EVALUATION OF MAIZE-DESMODIUM -SOYBEAN CROPPING EFFECT ON SOIL QUALITY AND CROP YIELDS IN AN ALFISOLS OF NORTHERN GUINEA SAVANNA, NIGERIA

BY

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Declaration

I declare that the work in this dissertation entitled "Evaluation of Maize-Desmodium-Soybean Cropping Effect on Soil Quality and Crop Yields in an Alfisol of Northern Guinea Savanna, Nigeria" was performed by me in the Department of Soil Science.The information derived from literature has been duly acknowledged in the text and a list of references provided. Subject matter herein has not been presented in any previous application for higher degree at Ahmadu Bello University or any other institution.

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(Student)

Certification

This dissertation entitled “EVALUATION OF MAIZE-DESMODIUM-SOYBEAN CROPPING EFFECT ON SOIL QUALITY AND CROP YIELDS IN AN ALFISOL OF NORTHERN GUINEA SAVANNA, NIGERIA”by Yusuf Destiny MUSA, meets the regulation governing the award of the degree of MASTER OF SCIENCE (Soil Science) of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

Chairman, Supervisory Committee Prof. A.C. Odunze	Date
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Dedication

I dedicate this work to ALMIGHTY ALLAH, My Gratitude goes to Almighty Allah, Who, In spite of security challenges, spared my life, provided for me, gave me wisdom and sustained me through the entire period of the programme, I cannot thank Him enough for His wonders and Mercies. May Almighty Allah be praised.

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ABSTRACT

Soil quality protection under intensive land use and fast growing economic development has become a major challenge for sustainable resource use in developing countries such as Nigeria. Soil quality is fundamentally important in agricultural production and soil fertility is becoming a central issue in decision on food security. Intercropping is the most common practice in traditional agricultural systems in the continent. Declining soil quality is emerging as an environmental and economic issue of increasing global concern. This is because degraded soils are becoming prevalent due to intensive use and poor management. Declining soil productivity due to poor soil quality (such as N and P deficiency and low organic matter) has been a major limiting factor to food production in Nigeria.Evaluation of Maize-Desmodium -Soybean cropping effect on soil quality and crop yields in Alfisol of Northern Guinea Savanna, Nigeria was conducted in 2014 and 2015 cropping seasons at the Institute for Agricultural Research (IAR) Farm, Ahmadu Bello University, Zaria. The trial was established in 2014 and repeated in 2015 at the IAR Meteorological site located between latitude 11^{o}11'19.3"N and Longitude 7^{o}37'02"E in the Northern Guinea Savanna ecology of Nigeria. The experiment was laid out in a Randomize Complete Block Design (RCBD) and replicated three times. Plots (M), (D) and (S) were planted with sole Maize, *Desmodium* and Soybeans respectively. Plots with (MS) and (MD) were inter cropped while plots MS 2:4 and M:D 2:4 were planted two strips of maize to four rows of Soybeans and strips of two maize to strips of four rows of *Desmodium* respectively. The variety of soybean used was IITA-TGX-1951, Maize was SAMMAZ 14. Soil sample obtained were evaluated for soil chemical properties organic carbon (OC), available phosphorus (avail P), total nitrogen (TN), soil pH, and cation exchange capacity (CEC), physical soil properties bulk density (BD), soil moisture content (SMC) and mean weight diameter (MWD). Plant height, stover yield, maize and soybean grain yield were also measured. Results showed that in 2014, mean pH water was 6.37, mean pH $CaCl_2$ was5.78, mean organic carbon was 5.23 gkg^{-1}, mean total nitrogen was 0.66 gkg^{-1}, and mean available phosphorus was 10.90 mg kg^{-1}. Analysis from combing the two years shows that maize/Desmodium strip cropping best increase soil pH, OC and TN than other treatments. The soil available phoshorus was best increase under sole soybean. Average mean weight diameter (MWD) increased from 0.59 in 2014 to 0.99 in 2015 indicating a better aggregation across the treatments. However, treatment under maize/soybean intercropping (MS) had a higher MWD. Bulk density at 8 and 16 WAP were 1.54 Mgm^{-3} and 1.43 Mgm^{-3}, respectively in 2014. Treatment under sole maize resulted in higher BD than other treatment at 8WAP and 16WAP. Best grain yield was under sole maize and maize/ *Desmodium* strip cropping in both years. Maize-*Desmodium*intercropping resulted in higher grain yield in the first year than other treatments while sole maize gave higher yield in the 2015. Treatment under maize *Desmodium* strip improved soil chemical most quality while physical quality was best improved under sole soybean in this study. Generally, adoption of maize *Desmodium* stripandmaize-soybean intercrop favoured better soil chemical and physical properties relative to sole maize. The use of treatment maize *Desmodium* strip improved soil quality better than all other treatments. Amount of SOC sequestered under treatment maize soybean intercrop was significantly higher than other cropping systems and the least was under MD. Carbon sequestered in macro aggregates were higher relative to other aggregates. The total land equivalent ratio (LER) for intercropping and strip-cropping were 1.15 and 1.37 and showing 13 % and 27 % land saved in 2014 cropping seasons respectively and in 2015; the ratio was 1.21 and 1.37 and showing 17 % and 27 % land saved in 2015 cropping seasons, respectively.Maize yield were best improved under sole maize and

maize/Desmodium intercropping. Adoption of maize/Desmodium strip cropping best improves soil quality.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Degradation of soil as a consequence of improper land use management practices poses a threat to sustainable agriculture, resulting in the need for appropriate soil protection and policy enactment. Over-exploitation of the soil for many decades has resulted in exhaustion of intensive agricultural production systems, steady declining productivity (Reginald *et al*., 2007) and impoverished soil quality.Soil quality is fundamentally important in agricultural production, and soil fertility management is increasingly becoming a central issue in decisions on food security, poverty reduction and environmental management. Soil is the end product of soil degrading, conserving or conserving processes and is controlled by chemical, physical and biological components of soil and their interactions (Papendick and Parr, 1992).

Soils of the Nigerian Northern Guinea Savanna are intensively cultivated with maize, sorghum, cowpea, groundnut, cotton and soybeans, and have resulted in the soils being inherently poor in fertility status (Jones and Wild, 1975; Odunze, 2006), have poor moisture retention capacity, rich in low activity clays and sesquioxides (Odunze *et al*., 2013) and have very low organic carbon content. The soils are therefore in a degraded condition to support sustainable agricultural production and require appropriate management practices that will enhance quality of the soils. Due to the fragile nature of the soil, they degrade rapidly under continuous and intensive cultivation (Abu and Abubakar, 2012). Frequent tillage can reduce the amount of organic matter in soils; an importantaspect of its quality (Tanimu*et al.,* 2007); which improves biological, chemical and physical properties of soils and provide readily available nutrients for plant and microbial uptake.

Many issues of sustainability are related to soil quality and its assessment. The direction of change in soil quality with time is therefore a primary indicator of whether or not agriculture is sustainable (Karlen *et al*., 1997). In the Northern Guinea Savanna zone for example, crop residues are harvested for fencing, fuel wood or livestock feed (Balasubramanian and Nnadi, 1980), and therefore not returned to the soil to restore soil fertility and quality. The continued intensive cultivation, coupled with annual non-return of crop residues to the soil has conferred impoverished soil quality status to the soils and necessitated the study on 'effects of legumes integration into maize cropping systems for soil quality assessment and crop yields'. Commonly, cereal based cropping systems farmers in the Northern Guinea Savanna of Nigeria practice legume relays into cereals, strip cropping of cereals with legumes, sole cropping of cereals and legumes. However, the focus for these management practices is on crop yield with little or no attention to resulting soil quality and fertility status that would support subsequent cropping. The present study therefore intends to evaluate soil quality under varying cereal/legume intercrop practices, as well as the resulting crop yield under the practices, with a view to determining management practices most suitable for soil quality improvement/maintenance and sustainable crop yields in the Northern Guinea Savanna zone Alfisols.

Desmodium uncinatum is a perennial forage legume capable of standing on the field for two or more growing seasons under suitable climate conditions. Whiteman (1971) reported that *Desmodium* added 121kgN/ha in soil under *Desmodium*-cereal intercropping. Gachene and Kimaru (2003) also reported that *Desmodium* contains 3.44% nitrogen (N) and 0.15% phosphorus (P) when decomposed, making it an option in soil quality and fertilityimprovement. The intercropping of legumes into cereal cropping systems could be a way of improving and maintaining soil fertility and quality in Northern Guinea Savanna (Yusuf *et al*., 2009). Maize production in most smallholder farms in Africa is characterized by intensive cultivation of land continuously, coupled with low external inputs which results in reduction of soil fertility and productivity, as well as its quality (Mrabet, 2002). In the past few decades alone, global grain production growth rate dropped from 3% in the 1970s to 1.3% in the early 1990s, which is one of the key indicators of declining soil quality on a global scale (Steer, 1998). Enhancing soil quality is a very good factor in sustaining soil resources for high quality soil to be better producers of food and fibre for the world's growing population and also play a major role in stabilizing natural ecosystems, enhancing air and water quality (Doran, 2002), improving crop land per capital output and sustaining natural food security (Odunze*et al.*,2012). Therefore, an integration of forage legumes like *Desmodium uncinatum* and Soybean (*Glycine max.*) under suitable intercroppping or strip farming systems has the potential to improve degraded soil fertility and quality, ensure its sustainability and reduce inorganic fertilizer use.

1.2 Problem statement

Declining soil quality is emerging as an environmental and economic issue of increasing global concern. This is because degraded soils are becoming more prevalent due to intensive use and poor management; often the result of higher population (Eswaran *et al.*, 2005).Declining soil productivity due to poor soil quality (such as N and P deficiency and low soil organic matter) has been a major limiting factor to food production in Nigeria; especially in the Northern Guinea Savanna belt (Sanginga *et al*., 2001;Yusuf *et al.*, 2003)

Studies have shownthat within a year of opening up a fallow land for cultivation, Nigeria soils undergo about 30% loss in organic matter (Adepetu, 1997).Soil fertility degradation presents an unprecedented challenge to the Nigeria agriculture. The low agricultural productivity in Nigeria has been strongly related to poor quality of the soil resource. Soil fertility depletion therefore, has been described as the fundamental cause of low per capital food production in small holder farms in West Africa (Bationo,2004)

1.3 Justification

In order to improve and maintain soil fertility under continuous cultivation in the Northern Guinea savanna Alfisols, soil N and P content will need to be increased through modification of traditional cropping system with minimum fertilizeruse that satisfies the economic need of farmers while improving quality and nutrient status of the soil.

Intercropping is the most common multiple cropping practice intraditional agricultural systems in the continent. The residual benefits of N-fixing grain legumes on yield of subsequent cereals and other crops are well documented (Adjei-Nsiah *et al*., 2008). Apart from the direct N benefit derived from legumes, rotational benefits arise due to other factor such as suppression of parasitic “witchweed” or striga which can devastate cereal crops (Franke*et al*., 2006; Rusinamhodzi*et al*., 2012). In view of this, *Desmodiumuncinatum* and Soybeans (*Glycinemax*) are legumes that have proven to have beneficial effect on soil quality, soil erosion control, enhance soil moisture conservation through returns of crop residue and “fixing” nitrogen into the soil (Khan *et al*., 2008), improving productivity and quality of soils in which each will be intercropped and/or strip cropped with maize. Efficacy of these legumes for soil quality improvement was evaluated in this study for Alfisols in the Northern Guinea Savanna of Nigeria.

According to Natural Resources Conservation Services (NRCS, 2011), the six components of soil quality management are: enhance organic matter, avoid excessive tillage, manage pest and nutrients efficiently, prevent soil compaction, keep the ground covered and diversify cropping systems.

1.4 General objective

This study therefore aims at evaluating maize/legumes intercrop practices for their effect on soil quality enhancement and sustainable crop yields.

1.4.1 Specific Objectives

1. To evaluate soil quality under maize/legume intercrop
2. To evaluate maize and legume yields under selected management practices
3. To determine soil carbon sequestration potentials of selected cropping system

CHAPTER TWO

2.0: LITERATUR REVIEW

2.1: Agricultural and Environmental Sustainability

Food security depends on abundance of food, even distribution and ability to purchase food, as well as political stability. Unfortunately, in the worldtoday about 3 billion out of the 6.3 billion (PRB, 2003) persons are malnourished because of shortage of calories, proteins, several vitamins, iron and iodine(WHO, 2000). Based on current rate of increase, the world population is projected to double to 12 billion in less than 50 years (PRB, 2003)

At a time when the world population continues to expand at a rate of 1.3% per year, adding more than a quarter million people daily, producing adequate food becomes an increasing problem. As the world population continues to expand, greater pressure than ever before is being placed on all basic resources that are essential for production and protection from diseases. Unfortunately, while the human population grows geometrically, food production only increases linearly. More than 99.7% of the world's food supply comes from the land, while less than 0.3% is from oceans and other aquatic habitats (FAO, 1997). Thus, the continued production of adequate food supply is directly dependent on ample quantities of fertile land, freshwater, energy and natural biodiversity.

Throughout the world, fertile crop land is being lost from production at an alarming rate. True for all cropland, it is illustrated by the diminishing amount of land now devoted to cereals grains (Lal *et al.*,2002). Soil erosion by wind and water as well as overuse is responsible for the loss of about 30% of the world crop land during the past 40years (WRI, 1994; Pimental *et al*., 1995).

Cereal grains provide more than 80% of the world's food (Pimental*et al.,* 1999). Corn is one of the world's major grain crops (FAO, 1997). Under favorable soil, rainfall, and temperature conditions, corn is one of the most productive crops per unit area of land (Pimental, 2004).

Strategies for global food security must be based; first, on sustainable conservation and management of land, water, energy and biological resources required for food production. Along with this, more efficient and environmentally friendly agricultural technologies must be developed and put into practice to support continued production of food (Pimental and Pimental, 1996).

Sustainable agriculture is globally recognized as a potentially viable means of meeting the future food demands of an ever growing world population; as it seeks to balance agricultural productivity, economic stability, resource utilization, degradation and environmental impact. Soil resource management is one aspect of sustainable agriculture that is necessary to overcome limitation to productivity, while maintaining or enhancing environmental quality. An overall understanding of soil quality will allow management of soil resource to ensure sustainable food, fiber and feed production globally.

Soils in the tropics are highly susceptible to degradation under continuous cultivation; particularly in the absence of conservation measures put in place, or if mechanized land clearing and tillage practices are not carefully implemented. The impact of such soil degradation is difficult to reverse, depending on its severity (Kirchlof and Salako, 2000; Salako *et al.,* 2001). Studies have shown that within a year of opening up a fallow land for cultivation, Nigeria soils undergo about 30% loss in organic matter (Adepetu, 1997). The characteristic low organic matter content of most soils in Nigeria suggests that the soil may be vulnerable under continuous cultivation unless a reasonable amount of organic matter can be maintained.

2.2 Soil Quality and Quality Changes

Over the last decades, soil quality has been one of the topics of great interest in Soil Science, so much so that a data base such; as the Soil Science CAB Database (CAB International Publishing) supplies more than 1500 publications that use the term ‘soil quality’ as a key word. Interests have been focused on defining the concept of soil quality that has put into consideration key involvement of soil in crop production, water and atmospheric purification. Therefore, emphasis is laid on the role of soil, both for production and for environmental quality improvement. This has led to profusion of definition of soil quality, but that of Karlen *et al.* (1997), which states that “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, air quality, human health and habitation”, is widely accepted and will be adopted in this study. Some important soil functions include; water flow and retention, solute transport and retention, physical stability and support, retention and cycling of nutrients, buffering and filtering of potentially toxic materials and maintenance of biodiversity and habitat (Andrews *et al*., 2004).

