tillage 0 kg N ha^{-1}	Cowpea Conventional tillage 90 kg N ha^{-1}	Cowpea Conventional tillage 30 kg N ha^{-1}	Cowpea Conventional tillage 60 kg N ha^{-1}
Cowpea Conventional tillage 90 kg N ha^{-1}	Cowpea Conventional tillage 30 kg N ha^{-1}	Cowpea Conventional tillage 0 kg N ha^{-1}	Cowpea Conventional tillage 60 kg N ha^{-1}		Soybean Conventional tillage 0 kg N ha^{-1}	Soybean Conventional tillage 30 kg N ha^{-1}	Soybean Conventional tillage 60 kg N ha^{-1}	Soybean Conventional tillage 90 kg N ha^{-1}		**Soybean Reduced tillage 60 kg N ha^{-1}**	**Soybean Reduced tillage 60 kg N ha^{-1}**	**Soybean Reduced tillage 60 kg N ha^{-1}**	**Soybean Reduced tillage 60 kg N ha^{-1}**

3.3 Cultural Practices

3.3.1 Land preparation

The conventional tilled plots were manually ridged at 0.75 m inter-row spacing, the reduced tillage plots were not ridged, but seeds were also sown at 0.75 m inter-row spacing using a rope to mark the planting points. In addition, the ridges were manually remoulded with hoe at 8 weeks after sowing (WAS) in the conventional plots while the reduced plots were not remoulded.

3.3.2 Plot size

The main plot and sub plot both measured 4.5 m x 6 m giving an area of 27 m^2, with a total of 6 ridges per plot, separated 1 m between block and 0.5 m between plots. Within the plots, four (4) ridges were the net plot while the outer rows were regarded as the border rows which destruction samples were taken.

3.3.3 Sowing

All plots were sprayed with glyphosate at 2 litres per hectare at approximately 2 weeks before sowing. SAMMAZ 14 seeds were sown in 2013 manually at the rate of two seeds per hole. This was later thinned to one plant per stand at an intra-row spacing of 25 cm and inter-row spacing of 75 cm. This brought the plant population to 24 plants per ridge and 144 plants per plot.

3.3.4 Fertilizer application

Phosphorus and potassium fertilizers were applied by drill method once at planting based on the recommended rate of fertilizer application for maize at 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}. Nitrogen was applied in two split dose (also using drill method) at 3 WAS and 6 WAS at 0 kg N ha^{-1}, 30 kg N ha^{-1}, 60 kg N ha^{-1} and 90 kg N ha^{-1} levels in the various experimental plots corresponding to the N level.

3.3.5 Weeding and earthen up

Weeding was done twice at both the conventional tillage plots and reduced tillage plots at three weeks after sowing and at six weeks after sowing. The conventional tillage plots were earthened up using hoe at 8WAS only, while the reduced tillage plots were not earthen up.

3.4 Data Collection

Four plants were randomly tagged in each plot on the ridges adjacent to the border rows. Data on growth parameters were recorded on the tagged plants at two weeks intervals, beginning from 4 WAS and continued until 12 WAS. The parameters observed were:

3.4.1 Plant height (cm)

This was determined by measuring the height of each tagged plant, from the ground level to the growing tip of the stem with a meter rule. The average height was calculated and the mean recorded.

3.4.2 Number of leaves per plant

Number of leaves per plant was obtained by counting the leaves on each tagged plant and the average was recorded.

3.4.3 Leaf width

This was recorded by measuring the length of a sub-sampled leaf within a sampled plant at its widest part.

3.4.4 Leaf length

This was recorded by taking the length of a sub-sampled leaf within a sampled plant.

3.4.5 Leaf area (LA) cm^2 $plant^{-1}$

This was determined by the method described by Watson (1958) as:

Leaf area (Y) = $0.5L\frac{n}{w} + 1.05n + 53.61$ ……..eqn. 12

Where L = Leaf length.

w = Leaf width

n = Number of leaves

3.4.6 Dry matter yield of maize

Dry matter yield per plant was determined at five different stages of plant growth (4 WAS, 6 WAS, 8 WAS, 10 WAS and 12 WAS) during the experiment. Five plants were uprooted from the border rows in the gross plot. They were inserted into a labeled envelope and oven dried for 3 to 4 days, at a temperature of 70 ^oC. This was weighed and the average was calculated to obtain the weight per plant.

3.5 Harvesting

Harvesting of the maize cob was done when the plant reached its harvest maturity. Harvesting was done by hand and 15 maize plants were selected and uprooted to determine both growth and yield parameters.

3.6 Grain Yield

3.6.1 100 grain weight (g)

One hundred grains were randomly selected and weighed to determine 100 seed weight from the 15 maize plants harvested.

3.6.2 Grain Yield (kg/ha)

Fifteen maize plants were uprooted, 15 cobs were threshed, weighed and extrapolated as shown below:

a. Grain yield per plot = Grain weight per cob x Total number of cobs

b. Grain yield per hectare = (grain yield per plot x 10,000 m^2) / plot area

3.7 Soil sampling

Soil samples were collected from plots that received 0 kg N ha^{-1} and 90 kg N ha^{-1} since the commencement of the trial. Soil sampling was done at three depths; 0 – 5 cm, 5 – 15 cm and 15 – 25 cm before planting and after harvesting. The field moist soil was sieved (2 mm and 0.5mm) then divided into two subsamples: a. One was air-dried for soil chemical and soil physical determination.

b. The second subsample was stored in the refrigerator at 4 ^oC in polythene bag for soil biological determination.

Three (3) core samples (measuring 5 cm x 5cm in diameter) per plot were collected at 0 - 5 cm, 5 - 15 cm and 15 - 25 cm depth from plots that received 0 kg N ha^{-1}, 90 kg N ha^{-1} plots, then composited for further analysis.

3.8 Physical and Chemical Characterization of the Soil

3.8.1 Measurement of soil physical properties

a. Soil particle size determination

Bouyocous hydrometer method was used to determine soil particle size (Agbenin, 1995). Fifty grams of soil was weighed into a 250 mL plastic beaker. 100 mL of 50 % calgon was added into the beaker and stirred with a glass rod. Then 100 mL of distilled water was added and stirred. It was then left to stand for 30 minutes with occasional stirring. The mixture was then transferred into 1000 cm^3 measuring

cylinder and was made to the mark with distilled water. The suspension was mixed vigorously using a long handled-plunger to disturb thoroughly the sediments at the bottom. A hydrometer was put carefully in the solution for the reading to be taken 40 seconds later. The hydrometer was removed from the suspension for it to be given another shaking. The hydrometer was inserted again to take 2 hours reading. The times are recommended for 20 micrometer and 2 micrometer fractions respectively. Blank was prepared in the same way but without soil and readings were taken for the blank. Also temperatures of suspensions and blank were taken.

Corrected hydrometer readings [C (g/L)] were obtained by subtracting the blank reading [RL(g/L)] from hydrometer reading in the soil suspension [R(g/L)] and adding 0.36 g/L for every degree above 20˚C.

% Clay = R – RL + (0.36T)……...eqn 1

% Silt = (C40 seconds x 100) / (weight of soil taken)) - % Clay……..eqn 2

% Sand = 100 – (% Silt - % Clay)……...….eqn 3 (Girei, 2015).

b. Saturated hydraulic conductivity (Ks) was determined using the constant head permeameter method (Agbenin, 1995) as follows:

The undisturbed core samples representing each plot was covered at one end with a piece of muslin cloth held in place with the aid of rubber bands and allowed to stand overnight in water to ensure complete saturation. These saturated samples were then arranged in a permeameter and the volume of flow and changes in hydraulic heads determined **(**Dipak and Abhijit, 2005). Saturated hydraulic conductivity was calculated using Darcy's equation.

$$Ks = \frac{VL}{At\Delta H} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{eqn. 4}$$

Where

Ks = Saturated hydraulic conductivity (cm/min)

V = Volume of soil (cm^3)

t = Time (minutes)

A = Area (cm^2)

L = Length of soil core (cm)

ΔH = Change in hydraulic head (cm)

c. Bulk Density was determined by the core method (Blake and Hartge, 1986) and equation. 5 was used to calculate the bulk density

$$BD = \frac{Mass\ of\ Oven\ dry\ soil}{Bulk\ volume\ of\ soil\ (volume\ of\ core)} \text{..... eqn. 5}$$

d. Moisture content: Moist soil samples collected for determination of bulk density was covered at both ends and taken immediately to the lab and weighed. The sample was oven-dried for at least 24 hours at 105ºC and then weighed. The soil moisture content was then determined by the following formula:

$$\text{Soil moisture content (g)} = \frac{Soil\ moist\ Weight - oven\ dry\ weight}{oven\ dry\ weight} \text{.....eqn. 6}$$

(Agbenin, 1995).

3.8.2 Measurement of soil chemical properties

a. Total N (Kjeldahl method)

Ten grammes of the disturbed soil sample was ginded and sieved with a 0.5 mm sieve and then added to a Kjeldahl flask (600 - 800 mL capacity). Thirty five millilitre of sulphuric-acid salicylic-acid mixture was added. It was shaken and let to stand for 30 minutes for the nitrates to react with the salicylic acid. Then 5 g of $Na_2S_2O_3$. $5H_2O$ was added and heated gently on low flame for 5 minutes taking care to avoid

frothing. When cool, 10 g of the mixture was added and let to continue digestion gradually raising the temperature until the solution becomes clear and acquires a grayish blue colour (usually a total of about 2-3 hours for digestion). It was let to cool and 300 mL of distilled water was added, with intermittent shaking; the solution was left to further cool. Distillation was carried out as by adding to the digest 100 mL of concentrated sodium hydroxide and several pieces of granulated zinc. One teaspoon glass beads were also added. The distillation head was connected and 150 mL of the digest was distilled into 25 mL of standard 0.1N H_2SO_4 solution containing methyl red indicator. A blank titration was done with the excess acid and standard alkali (0.1N NaOH). Blank titration was done exactly in the same manner without the soil (Dipak and Abhijit, 2005).

b. Soil organic carbon: Soil organic carbon was determined by Walkley-Black method (Agbenin, 1995).

The procedure is as follows:

The disturbed soil sample was grinded and sieved with a 0.5 mm sieve. One gramme of the disturbed soil sample was weighed and poured into a clear and dry 500 mL conical flask. Ten millilitres of 1N $K_2Cr_2O_7$ was added by means of a pipette and swirled gently. Then 20 mL of concentrated H_2SO_4 was added rapidly into the solution, and immediately mixed by swirling gently at first and then vigorously for a total of one minute. The flask was kept on an asbestos pad for 30 minutes. Two hundred millilitres of distilled water was added, followed with 10 mL of orthophosphoric acid and 1 mL of diphenylamine indicator. A blue colour appeared. Titration was done with ferrous ammonium sulphate solution till colour changed from blue violet to green. A blank was determined using all the reagents similarly but no soil sample. The blank value was recorded and soil organic carbon was determined using equation 7 below (Dipak and Abhijit, 2005).

Calculation:

%Org. C = ((meq $k_2Cr_2O_7$ – meq $FeSO_4$) x 0.003 x 100 x F)) / wt of air dry soil taken…….eqn 7

Where f= Correction Factor or 1.33 (Agbenin, 1995).

3.8.3 Measurement of soil biological properties

a. Assay Method for Urease according to Frankenberger and Tabatabai (1980a, b)

Five gram of soil (< 2 mm sieve) was placed in a 50 mL volumetric flask to which was added 0.2 mL toluene and 9 mL of THAM buffer, the flask was swirled for a few seconds to mix the contents, and the 1 mL of 0.2M urea solution was added, swirled again for a few seconds. The flask was placed in an incubator at 37˚C. After 2 hours, the stopper was removed, approximately 35 mL KCl-UO_2 ($C_2H_3O_2$) $2H_2O$ solution was added, swirled for a few seconds, and then allowed to stand until the contents had cooled to room temperature (5 minutes). The content was reduced to 50 mL by KCl-UO_2 ($C_2H_3O_2$) $2H_2O$ solution, stoppered and mixed several times. To determine NH_4^+-N in the resulting soil suspension, a 20 mL aliquot of the content was pipetted into a 100 mL distillation flask with 0.2 g of MgO left for 4 minutes. The same procedure used for urease activity was followed, but the addition of 1mL of 0.5M formamide solution after the addition of 35 ml of KCl-Ag_2SO_4 solution was used (Tabatabai and Bremner, 1972).

b. Soil microbial biomass carbon and nitrogen:

The soil microbial biomass C (SMBC) and N (SMBN) were estimated by the chloroform fumigation – extraction method (Adeboye, 2006), using moist, 2 mm sieved soil samples. A 10 g sub-sample was extracted immediately after collection with 50 ml of 0.5M K_2SO_4. A second sub sample of 10g was

immediately fumigated in an incubator using chloroform. The ethanol in the chloroform was removed by washing the chloroform with about 5 % by volume concentrated sulphuric acid (Conc. H_2SO_4) by shaking in a separating funnel. After separation with acid, the chloroform was washed with 12 rinses of distilled water (Okalebo *et al*., 2002). Water saturated filter paper was placed in the incubator to keep the soil samples moist. Five days after, the incubator was opened so as to allow the chloroform to dissipate. The soil was then removed and immediately extracted with 0.5M K_2SO_4 as done for the unfumigated sample. The extractable C and N in both fumigated and unfumigated samples was then determined. Microbial biomass C was estimated by dividing the difference in extractable C between fumigated and unfumigated samples by a conversion factor (K_n) of 2.64 (Vance *et al*., 1987). Microbial biomass N was estimated by dividing the difference in extractable N between fumigated and unfumigated sample by a conversion factor (K_n) of 1.46 (Brookes *et al*., 1985). Total C and N in extract were determined by the dichromate oxidation (Nelson and Sommers, 1982) and Kjeldahl (Bremner and Mulvaney, 1982) methods respectively.

Soil microbial biomass C and N were calculated as:

- SMB_C = (C fumigated – C unfumigated)/Kc……eqn 8

  where K_n = 2.64 (Vance *et al*., 1987) and Kc refers to the fraction of biomass C mineralized to CO_2 over a 5-day incubation period.

- SMB_N = (N fumigated – N unfumigated)/K_n……eqn 9

  where K_n = 1.46 (Brookes *et al*., 1985) and Kn refers to the fraction of microbial N mineralized at the 5-day incubation period (Tabatabai and Bremner, 1972a)

3.9 Soil Quality Determination

3.9.1. Selection of minimum data set (Indicators)

Basic soil quality indicators for a minimum data set in this study were relevant soil properties as described by Doran and Parkin (1994) obtained for the northern Guinea savanna zone of Nigeria. These properties were:

a. Physical properties: Hydraulic conductivity, Bulk density and moisture content.

b. Chemical properties: Total nitrogen and soil organic carbon content.

c. Biological properties: Urease, soil microbial biomass N and C.

3.9.2 Interpretation of indicators

The data from the laboratory analysis of the soil properties (Table 2.1 to Table 2.6) and the yield of the maize (Table 2.6) was given a score from 1 – 5 (Where: 1 = Very high, 2 = High, 3 = Moderate, 4 = Low and 5 = Very low). This was used to plot graphs of soil quality (y axis) against each indicator (x axis). The graph was used to interpret the indicators.

3.9.3 Soil Quality Index

Soil quality was expressed using the Parr *et al*. (1992) equation:

SQ = f(SP,P,E,H,ER,BD,FQ,MI)……..eqn 10

Where SQ = soil quality

SP = Soil Properties (e.g Soil quality indicators above e.g Urease, total N etc)

P = Potential productivity (Yield parameters e.g Seed weight/ha, 100 seed weight).

E = Environmental factors

H = Health / Animals

ER = Erodibility

BD = Biodiversity

FQ = Food quality

MI = Management input

However, E, H, ER, BD, FQ, and MI were scored 1.0 because the research field chosen for this experiment had been on long-term research use and is being optimally managed to satisfy the factors mentioned above (Odunze, 2013).

Hence SQ = f(SP,P)…….eqn 11.

The soil quality values were arranged in a tabular form using Equation 11 and relating it to all the treatments of the experiment, finally the soil quality values were added up and ranked. The mean of each treatment was tabulated and then ranked using Equation 11. To get the overall SQ ranking per treatment, all the ranked figures from the treatment column were added and then divided by 9 (which was the sum total of the soil properties (9) and maize yield, making a total of 10). Then conclusions and recommendations were made. This can be shown at a glance using Figure 3.1 below.

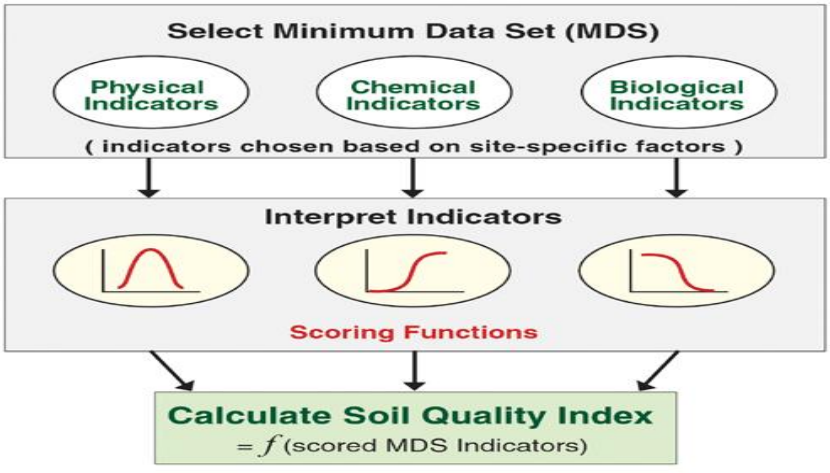


Figure 3.1. Soil quality determination

Source: (NRCS, 2014).

3.10 Statistical Analyses

The data obtained was analyzed using the standard ANOVA procedures for a Split plot design. Analysis of variance was performed using the General Linear Model Proc. of SAS (SAS, 2002); treatment means were compared using Duncan's Multiple Range Test (Duncan, 1955) at 5% level of significance ($p< 0.05$).

3.11. Correlation

The grain yield was correlated using Pearson correlation coefficients with all the soil quality indicators per soil depth (0 – 5 cm, 5 – 15cm and 15 – 25 cm). Then the grain yield was correlated with the mean of all the three soil depths across all soil properties and studied relationships between the soil quality indicators and the depths were derived.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Growth Parameters

4.1.1 Plant height

The effects of crop rotation, tillage and nitrogen rates on maize plant height are shown in Table 4.1. The result shows that crop rotation was not significant ($P > 0.05$) throughout the period of the experiment. However, tillage significantly affected plant height throughout the period of the experiment with conventional tillage giving the highest plant height from 4 weeks after sowing (WAS) to 12 WAS and the reduced tillage giving the lowest height from 4 WAS to 12 WAS. Nitrogen rate did not have a significant ($P > 0.05$) effect on plant height at 4 WAS and 6 WAS, but was significant ($P < 0.05$) on plant height from 8 WAS to 12 WAS with 90 kg N ha^{-1} having the highest height at 8 WAS, 10 WAS and 12 WAS, while 0 kg N ha^{-1} had the lowest height at 8 WAS, 10 WAS and 12 WAS. There was also no significant ($P > 0.05$) difference between the nitrogen rate of 0 kg N ha^{-1} and 30 kg N ha^{-1} at 8 WAS and 10 WAS. The interaction of the treatments on plant height was not significant throughout the period of the experiment.

The plant height was taller in the conventional tillage plots than in the reduced tillage plots because it helps in loosening and aerating the top layer of the soil, it helps destroy weed mechanically, it helps to mix crop residue, organic matter (humus), and nutrients evenly into the soil (Ray, 2013). This result collaborates with the work of Lawal (2015) who reported maize plant height in the conventional tillage to be significantly higher than in reduced or no tillage at 6 WAS in 2013 cropping season. Conventional tillage increased plant height.

Table 4.1: Effect of crop rotation, tillage and nitrogen rates on maize plant height (cm).

Treatment	Weeks after sowing				
	4	6	8	10	12
Rotation					
Maize	40.27	79.88	149.67	186.81	198.19
Cowpea	39.60	92.19	155.07	195.56	206.53
Soybean	44.30	90.28	157.57	194.48	205.04
SE±	4.18	5.00	9.70	7.49	6.62
Tillage					
Reduced	36.22^{b}	75.64^{b}	142.08^{b}	181.74^{b}	194.23^{b}
Conventional	46.57^{a}	99.26^{a}	166.13^{a}	202.68^{a}	212.28^{a}
SE±	6.28	7.51	14.55	11.23	9.93
Nitrogen rate (kg N ha^{-1})					
0	44.34	82.15	141.56^{b}	178.51^{b}	181.38^{c}
30	42.64	83.81	145.35^{b}	189.31^{b}	197.96^{b}
60	40.06	86.45	154.19^{b}	193.84^{ab}	206.58^{b}
90	38.52	87.39	175.32^{a}	207.62^{a}	227.10^{a}
SE±	4.14	3.75	7.27	5.62	4.97
Interaction					
Tillage*Rotation	NS	NS	NS	NS	NS
Tillage*N rate	NS	NS	NS	NS	NS
Rotation*N rate	NS	NS	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant.

Nitrogen fertilizer was applied at 2 WAS and 6 WAS for the first and second dose respectively, so the effect of the fertilizer was seen from 8 WAS. The result showed plant height of maize increasing as the nitrogen fertilizer rate was increasing from 30 kg N ha^{-1} to 90 kg N ha^{-1}. This shows that nitrogen contributes to forage biomass production. A steady supply is needed during the early growth stage and this steady supply can be provided by the action of soil microorganisms on the soil organic matter (SOM) or by application of inorganic fertilizers (Eche, 2011).

4.1.2 Leaf area (LA) per plant

There was no significant ($P> 0.05$) difference in leaf area due to crop rotation or nitrogen fertilizer throughout the period of the experiment (Table 4.2), However tillage was significant ($P< 0.05$) throughout the period of the experiment, with the conventional tillage giving the highest LA from 4 WAS to 12 WAS. Nitrogen rate and the interaction of the treatments to leaf area were not significant ($P> 0.05$) throughout the period of this experiment.

Conventional tillage helps to reduce competition for moisture, plant nutrients and sunlight, thereby increasing aeration and yield of the plant (Ray, 2013), hence the maize plant in conventional tillage plots grew better than those under the reduced tillage.

4.1.3 Total dry matter yield per plant (g)

The effects of crop rotation, tillage and nitrogen rates on maize dry matter yield (DMY) are shown in Table 4.3. From the table, crop rotation had no effect ($P>0.05$) on DMY at 4WAS but a significant ($P<0.05$) effect was observed from 6 WAS to 12 WAS. During these periods, maize in rotation with cowpea had the highest DMY, followed by maize in rotation with soybean, Continuous maize had the lowest DMY from 6 WAS to 12 WAS. The result also shows that there was no significant difference ($P>0.05$) between maize following cowpea and maize following soybean at 10 WAS and 12 WAS, with

Table 4.2: Effect of crop rotation, tillage and nitrogen rate on maize leaf area (cm^2).

Treatment	Weeks after sowing				
	4	6	8	10	12
Rotation					
Maize	87.65	108.75	118.67	105.88	101.73
Cowpea	88.98	107.57	117.95	105.35	101.34
Soybean	89.73	107.66	117.40	106.43	103.29
SE±	3.10	3.70	4.96	5.01	2.55
Tillage					
Reduced	85.30[b]	102.44[b]	115.00[b]	103.29[b]	101.18[b]
Conventional	92.27[a]	113.55[a]	121.01[a]	108.49[a]	103.05[a]
SE±	4.65	5.55	7.44	3.34	3.82
Nitrogen rate (kg N ha^{-1})					
0	90.01	109.84	118.38	106.83	101.46
30	88.77	108.02	113.60	103.89	100.01
60	87.46	109.92	123.10	106.67	105.07
90	88.90	104.20	116.95	106.17	101.93
SE±	2.32	2.77	3.72	2.51	1.91
Interaction					
Tillage*Rotation	NS	NS	NS	NS	NS
Tillage*N rate	NS	NS	NS	NS	NS
Rotation*N rate	NS	NS	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at $P<0.05$ level of probability. NS = Not Significant.

both being superior to continuous maize. Tillage effect was not significant (*P>0.05*) at 4 WAS but was significant from 6 WAS to 12 WAS, with conventional tillage giving the highest weight from 6 WAS to 12 WAS while the reduced tillage had the lowest DMY during this period. Nitrogen rates were significant (*P<0.05*) throughout the period of the experiment with 90 kg N ha^{-1} constantly giving higher DMY during sampling periods , 60 kg N ha^{-1} and 30 kg N ha^{-1} had no significant difference (*P>0.05*) at 8 WAS, 10 WAS and 12 WAS. Similarly, 30 kg N ha^{-1} and 0 kg N ha^{-1} were not different statistically at 8 WAS, 10 WAS and 12 WAS. The Interaction between crop rotation, tillage and Nitrogen rate was not significant (*P>0.05*) throughout the period of the experiment.

Cowpea and soybean are both legumes as compared to maize which is a cereal and they both produced higher DMY than the cereals. Studies have shown that legume - cereal rotation produce relatively higher grain yields and dry matter yield than either crop grown alone (Mpairwe *et al*., 2002 and Dapaah *et al*., 2003).

Nutrients cycling needs time to take full effect on the maize, Hence there was no significant effect on crop rotation at the first week of the experiment, however, the effect was seen from 6 WAS to the end of the experiment, hence tillage affected DMY by reducing competition for nutrient and improving aeration to the maize plant.

Table 4.3: Effect of crop rotation, tillage and nitrogen rate on maize total dry matter yield (g).

Treatment	Weeks after sowing				
	4	6	8	10	12
Rotation					
Maize	3.87	13.17^{b}	38.68^{c}	52.55^{b}	54.54^{b}
Cowpea	4.02	15.30^{a}	66.89^{a}	80.76^{a}	82.75^{a}
Soybean	4.10	14.94^{ab}	58.05^{b}	71.92^{a}	73.91^{a}
SE±	0.14	1.10	8.24	8.24	8.24
Tillage					
Reduced	3.93	13.41^{b}	37.15^{b}	51.01^{b}	53.01^{b}
Conventional	4.06	15.53^{a}	71.94^{a}	85.80^{a}	87.80^{a}
SE±	0.22	1.65	12.36	12.36	12.36
Nitrogen rate (kg Nha^{-1})					
0	1.88^{d}	7.99^{d}	29.80^{c}	43.67^{c}	45.66^{c}
30	4.09^{c}	12.38^{c}	46.41^{bc}	60.27^{bc}	62.27^{bc}
60	4.78^{b}	15.30^{b}	56.88^{b}	70.75^{b}	72.74^{b}
90	5.24^{a}	22.21^{a}	85.08^{a}	98.94^{a}	100.94^{a}
SE±	0.11	0.83	6.18	6.18	6.18
Interaction					
Tillage*Rotation	NS	NS	NS	NS	NS
Tillage*N rate	NS	NS	NS	NS	NS
Rotation*N rate	NS	NS	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant.