Similarly, attempts have been made to separate concept of soil quality from that of soil health. Limits of the two concepts are not particularly clear, but it is currently accepted that the term quality refers to its overall condition (Doran and Safely, 1997; Doran, 2002). In spite of the large number of scientific papers that choose soil quality as a key word, less than 20% deal with estimation and quantification of the level of soil quality. This lack of proper evaluation of soil quality may well be a reflection of its difficulty.Nortcliff (2002) stated that the search for quantitative index for soil quality is difficult. This is especially so when one considers that many changes take place over the long term; thus, a change in soil quality can only be perceived when all the effects are combined over a long period of time. Authors often concentrate on finding out which soil properties best reflect change in soil quality. Though soil quality is affected by a large number of properties, majority choose a small group of edaphic properties (basically biological and biochemical properties) to assess soil quality. Unfortunately, there is a notable absence of conventional evaluation procedures by which these properties are adequately measured.

In order that the quality of soils are adequately protected, basic assessment of soil health and quality is necessary to assess degradation status and changing trends following different land use and agricultural management practices (Lal and Stewart,1995; Larson and Pierce, 1994). This is intended to provide a baseline for monitoring and evaluating soil status over time, mitigate degradation trends and ensure environmental and crop production sustainability (Hedlund *et al*., 2003; Doran *et al.*, 1997; Doran and Zeiss, 2000). In Asia, adverse effects on soil health and quality arise from nutrient imbalance in soil, excessive fertilization, soil pollution and soil loss processes (Zhang *et al*., 1996; Odunze *et al.*,2012). The continued absence of easily applicable checklist and threshold limits for monitoring soil quality place limitations on scientists' efforts at ensuring sustainable crop production and environmental quality maintenance (Odunze *et al.*, 2012). Changes in soil quality can be assessed by measuring appropriate indicators and comparing them with desired values (critical level or threshold level), at different time intervals, for a selected agro-ecosystem (Odunze *et al.*,2012). Such a monitoring system will provide information on the effectiveness of selected farming systems, land use practices, technologies and policies (Arshad and Martin, 2002). Also, Gomez *et al.* (1996) proposed a framework for evaluating sustainability at farm level in the Philippines based on field indicators that take into account both farmer's satisfaction and resource conservation usually associated with soil-depth, water holding capacity, nutrient balance, organic matter content, ground cover, and biological diversity (Reginald *et al.*,2007; Odunze*et al.*,2012). According to these researchers, an indicator is said to be at a sustainable level if it exceeds a designated trigger or threshold level and thresholds are tentatively set, based on the average local conditions (Gomez *et al.*, 1996).

2.3 Agricultural Systems of the Northern Guinea Savanna and their Constraints

Agricultural system of the Northern Guinea savanna (NGS) are based mainly on cereals; such as maize, sorghum, millet and rice which are well adapted to ecological conditions prevailing in the zone. Traditional systems are based on sorghum and millet with occasional fallow periods. These are largely changing to more intensive land use systems with reduced fallow periods (Weber *et al.*, 1995a). In areas where agricultural inputs are rarely available and soil fertility is low, sorghum and millet still continue to dominate the systems.Increasing population density, marketing infrastructure and the need for food has raised demand for agricultural products. This in turn has resulted in the opening of new frontiers and/or intensification of cropping systems (de Ridder and van Keulen, 1990; Weber *et al.*, 1995b). This process of intensification results from misuse of chemical fertilizers, and a build-up of pest problems affecting productivity of the land (Weber *et al.,* 1996).

Some socio-economic constraints to expansion of the country in the mid-eighties led to increase in fertilizer/grain price ratios in spite of the 80 percent subsidy on fertilizers. Fertilizer has become very expensive and most farmers who cannot purchase them abandoned maize production for sorghum, which is more adapted to poor soils and relatively non-responsive to nitrogen fertilization. In order to sustain maize-based system, strategies are therefore required for efficient use of native nitrogen and for a judicious application of inorganic fertilizers.

2.4 Effect of Tillage on Soil Properties

Several studies have shown positive effects of no till on improving soil physical, chemical and biological properties (Moreno *et al*., 1997; Canter-Martinez *et al.,* 2003; Acosta-Martinez *et al*., 2007; Melero *et al*., 2009) compared to conventional or traditional tillage. Improvement of soil structure allows better soil aeration, water infiltration, and the preservation of surface cover or residue that enhances microbial activity and soil microbial biomass content (Doran *et al*., 1994). It has also been widely reported that continuous no-tillage results in increased nutrient concentration in the surface soil with a rapid decrease with depth, while conventional tillage resulted in more homogenous soil with low soil fertility status (Hargrove *et al.*, 1982; Ike, 1985). Blevins *et al*. (1997) reported that there is rapid lowering of soil surface pH under no-tillage when nitrogen fertilizers are applied. They indicated that after five years, pH of the surface (5cm) soil under no-tillage was lowered from pH 6.1 to 4.1 compared to pH 4.7 underconventional tillage when an annual rate of 336 N kg/ha was applied. Hargrove *et al.* (1982) also reported that in no-tillage Ca, Mg, P, Mn and Zn accumulated more on the surface than on tilled treatments. Dhiman *et al.*,(2001) reported increase in bulk density of the soil from 1.50g cm^{-3} in conventional to 1.58gcm^{-3} in no-tillage plots.

Shear and Moscher (1969) reported that K availability was not affected by tillage and P accumulated more in the upper 5cm surface in no-till soils. A similar result was reported by Nangya(1979) who suggested that the accumulation of P at the surface may be because most of the P fertilizers remained on the surface since P is not a mobile element. Ike(1985) reported that at 0-5 and 20-30cm depths, the soil under zero tillage had more exchangeable Ca and Mg than the soils under conventional tillage system though the differences were not significant. Lal, (1979) reported that no-tillage had higher organic matter in the surface soil horizons than the ploughed treatments and this result was supported by Blevins *et al*.(1983). Malik *et al.*(2002) showedthat physical properties of no-till soils are improved after four years of adoption. Nevertheless, the effect of soil tillage depends on its frequency, depth and soil texture (Six *et al*., 2002; Cookson *et al*., 2008

2.5 Effect of Tillage Systems on Crop Performance and Yield

Results of tillage systems on crop performance and yield has been quite variable. Lal and Dinkins(1979) reported that grain yield of maize and rice was significantly higher for no-till plot than conventional tilled plots. Nanjyu(1979) reported that cowpea grown on ridges produced lowest yield in the first season, but in the second and third seasons, yields were not significantly affected by tillage treatments and no-till yielded 30% less than conventional tillage respectively. The poor stand may be due to wide range of factors; including unavailability of proper equipment or seed drill, poor seed-soil contact, lowsoil moisture, unfavorable soil temperature, pest infestation and damage by birds and rodents. Mean seedling establishment by no tillage method was reported to be about 20% less than that by conventional tillage (Baeumer and Bakermans, 1973). He indicated that zero tillage may be covered by trash and too hard to allow sufficient penetration and covering at planting. Under conditions of limited soil moisture and limited precipitation or irrigation, crop yield were equal and often significantly higher with poor seedling emergence. Lal(1979) reported that tillage caused no significant differences in plant height at initial stages but the differences in plant height between no- till and conventional tillage increased with time; with no till treatments having taller plants with higher leaf area index. Root elongation was reported to be slower under no-till than with conventional tillage (Baeumer and Bakermans, 1973; Chaudhary and Prihar, 1974).Allmaras and Nelson (1971) observed that straw mulch with no tillage enhanced root growth in the upper 15cm of soil and increased lateral spread of roots during the early stage of the crop development.

The contrasting results of crop performance and yield may be due to soil type and nature of crop grown. For instance, soils of the Nigerian Savanna are different from those of the rain forest regions. Consequently, crop responses to tillage practices may not be similar in both regions. A work done in Ife, Nigeria by Aina (1976), reported that while yields of cassava and maize were significantly affected by tillage, cowpea yield was not significantly affected.

2.6 Effect of soil Cover and Legume Green Manure on Soil and Crop YieldImprovement

Green manuring has been known to increase soil fertility. The benefits of green manuring are multifold. It increases soil organic matter, available nitrogen, concentration of nutrient near the soil surface in available form, and reduces N losses through leaching and soil erosion. Increased organic matter in soil as a result of green manure improves soil physical properties by increasing the distribution and stability of soil aggregates and decreasing soil bulk density (McRae Mehuys, 1988). Green manure is the most important way to influence topsoil. Vegetative cover reduces runoff as well as the concentration and size of transported sediment particles, thus reducing the rates of loss of both soil and moisture. It also influences soil moisture and temperature dynamics (Sultani*etal*., 2007) in the following ways**:** (i) significant reduction in the rate of surface evaporation and surface runoff, and (ii) increase in infiltration rates of surface soils and moisture retention capacity of the soil. Biological nitrogen fixation (BFN) is one of the most important processes for the maintenance of life on earth as it contributes about 70% of all nitrogen required by natural and agricultural ecosystems and is environmentally friendly (Wani *et al.* 1995; Moreira, 2008). Legumes are known to improve soil fertility by adding much needed organic matter in the soils and fixing nitrogen biologically (Moreira, 2008). Use of annual legumes such as *Mucunapruriens, Macrotyloma uniflorum and Centrosema pascuorum*as green manure, can improve soil fertility and can help increase productivity of succeeding crops (Odunze, 2003). Legumes are able to accumulate soil N because they provide biological N fixation, which results in the fixation of about 15 to 40kg N for every 1000kg of dry matter of shoot produced

(Humpherys, 1995).Several reports have shown the use of accumulated N due to biological fixation to increase yield of subsequent crops. Cheruiyot *et al*. (2001) reported improved soil N status and increased grain yield of maize following legumes in a study to determine the contribution of five different legumes to soil nitrogen status and performance of succeeding maize in short fallow. Their result was also supported by Whitbread (2004); Mulongoy and Akonbundu (1990) who reported that *Mucunapruriens* significantly improved maize grain yield when planted as fallow.Further to this, some legumes have been found to facilitate utilization of soil P in low P soils of Northern Guinean Savanna of Nigeria (Kalm *et al*., 2002).Therefore, it is possible to increase yields of crops and improve soil quality by using green manure and nitrogen-fixing legumes.

2.7 Soil Quality Degradation and the Need for Standards

Declining soil quality is emerging as an environmental and economic issue of increasing global concerns; as degraded soils are becoming more prevalent due to intensive use and poor management, often the result of over-population (Eswaran *et al*., 2005). Pressing problems such as soil erosion, compaction, acidification, organic matter losses, nutrient losses and desertification reduce agricultural production capacity. Soil quality decline severely impact environment and agricultural viability; thus ecosystems and the humans' health, food security and livelihoods. Tests to monitor air and water quality have been standardized and widely adopted internationally (Riley, 2001). However, though an estimated 65% of land area worldwide is degraded (FAO, 2005), no standardized soil quality tests exist currently, especially for use in the tropics (Winder, 2003). The World Soils Agenda developed by International Union of Soil Science lists as the first two agenda items (a) assessment of status and trends of soil degradation at the global scale and (b) definition of impact indicators and tools for monitoring and evaluation (Hurni *et al*., 2006). There is clearly a need for international standards to measure soil quality. These could be useful for agricultural research and extension agencies, non-governmental organizations, governments and farmers to better understand, implement and monitor sustainable soil management practices.

2.8 Assessment of Soil Quality

Understanding soil quality means assessing and managing soil so that it functions optimally now and is not degraded for future use. By monitory changes in soil quality, a land manager can determine if a set of practice is sustainable. Soil quality assessment is a tool focused on dynamic soil properties and processes that are useful for assessing the sustainability of soil management practices. While it is true that soil testing serves the purpose of monitoring soil,testing focuses mainly on the ability to provide the tools of measuring overall soil quality. Soil quality assessment helps to determine the status of soil functions and environmental risk associated with production practices. To assess the status of a given soil, one needs to be aware of standard values for indicators of optimal soil quality determined. Soil quality cannot be measured directly. According to Kinyangi (2007), soil health indicators are needed to help smallholder farmers understand the chain of causes and effect that link farm decisions to ultimate productivity and health of plants and animals. Approaches to assess soil health are better applied when specific goals are defined for a desired outcome from a set of decisions. Therefore, soil quality is seen as an evaluation process which consists of a series of actions namely,

a. Selection of soil quality indicator
b. Determination of a minimum data set (MDS)
c. Development of an interpretation scheme of indices
d. Assessment and validation of data generated (Odunze *et al.,* 2012, 2013)

2.9 Soil Quality Indicators

The soil quality concept encompasses chemical, physical, and biological soil characteristics needed to maintain environmental quality and agricultural sustainability (Moebius *et al*., 2007; Doran and Parkin, 1994; Andrew and Carol, 2011; Herrick, 2000; Shukla *et al*., 2006). Soil quality indicators are the physical, chemical and biological properties, processes and characteristics that can be measured to monitor changes in the soil (Wikipedia, 2008; Odunze *et al*., 2012; 2013). The types of indicators that are most useful depend on the function of soil for which soil quality is being evaluated. In other words, integrative assessment of the three soil quality domains: chemical, physical, biological would be accomplished by soil quality indicators that represent soil processes relevant to soil functions and provide information that is useful for practical soil management (Moebius *et al.*, 2007; Idowu *etal*., 2008). Soil quality therefore involves an integrative assessment of the three soil quality domains physical, biological and chemical to be accomplished. These indicators represent soil process relevant to soil functions and provide information that would be useful for practical soil management. Measuring soil quality indicators must be inexpensive and dependent on minimal infrastructure if they are to be widely adopted beyond the research domain and especially in developing countries such as Nigeria. Soil quality indicator suitability can be judged by several criteria such as relevance, accessibility to users and measurability (Nambiar *et al*., 2001, Odunze *et al*., 2012; 2013).The following are some criteria to be considered when selecting soil health and soil quality indicators; they should be:

a. Easy to asses

b. Able to measure changes in soil function both at plot and landscape scales.

c. Assessing time to make management decisions

d. Accessible to many farmers

e. Sensitive to variations in agro-ecological zone

e. Representative of physical, biological or chemical properties of soil

g. Assessed by both qualitative and / or quantitative approaches (Kinyangi, 2007).

Soil quality indicator enables farmers to know the cause and effect of his farm output and how to link farm decision to ultimate productivity in terms of health of plant and animal. Indicators usually vary according to location, and the level of sophistication at which measurements are likely to be made (Riley, 2001).Hence, it is not possible to develop a single short list which is suitable for all purpose. Syers *et al*.(1995) emphasized the range of likely indicators rather than the use of a single indicator. They are as follows

2.9.1 Chemical Indicators

Soil nutrients are usually provided in large quantities by farmer in order to achieve high crop yield. This is mostly done by adding inorganic fertilizers, incorporating cover crops using other organic materials in form of manures and compost (Stocking, 2003). According to Kinyangi(2007), results of chemical tests are soil quality indicators which provide information on the capacity of soil to supply mineral nutrients which is dependent on soil pH (i.e the degree of hydrogen ions concentration in soil solution). It is also an indicator of plant available nutrients as lower soil pH status is not desirable, hence the soil may require liming.

2.9.2 Physical Indicators

Soil physical properties are estimated from the soil's texture, bulk density (a measure of compaction), porosity, water holding capacity (Hillel, 1982). According to Kinyangi(2007), the presence of hard pans usually present barriers to rooting depth. These properties are all improved through addition of organic matter to soils. Therefore, the suitability of soil for sustaining plant growth and biological activities is a function of its physical properties (porosity, water-holding capacity, structure and tilth). Anikwe (2006) reported that a decline of soil physical quality has serious consequences for the chemical and biological conditions of soils.

2.9.3 Minimum Data Set: Concept and Application

A minimum data set (MDS) was proposed to measure soil quality and its changes due to management practices through selection of key indicators such as soil texture, organic carbon, pH, nutrient status, bulk density, electrical conductivity and rooting depth (Larson *et al*., 1994). Collecting a minimum data set helps to identify locally relevant soil indicators and to evaluate selected indicators like soil and plant properties (Ashadand Martin, 2002; Odunze *et al*., 2012, 2013).According to Kinyangi(2007), minimum set of indicators are required to obtain a comprehensive understanding of soil quality/health status. They are therefore important tools for screening the condition, quality and health of soil (Larson *et al*., 1994; Doran and Parkin, 1994). For small holder farmers, these tools need to be simple measures of soil health and soil quality indicators such as consistency, color and workability (Murage *et al*.,2000; Mairura *et al*., 2007). For extension and policy personnel, they provide basic information needed to arrive at management decision (Barrios *et al*., 2006) and variations in order to conduct a meaningful assessment of soil status, often expressed as an index of soil quality (Kang *et al*., 2005).

2.10 Maize and its Importance

Maize (*Zea mays* L.) is an annual plant of the grass (Graminae) family. It is an out-pollinated plant which matures within 100-120days, although some variation exists. The male flower called tassel emerges 50-60 days after planting (DAP) at the apex of the plant. About the same time, the female flowers are formed in the axils of lower leaves. The stigmatic surfaces of the female flowers called silk only emerge from the left axils shortly after tasseling (Williams and Chew, 1980). 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 introduction of fertilizer, responsive improved cultivars and adoption of fertilizer use, maize cropping has dramatically transformed agriculture in the Northern Guinea Savanna (NGS) from subsistence to a cash-oriented system (Smith *et al.,* 1994).The crop is being utilized as a staple food, feed for livestock and in brewery and confectionery industries in Nigeria. It has a high yield potential and occupies about 40% of the area under arable crops in the savanna zones (Badu-Apra *et al*., 2003).

2.10.1 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 500mm to 3500mm, covering from the Sudan/Sahel savanna to the Mangrove forest. Solar radiation of maize growing zones in Nigeria ranges from 350-400 cal cm^{-2} day^{-1} in the North and averages about 250 cal cm^{-2} day^{-2} in the South, while corresponding mean daily air temperatures are $27^{o}C$ and $25^{o}C$ (FAO, 1997). High temperatures of $27^{o}C$ at tasseling and pollination speeds up differentiation process of the reproductive organs, resulting in high kernel abortion. When many kernels are aborted, the total sink size could limits yield (IITA, 1986). Maize is grown on a wide range of soil, but it grows best in deep, well drained, medium to moderately heavy textured soil, with adequate organic matter. It yields poorly on shallow, sandy soils because of high 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 mitigated with farmyardmanure or lime. It can also be grown in alkaline soils but deficiencies of iron and manganese must be corrected (William and Chew, 1980).

2.10.2 Nitrogen Requirement of Maize

Crop nitrogen requirement is the minimum crop N uptake required to obtain maximum yield. It is used in the determination of N fertilizer need of a crop. The N requirement for maize for instance, can be measured by investigating maize yield at different levels of N fertilization, and/or by determining the correlation between tissue N concentration or N content and maize yield performance. Often, crop which provides large amount of dry matter require more N than those producing less dry matter. This means that the potential dry matter production is an important factor in determining N needed for a given crop. Another important factor is the internal crop yield and N requirement defined as the N concentration in total above ground dry matter at near maximum yield (Liu, 1991). The N concentration in the crop tissue is only slightly affected by the N supply, and remains fairly stable over a wide range of environmental and cultural conditions (Binford *et al*., 1990).It is essential therefore, to maintain an adequate concentration of N in the photosynthetic organs in order to obtain high dry matter production. This, therefore, informs investigating N rate application suited for this farming system. Previous studies in this ecological zone have proven N requirement of maize to be 120kg N ha^{-1} (Chude, 1996).

2.10.3 Effect of Nitrogen on Maize

Declining soil productivity due to nitrogen and phosphorus deficiencies and low soil organic matter (SOM) has been a major limiting factor to food-cash crop production in Nigeria particularly, in the Guinea Savanna agro ecology (Sanginga *et al*., 2001; Yusuf *et al*., 2003). Past mismanagement and inappropriate practices adopted under continuous cultivation of soils are responsible for the continuous downward spiral in crop productivity within the ecology as continuous cultivation within soil fertility programme leads to soil structural degradation and loss of soil organic matter (Mrabet, 2002). A study by Thippayarugs *et al.*(2008) showed that leguminous plant species grown either for improved fallow, economic yields or weed suppression have the ability to fix atmospheric nitrogen (N_2) and increase its availability in soils. Residual yield benefits to cereal crop from legumes are well documented for tropical regions (Giller, 2001). Some studies attribute residual benefits from legumes to other effects apart from N (Sauerborn *et al*., 2000; Sanginga 2003).Nielsen and Vigil (2005) indicated that soil moisture was an important factor in determining residual benefit of legumes to cereals.

Nitrogen is the most important mineral nutrient limiting maize production in Nigeria Savanna (Uyovbisere*et al*., 1997; Carsky and Iwuafor, 1999; Sanginga*et al*. 2001; Yusuf *et al*., 2003).Traditionally, soil nitrogen deficiency has been addressed by the application of inorganic fertilizers, and this has brought increase in yield of cereal crop. Maize is known to tolerate high rate of nitrogen fertilizer without any depression in yields (Samuel and Aldich, 1980). However, in a cropping situation where stress related to other nutrient other than N, moisture or light occurs, too much nitrogen fertilization of maize may result in large accumulation of nitrate in the leaves, stems and portion of small grains which may cause nitrate poisoning among livestock that may graze on them (Samuel and Aldrich,1980). The environmental problem associated with excessive use of nitrogen fertilizer is now a continuous issue. In USA, research has shown that continuous nitrogen fertilizer use in maize production can result in widespread nitrate pollution of ground water and economic losses to farmers.

Fast population growth as well as increased industrialization and urbanization have put great pressure on agricultural land in sub-Saharan Africa. Therefore, increased food output per unit area of land cultivated in order to meet the target for sustainable food production in the next few decades may not be met (FAO, 1995). If agricultural production must be intensified, ways of making maximum use of the remaining land must be pursued so as to reduce land degradation and pollution, which may occur after intensive cultivation and fertilizer application. Appropriate measures to restore soil fertility and maintain good soil structure has to be put in place.

2.11 *Desmodium uncinatum*

*Demodium uncinatum*also known as silver leaf, is a perennial forage legume with cylindrical or angular stems, densely covered with short, hooked hairs which make the stem adhere to hand, clothing, etc. The leaflets are dark green on the upper side with an area of white shiny surface near the central vein, often surrounded by a dark shiny area. Lower side of it is lighter green and uniform in colour and both sides hairy. The flowers are pinkish in colour and later become bluish. The pods are sickle-shaped, light brown at maturity and densely covered with minute hooked hairs so that the segments adhere to clothing and coat of animals, hence making it easy to spread widely. *Desmodium uncinatum* originated from Deodora, Brazil and was later introduced to Kenya.

2.11.1 Soil and Rainfall Requirements

Desmodium uncinatum requires annual rainfall amount of about 900 mm. It is adapted to a wide range of soils from sandy to clay loam, though not as successful on sand as *Desmodium intortum*. It does well on soils with an open texture and not so well on compacted heavy clays. It grows at pH 5.5 to 6.5 up to 7.0. It does not tolerate salinity (Andrew and Robins, 1969). It performs best in well-prepared cultivated seedbed.

2.11.2 Economic Importance of *Desmodium*

(a) It is highly palatable and nutritious to dairy cows

(b) It is capable of repelling insects such as stem borer, thereby reducing the cost of buying pesticide which may be harmful to the environment.

(c) They are also capable of reducing drastically the devastating effects of parasitic weed, such as*Striga hermonthica* by releasing chemicals from their roots which are capable of undermining growth of weeds.

2.11.3: Impact of *Desmodium* on Soil Quality

Research has shown that *Desmodium* is able to increase significantly more beneficial soil organismin cereal-*Desmodium* field. Also, *Desmodium* could act as cover crop to control soil erosion and retain soil moisture (Khan *et al*., 2008). *Desmodium*enhances soil organic matter content which in turn improves soil quality (Khan *et al*., 2008)

N-fixing legume: Silver-leaf (*Desmodium*)is a N-fixing legume that improves soil N status and can provide nitrogen to companion crops. It was estimated that N-fixed range from 90kgN/ha in *Desmodium*/grass stands mixed on a 3:7 ratio. When sown in pure stands, 110 kg N/ha/year were returned to the soil according to FAO (2011).

Weed and weed controller: Silverleaf(*Desmosdium*) is considered a weed in Australia and Hawaii because it can outcompete native species.In association with maize crop, silver-leaf *Desmodium* may help to control *Strigahermonthica*; a deleterious parasitic weed of maize, due to an allelopathic action (Labrada, 2003).

2.12 Legume Integration into Cereal-Based Systems

Legumes play a major role in farming systems because in addition to being a source of protein, they provide alternative and inexpensive source of nitrogen for soil fertility maintenance, and dry or green matter for soil conservation and weed suppression (Muyinda *et al.,* 1988; Kang, 1992;

Danso, 1992).Legume can fulfill a major part of their N requirement through N_2 fixation, and contribute N to the soil for use by the companion or subsequent crops. Soil physical properties that are affected by incorporation of green manure include the structure, moisture retention capacity, macro porosity, consistency and density. Other properties such as porosity, aeration, conductivity, hydraulics and infiltration are allied to the modification of soil structure (Sultani *et al.*,2007). This effect depends on climatic factors and soil characteristics. Both legumes and non-legumes are used as green manures or soil cover. However, legumes are superior green manure as they fix atmospheric nitrogen and add it to the soil nitrogen pool (Carlson and Huss-Danell, 2003; Mayer *et al.*, 2003). Studies have shown that forage legumes like *Centrosemapascuorum, Centroscemabrasilianum, Lablab purpureus*and*Macrotylomauniflorum*can be integrated into cropping systems of the Guinea Savanna (Iwuafor, 1986; Odunze *et al.* 2002; Lawal, 2015 and Ogunsunya, 2015) because they have the potential of reducing surface runoff and thus reduce the rate of loss of both soil and moisture. A study by Ewansiha *et al.*(2008) also showed that forage legumes help to maintain soil properties and improve maize production.

2.13 Soil Organic Matter and Aggregation

Soil structure is an important property that mediates many physical and biological processes and controls soil organic matter decomposition (Van Veen; Kuikman, 1990). Soil aggregates are the basic units of soil structure and arecomposed of primary particles and binding agents that stabilize soil aggregates. Aggregate stability depends on the binding mechanisms; such as chemical binding by organic compounds and physical binding of particles by fungal hyphae and plant roots (Angers *et al*,. 1993). Plant carbon (C) is sequestered in soils through decomposition and conversion into soil organic C in aggregates. As a result, additions of carbon or nitrogen from plant residue may improve soil quality before improving microbial activities of N mineralization, aggregation and increasing C and N storage in the soil. Aggregation improves water infiltration capacity, root growth in the surface and subsurface soils in agricultural areas while tillage and other cultural practices disturb the land (Lawal, 2015 and Ogunsunya, 2015).

Agbenin and Goladi(1997) reported changes of carbon (C), Nitrogen (N) and Phosphorus (P) of Alfisol under continuous cultivation; complemented with farmyard manures and inorganic fertilization for forty-five years, caused significant losses of C, N and P. The N+P or N+P+K fertilizers could not mitigate these losses, and losses of N and P were mainly in organic forms. They concluded that farmyard manure applied alone or in combination with N+P or N+P+K was effective in maintaining soil quality under continuous cultivation in the Savanna. Ogunwole and Ogunleye(2004) also reported that soils under treatments involving cow dung (D), cow dung+phosphorus (DP) fertilizers and cow dung+nitrogen+phosphorus and potassium (DNPK) fertilizers recorded higher mean weight diameter, lower bulk density and higher percentage aggregates greater than 1 mm diameter. Their results show that these treatments were better aggregated to withstand wind erosion.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

This study was conducted at the experimental Farm of Institute for Agricultural Research (IAR), Samaru, Zaria. The experimental field is located between latitude $11^{0}11'19.3''$N and longitude $7^{0}37'02''$E in the Guinea Savanna ecology of northern Nigeria. Long-term mean annual rainfall of the study area is 986.5mm and is concentrated between May and October with a peak in August,(Odunze, 2011). The mean daily air temperature (minimum and maximum) ranges between 15^{o}C and 38^{o}C (Oluwasemire and Alabi, 2004).Soil type of the study area was classified as Typic Haplustalf according to USDA Soil Taxonomy (Soil Survey Staff, 1999) as cited by Ogunwole *et al.* (2001).The soil belongs to the order Acrisol in the FAO-UNESCO legend as cited by Valette and Ibanga(1986) and Uyovbisere *et al.*(2000). The soils were developed on deeply weathered pre-Cambrian basement complex (Ogunwole *et al*. 2001) that is overlain by Aeolian drift of varying thickness. The soils are low in inherently low inorganic matter and are dominated by low activity clays (Jones and Wild, 1975; Odunze, 2003). The experiment was conducted in 2014 and 2015.

3.2 Treatments and Experimental Design

Maize, Soybean and Desmodium were the planting materials used in the trial and they were obtained from seed production unit of the Institute for Agricultural Research (IAR), Samaru.Treatments of this experiment consisted of seven cropping system namely Sole Maize (M),Sole Soybeans (S), Sole *Desmodium* (D),Sole *Desmodium* (D) Maize/Soybeans Intercrop (MS), Maize/D. *uncinatum*inter cropping(MD), Maize/ SoybeansStrip cropping (MS 2:4)Maize/ D. *uncinatum* Strip cropping (MD 2:4).

The experiment was laid out in a randomize complete block design (RCBD).Size of the field was 50m by strips.35m which is 1750m^2 (0.175ha).

3.3 Field Establishment, Planting, Crop Varieties

The experiment was carried out in two planting seasons (2014 and 2015). In the first year (2014), land was cleared, ploughed, harrowed and ridged by disc harrow disc plough and disc ridger. The field was laid out into three replicates, where each replicate contained seven plots. In the second year (2015) manual equipment were used for land preparation i.e. cutlass and hoe. The experiment contained 21 plots. In each plot labeled M, D and S, were planted with sole Maize, *Desmodium* and soybean respectively. Plots with MS and MD were inter cropped while plots labeled MS 2:4 and M:D 2:4 were planted in strip of two rows of maize to four rows of soybean and strips of two rows of maize and strips of four rows to *Desmodium* respectively (Table 3.1).Two maize seeds per hole were planted on ridge peak at a distance of 25cm apart on a 75cm distance between ridges. Both soybeans and *Desmodium* were drilled on ridge slopes under intercropping arrangements and on ridge peaks planted sole or instrip

Table 3.1 Field lay-out of experimental plots

Rep1	S	MS	D	MD	MS 2:4	M	MD 2: 4
Rep 2	MS	MD 2: 4	S	MD 2: 4	M	MD	D
Rep 3	MD 2: 4	S	MS 2:4	MD	D	MS	S

Main treatments of the experiment are maize (M), soybean (S) and *Desmodium(D).*Other are

(1) Sole Maize (M)

(2) Sole Soybeans (S)

(3) Sole *Desmodium* (D)

(4) Maize/Soybeans Intercropping (MS)

(5) Maize/D. *uncinatum* intercropping (MD)

(6) Maize/ Soybean strip cropping (MS 2:4)

(7) Maize/ D. *uncinatum* strip cropping(MD 2:4)

Maize was planted 25 cm apart on the ridges while soybeans and *D. uncinatum* were planted by drilling on the ridge slopes. Size of the field was 50m by 35m which is 1750m^2 (0.175ha).

Crop varieties: The variety of soybean used was IITA-TGX-1951;this was selected because it has high grain yield,promiscuous breeding line, and medium maturity variety.Maize was SAMMAZ 14; this was selected because of its quality protein maize(QPM), early maturity, yield up to 3 to 4 tonnes per hectare and also subdue striga (*Striga hermanthica*) attack and *Desmodium* was *Desmodium uncinatum;*it was selected because of the following features, it is nitrogen fixing legume,help in weed control, repel insects and also conserve soil moisture.

Thinning and supplying was done two weeks after planting (2WAP). The two stands of maize were thinned to one plant per hole while those that did not germinate were re- supplied. Weeding was done manually by handpicking and hoe weeding at 3, 6 and 8 weeks after planting (WAP) for all the treatments Threshing was done when plants were air dried after harvest to separate seeds from cob.