The current N fertilizer recommendation for the northern Guinea savanna is 120 kg N ha^{-1} for open pollinated and 150 kg N ha^{-1} for hybrid (Chude, 1996); the DMY was highest for 90 kg N ha^{-1} as compared to 0 kg N ha^{-1}, 30 kg N ha^{-1} and 60 kg N ha^{-1} because the latter did not meet the fertilizer N requirement for maize production in the northern Guinea savanna, therefore potential DMY is an important factor in determining the nitrogen need of a given crop.

4.2 Yield Parameters

4.2.1 100 Grain weight (g)

The result shows that crop rotation was not significant (*P>0.05*) on 100 grain weight but the effects of tillage and nitrogen rates were significant (Table 4.4). Conventional tillage gave higher 100 grain weight than reduced tillage. Nitrogen rate was significant (*P<0.05*) with 90 kg N ha^{-1} producing higher 100 grain weight than 60 kg N ha^{-1}, 30 kg N ha^{-1} and 0 kg Nha^{-1}. However, there was no significant difference (*P>0.05*) in 100 grain weight between 90 kg N ha^{-1}, 60 kg N ha^{-1} and 30 kg N ha^{-1}. The Interaction level was not significant (*P>0.05*) to 100 grain weight throughout the period of the experiment.

Conventional tillage helps to optimize conditions for germination, seedling establishment and crop growth and development (Majiyebo 2014), hence conventional tillage had higher 100 grain weight than the reduced tillage.

Table 4.4: Long term effect of crop rotation, tillage and nitrogen rate on 100 grain weight and grain yield of maize.

Treatment	100 grain weight (g)	grain yield (kg/ha)
Rotation		
Maize	20.62	2327[b]
Cowpea	21.16	2791[ab]
Soybean	21.73	3263[a]
SE±	0.80	931
Tillage		
Reduced	20.58[b]	2186[b]
Conventional	21.76[a]	3401[a]
SE±	1.20	1396
Nitrogen rate (kg N ha^{-1})		
0	19.60[b]	1610[b]
30	21.48[a]	2134[b]
60	21.53[a]	3564[a]
90	22.07[a]	3866[a]
SE±	0.60	698
Interaction		
Tillage*Rotation	NS	*
Tillage*N rate	NS	NS
Rotation*N rate	NS	NS
Tillage*Rotation*N rate	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant. * = Significant.

Nitrogen fertilization at 90 kg N ha^{-1} is closer to the fertilizer recommended rate of maize at 120 kg N ha^{-1} than 60 kg N ha^{-1}, 30 kg N ha^{-1} or 0 kg N ha^{-1}, hence the 90 kg N ha^{-1} rate had higher 100 grain weight than the other rates in the experiment. From the results, it is clear that N fertilization was necessary because there was a clear difference between application of fertilizer and not applying fertilizer. This collaborates with the findings of Erisman *et al.* (2005) and Freney (2005) which states that fertilizer application has by far the most important effects in terms of increasing crop production such as in maize.

4.2.2 Grain yield (kg/ha)

The effects of crop rotation, tillage and nitrogen rates on maize grain yield per hectare are shown in Table 4.4. The effects were significant ($P<0.05$) for crop rotation, tillage practices and nitrogen rate. Maize in rotation with soybean had the highest grain yield, followed by maize in rotation with cowpea, while continuous maize gave the lowest grain yield. Maize in rotation with soybean and maize in rotation with cowpea had statistically similar effect on maize grain yield, while conventional tillage had higher grain yield per hectare than reduced tillage. Nitrogen rate also had a significant ($P<0.05$) effect on maize yield with 90 kg N ha^{-1} and 60 kg N ha^{-1} resulting in higher grain yield than 30 kg N ha^{-1} and 0 kg N ha^{-1}. The effects of 90 kg N ha^{-1} and 60 kg N ha^{-1} on grain yield were not significantly different from each other, while 30 kg N ha^{-1} and 0 kg N ha^{-1} were also significantly at par in grain yield ($P>0.05$). The interaction was significant ($P<0.05$) only between crop rotation and tillage practices.

The result of crop rotation with legumes – cereals produced higher grain yield than cereal – cereal rotation, this is because studies have shown that legume-cereal rotation produce relatively higher grain yields than either crop grown alone (Dapaah *et al*., 2003 and Eche, 2011), hence soybean and cowpea giving the highest grain yield.

The conventional tillage produced higher grain yield that the reduced, this is because tillage interacts with nitrogen and phosphorus rates positively to influence higher grain yield than the average of 2.0 t/ha normally obtained by farmers field in the Guinea savanna area of Nigeria (Chude, 1996 ; Ebirere, 2013).

The result of the interaction between crop rotation and tillage on maize grain weight per hectare shows that the interaction was significant (Figure 4.1), with maize in rotation with soybean under conventional tillage having the highest grain yield, followed by continuous maize under conventional tillage which was equal to maize in rotation with cowpea under conventional tillage. Maize in rotation with cowpea under reduced tillage was equal to maize in rotation with soybean under reduced tillage, while continuous maize under reduced tillage had the lowest grain yield.

Crop rotation with legumes and cereals under conventional tillage produced higher grain yield because studies have shown that cultivation practices such as tillage and crop rotation can modify soil organic matter content, thereby influencing the nutrient content of the soil (Melero *et al*., 2009), and influencing grain yield, hence the difference in crop rotation and tillage practices.

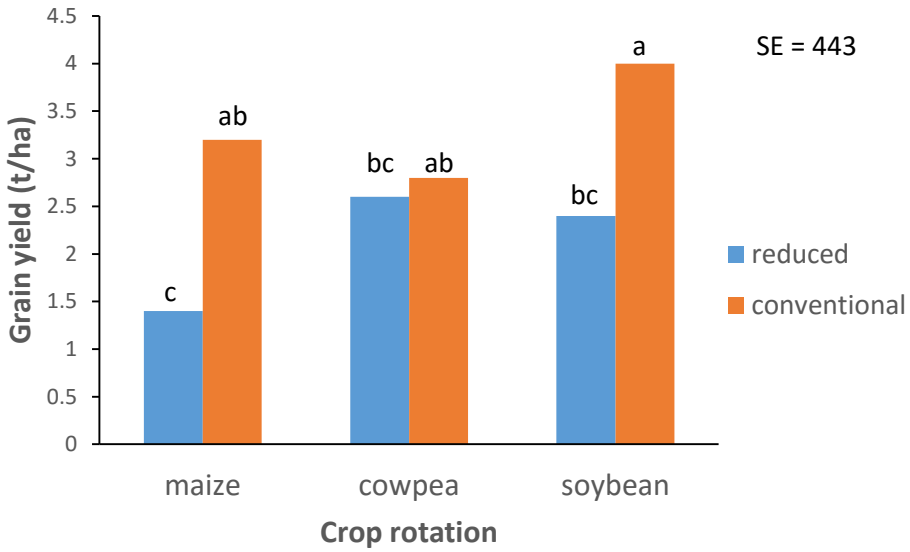


Figure 4.1: Interaction of tillage and crop rotation on maize grain yield

4.3 Soil Physical Properties

4.3.1 Effect on particle size distribution

The effects of crop rotation, tillage and N rates on particle size distribution (PSD) are shown in Table 4.5. Crop rotation had no significant (*P>0.05*) effect on PSD. However, there was a significant difference (*P<0.05*) in PSD between tillage practices. The conventional tillage had more clay and silt separates and less sand than the reduced tillage. The result also shows that there was no significant difference (*P>0.05*) between the 0 kg N ha^{-1} and 90 kg N ha^{-1} rates in terms of clay, silt and sand particles. There was also no significant interaction (*P>0.05*) between tillage type and N rate in terms of the particle size distribution. This indicates that N rate had no contribution to type of soil texture.

Conventional tillage had higher PSD than the reduced tillage. This result conforms slightly to the work of Lawal (2015) who reported that silt plus clay associated carbon was significantly higher by 9.82 % in conventional tillage plots than in reduced or no till system in the year 2013.

4.3.2 Saturated hydraulic conductivity (Ks)

The Ks was not significantly (*P>0.05*) influenced by crop rotation or nitrogen rate in all the three soil depths (0 – 5 cm, 5 – 15 cm, 15 – 25 cm), but it was significantly (*P>0.05*) affected by tillage practices (Table 4.6).

Table 4.5: Effect of tillage and n rate on soil particle size distribution at 0 – 5 cm depth

Treatment	Particle Size Distribution		
	Clay (%)	Silt (%)	Sand (g/kg)
Rotation			
Maize	2.91	15.48	652.5
Cowpea	3.39	16.42	661.4
Soybean	3.15	16.08	661.0
SE±	0.16	0.36	51.3
Tillage			
Reduced	4.44[b]	18.11[b]	771.1[a]
Conventional	5.22[a]	19.67[a]	761.1[b]
SE±	0.19	0.38	3.4
Nitrogen rate (kg Nha^{-1})			
0	6.67	19.00	76.11
90	5.00	18.78	76.11
SE±	0.19	0.38	0.34
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant.

The highest mean Ks was observed under conventional tillage across all the three soil depths and the reduced tillage had the lowest Ks across all the three soil depths. The interaction was not significant (*P>0.05*) at any of the studied soil depths. Saturated hydraulic conductivity was found to be significantly influenced by tillage with higher soil water conductivity under conventional tillage than under reduced tillage. This is because conventional tillage helps to improve water conductivity (Ahn and Hintze, 1990); also the presence of roots and plant materials after harvesting of the maize crop could also affect the Ks value (Girei, 2015), hence its influence on the conventional tillage practices.

4.3.3 Bulk density

The effects of crop rotation, tillage and nitrogen rates on maize bulk density are shown in Table 4.7. Crop rotation and N rate had no statistical difference on soil bulk density. However, tillage influenced soil bulk density, with the reduced tillage giving higher means at all soil depths than the conventional tillage. The Interactions between the various factors were not significant in all the soil depths.

Bulk density is influenced by vegetation and aggregation; high bulk density is an indication of low soil porosity and high compaction which may cause restriction of root growth and poor movement of air and water through the soil (Arshad and Lowery, 1996), In this study, high bulk density values were observed at the soil depth of 15 – 25 cm and lower bulk density values were obtained at 0 – 5 cm and 5 – 15 cm soil depths. Reduced tillage was found to give higher BD values than conventional tillage due to compaction and aggregation of the soil particles. This result corroborates with the findings of Dhiman *et al*. (2001) who reported an increase in bulk density of a soil from 1.5 Mg m^{-3} in conventional to 1.58 Mg m^{-3} in no-tillage plots. This indicates that bulk density is influenced by tillage activities, hence its significance to tillage activities and crop rotation.

Table 4.6: Long term effect of crop rotation, tillage and nitrogen rate on saturated hydraulic conductivity Ks (cm hr^{-1})

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation			
Maize	0.37	0.37	0.48
Cowpea	0.38	0.36	0.48
Soybean	0.37	0.40	0.44
SE±	0.02	0.03	0.02
Tillage			
Reduced	0.33^{b}	0.32^{b}	0.37^{b}
Conventional	0.43^{a}	0.43^{a}	0.56^{a}
SE±	0.02	0.02	0.02
Nitrogen rate (kg N ha^{-1})			
0	0.38	0.38	0.49
90	0.38	0.38	0.45
SE±	0.02	0.02	0.09
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant.

Table 4.7: Long term effect of crop rotation, tillage and nitrogen rate on bulk density (Mgm^{-3})

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation			
Maize	1.43	1.43	1.50
Cowpea	1.48	1.48	1.52
Soybean	1.46	1.46	1.51
SE±	0.02	0.02	0.02
Tillage			
Reduced	1.83[a]	1.83[a]	1.90[a]
Conventional	1.53[b]	1.54[b]	1.66[b]
SE±	0.02	0.02	0.02
Nitrogen rate (kg N ha^{-1})			
0	1.48	1.48	1.51
90	1.43	1.43	1.51
SE±	0.02	0.02	0.02
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant.

4.3.4 Moisture content

Moisture content (MC) at field capacity was not statistically affected (*P>0.05*) by crop rotation or nitrogen rate across all soil depths, but it was statistically (*P<0.05*) affected by tillage practices in all the soil depths (Table 4.8), with the reduced tillage having the higher moisture content than conventional tillage at all the soil depths. The Interactions between factors were not significant (*P>0.05*) in all the soil depths.

The presence of plant residue left on the soil surface under reduced tillage will favor more water retention in the soil than the conventional tillage. This agrees with the findings of Iwuafor *et al.* (1990) and Melero *et al.* (2009) that conservation or reduced tillage are based on the principle of mulch farming and they usually conserve soil and water simultaneously by controlling runoff.