Plant height (cm):Four Plant stand /plot/ treatment were tagged and monitored for plant height. The four plants across plots were measured from the base of each plant to the highest point at 4, 8 and 12 WAS. The average height was then recorded. Other growth parameters taken on maize and soybean include numbers of days to tasselling and flowering respectively.

Grain yield: The maize and soybean crop was harvested after maturity at some level of drying in the field. The-air dried ears were shelled, cleaned and weight of grains recorded on the basis of yield (cob weight, maize grain, soybean grain 1000 grain of maize and soya bean) per treatment. Grain yield was worked out and expressed in tonnes per hectare.

3.4 Soil Sampling

A total of 10 soil samples were taken from five locations at depths of 0-10 cm and 10-20 cm with soil auger. Soil samples for laboratory analysis were homogenized, air-dried, ground and sieved through a 2mm sieve. The less than 2 mm fractions were analyzed for their chemical properties (pH, particle size distribution, organic carbon, total nitrogen, available phosphorus, cation exchange capacity, exchangeable bases, exchangeable acidity and micronutrients). Also core samples were collected using 5cm by 5cm core samplers to determine bulk density and moisture content at a depth of 0-20cm. Soil aggregates were obtained to assess aggregates stability using dry sieving methods. Iron, Manganese and Magnesium content in aggregates were also determined in order to know the element (s) responsible for aggregation. Also soil organic carbon stock (SOC) was determined at depths of 0-20cm.At the end of every year, soil samples at the experimental fields were obtained from depth 0-20 cm using an auger at each replicate. The plots planted sole and strip were sampled at the ridge top while those intercrop were sampled at the slope of the ridge between the two crops

3.5 Laboratory Analysis

Particle Size Distribution: Particle size distribution was determined using the Bouyoucos (1951) hydrometer method as described by Gee and Bauder (1986),using distilled water and calgon (sodium hexametaphosphate) solution as dispersingagents. Textural classes were obtained from the textural triangle using the USDA (1975) approach.

Bulk density: Soil bulk density was determined and expressed as the ratio of the mass of ovendried soil to its total volume method (Blake and Hartge, 1986).

Aggregate stability: This was determined by dry sieving method as described by Van Bavel (1950) and modified by Kemper and Rosenau (1986). Sieve sizes used are 2.36- < 0.05. Aggregates in these sieve sizes were recorded and evaluated.

Dry sieving Method: Field-moist soils were air dried for 7 to 10 days. Aggregates were separated by placing 500g of air-dried soilin a nest of five sieves (2.36mm, 2mm, 0.25mm, 0.05mm and < 0.05mm) attached to a sieve shaker. These sieve sizes were chosen to separate soil aggregates as large macro aggregates (2.36–2.00 mm), small macro aggregates (2.00–0.25 mm), micro aggregates (0.25-0.05mm) and less than 0.05 mm fractions made up of silt + clay fractions (Six *et al.*, 2000). The sieves were shaken for 3 minutes and the aggregates retained in each sieve and those that passed through the last sieve were weighed. Soil samples obtained were used to determine aggregate size distribution and in the calculation of mean weight diameter (MWD) for soil structural quality.Mean weight diameter (MWD) was calculated by summing the product of mean diameter of aggregates and proportion of soil in each aggregate-size class (Kemper andRosenau, 1986) as given in equation below to define stability of the soil aggregates.

MWD = $\sum_{n=1}^{n} WiXi$

Where X_i = proportion by weight ofaggregate

W_i = mean diameter of proceeding and preceding sieve

Soil pH:Soil pH was determined electrometrically in a ratio of 1:2.5 soil to water and $CaCl_2$as described by Henderson *et al.*(1993).

Soil organic carbon was measured by wet oxidation method of Walkley and Black as described by Juo (1997).

Available phosphorus was measured by Bray No. 1 method as described by Brady and Kurtz (1945) and Jackson (1962).

Total nitrogenwas determined by the regular micro-Kjeldahl digestion method (Bremmer and Mulvaney, 1982).

Exchangeable acidity was determined by shaking the soil in 0.01M KCl and titrating the filtrate with 0.1M NaOH (Agbenin, 1995).

Exchangeable bases(Ca, Mg, K and Na) were extracted with 1N NH_4OA_C (Chapman, 1965). Exchangeable Ca, and Mg were determined by EDTA titration methods (Agbenin, 1995). Potassium (K) and Sodium (Na) was determined using flame photometry (Anderson and Ingram, 1993).

Cation Exchange Capacity (CEC) was determined by the1N Neutral Ammonium acetate (1N NH_4OA_C) method as described by Rhoades (1982).

The productivity from mean yield data of sole, intercropping and strip-cropping system were determined by land equivalent ratio (LER), (Willey, 1985).

$$\text{LER} = \frac{\textbf{Intercrop yield of crop A}}{\textbf{Sole crop yield of crop A}} + \frac{\textbf{Intercrop yield of crop B}}{\textbf{sole crop yield of crop B}}$$

Percentage Land Saved = 100-1/LER x 100

Where LER is equal to 1.0, it means that there is no advantage for intercropping over sole crop. LER above 1.0 shows an advantage to intercropping while number below 1.0 shows a disadvantage in intercropping.

Soil Carbon Sequestration

Soil samples (0-20 cm) were collected from plots of the fieldtrial. The samples were now air-dried for two weeks, after which they were physically separated with the aid of sieve into different aggregate sizes of 2.36-2.00mm (large macro aggregates), 2.0-0.25mm (small macro aggregates), 0.25-0.05mm (micro aggregates) and < 0.05mm (clay and silt fraction). Carbon sequestered in each aggregates fraction were now obtained by chemically analyzing for carbon content contained in soils of each sieve size.

Soil organic carbon stock

Procedure for determining the individual soil organic carbon (SOC) stocks

To estimate SOC stocks, requires knowledge of the vertical distribution of OC in profiles. Calculating SOC stocks for a given depth requires summing SOC Stocks by layer, determined as a product of bulk density (D_b), OC concentration, and layer thickness. For an individual profile with n layers, we estimated the organic carbon stock by

$$soc_s = \sum_{i}^{n} = 1 \ \boldsymbol{Dbi} \times \boldsymbol{OCi} \times \boldsymbol{Di}$$

where SOCs is the soil organic carbon stock (kg/ha), *D*b*i* is the bulk density (Mgm^{-3}) of layer *i*, OC*i* is the proportion of organic carbon (gkg^{-1}) in layer *i*, D*i* is the thickness of this layer (cm).

3.6 Soil Quality

Basic Soil Quality indicators selected for a minimum data set in this study were relevant soil data (Doran and Parkin, 1994; Andrew and Caroll, 2011) for Nigerian Northern Guinea Savanna zone Alfisols. They are

1. Data on total nitrogen, organic carbon, available phosphorus, pH, aggregate stability and bulk density of soils after crop harvest

2. Data on maize and soybean grain yield for study period

Soil Quality was assessed by using the Parr *et al.* (1992) equation; i.e.

SQ= f (SP, P, E, H, ER, BD, FQ, MI)

Where SQ= soil quality, SP= soil properties, P= potential productivity, E= environmental factors, H= Health (Human/Animals), ER= erodibility, BD= Biodiversity, FQ= food quality and MI= Management input. A score scale of 1 to 5 was used in the assessment of parameters in the model; where 1 is the best and 5 is worst condition. However, E, H, ER, FQ and MI were each scored 1.0 because the research field used for the experiment had been on a long-term research use (1922 to date) and is being optimally managed to satisfy optimal environmental conditions for sustainability, health factors for human and livestock optimal food quality obtained, biodiversity and input management (Odunze, 2013). Therefore, SQ= f(SP,P) was used to assess soil quality of Alfisols in the Nigeria Guinea Savanna Zone.

3.7 Statistical Analysis

Analysis of variance (ANOVA) was done using General Linear Model procedure of SAS 9.3 Software (SAS, 2011). Chemical quality indicators (pH, OC,TN and avail. P) and soil carbon sequestered in large and small macro aggregates, micro aggregates and silt and clay fraction were statistically analysed for each year and also combined analysis across the two years. Other physical and chemical properties were analysed based on each year of study. Differences between means were separated using Duncan's Multiple Range Test at 5% level of probability.

The productivity from mean yield data of sole, intercropping and strip-cropping system were determined by the land equivalent ratio (LER) (Willey, 1985).

CHAPTER FOUR

4.0 RESULTS

4.1 Samaru Weather Report for Year 2014 and 2015

Tables 4.1 and 4.2 show weather data in Samaru for year 2014 and 2015 (trial period).Data showed that in 2014 mean maximum air temperature ranged between 12.5 ^{O}C in December to36.9 ^{O}Cin April. Maximum temperature fluctuated within the year but highest maximum airtemperature was observed in April.Mean minimum air temperature ranged between 11.3^{O}C in November to23.3^{O}C in June.Total rainfall amount recorded in Samara in2014 was 1049.6 mm with the highest amount of rainfall recorded in the month of August (374.3 mm).The first rain recorded in Samaru was on April 7th amounting to 1.3 mm. It rained only nine (9) days in April that year and the total rainfall amount in that month amounted to 147 mm (Table 4.1) which was not sufficient to sustain crop production. In May, rainfall was recorded for nine (9) days amounting to127.2 mm, and in August, 14 days of rainfall was recorded which spread within the month and was sufficient to sustain crop production.The total amount of rainfall in August was 374.3 mm and also recorded the highest amount of rainfall in that year. Rainfall amount dropped sharply in October with a total rainfall amount of 9.3 mm in 4 days. The last rain in Samaru in year 2014 was recorded on October 11th with rainfall amount of 5.3 mm. (Table 4.1)

In 2015, maximum air temperature at Samaru ranged between 32.1^{o}C in December to37.6^{o}C in May. Maximum air temperature fluctuated within the year but data showed that maximum temperature was observed in November (Table 4.2). The minimum air temperature ranged between 12.8^{o}C in November to 25.4 ^{o}C in September.Total rainfall amount recorded in Samaru in 2015 was 1136.8 mm with the highest amount of rainfall recorded in the month of September (344.1mm), followed by August (300 mm) and the least was in October

(55.1mm). The first rain recorded in Samaru in 2015 was on April 14^{th} amounting to 4.3 mm. Generally in both years, days without rainfall were more than days with rains.Year 2014 recorded 143 days without rainfall and 71 days with rainfall. In 2015, there were 188days without rainfall and 66 days with rainfall within the months of April to October in both years. Tables 4.1 and 4.2 indicated that the highest amount of rainfall could be expected in August and September.The low number of days with rainfall events in June (10 days) in June and July 2014 and (7 days) in June 2015 would suggest insufficient soil moisture available for crop establishment due to dry spell occurrence at these periods in the zone. However, the reduced number of days (66) with rainfall events in 2015relative to 2014 (71), could suggest dry spell occurrence within the growing season of field crops, soil moisture depletion and a reduced number of effective crop growth period for crop production in the study area.

4.2 Initial Soil Condition

Soil pH in water was 5.80 at the surface soils and 6.80 in the sub-surface soil while soil pH in $CaCl_2$ at the surface was 4.89 and 5.20 in the sub-surface soils. Organic carbon values were higher at the surface 0-10 cm layer (2.11 gkg^{1}) than at 10-20 cm layer (1.99 gkg^{-1}).Total nitrogen of the soils was 0.50 gkg^{-1} at surface layer and 0.40 gkg^{-1}at the sub-surface layer. Available phosphorus of surface soils (0-10 cm) was 4.91 mg kg^{-1} and 4.99 mg kg^{-1} at the sub-surface soils (10-20 cm). Cation exchange capacity (CEC) of the soils were 7.75 cmol kg^{-1} at the surface soils (0-10 cm) and 7.50 cmol kg^{-1} at sub-surface layer (10-20 cm). Generally, CEC of the experimental area was low (< 10 $cmolkg^{-1}$) (Table 4.3).

Table 4.1 Samaru Mean Monthly Weather Report for Year 2014

MONTHS AIR TEMPERATURE (^{0}C) RAINFALL

MONTHS **AIR TEMPERATURE (^{0}C)** **RAINFALL**

	MAX	MIN	MEAN	Days with Rain (days)	Days without Rain (days)	Total rainfall (mm)
APR	36.9	21.4	29.15	9	21	147
MAY	31.4	21.2	26.3	9	22	127.2
JUNE	32.2	23.3	27.75	10	20	119.1
JULY	31	21.8	26.4	10	21	115.7
AUG	21.8	12.5	17.15	14	17	374.3
SEPT	30	21.9	25.95	15	15	157
OCT	31.8	21.3	26.55	4	27	9.3
NOV	35	11.3	23.15	0	0	0
DEC	12.5	11	11.75	0	0	0
TOTAL				71	143	1049.6

Source: IAR Samaru Meterological Unit (2014)

	MAX	MIN	MEAN	Days with Rain (days)	Days without Rain (days)	Total rainfall (mm)
	(^{0}C)	(^{0}C)				
MAY	37.4	24.2	30.8	7	24	90.1
JUNE	32.6	22.1	27.35	7	23	66.4
JULY	30.6	20.1	25.35	14	17	281.1
AUG	30	19.4	24.7	18	13	300
SEPT	31.6	25.4	28.5	15	15	344.1
OCT	33.2	18.2	25.7	5	26	55.1
NOV	33.8	12.8	23.3	0	0	0
DEC	32.1	14.6	23.35	0	0	0
TOTAL	261.3	156.8	209.05	66	118	1136.8

Table 4.2 Samaru Mean Monthly Weather Report for Year 2015

Source: IAR Samaru Meteorological Unit (2015)

Table 4.3 Physical and chemical properties of the experimental field at the beginning of the experiment in 2014

Soil properties	Depth (cm)	
	0-10	**10-20**
pH (H_2O)	5.8	6.80
pH ($CaCl_2$)	4.89	5.20
Avail. P (mg kg^{-1})	4.91	4.99
Organic C (gkg^{-1})	2.11	1.99
Total N (gkg^{-1})	0.50	0.40
CEC ($cmolkg^{-1}$)	7.75	7.50
Particle size distribution (g kg^{-1})		
Sand	490	450
Silt	430	460
Clay	80	90
Textural class	Loam	Loam

4.3 Effects of cropping systems on soil physical properties

4.3.1 Soil bulk density

Table 4.4 shows result of bulk density for all the treatments for both years. Highest BD was obtained under sole maize (M) with a mean value of 1.61 $Mgm^{-3}$and the least was observed under sole *Desmodium* (D), although the latter was not significantly different from the treatment under maize /*Desmodium* strip cropping (MD2:4) and maize/soybean strip cropping (MS2:4) at 8 weeks after planting (WAP). At 16 WAP, bulk density under all the treatments except that of sole maize (M), increased to 1.48 Mgm^{-3}in 2014. There were no significant difference (P>0.05) in BD among all the treatments in 2015 at 8 and 16 WAP.

4.3.2 Soil moisture content (SMC)

Table 4.5 presents data on soil moisture content under the different cropping systems evaluated at 8 and 16 weeks after planting (WAP) in 2014 and 2015. There were no significant ($P > 0.05$) differences in moisture content across all the treatments at 8WAP in 2014. At 16 WAP, there was a ($P < 0.05$) significant difference across the treatments in which Sole Soybean (S) retained significantly ($P < 0.05$) higher soil moisture content than the other treatments. At 16 WAP, there was no significant difference between soil moisture retained under sole *Desmodium* (D) and Maize *Desmodium* intercropping (MD). Treatment under sole maize (M) retained least SMC in 2014. At 8 and 16 WAP, there was no significant difference ($P > 0.05$) among the treatments in 2015. 4.3.3

Table 4.4 Effect of Cropping Systems on Bulk Density for 2014 and 2015

	2014		2015	
	8 WAP	**16 WAP**	**8WAP**	**16WAP**
	←	Mgm^{-3}		→
Treatment				
M	1.61^{a}	1.48a	1.57	1.46
S	1.59^{ab}	1.39^{b}	1.56	1.49
D	1.48^{c}	1.39^{b}	1.42	1.40
MS	1.53^{bc}	1.46^{ab}	1.45	1.42
MD	1.54^{abc}	1.46^{ab}	1.51	1.49
MS2:4	1.51^{c}	1.42^{ab}	1.44	1.41
MD2:4	1.49^{c}	1.42^{ab}	1.51	1.47
SE±	0.03	0.03	0.19	0.20

Means with the same letter for each factor are not significantly different at 5% level of Probability using Duncan Multiple Range test, **M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium,* **MS**=Maize/Soybean intercrop,**MD**=Maize/*Desmodium* intercropping, **MS2:4**=Maize/ soybean strip croppingand **MD 2:4**=Maize/ *Desmodium*stripcropping**,** WAP=Weeks AfterPlanting.**Trt=**Treatme

Table 4.5 **Effect of Cropping Systems on Soil Moisture content (MC) in 2014 and 2015**

	2014		2015	
	MC			
	8WAP	16WAP	8 WAP	16 WAP
	←	cm^3/cm^3		→
Treatment				
M	0.243	0.236^{c}	0.330	0.356
S	0.258	0.349^{a}	0.325	0.348
D	0.248	0.301^{ab}	0.298	0.329
MS	0.252	0.257^{bc}	0.308	0.333
MD	0.225	0.304^{ab}	0.319	0.346
MS2:4	0.225	0.247^{bc}	0.323	0.350
MD2:4	0.228	0.259^{bc}	0.311	0.340
SE±	0.018	0.022	0.013	0.015

Means with the same letterfor each factorare not significantly different at 5% level of Probability using Duncan Multiple Range test. **M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop,**MD**=Maize/*Desmodium* intercrop, **MS2:4**=Maize/strip crop soybean and**MD 2:4=**Maize/ *Desmodium*strip**,** WAP=Weeks after Planting

Soil mean weight diameter (MWD)

Table 4.6 shows that maize/soybean intercropping (MS) resulted in a significantly higher ($P < 0.05$) mean weight diameter (MWD) than the other cropping systems. The least MWD resulted under sole maize which was not significantly different from treatments under D, MS 2:4andMD 2:4 in 2014. There was no significant difference in MWD under all the treatment in 2015. However, MWD generally increased across all treatments with sole *Desmodium* giving significantly ($P < 0.05$) higher MWD than all other treatments.

4.4 Effect of cropping systems on soil chemical properties

4.4.1 Soil pH

Table 4.7 contains data on effect of cropping system on soil pH in 2014 and 2015. It shows that treatment MD 2:4 significantly ($P < 0.05$) increased soil pH in water and $CaCl_2$, followed by MS 2:4 and the least pH (high acidity) was recorded under sole maize. Treatments under S, D,MS, MD, MS 2:4 and MD 2:4 had similar pH value in water, while Treatment M, S, D, MS, MD andMS 2:4 also had similar pH in $CaCl_2$. The pH in $CaCl_2$ were slightly more acidic than pH in water. The pH in water and $CaCl_2$ were both lowest under treatment M. Generally in 2015, pH in water and $CaCl_2$ were slightly higher than those in 2014; except for treatment M, where pH in $CaCl_2$ reduced; i.e. more acidic. In Sole *Desmodium*, pH increased slightly from 6.10 to 6.13 (pH water) and 5.82 to 5.85 (pH $CaCl_2$)

Table 4.7 also presents the soil pH in 2014, 2015 cropping seasons and means across the two years. Means across the two years show that pH in water under sole maize had lower pH than all other treatments. The higher pH in water resulted under treatment MD 2:4 which was almost neutral. Other treatments had similar pH values apart from treatment under M and MD 2:4.Treatment under MD 2:4 had higher pH in $CaCl_2$ and the least was under sole maize.

Table 4.6 Effect of Cropping Systems on dry mean weight diameter of soils at harvest in 2014 and 2015

MWD 2014	2015	
Treatment		
M	0.5417^{b}	0.7067^{b}
S	0.6150^{ab}	0.9283^{a}
D	0.5633^{b}	0.7200^{b}
MS	0.6467^{a}	0.9317^{b}
MD	0.6040^{ab}	0.8820^{b}
MS2:4	0.5683^{b}	0.8567^{b}
MD2:4	0.5700^{b}	0.9986^{b}
SE±	0.02	0.0001

Means with the same letter for each factorare not significantly different at 5% level of probability using Duncan Multiple Range test.**Mean Weight Diameter (MWD), M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/*Desmodium* intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize*Desmodium* strip**.**

4.4 Effect of cropping systems on soil chemical properties

4.4.1 Soil pH

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Table 4.7 **Effect of cropping system on soil pH during the 2014, 2015 cropping season and the mean across the two years at Samaru, Northern Nigeria**

Treatment	2014		2015		Combined	
	pH (water)	pH ($CaCl_2$)	pH (water)	pH ($CaCl_2$)	pH (water)	pH ($CaCl_2$)
M	5.99^{f}	5.29^{c}	6.00^{e}	4.90^{b}	5.99^{e}	5.21^{d}
S	6.32^{cd}	5.72^{b}	6.35^{cd}	5.85^{a}	6.33^{d}	5.79^{c}
D	6.10^{ef}	5.82^{b}	6.13^{e}	5.85^{a}	6.43^{c}	5.84^{c}
MS	6.47^{bc}	5.91^{b}	6.50^{bc}	5.90^{a}	6.51^{bc}	6.01^{b}
MD	6.27^{de}	5.72^{b}	6.30^{d}	5.75^{a}	6.30^{d}	5.74^{c}
MS 2:4	6.54^{b}	5.95^{b}	6.55^{b}	5.95^{a}	6.55^{b}	6.07^{b}
MD 2:4	6.94^{a}	6.28^{a}	6.75^{a}	6.15^{a}	6.99^{a}	6.21^{a}
SE±	0.06	0.11	0.06	0.15	0.03	0.04

Means with the same letter within each factor are not significantly different at 5% level of probability using Duncan Multiple Range test.**M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/*Desmodium* intercropping, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize/strip crop *Desmodium*

The pH in 2015 was higher than pH in 2014 among all the treatments. The highest pH (6.20) in $CaCl_2$resulted under maize soybean strip (MS 2:4) in 2015.

4.4.2 Effect of Cropping Systems on Soil Organic Carbon (OC), Total Nitrogen (TN) and Available phosphorus (Avail. P) during the 2014, 2015 cropping season and the mean across the two years at Samaru, Northern Nigeria

Table 4.8 shows that Maize*Desmodium* strip (MD 2:4) resulted in 9.51gkg^{-1} OC content. It was also statistically ($P < 0.05$) higher than treatments under M, S, D, MS, MD and MS2:4 in 2014. Maize *Desmodium* intercrop (MD) resulted in least OC content with value of 2.72 gkg^{-1}. There was no significant difference among treatments MS 2:4 (4.25gkg^{-1}) and D (4.27gkg^{-1}). In 2015, soil OC slightly increased across the treatments; except for treatment M, which decreased slightly. Treatment under MD 2:4 had higher OC content and the least was under MD intercrop.

Table 4.8 presentseffect of cropping system on organic carbon (OC) content and total nitrogen (TN) during 2014, 2015 cropping season and means across the years. Means across the two years show that treatment MD 2:4 was significantly higher in OC content than all the other cropping system. Treatment MD 2:4 consistently had higher OC content than other cropping systems evaluated in two years of study and in the combined mean. Treatment MD had the least OC content when the two years were combined.Soil total nitrogen was higher in treatment MD 2:4 with a mean value of 1.32 gkg^{-1}, followed by treatmentMS and the least was under sole maize in 2014. In 2015,soil total nitrogen increased across all treatments while treatment MD 2:4 resulted in higher TN content than all other cropping systems and the least TN was obtained under sole maize.The soil TN under maize intercrop with legumes (Soybean and *Desmodium*) was higher than that under sole maize.

Table 4.8 Effect of Cropping Systems on Soil Organic Carbon (OC) and Total Nitrogen (TN) during the 2014, 2015 cropping season and the mean across the two years at Samaru, Northern Nigeria

Treatment	2014 OC (g kg^{-1})	2014 TN (g kg^{-1})	2015 OC (g kg^{-1})	2015 TN (g kg^{-1})	Combined OC (g kg^{-1})	Combined TN (g kg^{-1})
M	5.06^{b}	0.39^{d}	5.65^{c}	0.51^{c}	5.00^{c}	0.50^{d}
S	3.96^{de}	0.69^{c}	4.15^{c}	0.61^{c}	4.87^{d}	0.67^{c}
D	4.27^{d}	0.45^{d}	4.35^{c}	0.63^{c}	4.63^{e}	0.50^{d}
MS	5.85^{c}	0.93^{b}	6.85^{b}	0.98^{b}	6.60^{b}	0.96^{b}
MD	2.72^{e}	0.39^{d}	3.25^{c}	0.54^{c}	3.57^{g}	0.46^{e}
MS 2:4	4.25^{d}	0.47^{d}	4.50^{c}	0.56^{c}	4.13^{f}	0.51^{d}
MD 2:4	9.51^{a}	1.32^{a}	9.89^{a}	1.48^{a}	7.57^{a}	1.40^{a}
SE±	0.46	0.05	0.67	0.09	0.07	0.01

Means with the same letterwithin each factorare not significantly different at 5% level of probability using Duncan Multiple Range test. **M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/*Desmodium* intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize/strip crop *Desmodium*

The soil TN was significantly higher in plot planted with the treatment MD 2:4 in two years and means across the years. Treatment under MD had the least amount of TN content among means across the two years. (Table 4.8)

In 2014, available phosphorus was higher than those in 2015 among the treatments (Table 4.9) The result shows that available. P for all treatments were significantly ($P < 0.05$) different. However, treatment under S had significantly higher available phosphorus than other treatments and the least resulted under sole *Desmodium* in 2014. In 2015, treatment under S resulted in higher available. P and the least was under treatment D.The adoption of sole soybean would favored increased soil available phosphorus in the two years of trials and mean across the years of study. Though, there was a decrease in available P in 2015 when compared to that in 2014, avail. P under sole soybean was statically different from other cropping system. (Table 4.9).

4.4.3 Effect of Cropping Systems on Exchangeable Acidity (EA)

Table 4.10 presents information on exchangeable acidity of the soil. In 2014, Treatment MS,MS 2:4 and D were statistically the same ($P < 0.05$) and had higher values in exchangeable acidity than other treatments. The least was recorded under sole maize in exchangeable acidity values of the soil ranged between 0.03 and 0.10 cmol kg^{-1} which is below the threshold limit of 1.0 cmol kg^{-1} for acid soils (Table 4.10).

Table 4.9 **Effect of Cropping Systems on Available phosphorus (Avail. P) during the 2014, 2015 cropping season and the mean across the two years at Samaru, Northern Nigeria**

Treatment	2014 Avail. P (mg kg^{-1})	2015 Avail. P (mg kg^{-1})	Combined Avail. P (mg kg^{-1})
M	11.30^{bc}	10.30^{b}	13.80^{c}
S	17.32^{a}	15.05^{a}	18.68^{a}
D	6.24^{e}	6.20^{c}	9.26^{g}
MS	9.83^{cd}	10.83^{b}	13.32^{d}
MD	13.14^{b}	13.10^{a}	16.24^{b}
MS 2:4	10.81^{bcd}	6.81^{c}	11.81^{e}
MD 2:4	7.69^{de}	7.58^{c}	10.68^{f}
SE±	1.05	0.078	0.16

Means with the same letter are not significantly different at 5% level of probability using Duncan Multiple Range test.**M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/Desmodium intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize*Desmodium*strip *****= Significant, WAP=Weeks After Planting

Table 4.10 Effects of Cropping system on Exchangeable acidity(EA) at harvest in 2014 and 2015

	2014	2015
	Exchangeable acidity($H^+ + Al^{3+}$)	
	<------------------------cmol kg^{-1}----------------------------->	
Treatment		
M	0.04^c	0.10^a
S	0.05^{ab}	0.05^b
D	0.05^a	0.05^b
MS	0.06^a	0.05^b
MD	0.05^{bc}	0.05^b
MS 2:4	0.06^a	0.05^b
MD 2:4	0.03^d	0.03^b
SE±	0.003	0.01

Means with the same letter within each factor are not significantly different at 5% level of probability using Duncan Multiple Range test.**M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/*Desmodium* intercropping, **MS2:4**=Maize/ soybean strip croppingand **MD 2:4**=Maize/*Desmodium*stripcropping

4.4.4 Effect of Cropping Systems on Exchangeable Cation and Cation ExchangeCapacity (CEC)

Tables 4.11 and 4.12 present data on soil Exchangeable Cations (Ca, Mg, K and Na) and Cation Exchange Capacity (CEC). The result obtained shows that treatment MD 2:4 had higher calcium value followed by treatment MS and the least value was under treatment MD in 2014. In 2015, soil calcium values improved across the treatments and although MD2:4 treatment had higher Ca^{+2} content, it was not significantly different from treatment MS. Results also show that treatment under MS resulted in higher Magnesium (Mg^{+2}) content that was not significantly different from treatment MD 2:4.The least soil Mg^{+2} was under maize-*Desmodium* intercrop which was statistically similar with treatment D in 2014. Treatment under MS resulted in higher Mg^{+2} content and treatment MD resulted in the lowest Mg^{+2} content in 2015.Results also show that treatment underMD 2:4 had higher exchangeable potassium (K^{+}) content than all other treatments followed by treatment MS 2:4 and the least resulted under sole soybean, but which was statistically the same with all other treatments (Table 4.11).

The K^{+} values in 2015 were slightly higher than those in 2014. In 2015, treatment MD2:4 resulted in higher K^{+} content that was significantly ($P <0.05$) different from all the other treatments. The lowest was under sole soybean and was statistically the same with the other treatments (Table 4.12).Treatment M and MD 2:4 resulted in higher sodium (Na^{2+})content and were statistically different significantly ($P <0.05$) from other treatments. The least sodium (Na^{2+})content resulted from treatment MS and MS 2:4 in 2014.Treatment under MD2:4 resulted in higher Na^{2+} content and was significantly ($P < 0.05$) different from all other treatments. Maize soybean intercrop resulted in the lowest Na^{2+} content in

2015 (Table 4.12). Cation Exchange Capacity (CEC) under treatment MD 2:4 resulted in significantly ($P < 0.05$) higher value than all other treatments. Sole *Desmodium* and MS 2:4 had statistically similar CEC value, the lowest CEC content in 2014 (Table 4.11). In 2015, CEC across all the treatments reduced. Treatment MD2:4 had a higher CEC than all other treatments, while treatment MS 2:4 had the least soil CEC (Table 4.12). Interaction between Treatments and Depths were significantly different in exchangeable acidity and CEC in both years (2014 and 2015). Exchangeable acidity and CEC were affected by croppy systems since significant changes were recorded within treatments.

4.4.5 Effect of Cropping Systems on some soil binding agents (Fe, Mn and Mg)

In 2014, treatment under sole Desmodium resulted in higher amount of Fe with a value of 295.00mgkg^{-1} and was not significantly different from treatment under sole maize and maize strip crop soybean. Treatment under sole soybean resulted in the lowest amount of Fe with value of 100.16mgkg^{-1} which was not significantly different from treatment maize/soybean intercrop. Maize Desmodium strip resulted statistically in higher amount of Mg with value 39.95mgkg-1 which was not significantly different from MS intercrop. Treatment D resulted in lowest amount of Mg with value 29.89mgkg^{-1} which significantly different from other cropping systems.