4.4 Soil Chemical Properties

4.4.1 Total nitrogen (g kg^{-1})

The effects of crop rotation, tillage and nitrogen rates on total nitrogen (TN) are shown in Table 4.9. The result was significant (*P<0.05*) in all the soil depths. Maize in rotation with cowpea had the highest TN content at all depths while maize in rotation with soybean had the lowest. Conventional tillage has higher TN at all depths than reduced tillage. The nitrogen rate of 90 kg N ha^{-1} had the higher nitrogen content than 0 kg N ha^{-1} at 0 – 5 cm and at 5 – 15 cm, while 0 kg N ha^{-1} had the higher TN content at 15 – 25 cm depth. The interaction of the treatments to TN was significant (*P<0.05*) only at 0 – 5 cm for tillage by N rate, rotation by N rate and the interaction of rotation, tillage and N rate respectively.

Table 4.8: Long term effect of crop rotation, tillage and nitrogen rate on moisture content (cm^3/cm^3) at field capacity

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation			
Maize	0.15	0.15	0.18
Cowpea	0.18	0.19	0.17
Soybean	0.15	0.17	0.17
SE±	0.02	0.02	0.02
Tillage			
Reduced	0.23[a]	0.24[a]	0.23[a]
Conventional	0.10[b]	0.10[b]	0.12[b]
SE±	0.02	0.02	0.02
Nitrogen rate (kg N ha^{-1})			
0	0.16	0.17	0.19
90	0.17	0.17	0.16
SE±	0.02	0.02	0.02
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant.

Table 4.9: Long term effect of crop rotation, tillage and nitrogen rate on total nitrogen (g kg^{-1})

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation (R)			
Maize	0.10[b]	0.09[b]	0.09[b]
Cowpea	0.15[a]	0.15[a]	0.15[a]
Soybean	0.08[c]	0.08[b]	0.08[b]
SE±	0.004	0.01	0.01
Tillage (T)			
Reduced	0.08[b]	0.08[b]	0.09[b]
Conventional	0.14[a]	0.14[a]	0.13[a]
SE±	0.004	0.01	0.01
Nitrogen rate (kg N ha^{-1})			
0	0.03[b]	0.08[b]	0.13[a]
90	0.19[a]	0.14[a]	0.09[b]
SE±	0.004	0.01	0.01
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	*	NS	NS
Rotation*N rate	*	NS	NS
Tillage*Rotation*N rate	*	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant. * = Significant.

Legumes form a symbiotic association with the bacteria rhizobium for nodule production, there by fixing atmospheric nitrogen (Martin *et al.,* 2007). Yusuf *et al.,* (2009) stated that rotating maize with grain legumes is often targeted towards utilizing biologically fixed nitrogen by the legumes for the benefit of the maize. Hence cowpea – maize rotation and soybean – maize rotation had higher total soil N because maize responds well to soil fertility especially to high N availability.

Conventional tillage reduced competition for weed, moisture, air and soil nutrients which are important factors for improved crop production. Therefore the result on tillage correlates with Majiyebo (2014) who reported that tillage is a soil related action necessary for crop production, hence conventional tillage had higher TN than the reduced because it made use of the applied nitrogen properly than the reduced tillage.

The application of 90 kg N ha^{-1} increased total N level at 0 – 5 cm soil depth and also at 5 – 15 cm soil depth, while 0 kg N ha^{-1} had higher N rate at 15 – 25 cm. This could be due to poor root development and low N uptake at 15 – 25 cm soil depth. Also, nitrogen in the soil is the most important element for plant development. It is required in large amounts and must be added to the soil to avoid a deficiency (Veenstra *et al.,* 2006).

The result of the interaction of tillage and nitrogen rate on TN is shown in Figure 4.2. The result was significant ($P<0.05$) with the conventional tillage at 90 kg N ha^{-1} giving the highest level, followed by the reduced tillage at 90 kg N ha^{-1}, followed by conventional tillage practice at 0 kg N ha^{-1}, followed by conventional tillage at 0 kg N ha^{-1}; reduced tillage at 0 kg N ha^{-1} had the lowest TN content

Both conventional tillage and 90 kg Nha^{-1} were found to increase total soil N. Also this collaborate with the study of Sawyer (2008) who reported that if no N is applied for many years, the soils ability to supply plant available nitrogen becomes depleted, hence the necessity for N fertilization.

The effect on the interaction of crop rotation and N rate on total nitrogen at 0 – 5 cm soil depth was significant (*P<0.05*) (Figure 4.3) and maize in rotation with cowpea at 90 kg N ha^{-1} , had the highest total soil N content, followed by maize in rotation with soybean and also continuous maize both at 90 kg N ha^{-1}, while maize in rotation with cowpea, continuous maize and maize in rotation with soybean all at 0 kg N ha^{-1} had the lowest total soil N.

The application of 90 kg N ha^{-1} improved TN in addition to maize in rotation with cowpea than when compared to 0 kg N ha^{-1} N rate on continuous maize or on maize in rotation with soybean. This is because cowpea is a legume and it fixes N in the soil via biological N fixation (Martin *et al.*, 2007) more than maize and soybean. The presence of mulch, organic matter and other plant biomass on the surface and below ground level could also help in improving the total N content in the soil, though excessive application of N fertilizer reduces the soil pH, making the soil acidic (Blevins *et al.*, 1977),

The interaction of crop rotation, tillage and N rate on total nitrogen at 0 – 5 cm soil depth is shown in Figure 4.4. The result shows that crop rotation involving legume – cereal under conventional tillage at 90 kg N ha^{-1} produced the highest TN than cereal - cereal (continuous maize) rotation under conventional tillage at 90 kg N ha^{-1}, while reduces tillage irrespective of crop rotation produced the lowest TN content at 0 kg N ha^{-1}.

Tillage interacts with nitrogen and phosphorus rates positively to influence higher grain yield than the average of 2.0 t/ha normally obtained by farmers field in the guinea savanna area of Nigeria (Chude, 1996 ; Ebirere, 2013). The result also collaborates with the work of Veenstra *et al.* (2006) which showed an increased total N in both conservation and conventional (reduced) tillage system. The total N content can also be enhanced when legumes are used for crop rotation such as cowpea, hence taller bars were seen from the chart showing the importance of legume cereal rotation.

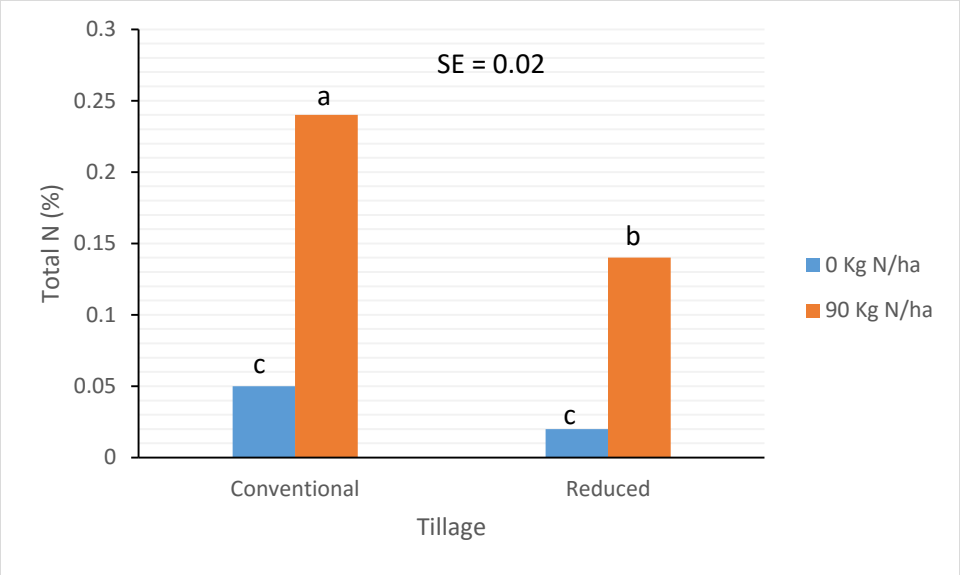


Figure 4.2: Interaction of tillage and N rate on total nitrogen (g kg^{-1}) at 0 – 5 cm soil depth

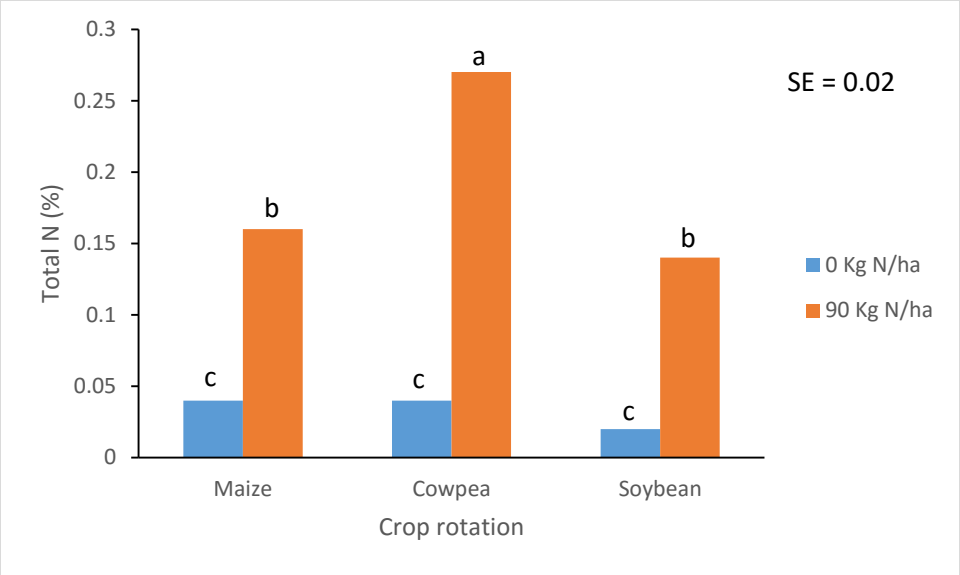


Figure 4.3: Interaction of crop rotation and N rate on total nitrogen (g kg^{-1}) at 0 – 5 cm soil depth

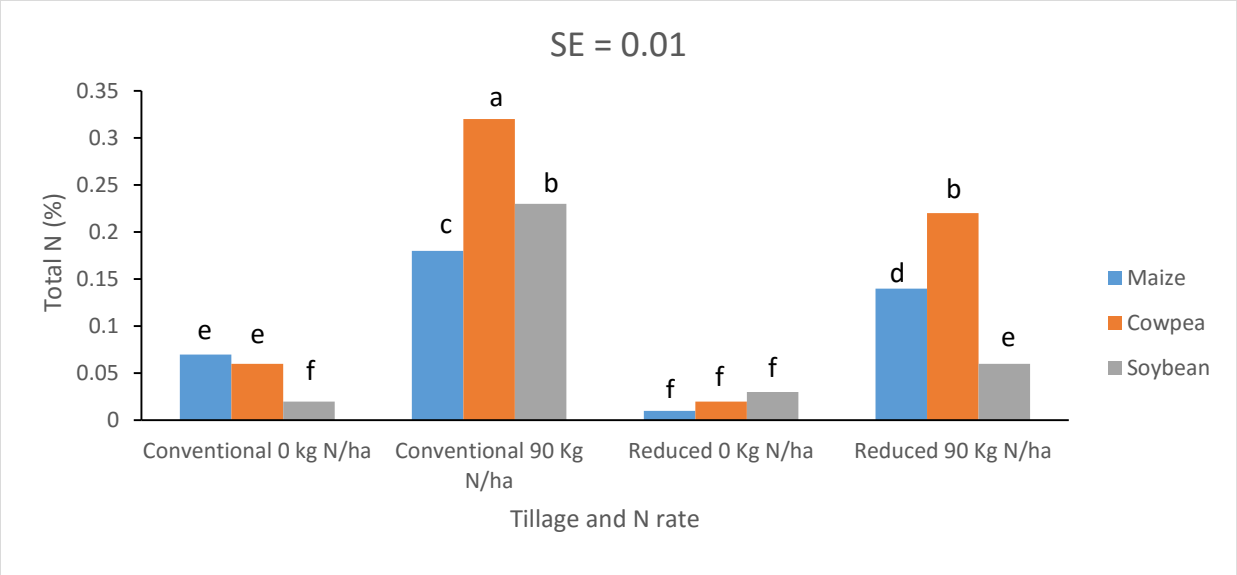


Figure 4.4 Interaction of rotation, tillage and N rate on total nitrogen (g kg^{-1}) at 0 – 5 cm soil depth

4.4.2 Soil organic carbon (g/kg)

The result on the effects of crop rotation, tillage and nitrogen rates on total soil organic carbon (SOC) are shown in Table 4.10. Tillage did not affect SOC at all the three soil depths, but crop rotation and nitrogen rate in all the soil depths affected the SOC because of the significant differences ($P<0.05$) between the means. Maize in rotation with cowpea had the highest SOC across all soil depths, while continuous maize and maize in rotation with soybean were statistically the same ($P>0.05$) across all depths. Nitrogen rate of 0 kg N ha^{-1} had the highest SOC content at all depths, while 90 kg N ha^{-1} had the lowest level across all depths. The interaction of the treatments on soil organic carbon was not significant ($P>0.05$).

From the result, as the soil depths was increasing, soil organic carbon content was also increasing, this collaborates with Veenstra *et al*. (2006) that reported an increase in SOC with increase in soil depth when using conventional tillage because the residues are incorporated and mixed into the soil. Also according to Veenstra *et at*. (2006), they reported that cover cropping and residue management increases SOC regardless of tillage practice, by adding more biomass to the system which increases carbon inputs to the soil, Therefore, cereal - legume rotation, such as cowpea in rotation with maize, yielded the best organic carbon content because cowpea produces more biomass and hence, more soil organic carbon.

From the result, tillage practices influenced SOC content as the soil depth increased. Other reports have shown that reduced or no till also increases soil organic carbon content (Majiyebo, 2014). In addition, conventional tillage operations loosen, granulate, crush or compact soil structure, changing soil properties such as bulk density, pore size distribution and the composition of the soil atmosphere that affect plant growth (Ohiri and Ezumah, 1990), hence reduced tillage having higher SOC content.

Table 4.10: Long term effect of crop rotation, tillage and nitrogen rate on soil organic carbon (g/kg)

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation			
Maize	1.25[b]	1.32[b]	1.39[b]
Cowpea	1.39[a]	1.43[a]	1.48[a]
Soybean	1.22[b]	1.30[b]	1.38[b]
SE±	0.02	0.02	0.02
Tillage			
Reduced	1.30	1.36	1.42
Conventional	1.28	1.34	1.41
SE±	0.01	0.01	0.01
Nitrogen rate (kg N ha^{-1})			
0	1.36[a]	1.42[a]	1.49[a]
90	1.21[b]	1.28[b]	1.34[b]
SE±	0.01	0.01	0.01
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at $p<0.05$ level of probability. NS = Not significant.

Nitrogen fertilization increased the total nitrogen content, thereby increasing the organic matter content associated with cover cropping and hence the increase in soil organic carbon content (Veenstra *et al.* (2006).

4.5 Soil Biological Properties

4.5.1 Urease Activity $\mu gmL^{-1}hr^{-1}$

The effects of crop rotation, tillage and nitrogen rates of maize on urease are shown in Table 4.11. Crop rotation had no significant (*P>0.05*) effect on urease activity in all the three soil depths but the effects on both tillage practices and nitrogen rate were significant (*P<0.05*). Reduced tillage had higher urease activity across all soil depths than conventional tillage. The nitrogen rate of 90 kg N ha^{-1} had higher urease activity at all depths than 0 kg N ha^{-1}. The interaction of the treatments on urease activity was not significant (*P>0.05*) in this experiment.

The urease activities were observed to decrease with increase in depth under tillage practices and N fertilization this could be as a result of rhizosphere effect which also decreases with depth due to lower root biomass and it increases in depth with soil organic matter content. This is because soil enzyme activities are potential indicators of soil quality because they play an important role in soil biology and respond rapidly to changes in soil management (Wick *et al*., 1998). They are shown to respond to agronomic practices like fertilizer, amendments, vegetation cover and conservation practices (Dick *et al*., 2000).

Urease, which originates from plants and microorganism has been shown to respond to tillage practices (Dick *et al*., 2000). Conventional tillage interrupts its activities and exposes

Table 4.11: Long term effect of crop rotation, tillage and nitrogen rate on urease (μg mL^{-1} hr^{-1})

Treatment	Depth (cm)		
	0 - 5	5 – 15	15 – 25
Rotation			
Maize	2.93	2.64	2.45
Cowpea	2.87	2.61	2.31
Soybean	2.95	2.69	2.31
SE±	0.05	0.07	0.09
Tillage			
Reduced	3.09[a]	2.82[a]	2.60[a]
Conventional	2.74[b]	2.47[b]	2.11[b]
SE±	0.04	0.06	0.07
Nitrogen rate (kg N ha^{-1})			
0	2.74[b]	2.47[b]	2.08[b]
90	3.10[a]	2.82[a]	2.62[a]
SE±	0.04	0.06	0.07
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant.

them to sunlight and aeration while the reduced tillage has a minimum disturbance to urease enzyme. Hence the significance favoring reduced tillage.

Urease is a nitrogen cycling enzyme and it is responsible for the hydrolysis of urea fertilizers applied to the soil into ammonia (NH_3) and carbondioxide with the concomitant rise in soil pH. This in turn results in a rapid N loss to the atmosphere through NH_3 volatilization (Simpson *et al.,* 1984; Simpson and Freney, 1988). Urease activity in soil is influenced by many factors, including cropping history, organic matter content, soil depth and environmental factors such as temperature. Urease activity increases with increase in temperature, therefore, higher temperatures increases the activity coefficient of this enzyme, thus it is recommended that urea fertilizer should be applied at times of the day when the temperatures are low, since urea plays a vital role in the hydrolysis of fertilizer, hence its significance to N fertilization in this experiment.

4.5.2 Soil microbial biomass carbon

The effects of crop rotation, tillage and nitrogen on soil microbial biomass carbon (SMBC) are shown in Table 4.12. The effects were significant ($P<0.05$) for crop rotation, tillage and nitrogen rate in all the three soil depths. Soybean and cowpea were statistically the same and they had the highest SMBC, while the maize had the lowest SMBC across all soil depths. Conventional tillage had the higher SMBC than the reduced tillage at all depths. The nitrogen rate of 90 kg N ha^{-1} also had higher SMBC at all depths, than 0 kg N ha^{-1}. The interaction was only significant ($P<0.05$) for tillage and rotation and not significant for others.

Table 4.12: Long term effect of crop rotation, tillage and nitrogen rate on soil microbial biomass carbon (mg C kg^{-1})

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation			
Maize	211.14[b]	301.21[b]	421.14[b]
Cowpea	462.12[a]	571.14[a]	682.12[a]
Soybean	451.01[a]	541.15[a]	641.11[a]
SE±	20.17	24.14	21.12
Tillage			
Reduced	311.17[b]	401.14[b]	491.10[b]
Conventional	434.17[a]	551.05[a]	671.11[a]
SE±	20.12	22.12	20.15
Nitrogen rate (kg N ha^{-1})			
0	306.12[b]	391.12[b]	491.14[b]
90	442.12[a]	562.18[a]	672.14[a]
SE±	20.15	20.17	21.18
Interaction			
Tillage*Rotation	*	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant. * = Significant.

Studies have shown that legumes accumulate greater amounts of SMBC in the soil than cereals (Walker *et al.*, 2003), hence its significance to crop rotation favoring cereal – legume rotation.

Tillage was found to increase SMBC, with its activity highest in the conventional plots, this is because SMBC have been shown to have highest values in cropped land and grassland, while it lowest are shown in bare cultivated soils (Walker *et al.*, 2003).

Soil microbial biomass carbon increases as the soil depth increases due to nutrient movement as a result of leaching to lower soil depth, this is because studies have shown that fertilizer application especially N could have positive effect on SMBC (Fauci and Dick, 1994), hence its effect on nutrients movement.

The result on the interaction between crop rotation and tillage on soil microbial biomass carbon is shown in Figure 4.5. The result shows that maize in rotation with soybean under conventional tillage and maize in rotation with cowpea under conventional tillage produced higher SMBC content, followed by maize in rotation with soybean and maize in rotation with cowpea both under reduced tillage, followed by continuous maize under conventional tillage. The lowest SMBC content was produced by continuous maize under reduced tillage.

Higher SMBC content could be gotten when crop rotation of maize in rotation with cowpea and maize in rotation with soybean is practiced under conventional tillage. Studies have shown the positive impact of tillage and legume rotation to SMBC (Fauci and Dick, 1994),

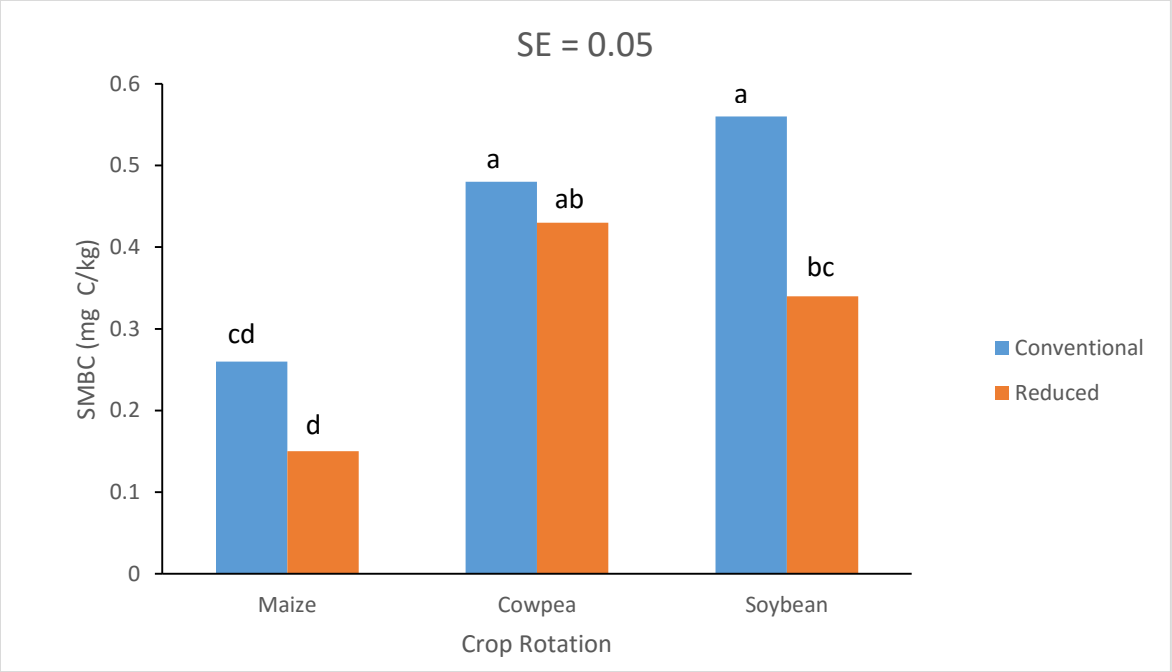


Figure 4.5: Interaction of tillage and crop rotation on soil microbial biomass carbon

4.5.3 Soil microbial biomass nitrogen (SMBN)

The result of SMBN was not significantly (*P>0.05*) affected by nitrogen across the three depths (Table 4.13); but it was significantly (*P<0.05*) affected by tillage and crop rotation across all the soil depths. Maize in rotation with cowpea or maize in rotation with soybean gave the highest SMBN, while continuous maize rotation gave the lowest SMBN across all the soil depths. Conventional tillage had higher SMBN across all the soil depths than the reduced tillage. The effects of the interaction between factors were not significant (*P> 0.05*) to this experiment.

The result shows that SMBN increases with increase in depth. This is because soil management and crop management strategies like residue management and fertilization and crop rotation have been observed to affect microbial biomass (Fauci and Dick, 1994). Therefore crop rotation with grain legumes increases SMBN and as the nutrient leaches down in to the soil, SMBN increases with increase in soil depth, hence the significance favoring crop rotation involving cereals and legumes.

The reason why conventional tillage was higher than reduced tillage could be due to aeration to enhance soil microbial activities because tillage activities enhances N assimilation, this could have affected the reduced tillage plots to have low level of SMBN and favored the conventional tillage plots, this result collaborates with the findings of Fauci and Dick (1994) that soil and crop management strategies like tillage have been observed to affect microbial biomass.

Table 4.13: Long term effect of crop rotation, tillage and nitrogen rate on soil microbial biomass nitrogen (mg N kg^{-1})

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation			
Maize	20.12[b]	34.14[b]	51.12[b]
Cowpea	30.15[a]	62.18[a]	72.11[a]
Soybean	30.14[a]	55.14[a]	73.12[ab]
SE±	2.01	3.12	4.15
Tillage			
Reduced	21.11[b]	44.16[b]	61.11[b]
Conventional	31.12[a]	54.18[a]	71.13[a]
SE±	1.14	2.55	4.14
Nitrogen rate (kg N ha^{-1})			
0	32.21	50.14	70.12
90	20.18	40.22	60.22
SE±	10.24	21.01	31.24
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant.

4.6 Soil Quality

4.6.1 Total soil quality assessment

Table 4.14 shows the mean effect and soil quality (SQ) ranking of crop rotation, tillage and nitrogen rates on soil quality indicators. The result shows that SQ = 4, which means that the soil used with respect to the indicators was a soil with low health status.

When considering the soil quality indicators, the soil is considered to be low in health. This result collaborates with the findings of Abu and Abubakar, (2013) which states that agricultural production in Nigeria is mainly on fragile soils that degrade rapidly under continuous and intensive cultivation.

4.6.2 Overall effect of crop Rotation, tillage and nitrogen rates on soil quality

Table 4.15 shows the mean values of the of soil quality indicators selected in this study as affected by crop rotation, tillage and N rates. Table 4.16 shows the ranking of the selected indicators. Continuous maize under conventional and reduced tillage at both 90 kg N ha^{-1} and 0 kg N ha^{-1} of all had soil quality ranking of 4 (SQ = 4), which means that the soil is of low quality, while maize in rotation with cowpea and maize in rotation with soybean both under conventional and reduced tillage at both 0 kg N ha^{-1} and 90 kg N ha^{-1} both had SQ = 3 which means that the soil is of medium quality,

High crop productivity of cereal – legume system can be attributed to better soil quality as observed in this study. This system can be used to enhance the productivity of savanna soils that have long been characterized to have low inherent fertility status, low organic matter, low total nitrogen and phosphorus, low water infiltration capacity, poor internal drainage due to poor structure (Abu and Abubakar, 2013). Therefore in the long term, will result in a low to medium soil quality ranks of the Nigerian savanna soils.