Treatment MD 2:4 resulted in higher amount of Mn with value 63.33mgkg-1 which was significantly different from other treatment. The lowest amount of Mn resulted under treatment S with value 38.43mgkg-1 and was significantly different from other treatment. Treatment under sole desmodium had highest binding agent. This suggest that the treatments with higher binding agent could hold the soil better than those with lower amount of binding agent and can also form better soil aggregates. (Table 4.13)

Table 4.11 Effect of Cropping Systems on exchangeable cations and CEC at harvest in 2014

	Exchangeable Cation				
	Ca	**Mg**	**K**	**Na**	**CEC**
Treatment	<----------------------------	--------cmol kg^{-1}	-------	------------------	---------->
M	1.50^{cd}	0.52^{b}	0.14^{b}	0.11^{a}	5.09^{b}
S	1.70^{c}	0.47^{b}	0.12^{b}	0.04^{b}	5.03^{b}
D	1.20^{de}	0.32^{c}	0.12^{b}	0.04^{b}	4.42^{c}
MS	2.55^{b}	0.87^{a}	0.15^{b}	0.03^{b}	6.76^{a}
MD	1.00^{e}	0.30^{c}	0.14^{b}	0.07^{ab}	4.98^{bc}
MS 2:4	1.60^{c}	0.84^{b}	0.17^{b}	0.03^{b}	4.42^{c}
MD 2:4	3.15^{a}	0.84^{a}	0.24^{a}	0.012^{a}	6.98^{a}
SE±	0.13	0.03	0.02	0.02	0.19

Means with the same letter within each factorare not significantly different at 5% level of probability using Duncan Multiple Range test,**M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/Desmodium intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize/strip crop *Desmodium.*

Table 4.12 Effect of Cropping Systems on exchangeable cations and CEC at harvest in 2015

	Exchangeale Cation				
	Ca	**Mg**	**K**	**Na**	**CEC**
Treatment	<------------------------------cmol kg^{-1}-------------------------->				
M	2.10^{b}	0.57^{b}	0.19^{b}	0.09^{a}	4.63^{b}
S	1.80^{c}	0.51^{bc}	0.14^{b}	0.03^{b}	4.52^{bc}
D	1.30^{d}	0.37^{d}	0.17^{b}	0.03^{b}	4.03^{bc}
MS	3.10^{a}	0.93^{a}	0.16^{b}	0.02^{b}	6.05^{a}
MD	1.10^{d}	0.33^{d}	0.15^{b}	0.07^{ab}	4.38^{bc}
MS 2:4	1.70^{d}	0.49^{c}	0.18^{b}	0.06^{ab}	4.00^{c}
MD2:4	3.20^{a}	0.87^{a}	0.26^{a}	0.11^{a}	6.44^{a}
SE±	0.09	0.02	0.02	0.02	0.19

Means with the same letterwithin each factorare not significantly different at 5% level of probability using Duncan Multiple Range test,****=**highly significant**,M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/*Desmodium* intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize*Desmodium*strip

Table 4.13 Effects of Cropping System on Soil Binding Agent in 2014 and 2015

	2014			2015		
Treatment	**Fe ($mgkg^{-1}$)**	**Mg ($cmolkg^{-1}$)**	**Mn ($mgkg^{-1}$)**	**Fe ($mgkg^{-1}$)**	**Mg ($cmolkg^{-1}$)**	**Mn ($mgkg^{-1}$)**
M	292.03^{a}	35.07^{bc}	53.83^{abc}	310.24^{a}	36.86^{b}	53.94^{abc}
S	100.16^{c}	34.44^{bc}	38.43^{d}	86.93^{d}	35.80^{b}	36.30^{d}
D	295.00^{a}	29.89^{d}	43.62^{dc}	281.82^{a}	30.69^{c}	42.15^{d}
MS	141.92^{c}	38.04^{a}	57.29^{ab}	178.98^{c}	38.70^{a}	55.94^{ab}
MD	268.34^{ab}	32.57^{cd}	47.49^{bcd}	254.66^{ab}	33.83^{b}	46.48^{bcd}
MS 2:4	280.74^{a}	37.15^{ab}	46.33^{cd}	268.18^{a}	35.69^{b}	44.82^{cd}
MD 2:4	214.19^{b}	39.95^{a}	63.33^{a}	200.57^{bc}	39.22^{a}	62.23^{a}
SE±	19.132	0.941	3.524	20.096	0.908	3.435

Means with the same letter within each factorare not significantly different at 5% level of probability using Duncan Multiple Range, **M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/*Desmodium* intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize/strip crop *Desmodium*

4.4.6 Effect of cropping system on Organic Carbon sequestration in large and small macro aggregate during the 2014, 2015 cropping season and the means across the two years at Samaru, Northern Nigeria

Table 4.14 depicts the effect of cropping system and sampling depth on organic carbon (OC) content in large macro aggregate (LMa) (2.36-2.00mm) and small macro aggregate (SMa) (2.00-0.25mm) during the 2014, 2015 and means across the years at Samaru. Resulting aggregates due to cropping system shows that adoption of MS resulted in highest OC content sequestered in large macro aggregate in each of the two years (2014 and 2015) with OC values of 1.35gkg^{-1} and 0.93 gkg^{-1} respectively and when the years were combined, the OC value was 1.36 gkg-1. The least amount of OC content sequestered in large macro aggregate resulted under MD intercrop with OC value of 0.38 gkg^{-1} when the two years were combine.In 2014 and 2015 higher OC content resulted significantly under MS in both large and small macro aggregates followed by MD 2:4 and the least resulted under MD intercrop.

. The mean OC content sequestered in large macro aggregates in 2014, 2015 and means across the years were more than that sequestered in small macro aggregates. (Table4.14)

4.4.7 Effect of cropping system on Organic Carbon sequestration in micro aggregate and silt and clay fraction during the 2014, 2015 cropping season and the means across the two years at Samaru, Northern Nigeria

Table 4.15 depicts the effect of cropping system and sampling depth on soil organic carbon (OC) content in micro aggregate (MIa) (0.25-0.05mm) and silt and clay (SCa) fraction (0.05 - < 0.05mm) during the 2014,2015 and means across the years at Samaru.Effect due to cropping systems show that adoption of MS resulted in highest OC content sequestered in micro aggregate and higher in silt and clay fraction under sole maize in 2014.

Table 4.14 Effect of cropping system on Organic Carbon sequestration in large and small macro aggregate during the 2014, 2015 cropping season and the means across the two years at Samaru, Northern Nigeria

	2014		2015		combined	
	←-------------------- Organic carbon (gkg^{-1})------------------------->					
Treatment	**LMa**	**SMa**	**LMa**	**SMa**	**LMa**	**SMa**
M	0.70^{c}	0.73^{c}	0.76^{c}	0.77^{c}	0.73^{c}	0.75^{c}
S	0.63^{d}	0.59^{d}	0.64^{d}	0.68^{e}	0.64^{d}	0.64^{d}
D	0.49^{e}	0.53^{e}	0.57^{e}	0.54^{f}	0.53^{e}	0.53^{f}
MS	1.35^{a}	0.87^{a}	1.38^{a}	0.93^{a}	1.36^{a}	0.89^{a}
MD	0.39^{g}	0.37^{g}	0.40^{g}	0.39^{g}	0.39^{g}	0.38^{g}
MS 2:4	0.42^{f}	0.49^{f}	0.49^{f}	0.72^{d}	0.46^{f}	0.60^{e}
MD 2:4	0.78^{b}	0.83^{b}	0.90^{b}	0.80^{b}	0.84^{b}	0.82^{b}
SE±	0.004	0.001	0.006	0.006	0.004	0.003

Means with the same letterwithin each factor are not significantly different at 5% level of probability using Duncan Multiple Range.: **LMa** and **SMa** are 2.36mm-2mm and 2mm-0.25mm respectively**. Trt=**Treatment**, Dpt=** Depth**, Yr=** Year, **M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/Desmodium intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize/strip crop *Desmodium.*

1n 2015, soil OC was more sequester under MS in micro aggregates and higher under MD 2:4 in silt and clay fraction. When the years were combined, the highest amount of OC was under MS and the least resulted under MD and the highest OC content was under sole maize in silt and clay fraction. The mean OC content sequestered in micro aggregate in 2014, 2015 and means across the years were more than that sequestered in silt and clay fraction. The interactions in 2014, 2015 and means across the years were significant. Treatment MD 2:4 had highest OC content in micro aggregate. Soil OC sequestered in micro aggregate and silt and clay fraction were affected by treatments such that soil OC content gradually changed with type of management practice adopted; especially when legumes are used**.**

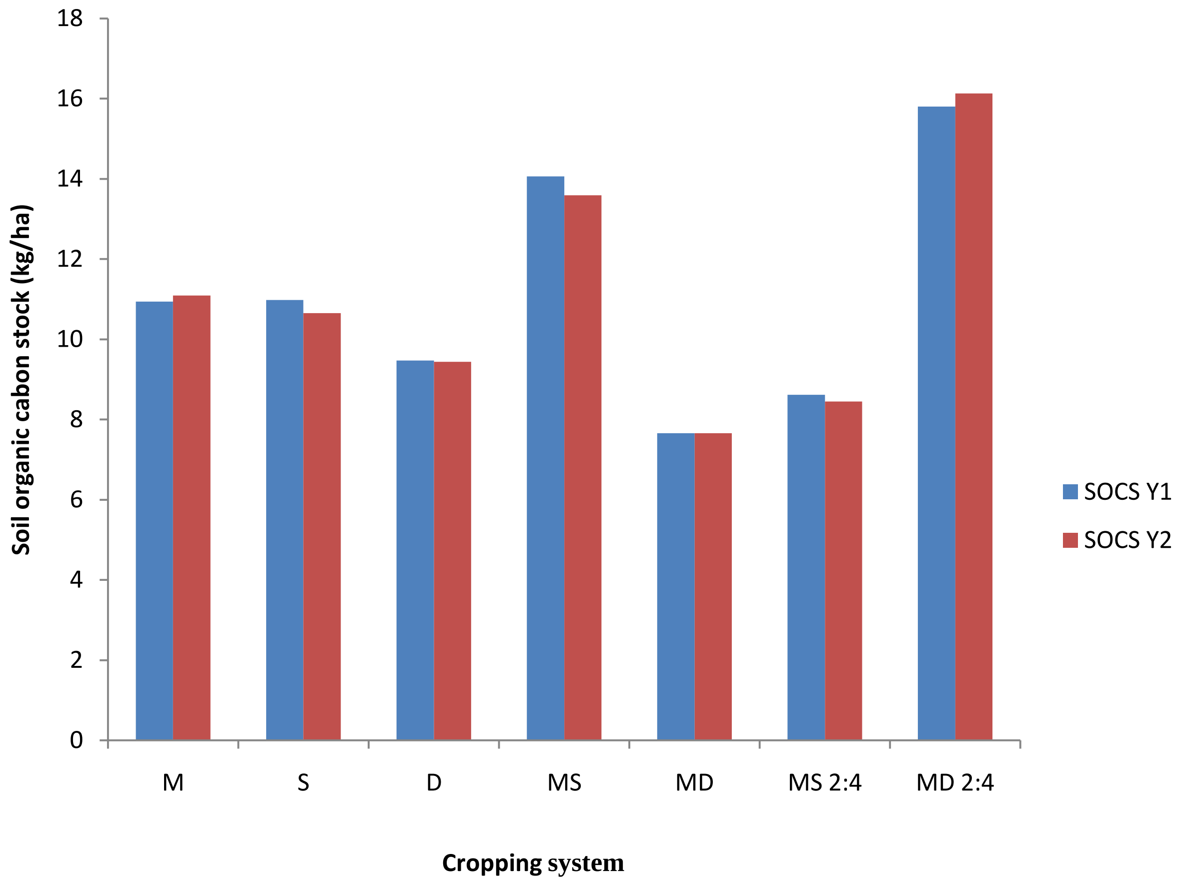
4.4.8 Effect of cropping system on Soil Organic Carbon stock (SOCs) in 2014.

Fig 4.15 presents result on effect of cropping system on Soil organic carbon stock (SOCs) in 2014 and 2015. Treatments under maize/*Desmodium* strip cropping (MD2:4) had higher SOCs with values of 15.80kg ha^{-1} and the lowest was under maize/*Desmodium* intercropping in 2014.in 2015,soil organic carbon stock was increase slightly among treatments and the organic carbon stock was higher under maize/*Desmodium* strip cropping (MD2:4) with organic carbon content of 16.13kg ha^{-1} and the lowest was under maize/*Desmodium* intercropping with organic carbon content of 7.69kg ha^{-1} .Soil organic carbon stock under MD2:4 and MS 2:4 was higher than that under sole maize in both years (Fig: 4.2).

Table 4.15 Effect of cropping system on Organic Carbon sequestration in microaggregate and silt and clay fraction during the 2014, 2015 cropping season andthe means across the two years at Samaru, Northern Nigeria

	2014		2015		combined	
	←---------------------**Organic carbon** (gkg^{-1})--------------------->					
Trt	**MIa**	**SC_f**	**MIa**	**SC_f**	**Mia**	**SCa**
M	0.76^b	0.75^a	0.76^c	0.72^b	0.76^b	0.74^a
S	0.55^e	0.54^d	0.57^e	0.55^e	0.56^e	0.55^d
D	0.39^f	0.37^f	0.44^f	0.41^g	0.41^f	0.39^f
MS	0.80^a	0.61^c	0.80^a	0.61^d	0.79^a	0.61^c
MD	0.34^g	0.45^e	0.42^g	0.50^f	0.38^g	0.47^e
MS 2:4	0.59^d	0.66^b	0.60^d	0.67^c	0.59^d	0.66^b
MD 2:4	0.68^c	0.54^d	0.79^b	0.78^a	0.74^c	0.66^b
SE±	0.003	0.003	0.007	0.008	0.004	0.004

Means with the same letter within each factor are not significantly different at 5% level of probability using Duncan Multiple Range**.** Mia and SC_f = sieve sizes 0.25 - 0.05mm and 0.05 - <0.05mmrespectively**. Trt=**Treatment, **M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium,* **MS**= Maize/Soybean intercrop, **MD**=Maize/*Desmodium* intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize*Desmodium*strip



M=Sole maize, S=sole Soybean, D=sole *Desmodium*, MS=Maize soybean intercrop, MD=Maize Desmodium intercrop, MS 2:4=maize strip crop soybean, MD 2:4=Maize *Desmodium* strip. SOCS=soil organic carbon stock,Y1=2014, Y2=2015

Fig: 4.1 Effect of cropping system on Soil Organic Carbon stock (SOCs) in 2014 and 2015

4.5 Crop Performance

4.5.1 Effect of Cropping Systems on Crop Height (2014 and 2015)

Table 4.16 presents maize height at 4,8 and 12 WAP. Treatment under maize/soybean intercrop (MS) recorded tallest maize plants compared with the other cropping systems. This treatment was significantly ($P < 0.05$) higher than all other cropping system at 8 WAP in 2014. It also shows statistically that there was no difference among all the treatment at 4, and 12 WAP. At 4 WAP, Maize-*Desmodium* intercropping (MD) was higher in height than all other cropping systems. In 2015, there were improvements in plant height across the treatment at 4, 8 and 12 WAP. At 8 and 12 WAP MS was higher than all other cropping system (Table 4.16).

4.5.2 Effect of cropping system on maize grain, stover and cob yield of maize at harvest in 2014 and 2015

Results obtained show that in 2014, maize/*Desmodium* intercropping (MD) produced significantly ($P < 0.05$) higher grain yield and the lowest grain yield resulted under Maize/Soybean intercrop (MS). Treatment MD resulted in higher cob yield that was significantly ($P < 0.05$) different from other treatments. The lowest cob yield was obtained under treatment MS and was significantly the same with MS 2:4. Treatment under MD resulted in higher stover yield, which was also significantly different from the other treatments. The lowest stover yield was obtained under treatment MS. (Table 4.17). Grain yields (GY), stover yield (SY) and Cob weight in 2015 were generally improved when compared with those in 2014. Treatment under sole maize (M) had higher grain yield which was not significantly ($P > 0.05$) different from treatment under maize-*Desmodium* intercrop

(MD). Lowest grain yield resulted under treatment MS and was significantly ($P < 0.05$) different from other treatments.