Table 4.14: Effect of crop rotation, tillage and nitrogen rate on total soil quality in relation to soil depth

Measured soil quality indicators	Depth (cm)			Mean	Soil quality assessment SQ=f(SP, P)
	0 – 5	5 – 15	15 – 25		
Productivity (P)					
Grain yield (t/ha)	-	-	-	2.79	3
Soil Properties (SP)					
Soil physical properties					
Saturated hydraulic conductivity (cm hr^{-1})	0.38	0.37	0.47	0.41	3
Bulk density (M gm^{-3})	1.46	1.46	1.51	1.47	3
Moisture content (vol/vol)	0.12	0.11	0.13	0.12	5
Soil chemical properties					
Total nitrogen (g/kg)	0.11	0.12	0.12	0.11	4
Organic carbon (g/kg)	1.29	1.35	1.42	1.35	3
Soil Biological properties					
Urease (μ gm L^{-1} hr^{-1})	2.92	2.64	2.35	2.64	5
Soil microbial biomass nitrogen (mg N kg^{-1})	20.02	42.04	61.02	41.04	5
Soil microbial biomass carbon (mg C kg^{-1})	371.07	471.51	581.31	474.47	2
Total					33
Rank					4

Note: Grain yield is not available at lower depths, an overall value was used.

Table 4.15: Mean values of grain yield and soil properties as influenced by crop rotation, tillage and nitrogen fertilizer

Measured soil quality indicators	Continuous maize under conv. tillage at 0 kg n ha^{-1}	Continuous maize under conv. tillage at 90 kg n ha^{-1}	Continuous maize under red. tillage at 0 kg n ha^{-1}	Continuous maize under red. tillage at 90 kg n ha^{-1}	Maize after cowpea under conv. tillage at 0 kg n ha^{-1}	Maize after cowpea under conv. tillage at 90 kg n ha^{-1}	Maize after cowpea under red. tillage at 0 kg n ha^{-1}	Maize after cowpea under red. tillage at 90 kg n ha^{-1}	Maize after soybean under conv. tillage at 0 kg n ha^{-1}	Maize after soybean under conv. tillage at 90 kg n ha^{-1}	Maize after soybean under red. tillage at 0 kg n ha^{-1}	Maize after soybean under red. tillage at 90 kg n ha^{-1}
Productivity (P)												
Grain weight (t/ha)	1.79	4.46	0.80	2.16	1.08	4.87	2.00	3.64	2.50	4.78	1.50	3.29
Soil Properties (SP)												
Physical properties												
Ksat (cm hr^{-1})	0.48	0.43	0.38	0.33	0.47	0.47	0.32	0.38	0.49	0.51	0.34	0.30
Bulk density (M gm^{-3})	1.51	1.44	1.43	1.43	1.54	1.47	1.48	1.49	1.48	1.50	1.51	1.43
MC (vol/vol)	0.11	0.11	0.12	0.12	0.10	0.11	0.13	0.12	0.11	0.11	0.12	0.12
chemical properties												
Total nitrogen (g/kg)	0.10	0.14	0.04	0.09	0.11	0.25	0.09	0.16	0.07	0.15	0.05	0.05
Organic carbon (g/kg)	1.40	1.20	1.42	1.26	1.59	1.34	1.45	1.35	1.28	1.25	1.41	1.27
Biological properties												
Urease (µg $mL^{-1}hr^{-1}$)	2.30	2.70	2.50	2.97	2.25	2.43	2.57	3.14	2.31	2.67	2.64	2.97
SMBC(mg kg^{-1})	302.30	170.17	151.15	321.32	521.52	521.73	462.43	561.46	551.55	521.02	461.46	531.23
SMBN (mg kg^{-1})	51.05	31.03	31.03	21.02	71.03	61.06	83.04	41.05	52.05	51.05	81.05	51.03

Where SQ= Soil quality, Ks = Saturated hydraulic conductivity, MC = Moisture content at field capacity, SMBC = Soil microbial biomass carbon, SMBN = Soil microbial biomass nitrogen, Red = Reduced tillage, Conv = Conventional tillage

Table 4.16: Total soil quality rating as affected by crop rotation, tillage and nitrogen fertilizer

Measured soil quality indicators	Rating according to treatment means											
	Continuous maize under conv. tillage at 0 kg n ha^{-1}	Continuous maize under conv. tillage at 90 kg n ha^{-1}	Continuous maize under red. tillage at 0 kg n ha^{-1}	Continuous maize under red. tillage at 90 kg n ha^{-1}	Maize after cowpea under conv. tillage at 0 kg n ha^{-1}	Maize after cowpea under conv. tillage at 90 kg n ha^{-1}	Maize after cowpea under red. tillage at 0 kg n ha^{-1}	Maize after cowpea under red. tillage at 90 kg n ha^{-1}	Maize after soybean under conv. tillage at 0 kg n ha^{-1}	Maize after soybean under conv. tillage at 90 kg n ha^{-1}	Maize after soybean under red. tillage at 0 kg n ha^{-1}	Maize after soybean under red. tillage at 90 kg n ha^{-1}
Productivity (P)												
Grain weight (t/ha)	4	2	5	4	2	2	4	3	3	2	4	3
Soil Properties (SP)												
Physical properties												
Ksat (cm hr^{-1})	3	3	3	3	3	3	3	3	3	3	3	3
Bulk density (Mgm^{-3})	3	3	3	3	3	3	3	3	3	3	3	3
MC (vol/vol)	5	5	5	5	5	5	5	5	5	5	5	5
chemical properties												
Total nitrogen (g/kg)	4	4	5	4	4	2	4	3	4	3	4	4
Organic carbon (g/kg)	3	3	3	3	3	3	3	3	3	3	3	3
Biological properties												
Urease (µg $mL^{-1}hr^{-1}$)	5	5	5	5	5	5	5	4	5	5	5	5
SMBC(mg Ckg^{-1})	3	4	4	2	1	1	1	1	1	1	1	1
SMBN (mg Nkg^{-1})	5	5	5	5	4	4	3	5	4	5	3	4
Total	35	33	38	34	28	28	31	30	31	30	31	31
Rank (SQ = f(P, SP)	**4**	**4**	**4**	**4**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**

Where SQ= Soil quality, Ks = Saturated hydraulic conductivity, MC = Moisture content at field capacity, SMBC = Soil microbial biomass carbon, SMBN = Soil microbial biomass nitrogen, Red = Reduced tillage, Conv = Conventional tillage.

Soil Quality key: 1 = Very high, 2 = High, 3 = Medium, 4 = Low, 5 = Very low.

4.6.3 Effect of continuous maize cultivation, tillage and nitrogen rate on soil quality in relation to soil depth

Table 4.17 shows the mean value of the selected soil quality indicators in each soil depth, including grain yield as influenced by continuous maize cultivation, tillage and nitrogen fertilizer. The ranking of these values to determine the actual soil quality is presented in Table 4.18. The result shows that soil quality was low (SQ = 4) across all sampling depths irrespective of the treatments. Although the rating of grain yield was higher with the application of 90 kg N ha^{-1} under conventional tillage, the yield did not influence the overall soil quality rating due to lack of commensurate improvement in the soil quality indicators, this suggest that the high yield was not due to improvement in soil properties, instead intensive maize cultivation may lead to decline in soil quality over a long period of time.

Maize is a cereal crop and it requires plant nutrients especially N in a very large quantity of 120 kg N ha^{-1} (Chude, 1996) while excessive application of N fertilizer may cause soil acidity (Ebirere, 2013). Therefore this describes the result of the soil quality being equal to 4 which means it is low. In this study, only 90 kg N ha^{-1} was applied, this affected the final ranking as maize productivity was low, coupled with poor fertility status of these soils.

4.6.4 Effect of maize – cowpea rotation, tillage and nitrogen rates on soil quality in relation to soil depth

Table 4.19 shows the mean value of the selected soil quality indicators in each soil depth including grain yield as influenced by maize in rotation with cowpea cultivation, tillage and nitrogen fertilizer. The ranking of these values to determine the actual soil quality is presented in Table 4.20. The result shows that soil quality was low (SQ = 4) at all nitrogen fertilizer levels of 0 kg N ha^{-1}, irrespective of tillage practices across all sampling depths. At 90 kg N ha^{-1}, soil quality was medium (SQ = 3) irrespective of tillage practices. Although the rating of grain yield was very high at 90 kg N ha^{-1} irrespective of tillage practices. It did not single handedly influence the overall soil quality rating to medium, improvement in the soil

quality indicators contributed too, this suggest cereal legume rotation with addition of 90 kg N ha^{-1} contributed to high yield and improvement in the soil quality rating to medium.

The result on SQ = 3 at 90 kg N ha^{-1} shows that crop rotation with legume with fertilizer N application improves the soil quality of an area over a long period of time. This agrees with the findings of Yusuf *et al*. (2007) that reported maize grown in rotation with cowpea or soybean had significantly higher grain and stover yields than continuous maize. Also, it was reported by Yusuf *et al*., (2009) that rotating maize with grain legumes is often targeted towards utilizing biologically fixed nitrogen by the legumes for the benefit of the maize.

4.6.5 Effect of maize in rotation with soybean cultivation, tillage and nitrogen rates on soil quality in relation to soil depth

Table 4.21 shows the mean value of the selected soil quality indicators with respect to the three soil depths including grain yield as influenced by maize in rotation with soybean cultivation, tillage and nitrogen fertilizer. The ranking of these values to determine the actual soil quality is presented in Table 4.22. The result shows that soil quality was low (SQ = 4) at 0 kg N ha^{-1} in conventional tillage (0 – 5 cm depth) and reduced tillage (5 – 15 cm and 15 – 25 cm). Reduced tillage at 90 kg N ha^{-1} and 15 – 25 cm depth also had SQ ratings of 4. All the other plots had SQ ratings of 3. The rating of grain yield was high at 90 kg N ha^{-1} irrespective of tillage practices. The grain yield did not single handedly influence the overall soil quality rating to medium, improvement in the soil quality indicators contributed too, this shows the importance of cereal - legume rotation with addition of 90 kg N ha^{-1} contributed to high yield and improvement in the soil quality rating to medium.

Recent studies have shown that biologically fixed-N from cowpea or soybean is not enough to meet all the N demand of subsequent maize crop, supplementary fertilizer N is necessary for optimum maize yield

Table 4.17 Mean values of grain yield and soil properties at varying soil depths as influenced by continuous maize cultivation, tillage and nitrogen fertilizer.

Measured soil quality indicators												
Treatment	Continuous maize under conv. tillage at 0 kg n ha^{-1}			Continuous maize under conv. tillage at 90 kg n ha^{-1}			Continuous maize under red. tillage at 0 kg n ha^{-1}			Continuous maize under red. tillage at 90 kg n ha^{-1}		
Depth	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25 cm	0 – 5 cm	5 – 15 cm	15 – 25 cm	0 – 5 cm	5 – 15 cm	15 – 25cm
Productivity (P)												
Grain weight (t/ha)	1.79	1.79	1.79	4.46	4.46	4.46	0.80	0.80	0.80	2.16	2.16	2.16
Soil Properties (SP)												
Physical properties												
Ksat (cm hr^{-1})	0.42	0.42	0.60	0.37	0.37	0.55	0.36	0.36	0.41	0.31	0.31	0.37
Bulk density (Mgm^{-3})	1.49	1.49	1.53	1.42	1.42	1.49	1.42	1.42	1.45	1.38	1.38	1.53
MC (vol/vol)	0.11	0.11	0.13	0.16	0.10	0.11	0.12	0.12	0.13	0.12	0.14	0.12
chemical properties												
Total nitrogen (g/kg)	0.07	0.12	0.13	0.18	0.12	0.10	0.01	0.04	0.08	0.14	0.09	0.06
Organic carbon (g/kg)	1.35	1.41	1.47	0.16	1.19	1.24	1.35	1.41	1.49	0.16	1.27	1.36
Biological properties												
Urease (µg $mL^{-1}hr^{-1}$)	2.59	2.34	1.97	2.95	2.64	2.52	2.78	2.41	2.32	3.38	3.17	2.98
SMBC(mg kg^{-1})	154.32	281.28	461.41	271.21	270.57	357.47	89.03	89.12	250.22	23.21	31.11	41.21
SMBN (mg kg^{-1})	32.32	52.05	61.36	22.02	31.05	35.05	13.41	20.13	40.02	10.01	1011	51.03

Where SQ= Soil quality, Ks = Saturated hydraulic conductivity, MC = Moisture content at field capacity, SMBC = Soil microbial biomass carbon, SMBN = Soil microbial biomass nitrogen, Red = Reduced tillage, Conv = Conventional tillage.

Note: grain yield is not available at lower depths, an overall value was used per treatment.

Table 4.18: Soil quality rating at varying depths as affected by continuous maize cultivation, tillage and nitrogen fertilizer

Measured soil quality indicators	Rating according to treatment means											
Treatment	Continuous maize under conv. tillage at 0 kg n ha^{-1}			Continuous maize under conv. tillage at 90 kg n ha^{-1}			Continuous maize under red. tillage at 0 kg n ha^{-1}			Continuous maize under red. tillage at 90 kg n ha^{-1}		
Depth	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm
Productivity (P)												
Grain weight (t/ha)	4	4	4	2	2	2	5	5	5	4	4	4
Soil Properties (SP)												
Physical properties												
Ksat (cm hr^{-1})	3	3	3	3	3	3	3	3	3	3	3	3
Bulk density (Mgm^{-3})	3	3	3	3	3	3	3	3	3	3	3	5
MC (vol/vol)	5	5	5	5	5	5	5	5	5	5	5	5
chemical properties												
Total nitrogen (g/kg)	4	4	4	3	4	4	4	5	4	4	4	4
Organic carbon (g/kg)	4	4	4	5	4	4	4	4	4	5	4	4
Biological properties												
Urease (μg $mL^{-1}hr^{-1}$)	5	5	5	5	5	5	5	5	5	4	4	5
SMBC(mg kg^{-1})	4	3	1	3	3	2	5	5	3	5	5	5
SMBN (mg kg^{-1})	5	5	4	5	5	5	5	5	5	5	5	5
Total	37	36	33	34	34	33	38	40	37	38	37	40
Rank (SQ = f(P, SP)	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**

Where SQ= Soil quality, Ks = Saturated hydraulic conductivity, MC = Moisture content at field capacity, SMBC = Soil microbial biomass carbon, SMBN = Soil microbial biomass nitrogen, Red = Reduced tillage, Conv = Conventional tillage.

Soil Quality key: 1 = Very high, 2 = High, 3 = Medium, 4 = Low, 5 = Very low.

Note: grain yield is not available at lower depths, an overall value was used per treatment.

Table 4.19 Mean values of grain yield and soil properties at varying soil depths as influenced by maize after cowpea cultivation, tillage and nitrogen fertilizer.

Measured soil quality indicators												
Treatment	Maize after cowpea under conv. tillage at 0 kg n ha^{-1}			Maize after cowpea under conv. tillage at 90 kg n ha^{-1}			Maize after cowpea under red. tillage at 0 kg n ha^{-1}			Maize after cowpea under red. tillage at 90 kg n ha^{-1}		
Depth	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm
Productivity (P)												
Grain weight (t/ha)	1.08	1.08	1.08	4.87	4.87	4.87	2.00	2.00	2.00	3.64	3.64	3.64
Soil Properties (SP)												
Physical properties												
Ksat (cm hr^{-1})	0.42	0.42	0.57	0.43	0.43	0.54	0.33	0.23	0.39	0.35	0.35	0.43
Bulk density (Mgm^{-3})	1.53	1.53	1.56	1.45	1.45	0.49	1.48	1.47	0.50	1.46	1.49	0.52
MC (vol/vol)	0.16	0.11	0.13	0.11	0.11	0.14	0.13	0.13	0.13	0.13	0.13	0.11
chemical properties												
Total nitrogen (g/kg)	0.06	0.11	0.16	0.32	0.24	0.19	0.02	0.0	0.16	0.23	0.17	0.09
Organic carbon (g/kg)	1.54	1.59	1.65	1.30	1.35	1.39	1.41	1.44	1.51	1.30	1.34	1.39
Biological properties												
Urease (µg $mL^{-1}hr^{-1}$)	2.56	2.35	1.83	2.66	2.42	2.19	2.84	2.57	2.32	3.43	3.09	2.89
SMBC(mg kg^{-1})	431.23	531.53	503.60	531.04	521.75	541.91	381.58	461.16	521.54	482.43	551.05	543.16
SMBN (mg kg^{-1})	52.05	74.03	63.10	41.104	63.06	71.07	26.02	41.04	62.03	21.02	51.08	51.05

Where SQ= Soil quality, Ks = Saturated hydraulic conductivity, MC = Moisture content at field capacity, SMBC = Soil microbial biomass carbon, SMBN = Soil microbial biomass nitrogen, Red = Reduced tillage, Conv = Conventional tillage.

Note: grain yield is not available at lower depths, an overall value was used per treatment.

Table 4.20 Soil quality rating at varying depths as affected by maize in rotation with cowpea cultivation, tillage and nitrogen fertilizer

Measured soil quality indicators	Rating according to treatment means											
Treatment	Maize after cowpea under conv. tillage at 0 kg n ha^{-1}			Maize after cowpea under conv. tillage at 90 kg n ha^{-1}			Maize after cowpea under red. tillage at 0 kg n ha^{-1}			Maize after cowpea under red. tillage at 90 kg n ha^{-1}		
Depth	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm
Productivity (P)												
Grain weight (t/ha)	4	4	4	1	1	1	4	4	4	2	2	2
Soil Properties (SP)												
Physical properties												
Ksat (cm hr^{-1})	3	3	3	3	3	3	3	3	3	3	3	3
Bulk density (Mgm^{-3})	3	3	3	3	3	3	3	3	5	3	3	5
MC (vol/vol)	5	5	5	5	5	5	5	5	5	5	5	5
chemical properties												
Total nitrogen (g/kg)	4	4	3	2	3	3	5	4	3	3	3	4
Organic carbon (g/kg)	4	4	4	4	4	4	4	4	4	4	4	4
Biological properties												
Urease (µg $mL^{-1}hr^{-1}$)	5	5	5	5	5	5	5	5	5	4	4	5
SMBC(mg kg^{-1})	1	1	1	1	1	2	1	1	1	1	1	1
SMBN (mg kg^{-1})	4	4	4	5	4	4	5	5	4	5	5	4
Total	33	33	32	30	30	30	35	34	34	31	31	34
Rank (SQ = f(P, SP)	**4**	**4**	**4**	**3**	**3**	**3**	**4**	**4**	**4**	**3**	**3**	**4**

Where SQ= Soil quality, Ks = Saturated hydraulic conductivity, MC = Moisture content at field capacity, SMBC = Soil microbial biomass carbon, SMBN = Soil microbial biomass nitrogen, Red = Reduced tillage, Conv = Conventional tillage

Soil Quality key: 1 = Very high, 2 = High, 3 = Medium, 4 = Low, 5 = Very low.

Note: grain yield is not available at lower depths, an overall value was used per treatment.

Table 4.21 Mean values of grain yield and soil properties at varying soil depths as influenced by maize after soybean cultivation, tillage and nitrogen fertilizer.

Measured soil quality indicators												
Treatment	Maize after soybean under conv. tillage at 0 kg n ha^{-1}			Maize after soybean under conv. tillage at 90 kg n ha^{-1}			Maize after soybean under red. tillage at 0 kg n ha^{-1}			Maize after soybean under red. tillage at 90 kg n ha^{-1}		
Depth	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm
Productivity (P)												
Grain weight (t/ha)	2.50	2.50	2.50	4.78	4.78	4.78	4.50	1.50	1.50	3.29	3.29	3.29
Soil Properties (SP)												
Physical properties												
Ksat (cm hr^{-1})	0.43	0.45	0.57	0.48	0.49	0.56	0.32	0.32	0.39	0.32	0.32	0.24
Bulk density (Mgm^{-3})	1.45	1.46	1.53	1.48	1.48	1.54	1.53	1.53	0.49	1.39	1.39	0.47
MC vol/vol)	0.14	0.11	0.12	0.11	0.16	0.11	0.12	0.12	0.14	0.12	0.12	0.13
chemical properties												
Total nitrogen (g/kg)	0.0	0.07	0.14	0.23	0.17	0.06	0.03	0.05	0.09	0.06	0.04	0.03
Organic carbon (g/kg)	1.19	1.28	1.36	1.16	1.24	1.36	1.35	1.41	1.46	1.21	1.27	1.33
Biological properties												
Urease (µg $mL^{-1}hr^{-1}$)	2.72	2.46	1.76	2.99	2.62	2.41	2.93	2.67	2.31	3.17	2.99	2.75
SMBC(mg kg^{-1})	481.48	531.53	521.13	512.64	531.71	541.83	448.75	441.05	472.47	421.42	531.15	531.63
SMBN (mg kg^{-1})	61.03	51.05	82.01	31.03	51.05	61.06	82.03	51.05	71.07	82.02	85.02	52.05

Where SQ= Soil quality, Ks = Saturated hydraulic conductivity, MC = Moisture content at field capacity, SMBC = Soil microbial biomass carbon, SMBN = Soil microbial biomass nitrogen, Red = Reduced tillage, Conv = Conventional tillage.

Note: grain yield is not available at lower depths, an overall value was used per treatment.

Table 4.22: Soil quality rating at varying depths as affected by maize in rotation with soybean cultivation, tillage and nitrogen fertilizer

Measured soil quality indicators	Rating according to treatment means											
Treatment	Maize after soybean under conv. tillage at 0 kg n ha^{-1}			Maize after soybean under conv. tillage at 90 kg n ha^{-1}			Maize after soybean under red. tillage at 0 kg n ha^{-1}			Maize after soybean under red. tillage at 90 kg n ha^{-1}		
Depth	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm	0 – 5 cm	5 – 15 cm	15 – 25cm
Productivity (P)												
Grain weight (t/ha)	3	3	3	2	2	2	2	4	4	3	3	3
Soil Properties (SP)												
Physical properties												
Ksat (cm hr^{-1})	3	3	3	3	3	3	3	3	3	3	3	3
Bulk density (gcm^{-1})	3	3	3	3	3	3	3	3	5	3	3	5
MC (vol/vol)	5	5	5	5	5	5	5	5	5	5	5	5
chemical properties												
Total nitrogen (g/kg)	5	4	4	3	3	4	5	4	4	4	5	5
Organic carbon (g/kg)	4	4	4	4	4	4	4	4	4	4	4	4
Biological properties												
Urease (µg $mL^{-1}hr^{-1}$)	5	5	5	5	5	5	5	5	5	4	5	5
SMBC(mg kg^{-1})	1	1	1	1	1	1	1	1	1	1	1	5
SMBN (mg kg^{-1})	4	4	3	5	5	4	3	4	4	3	3	4
Total	34	28	31	31	30	30	31	36	35	31	31	35
Rank (SQ = f(P, SP)	**4**	**3**	**3**	**3**	**3**	**3**	**3**	**4**	**4**	**3**	**3**	**4**

Where SQ= Soil quality, Ks = Saturated hydraulic conductivity, MC = Moisture content at field capacity, SMBC = Soil microbial biomass carbon, SMBN = Soil microbial biomass nitrogen, Red = Reduced tillage, Conv = Conventional tillage.

Soil Quality key: 1 = Very high, 2 = High, 3 = Medium, 4 = Low, 5 = Very low.

Note: grain yield is not available at lower depths, an overall value was used per treatment.

under crop rotation, though the quantity required is lower than under continuous maize cultivation (Yusuf *et al*., 2009). It was also reported by Yusuf *et al*. (2007) that maize grain yield was significantly higher with the application of 90 kg N ha^{-1} than with 0 kg N/ha and 30 kg N ha^{-1}. Hence the improvement in soil quality to medium at the plots where 90 kg N/ha was applied.

Savanna soils that have long been characterized to have low inherent fertility status, low organic matter, low total nitrogen and phosphorus, low water infiltration capacity, poor internal drainage due to poor structure (Abu and Abubakar, 2013). This collaborates with the result in this study that shows low soil quality (SQ = 4) at 0 kg N/ha.

4.7 Correlation of Crop Rotation, Tillage and Nitrogen Rate on Soil Quality

Correlation effect was carried between grain yield and soil quality indicators by each depth. Correlation was also carried out between the mean depths of the soil quality indicators and grain yield as follows:

4.7.1 Correlation of grain yield and soil properties at 0 – 5 cm soil depth

Table 4.23 shows the correlation matrix of soil properties and grain yield at 0 – 5 cm soil depth. Grain yield was weakly negatively correlated with bulk density, moisture content and organic carbon. It was also weakly positively correlated to hydraulic conductivity, urease and soil microbial biomass N. Grain yield was highly positively correlated to total N and soil microbial biomass carbon. Ks was weakly negatively correlated to moisture content (MC) and urease activity but weakly positively correlated to other soil properties. Bulk density (BD) was weakly negatively correlated to moisture MC, total nitrogen (TN) and urease activity but weakly positively correlated to other soil properties. Moisture content was weakly negatively correlated to saturated hydraulic conductivity (KS), BD TN,

soil microbial biomass nitrogen (SMBN) and soil microbial biomass carbon (SMBC) but weakly positively correlated to other soil properties. Total nitrogen was weakly negatively correlated to MC, organic carbon (OC) and urease activity but weakly positively correlated to other soil properties. Organic carbon was weakly negatively correlated to TN, SMBC and urease activity but weakly positively correlated to other soil properties. Urease activity was weakly negatively correlated to KS, BD OC and SMBN but weakly positively correlated to other soil properties. Soil microbial biomass N was weakly negatively correlated to MC and urease activity but weakly positively correlated to other soil properties. Soil microbial biomass C was weakly negatively correlated to OC and MC but weakly positively correlated to other soil properties.

Saturated hydraulic conductivity is influenced by total porosity of the soil, which in turn is affected by the bulk density and available water content and other factors (Abdulkardir, 2006) hence its weakly positively correlated to grain yield.