Table 4.16 Effects of cropping systems on maize height in 2014 and 2015

<----------------------------Maize Height (cm)------------------------------->						
		2014			**2015**	
	4	**8**	**12**	**4**	**8**	**12**
Treatment	<--------------------------------		**WAP**	---------------------------------->		
M	56.50	99.57[ab]	120.97	61.80[ab]	110.00	139.27
MS	59.01	112.70[a]	131.23	60.87[ab]	133.00	151.30
MD	59.64	103.40[ab]	126.33	64.77[ab]	115.00	143.87
MS2:4	59.60	96.07[b]	118.03	65.27[a]	138.00	141.40
MD2:4	53.82	90.53[b]	122.97	59.93[b]	106.00	146.03
SE±	1.84	5.07	5.88	1.56	1.68	6.36

Means with the same letterwithin each factorare not significantly different at 5% level of probability using Duncan Multiple Range test.**M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/*Desmodium* intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize*Desmodium*strip. WAP=Weeks after Planting.

Table 4.17 Effects of Cropping System on Maize Yield (t ha^{-1}) at harvest in 2014 and 2015

	2014			2015		
	GY	CY	SY	GY	CY	SY
Treatment	←			t ha^{-1}		→
M	2.133^{ab}	0.800^{ab}	3.767^{ab}	3.133^{a}	1.200	4.527^{ab}
MS	0.493^{c}	0.233^{b}	1.950^{c}	0.867^{b}	0.300	2.633^{b}
MD	2.233a	1.050^{a}	4.683^{a}	2.900^{a}	1.433	4.897^{a}
MS 2:4	0.960^{bc}	0.333^{ab}	3.283^{abc}	1.633^{ab}	0.400	4.633^{ab}
MD 2:4	1.267^{ac}	0.233^{b}	2.950^{c}	1.633^{ab}	0.300	3.633^{ab}
SE±	**0.384**	**0.249**	**0.460**	**0.503**	**0.399**	**0.70**

Means with the same letter within a column or treatments are not significantly different at 5% level of probability using Duncan's Multiple Range test. **M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/*Desmodium* intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize*Desmodium* strip
GY = Grain yield
CY = Cob yield
SY = Stover Yield

There was nosignificant difference in Cob Weight. Treatment MD resulted in higher stover weight which was significantly ($P < 0.05$) different from other treatment, while treatment MS resulted in the lowest stover weight (Table 4.15).

4.5.3 1000-grain weight (1000GW) and days to 50% tasseling (DTT) of maize

Table 4.18 presents data on effect of cropping system on 1000-grain yield and days to 50% tasseling of maize. It shows that treatment MS resulted in significantly higher 1000-grain weight than other treatments while treatment MS 2:4 resulted significant the lowest 1000-grain yield. Treatment MS had 172.33g weight of 1000GW of maize while MS 2:4 had 156.67g weight of 1000GW of maize.Treatment under Sole maize (M) reached 50% days to tasseling at 45 days earlier than other treatments. Treatment MS and MS 2:4 reached 50% tasseling late; 60 days and 60 days respectively than other treatment in 2014.There was no significant difference in 1000-grain weight and days to 50% tasseling in 2015.

4.5.4 1000-grain weight (1000 GW) and days to 50% flowering (DTF) of Soybean: Table 4.19 presents data on 1000-grain weight (1000 GW) and days to 50% flowering (DTF) of Soybean. It shows that in 2014, sole Soybean (S) treatments resulted in higher 1000-grain weight with a value of 148.33g than MS and MS 2:4; while MS and **MS**2:4 were significantly ($P > 0.05$) same. Table 4.18 also shows that Sole Soybean reached 50% flowering stage earlier at 44 days than MS while MS 2:4 further delayed flowering (59 days).

Table 4.18 Effects of cropping system on 1000 GW and DTT of Maize in 2014 and2015.

	2014		2015	
Treatment	**1000GW (g)**	**DTT (#)**	**1000GW(g)**	**DTT(#)**
M	167.33^{ab}	45.00c	243.67	44.67
MS	172.33^{a}	60.00^{a}	254.00	47.00
MD	170.50^{ab}	49.00^{b}	252.33	47.00
MS 2:4	156.67^{b}	60.00^{a}	241.67	42.67
MD 2:4	168.17^{ab}	49.00^{b}	251.00	48.67
SE±	3.52	0.59	3.94	6.39

Means with the same letter are not significantly different at 5% level of probability using Duncan's Multiple Range test.**M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/*Desmodium* intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize/strip crop *Desmodium*.**GW**=Grain weight, **DTT**=Days to 50% tasseling, **GW = Grain weight**, **DTT=Days to 50% Tasseling**

Table 4.19 Effects of cropping system on 1000-grain weight (GW) and Days to 50% flowering of Soybean; 2014 and 2015

	2014		2015	
Treatment	**1000GW(g)**	**Days to 50% Flowering (#)**	**1000GW(g)**	**Days to 50% Flowering(#)**
S	148.33a	44b	159.00	45
MS	139.61b	56a	146.53	55
MS 2:4	136.00b	59a	143	56
SE±	2.94	1.96	3.62	3.07

Means with the same letter are not significantly different at 5% level of probability using Duncan Multiple Range test. **M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium*, **MS**= Maize/Soybean intercrop, **MD**=Maize/*Desmodium* intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize *Desmodium* strip,**GW**=Grain Weight, **DFF**=Days to 50% flowering

4.6 Assessment of the Productivity of intercropping and strip-cropping

The results of land equivalent ratio (LER) obtained for maize productivity under maize/soybean intercrop and strip cropping systems are presented in Table 4.20. The value of land equivalent ratio (LER) was higher under maize/soybean intercropping system compared to that of maize/soybean strip-cropping in both years. The percentage differences were19.13 % for 2014 and 13.22 % for 2015.However, results also indicated that the LER obtained under intercrop was similar in 2014 and 2015 whereas reverse was the case for strip cropping. Values of LER recorded in both cropping systems were greater than 1, which indicated higher productivity of maize; advantage in strip and intercrop systems, than when maize is grown under sole cropping.

4.7 Soil quality and maize yield assessment on the cropping system

Soil quality assessment on the cropping systems used in this study are presented in Table 4.22.Soil reaction was slightly acidic in M and almost neutral in MD 2:4 while other cropping systems were moderately acidic. Total nitrogen, organic carbon and pH were generally best improved under MD 2:4 relative to other cropping systems and moderate under MS. Treatment under sole maize and maize/ *Desmodium* intercroppingwerebest scored in maizeyield, while maize soybean intercrop was ranked the least. Scores assigned to selected soil quality indicators ranked soil under maize strip crop *Desmodium*as the best quality,other treatment were ranked moderate and the least ranking in soil quality was under sole maize.

Table 4.21 Productivity from mean yield data of sole, intercropping andStrip-cropping system

Cropping system	Maize 2014	Soybean 2014	Maize 2015	Soybean 2015
Sole crop yield (t ha^{-1})	2.133	2.383	3.133	3.300
Intercrop yield (t ha^{-1})	0.493	2.187	0.867	3.070
Strip crop yield(t ha^{-1})	0.960	2.185	1.633	2.804
LER*i*	1.15		1.21	
Land saved (%)	13		17	
LER*s*	1.37		1.37	
Land saved (%)	27		27	

LER*i* = Land equivalent ratio (inter-cropping)
LER*s* = Land equivalent ratio (strip-cropping)

Table 4.21 **Soil Quality and Maize Yield Assessment on the Different Cropping System**

Treatments	**M**	**S**	**D**	**MS**	**MD**	**MS 2:4**	**MS 2:4**
pH (H_2O)	3	2	2	2	2	2	1
Org. C	3	3	3	2	4	3	1
Avai. P	3	1	4	3	2	4	4
Total N	4	3	4	2	4	4	1
BD	2	2	1	1	2	1	1
MWD	3	2	2	3	1	3	2
G/YD	1	Nil	Nil	3	1	2	2
Total score	19	13	16	16	16	19	11
SQ ranks	3	2	2	2	2	2	1

1=Best while **5=**Worst**. M**=sole maize, **S**=Sole soybean **D**=Sole *Desmodium***MS**= Maize/Soybean intercrop,**MD**=Maize/*Desmodium* intercrop, **MS2:4**=Maize/strip crop soybean and **MD 2:4**=Maize *Desmodium*strip, SQ= Soil Quality, G/YD= Grain yield

CHAPTER FIVE

5.0 DISCUSSION

5.1 Soil Physical Properties

5.1.1 Effect of cropping systems on bulk density

Bulk density of the soils increase from 1.39 Mg m^{-3} to 1.61 Mg m^{-3} at a depth of 0-20cm. This suggests that the soils were compact perhaps due partly to increasing use of agricultural machinery for tillage operations (Ike, 1987), and effect of uncontrolled grazing (Balasubramanian and Nnadi , 1980) in the area. Bulk density value under all the treatments increased at 8 WAP in 2014. These increases may have resulted from effect of surface crusting (Ike , 1987; Kowal, 1972). At 16 weeks after planting (WAP), BD under all the treatments; except that of sole maize (M), reduced. This suggests a reduction in compaction of the soils, perhaps due to influence of plant roots and soil fauna (Earth worm) within the surface soils at 16 WAP in 2014. There was no significant difference at 8 and 16 WAP in 2015 (Table 4.4)

5.1.2 Effect of cropping systems on soil moisture content (SMC)

At 16 WAP in 2014, treatmentunder sole soybean (S) had the highest SMC and treatment under Sole maize (M) resulted in the least SMC. Hence, soil under sole maize retained less moisture content. Treatment under legumes as intercrop and strip treatment,as well as the sole legumes had higher SMC values than the sole maize.This couldsuggest that at 16 WAP, treatment under legumes containing treatment would not cause adverse reduction in soil moisture. In situation of short dry spells occurring between 8 and 16 WAP, crops planted under legumes containing treatmentwould resist soil moisture stress better than those under sole maize.

Data contained in Table 4.5 therefore implies that under rain fed agriculture, when early rains are followed by short drought periods, Sole Soybean treatment would retain significantly more soil moisture than the other treatments. With respect to crop growth and performance, availability of soil water and nutrients will determine the survival of crops. (Adeoye, 1984).In Samaru area, straw materials are rarely available for mulching purposes. Therefore, Sole Soybean (S), sole *Desmodium* (D) and Maize-legumesintercrop are recommended for enhanced soil moisture storage in the absence of straw mulch. At 8 and 16 WAP in 2015, there was no significant ($P > 0.05$) difference under all treatments. Table 4.5

5.1.3 Effect of Cropping Systems on soil aggregates.

Table 4.6 shows that Maize/Soybean intercrop (MS) resulted in significantly ($P \leq 0.05$) higher mean weight diameter (MWD) than the other cropping systems in 2014. Mean weight diameter for M, D, and MS2:4andMD 2:4 were same and also lower, followed by S and MD. Maize-soybean intercrop (MS) havinghigher MWD, suggest that MS impacted positively on MWD of soils that could withstand wind erosion better compared to the other treatments. These results agree with the findings of McRae and Muhuys(1988) that legumes increase soil organic matter, which in turn improves soil physical properties by increasing the distribution and stability of soil aggregates. This also suggests that planting legumes in sole or legumes intercropped with cereals could improve soil aggregation than sole maize. Maize/soybean intercrop is therefore recommended in Samaru area to increase soil aggregates.

5.2 Effect of cropping systems onsoil chemical properties

5.2.1 Soil pH

In 2015, pH in water and $CaCl_2$ were slightly higher than in 2014; except for treatment M in which pH in $CaCl_2$ reduced; i.e. more acidic. These findings imply that these selected cropping systems (MD2:4) modified soil acidity to slightly acid range, at which most nutrients are readily available for crop roots uptake and fall within the best pH range (5.5 – 6.9) for maize cultivation William and Chew (1980). Treatment under sole legumes and those with legumes intercrop and strip treatments best increase soil pH; suggesting treatmentscould be effective in improving the soil acidic condition if left for at least one year or for several years. This finding is in accordance with the work of Odunze *et al*.(2013); who observed increase in pH of soil after one year fallow of legume *Centrocema pascuorum* under conservation tillage. In 2014 therefore, pH both in water and $CaCl_2$ were slightly acidic than those in 2015(Table 4.7).

Reasons for higher pH in plots planted with legumes and legumes intercrop with maize could have resulted from the effect of plant roots to resist leaching losses of nutrients and this is similar to earlier finding by Rusesel(1973). This could also be attributed from decomposed plant materials under the legumes-maize intercrop treatment and in accordance with the findings by (Brady, 1975).However, pH values under sole maize having lower pH than other treatment could have resulted from effects of leaching and continuous cultivation which led to decrease in soil pH. This is in accordance with the findings of Lal and Okigbo (1990) (Table 4.7).Values of pH in water were consistently higher than the values in $CaCl_2$ suggesting that the soils were net negatively charged. Means across the two years show that treatment under maize strip crop *Desmodium* had higher pH and the least was under sole maize. Treatment under MD 2:4 having higher pH could be attributed to higher organic matter (OM) content retained in MD 2:4 treatment plots, which accrues from return of crop residues to soils, since OM serves as buffer for soil pH. Lower pH under sole maize could be the result of continuous mining of nutrient by maize plant, use of chemical fertilizer (nitrogenous) and removal of crop residue after harvest (NCRCS, 2013).

5.2.2: Effect of Cropping Systems on Soil Organic Carbon (OC), Total Nitrogen(TN) and Available phosphorus (Avail. P) during the 2014, 2015 cropping season and the means across the two years at Samaru, Northern Nigeria.

Treatment under maize strip crop *Desmodium* (MD 2:4) having higher OC content in the soil could be attributed to the contribution of OC from *Desmodium* through litter fall biomass and root nodules decomposition. This agreed with the findings of Odunze*et al*.(2013) which says that natural fallow sequestered less organic carbon than plot where forage legume are planted. The relatively high OC content of soils under the legumes-maize intercrop is attributed to organic matter accumulation from root and leaf litter materials of the legumes and maize plants (Table 4.8). In 2015, soil organic carbon slightly increased across the treatments; except for the treatment M which decreased slightly. Reduction in OC content in soils under sole maize could suggest that soils would degrade with increasing years of cultivation in Samaru area (Table 4.8) Treatment under MD 2:4 resulted in higher soil total nitrogen value; followed by treatmentMS and the least resulted under sole maize which was not significantly different from treatment under maize-*Desmodium* intercrop (MD) (Table 4.8).

This suggest that legumesin maize based cropping systems could be considered better alternatives for securing nitrogen economy and increasing yield of maize; besides bonus yield, greater productivity per unit time and space and higher net returns of intercropping system over monoculture (Thayamini and Brintha, 2010).Also, legumes can relocate fixed N to intercropped cereals during their growing period and this N is an imperative resource for the cereals (Bhagad *et al*., 2006). Cereal and legumes have become a popular combination among farmers, probably due to legumes ability to combat erosion and raise soil fertility levels (Matusso *et al*., 2012) (Table 4.8).

The increases in TN under sole maize were attributed to the residual nitrogen following fertilizer (NPK) application to maize crop. The generally low soil N values in some of the legume-maize intercrop would be partly attributed to the loss of N from the residue; probably due to ammonia volatilization (Soil Management CRSP, 1992 and Russel 1973) of decomposing residue on soil surfaces.Legumes are viewed as serious component in conservation Agriculture (Meyer, 2010).Li *et al*. (2001) reported that nitrogen acceptance by maize in an intercrop is greater as relate to sole cropping. The greater N acquisition by a non - legume crop intercropped with a legume is often reported in literature (Francis, 1986; Vandermeer, 1989; Stern, 1993) (Table 4.8).

Means across the two years shows that MD 2:4 had higher TN. This may suggest that increase in TN was caused by the leguminous crop contained in the treatment. Treatment under MD having lower TN may be an indication of higher N utilization by both the cover crop and test crop (maize) growing concurrently on the soil. It was expected that the N utilized by the leguminous cover crops will be immobilized and later released back into the soil via the root nodules of legumes.