Nitrogen is the most limiting element for plat development, it is required in large amounts and must be added to avoid its deficiency (Sawyer 2008). Soil microbial biomass makes up 1 – 4% of the total soil organic carbon (Wardle, 1992). It has its highest values in crop land and grass lands and lowest in bare cultivated land (Walker at al., 2003)

Table 4.23: Correlation Matrix of grain yield and soil properties at 0 – 5 cm soil depth of the study soils

	Grain yield	Saturated hydraulic conductivity	Bulk density	Moisture content	Total N	Organic C	Urease activity	Soil microbial biomass N	Soil microbial biomass C
Grain yield	1.00								
Hydraulic conductivity	0.23	1.00							
Bulk density	-0.28	0.00	1.00						
Moisture content	-0.11	-0.45	-0.18	1.00					
Total N	0.70	0.23	-0.05	-0.23	1.00				
Organic C	-0.43	0.14	0.28	0.03	-0.30	1.00			
Urease activity	0.22	-0.38	-0.31	0.39	0.24	-0.37	1.00		
Soil microbial biomass N	0.12	0.34	0.14	-0.34	0.03	0.25	-0.49	1.00	
Soil microbial biomass C	0.64	0.30	0.11	-0.10	0.51	-0.24	0.11	0.42	1.00

4.7.2 Correlation of grain yield and soil properties at 5 – 15 cm soil depth

The Table 4.24 shows the correlation matrix of soil properties and grain yield at 5 – 15 cm soil depth. Grain yield was weakly negatively correlated with bulk density, moisture content and organic carbon. It was also weakly positively correlated to hydraulic conductivity, urease and soil microbial biomass N. Grain yield was highly positively correlated to total N and soil microbial biomass carbon. The correlation of Ks was weakly negatively correlated to MC, OC and urease activity but weakly positively correlated to other soil properties. Bulk density was weakly negatively correlated to MC and Urease activity but weakly positively correlated to other soil properties. Moisture content was weakly negatively correlated to KS, BD TN, SMBN and SMBC but weakly positively correlated to other soil properties. Total nitrogen was weakly negatively correlated to MC, OC and urease but weakly positively correlated to other soil properties. Organic carbon was weakly negatively correlated to KS, TN and urease activity but weakly positively correlated to other soil properties. Urease activity was weakly negatively correlated to KS, BD OC and SMBN but weakly positively correlated to other soil properties. Soil microbial biomass N was weakly negatively correlated to MC and urease activity but weakly positively correlated to other soil properties. Soil microbial biomass C was weakly negatively correlated to OC and MC but weakly positively correlated to other soil properties.

Table 4.24: Correlation Matrix of grain yield and soil properties at 5 – 15 cm soil depth of the study soils

	Grain yield	Saturated hydraulic conductivity	Bulk density	Moisture content	Total N	Organic C	Urease activity	Soil microbial biomass N	Soil microbial biomass C
Grain yield	1.00								
Hydraulic conductivity	0.18	1.00							
Bulk density	-0.28	0.05	1.00						
Moisture content	-0.10	-0.63	-0.20	1.00					
Total N	0.58	0.34	0.07	-0.29	1.00				
Organic C	-0.52	-0.06	0.28	0.10	-0.13	1.00			
Urease activity	0.16	-0.28	-0.21	0.30	-0.07	-0.30	1.00		
Soil microbial biomass N	0.04	0.32	0.34	-0.32	0.36	0.32	-0.39	1.00	
Soil microbial biomass C	0.66	0.35	0.03	-0.27	0.63	-0.25	0.10	0.49	1.00

Studies have shown that fertilizer application especially N could have positive effect on SMBC (Fauci and Dick, 1994), increasing as the soil depth increases due to nutrient movement as a result of leaching to lower soil depth. Hence its correlation to grain yield. Nitrogen in the soil is the most important element for plant development. It is required in large amounts and must be added to the soil to avoid a deficiency (Veenstra *et al.,* 2006), hence the N application increased total N level at 5 – 15cm soil depth.

4.7.3 Correlation of grain yield and soil properties at 15 – 25 cm soil depth

Table 4.25 shows the correlation matrix of soil properties and grain yield at 15 – 25 cm soil depth. Grain yield was weakly negatively correlated with bulk density, moisture content, total nitrogen, organic carbon and soil microbial biomass N. It was also weakly positively correlated to hydraulic conductivity and urease. Grain yield was highly positively correlated soil microbial biomass carbon. Saturated hydraulic conductivity was weakly negatively correlated to MC and urease activity but weakly positively correlated to other soil properties. Bulk density was weakly negatively correlated to KS, MC, OC and urease activity but weakly positively correlated to other soil properties. Moisture content was weakly negatively correlated to KS, BD TN and SMBC but weakly positively correlated to other soil properties. Total N was weakly negatively correlated to MC and urease but weakly positively correlated to other soil properties. Organic C was weakly negatively correlated to BD, urease and SMBC but weakly positively correlated to other soil properties. Urease activity was weakly positively correlated to MC but weakly negatively correlated to other soil properties. Soil microbial biomass N was weakly negatively correlated to urease but weakly positively correlated to other soil properties. Soil microbial biomass C was weakly negatively correlated to OC, MC and urease activity but weakly positively correlated to other soil properties.

Table 4.25: Correlation Matrix of grain yield and soil properties at 15 – 25 cm soil depth of the study soils

	Grain yield	Saturated hydraulic conductivity	Bulk density	Moisture content	Total N	Organic C	Urease activity	Soil microbial biomass N	Soil microbial biomass C
Grain yield	1.00								
Hydraulic conductivity	0.08	1.00							
Bulk density	-0.19	0.21	1.00						
Moisture content	-0.33	-0.39	-0.26	1.00					
Total N	-0.12	0.41	0.24	-0.14	1.00				
Organic C	-0.49	0.19	-0.11	0.24	0.29	1.00			
Urease activity	0.12	-0.53	-0.05	0.06	-0.56	-0.35	1.00		
Soil microbial biomass N	-0.06	0.30	0.05	0.00	0.43	0.25	-0.50	1.00	
Soil microbial biomass C	0.65	0.24	0.03	-0.35	0.26	-0.20	-0.02	0.30	1.00

Soil microbial biomass carbon shows the highest values in crop land and grassland and lowest in bare cultivated soils (Walker *et al.,* 2003). Hence its effect on grain yield. Studies have shown that fertilizer application especially N could have positive effect on SMBC (Fauci and Dick, 1994), increasing as the soil depth increases due to nutrient movement as a result of leaching to lower soil depth.

4.7.4 Correlation of grain yield and mean soil depth of soil properties

The Table 4.26 shows the correlation matrix of mean soil depth of soil properties and grain yield. Grain yield was weakly negatively correlated with hydraulic conductivity, bulk density and moisture content. It was strongly negatively correlated to soil organic carbon. It was also weakly positively correlated to, total N, urease activity, soil microbial biomass N and soil microbial biomass C. the correlation of Ks was weakly negatively correlated to BD,MC, OC and urease but weakly positively correlated to other soil properties except at SMBN which was strongly positively correlated. Bulk density was weakly negatively correlated to KS, MC, TN and urease activity but weakly positively correlated to other soil properties except SMBN which was strongly positively correlated. Moisture content was weakly negatively correlated to KS, BD TN, SMBN and SMBC but weakly positively correlated to other soil properties. Total N was weakly negatively correlated to BD, MC, OC, urease activity, SMBC but weakly positively correlated to other soil properties. OC was weakly negatively correlated to KS, TN, urease, SMBN and SMBC but was weakly positively correlated to other soil properties. Urease activity was weakly negatively correlated to KS, BD, TN, OC, SMBN and SMBC but it was weakly positively correlated to other soil properties. SMBN was weakly negatively correlated to MC, OC and urease but weakly positively correlated to other soil properties. Soil microbial biomass C was weakly negatively correlated to MC, TN, OC and urease activity but weakly positively correlated to other soil properties.

The result showed that there is a relationship between SMBN, SMBC and urease activity. This is because urease is a nitrogen cycling enzyme and is responsible for the hydrolysis of urea fertilizers applied to the soil into ammonia (NH_3) and carbon dioxide with the concomitant rise in soil pH. This, in turn, results in a rapid N loss to the atmosphere through NH_3 volatilization (Simpson *et al.,* 1984; Simpson and Freney, 1988), while SMBN and SMBC are soil microorganisms that are related to increase in soil fertility. The soil microorganisms produce a variety of proteases capable of mineralizing organic N (Moore *et al*., 2000; Walker, *et al.*, 2003). Soil microbial biomass nitrogen make up about 5 % of the total soil N while SMBC make up 1 – 4 % of the total soil organic carbon (Insam *et al.*, 1991), therefore TN, OC, SMBN and SMBC increases soil fertility as they increase, while urease decreases soil fertility as it increases, therefore, their presence will affect grain yield of maize.

Table 4.26: Correlation Matrix of grain yield and mean soil properties of the study soils

	Grain yield	Saturated hydraulic conductivity	Bulk density	Moisture content	Total N	Organic C	Urease activity	Soil microbial biomass N	Soil microbial biomass C
Grain yield	1.00								
Hydraulic conductivity	-0.29	1.00							
Bulk density	-0.10	-0.21	1.00						
Moisture content	-0.12	-0.70	-0.06	1.00					
Total N	0.62	0.45	-0.25	-0.39	1.00				
Organic C	-0.66	-0.16	0.03	0.17	-0.16	1.00			
Urease activity	0.16	-0.43	-0.08	0.36	-0.07	-0.48	1.00		
Soil microbial biomass N	0.26	0.92	0.19	-0.69	0.34	-0.14	-0.46	1.00	
Soil microbial biomass C	0.06	0.28	0.87	-0.31	-0.05	-0.04	-0.29	0.64	1.00

CHAPTER FIVE

5.0 SUMMARY AND CONCLUSION

5.1 Summary

Soil fertility enhancement techniques are needed for sustainable crop production in the northern Guinea savanna zone of Nigeria because the soils are low in soil fertility status. This study was, therefore, conducted in a long term field experiment to study soil quality (soil health) on crop rotation (Maize following maize, maize following cowpea and maize following soybean), tillage practices (Conventional tillage and reduced tillage and N fertilization (0 kg N ha^{-1}, 30 kg N ha^{-1}, 60 kg N ha^{-1} and 90 kg N ha^{-1}). Maize was sown in 2013 raining season across all treatments in a split plot design with three replications and the effect was monitored using growth parameters, yield parameters, laboratory soil and plant analysis. The means were analyzed using the SAS system for windows and soil quality was calculated using the procedure of Parr *et al*. (1992).

The result of grain yield per hectare was significantly affected by crop rotation, tillage practices and N rates. Maize in rotation with soybean had the highest grain yield under conventional tillage at 90 kg N ha^{-1}. Soil particle size distribution was significantly affected by tillage practices, with the conventional tillage having the highest clay and silt content than under reduced tillage practice. Hydraulic conductivity was significantly affected by tillage practices on all the three depths, with the conventional tillage having the highest Ks value. Bulk density was significantly affected by tillage practices in all the soil depths, with the reduced tillage practice giving the highest mean. Moisture content was significantly affected by tillage practices on all the depths, with the reduced tillage having the highest mean. Total N was significantly affected by crop rotation, tillage practices and nitrogen rate in all the soil depths studied. Organic carbon was significantly affected by crop rotation and

nitrogen rate on all the soil depths. Urease activity was significantly affected by tillage practices and nitrogen rate. The result on soil microbial biomass nitrogen (SMBN) was significantly affected by tillage and crop rotation. Soil microbial biomass carbon (SMBC) was significantly affected by crop rotation, tillage practice and nitrogen rate on all the three soil depths. Soil quality result shows that the mean effect of soil quality ranking on crop rotation, tillage and nitrogen rates on soil quality indicators was low (SQ = 4). The result on the overall effect of soil quality indicators selected in this study as affected by crop rotation, tillage and N rates shows that continuous maize irrespective of tillage or N rates all had low soil quality (SQ = 4), while maize in rotation with cowpeas and maize in rotation with soybean irrespective of tillage and N rates all had medium soil quality (SQ = 3). The result of soil quality on continuous maize cultivation, tillage and nitrogen rates on soil quality in relation to soil depth shows that soil quality was low in quality (SQ = 4) across all sampling depths irrespective of the treatments. The result on soil quality of maize in rotation with cowpea, tillage and nitrogen rates in relation to soil depth shows that soil quality was low (SQ = 4) at 0 kg N ha^{-1}, irrespective of tillage practices across all sampling depths, also, at 90 kg N ha^{-1} was medium in quality (SQ = 3) irrespective of tillage practices. The correlation of soil properties and grain yield at 0 – 5 cm soil depth shows that grain yield was weakly negatively correlated bulk density, moisture content and organic carbon, it was also weakly positively correlated to hydraulic conductivity, urease activity and soil microbial biomass N, grain yield was highly positively correlated to total N and soil microbial biomass carbon. The correlation of soil properties and grain yield at 5 – 15 cm soil depth shows that grain yield was weakly negatively correlated bulk density, moisture content and organic carbon, it was also weakly positively correlated to hydraulic conductivity, urease activity and soil microbial biomass N, grain yield was highly positively correlated to total N and soil microbial biomass carbon. The correlation of soil properties and grain yield at 15 – 25 cm soil depth shows that grain yield was weakly negatively

correlated bulk density, moisture content, total nitrogen, organic carbon and soil microbial biomass N, it was also weakly positively correlated to hydraulic conductivity and urease activity, grain yield was highly positively correlated soil microbial biomass carbon.

5.2 Conclusion

Soils of the northern Guinea savanna of Nigeria was found to be low in quality, however crop rotation practices with legumes and cereals over a long period of time (e.g 12 years) will improve soil quality from low to medium.

5.3 Recommendation

From the study, due to the poor nature of the quality of the soils in the northern Guinea savanna of Nigeria, the use of legumes - cereal rotation such as maize in rotation with cowpea and maize in rotation with soybean, under conventional tillage and the application of N fertilizer at 90 $kgNha^{-1}$ is recommended to farmers for improved soil quality over a long period of years for soils in the northern Guinea savanna (Alfisol) of Nigeria. Also, from the study, legumes - cereal rotation such as maize in rotation with soybean under conventional tillage and the application of N fertilizer at 60 kg N ha^{-1} is recommended to farmers for higher grain yield of maize in the northern Guinea savanna (Alfisol) of Nigeria.

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