In 2014, treatment under sole soybean(S) resulted in significantly higher Avail. P than other treatments while treatment under sole *Desmodium* (D) had the lowest Avail. P. In 2015, there was reduction in soil available phosphorus across the treatments.Treatment under S resulted in higher available phosphorus; perhaps,attributableto legumes utilization of available phosphorus for protein synthesis(Kahn *et al.*,2002), Legumes facilitate utilization of soil Avail. P in the Northern Guinea Savanna of Nigeria. Therefore the slight reduction of available phosphorus found in 2015 may be as a result of the presence of these legumes (Soybean and *Desmodium*).These findings imply that these legumes (Soybean and *Desmodium*), increased soil organic carbon content and Soil total nitrogen and facilitated utilization of soil available phosphorus for protein synthesis; i.e., reduced the soil available phosphorus (Table 4.8)

Available phosphorus in the first year was higher than that in the second year. Means across the two years show that sole soybean had higher available P. The easily decomposable residues of soybean may have induced fast release of available P relative to the other cover crop in this study. Leaves,nodules and stalk of soybean are succulent in nature and therefore easily decompose to supply nutrients to the soil. Mineralization under soybean perhaps provide a significant portion of phosphorus in the soil.*Desmodium* having lower avail. P could suggest higher use of avail. P for protein synthesis by *Desmodium* (Table 4.9) than soybeans.

In addition low soil pH severely limits P availability to plant and may cause deficiency symptoms even where high soil test P level exist, because acidic soil hinder root growth which is critical to P uptake (USDA-NRCS, 2013). Generally, pH less than 5.5 typically reduces P availability in soil solution by 30% or more (USDA-NRCS, 2013). Higher P at the surface soils (0-10cm) may be due to the fact that application of P fertilizer was done at soil surface depth, since P is not a mobile element.Thus, there would occur a greater concentration of available P at the surface soil relative to the sub-surface soils. (Table 4.9)

5.2.3 Effect of Cropping Systems on soil Exchangeable Acidity (EA)

In both 2014 and 2015, acidity values of the soil ranged between 0.03 and 0.13 cmol kg^{-1} which is below the threshold limit of 1.0 cmol kg^{-1} for acid soils (Table 4.10). Treatments MS was higher in EA and was significantly the same with treatment under MS 2:4 in 2014. In 2015, the highest EA resulted under sole maize and there was no significant difference among other treatment. However, only treatment M increased from 0.04 to 0.10 cmol kg^{-1}. The values of exchangeable acidity obtained in this study were similar to those obtained by Odunze (1997) in thisecological zone and suggests that soils of the study site had no acidity problems(Table 4.10).

5.2.4 Effect of Cropping Systems on Cation Exchange Capacity (CEC)

Treatment;MD 2:4 resulted significantly ($P < 0.05$) in higher CEC than other treatments but was significantly the same with treatment MS. Treatments D and MS 2:4 were significantly the sameand resulted in the lowest CEC content. In 2015, CEC across all the treatments slightly reduced. Treatment MD2:4 resulted in higher CEC value and the least resulted under MS 2:4. (Table 4.12). The soil CEC were generally low (< 10cmol kg^{-1}). This suggests that the soils are dominated by low activity clays; Kaolinite and sexquioxides as reported by Odunze *et al*. (2013) and low in organic matter content (Table 4.11 and 4.12).

5.2.5 Effect of Cropping Systems on some soil binding agents (Fe, Mn and Mg) during 2014 and 2015 cropping season

In 2014, treatment under sole *Desmodium*(D)resulted in higher amount of Fe which was statistically the same with treatment under M and MS 2:4.Treatment S resulted in lowest amount of Fe and was also significantly the same with treatment MS. These suggest that legumes use more of soil Fe than cereal. Sole *Desmodium* having higher amount of Fe could result from perennial nature of the legumes (Table 4.13). Legumes involved in a nitrogen-fixing symbiosis have a greater requirement for iron (Tang *et al*., 1990)Iron is also required by numerous bacteria for the synthesis of nitrogen-fixing enzyme, nitrogenase, as well as cytochromes, ferredoxin, and hydrogenase (Guerinot, 1991; Delgado *et al*., 1998; O'Hara, 2001; Dixon and Kahn, 2004; Peters and Szilagyi, 2006). At nodule maturity soybean nodules have the highest iron concentration.Approximately 44% of iron within soybean plants is present in the nodules compared to 31% in leaves, 7% in seed, and 5% in roots (Burton *et al*., 1998). At seed maturity, soybean seed has the highest iron concentration of all organs approximately 35% compared to 27% in the nodule, 23% in leaves, 9% in roots, and 3% in the stem (Burton *et al*., 1998).

Treatment MD 2:4 resulted in higher amount of Mg, which was not significantlydifferent from treatment MS. Treatment MD 2:4 was slightly higher in Mg content than Treatment MS. Treatment D resulted in lowest amount of Mg in soil. Table 4.13 also presentsthe amount of Manganese (Mn) contained in the cropping system. Treatment MD 2:4 resulted in higher amount of Mn, followed by MS and the lowest Mn resulted under treatment S. Generally, the amount of Fe,Mg and Mn present under sole maize were higher than the amount present under sole legumes. This could suggest that legumes use more of Fe, Mg and Mn than maize (Table 4.13).

5.2.6 Effect of cropping system on Organic Carbon sequestration in large and small macro, micro aggregate and silt and clay fraction during the 2014, 2015 cropping season and the means across the two years at Samaru, Northern Nigeria

Organic carbon Contents of the soils were very low in both years and confirms the low organic carbon contents of Nigeria Guinea Savanna (NGS) soils (Jones and Wild, 1975;

Sanginga *et al*.,1996). Soil organic carbon (SOC) was more sequestered in macro aggregates than the micro aggregates and silt and clay fraction. This is in accordance with earlier findings of Elliot (1986) that carbon concentration increases with increasing aggregate size because large aggregate sizes are composed of micro aggregates and organic binding agents. Further more, younger and more labile organic matter is mostly contained in macro aggregates. Hence, soil organic carbon associated with aggregates is an important element protected from mineralization because it is less subjected to physical, microbial and enzymatic degradation (Trujilo *et al*., 1997). The relevance of macro aggregation lies on its positive impact in promoting crop establishment, resistance to erosion and enhanced water infiltration (Angers and Giroux, 1996). However, in most parts of the tropics, soil organic matter losses are high due to high mineralization rate and nutrient losses to soil erosion and leaching (Igwe, 2000); especially when soils are tilled (Onweremadu *et al*., 2007). Yet, most farmers in forested agro ecology hold tenaciously to clean weeding, conventional tillage and slash and burn techniques which reduces sequestration of carbon and alters aggregate size (Onweremadu *et al*., 2010). Plot planted with maize-soybean intercrop having higher soil OC in large and small macro aggregates could have resulted from decomposition of leaves of legumes and maize and also from nodulating potential of the legumes. This is in accordance with findings of Shiralipour *et al*. (1992) and Carpenter-Boggs *et al*. (2000). Higher C accumulation in macro aggregates could be due to the lower decomposable SOM associated with these aggregates and also the direct contribution of SOM to

stability of macro aggregates.Carbon-rich (C-rich) macro aggregates are able to withstand slaking due to binding materials contained; this is similar to earlier findings byTripathi *et al*. (2014).

5.3 Effect of Cropping Systems on Crop Performance

5.3.1 Effects of cropping system on Maize yield, Stover yield and cob weight

Sole maize produced significantly ($P < 0.05$) higher grain yield which was statistically the same with Maize-*Desmodium* intercrop (MD).Lowest grain yield resulted under treatment MS. The maize *Desmodium* intercrops having higher grain yield was perhapsbecause *Desmodium* fixed more microbial biomass nitrogen, which was used by maize for increased grain production. This is in accordance with (Seran & Brintha, 2010) findings; that intercropping have the potentials to give higher yield than sole crops, due to greater yield stability and efficient use of nutrients. Sole maize also having higher grain yield may be attributed to improved management Maize soybean intercrop have the lowest maize grain yield may be due to competition for nutrients, moisture and solar energy with soybean. This may also be due to low plant density and agrees with the finding of Flores-sanchez *et al*.(2013),thatplant density affects both intra- and interspecific competition and has a strong effect on grain yield of maize.

Treatment under MD resulted in higher Cob weight that was significantly ($P < 0.05$) different from other treatments. The lowest cob yield resulted from treatment MS and MS 2:4, which were not significantly different.Maize-*Desmodium* intercrop (MD) resulted in higher Maize Stover Yield. The lowest Stover yield resulted under treatment MS which was not significantly different from treatment MD 2:4.This suggests that MD resulted in increased stover yield better than sole maize and other legumes-maize intercrop treatments. Effects of cropping systems on Maize Grain Yield (GY), Stover Yield (SY) and Cob weight in 2015 shows that there were improvements in Grain Yield (GY), Stover Yield (SY) and Cob weight. Lower grain yield resulted from treatment MS and was significantly (P <

0.05)different from other treatments. The results also show that in both years, these selected cropping systems had higher grain yield than the average of 2.0 t ha^{-1} normally obtained in farmer’ fields in the Guinea Savanna of Nigeria (Goldsworthy, 1967; Chude, 1996). There was no significant difference among treatment in Cob yields in 2015. (Table 17).

The effect of legumes crops grown with maize on maize grain yield in year 2014,suggests a competition for soil nutrient between the legume crops and maize because,sole maize plots with no legume crops yielded higher amount of grains in year 2015 relative to the maize cover crops intercrop or strip.The higher maize grain yield in plots with *Desmodium* as legume crop in year 2014 may suggest that this maize crop benefited from nitrogen fixed in the decomposing root nodules of *Desmodium* grown in previous season. Additionally, higher nitrogen production by *Desmodium* could also be responsible for higher maize grain yield.

5.4: Assessment of Productivity of the intercropping and strip-cropping system

The productivity from mean yield data of sole, intercropping and strip-cropping system was determined by the land equivalent ratio (LER) according to Willey (1985). In 2014 and 2015, intercropping (maize/soybean) and strip-cropping (maize/soybean) resulted in yield advantage. However maize strip crop soybean (MS 2:4) had better LER and percentage land saved than treatment under maize/soybean intercrop (MS) in both years. Therefore, Farmers in the study area should adopt maize strip crop soybean cropping system in order to save more land compared to when maize are planted in sole or intercrop with soybean. The result obtained was in conformity withthe definition of land equivalent ratio i.e. combination of component species in the mixture (maize/soybean intercrop and maize strip crop soybean) were more productive than the same (maize) species when grown as sole crops. However, the LERs ratio, in almost all cases, were greater (over one) than the sole which was interpreted as advantage of mixture over sole. Similarly, Mazaheri and Overysi (2004) documented that an LER of 1.0 or less indicates that no difference inyield between the intercrop and the collections of monoculture, while any value greater than 1.0 indicates yield advantage for intercropping over sole cropping. Moreover, Dariush *et al* (2006) confirmed that LER is taken as a measure of relative yield advantage. For example,LER of 1.37 indicates that the area planted to monocultures would be 27% greater than the area planted to intercrop to produce the same combined yields, i.e. 27% more land would be required as a sole crop to produce thesame yield as intercropping(Table 4.21).

5.5 Soil quality and maize yield assessment on the cropping system

Soil quality assessment on the cropping systems used in this study is presented in Table 4.21.Soil reaction was slightly acidic in M and higher pH in MD 2:4, while other cropping systems were moderately acidic. Total nitrogen, organic carbon and pH were generally best under MD 2:4 relative to other cropping system and moderate under MS. Treatmentsunder sole maize and maize/*Desmodium*intercroppingwerebest scored in maizeyield while maize soybean intercrop was ranked the least. Scores assigned to selected soil quality indicators ranked soil under maize strip crop *Desmodium*, maize-soybean intercrop and sole soybean as the best quality, sole *Desmodium*, maize-*Desmodium* intercrop and maize strip crop soybean were ranked moderate and the least ranking was under sole maize.

CHAPTER SIX

6.0 SUMMARY AND CONCLUSION

6.1 Summary:

Objectives of this study were to evaluate Maize/legumes intercrop for soil quality status and changing trends**,** evaluate crop yields under selected management practicesand to determine carbon sequestration potentials of selectedcropping system. The selected management practices/cropping systems used in this research were sole maize (M), Sole soybean (S), Sole *Desmodium* (D), Maize/Soybean intercrop (MS), Maize/*Desmodium* intercropping (MD), Maize/strip crop soybean (MS 2:4) and Maize/strip crop *Desmodium* (MD 2:4). Performance of these treatments in relation to soil physical and chemical conditions was compared using randomized complete block (RCBD) design procedure. Grain yield, Stover yield and Cob yield were also compared. Soil quality was assessed using (Parr *et al.*(1992) as a model; a score of 1 to 5 to assess the soil quality, where 1 was rated best and 5 rated worst. These were done to aid selection of the most suitable cropping system for improvement in soil physical and chemical properties for sustainable maize and soybean production.

The study was conducted at the experimental farm of the Institute for Agricultural Research (IAR), Samaru , Zaria. The experiment was conducted in 2014 and repeated in 2015 at the IAR research field opposite the meteorological station ($11^0$10’58’’N, $7^0$37’0’’E) in the Northern Guinea Savanna ecology of Nigeria.

Following results obtained in 2014 and 2015, and conclusions were inferred:

In 2014, soil BD value under sole *Desmodium* and maize/*Desmodiun*strip cropping were significantly lower than other treatments at 8 and at 16 WAP. Bulk densityvalues under Sole soybean and Sole *Desmodium*were significantly lower than other treatments while the highest BD resulted under sole maize (M). In 2015, there was no significant difference among the treatment. Maize/Soybean intercrop resulted in significantly ($P < 0.05$) higher MWD than the other cropping systems in 2014.In 2015, MWD generally increased across all the treatments. Although, sole*Desmodium*resulted in significantly ($P < 0.05$) higher MWD. Soil organic carbon content (OC) underMD 2:4 resulted in significantly ($P <0.05$) OC content than other treatments and treatment under MD resulted in least OC content in 2014. Soil organic carbon slightly increased across all the treatments; except for under ole maize, which decreased slightly.

Treatment MD 2:4 resulted in significantly ($P <0.05$) higher soil TN, followed by treatmentMS and the leastwas under sole maize.In 2015, soil TN increased across the treatments, although treatment under MD 2:4 resulted in higher TN content. The soil TN under maize intercrop with legumes (Soybean and *Desmodium*) was higher than that of Sole maize. This implies that legumes in maize based cropping systems are considered better alternatives for securing N economy, increasing yield of maize and higher net returns of N in intercropping system over monoculture. This suggests that adopting intercropping or strip cropping maize with legumes in 2:4 row arrangement could improve soil TN in Samaru Alfisol.

Available phosphorus under all the treatments were significantly ($P <0.05$) different in 2014.Treatment under sole soybean resulted in significantly higher avail. P than other treatments. In 2015, there was a slight reduction in soil avail. P.However, soil under sole soybean had higher avail. P values and the least recorded was under treatment sole *Desmodium*. This suggests that legumes utilize more of available phosphorus than

Cereals.Therefore, the slight reduction of available phosphorus found in 2015 could be as a result of the presence of legumes (Soybean and *Desmodium*) using more phosphorus for protein synthesis. These findings show that these legumes (Soybean and *Desmodium*), increased soil OC content and Soil TN and facilitates utilization of soil avail. P; i.e., reduces the soil Avail. P in Samaru Alfisols.

Soil pH underMD 2:4 significantly (P <0.05) increased pH in water and $CaCl_{2,}$ followed by treatment MS 2:4 and the least pH recorded wereunder sole maize(M). The pH in water and $CaCl_2$ were both lowest under sole maize. In 2015, pH in water and $CaCl_2$ were slightly higher than those in 2014; except for treatment M, in which pH in $CaCl_2$ reduced. These findings show that the cropping systems modified soil acidity to slightly acid range, at which most nutrients were readily available for crop roots uptake and fall within the best pH range (5.5 – 6.9) for maize cultivation. This suggeststhat *Desmodium* could be effective in improving the soil acidic condition, if left for at least one year or for several years. In 2014 therefore, pH both in water and $CaCl_2$ were slightly acidic than those in 2015.

In 2014, maize *Desmodium* intercropping produced significantly (P <0.05) higher grain yield and was followed by sole maize. The lowest grain yield resulted from Maize/Soybean intercrop. Maize *Desmodium* intercrop resulted in higher Cob weight and significantly (P <0.05) different from other treatments. The lowest cob weight resulted under treatment MS. Maize *Desmodium* intercrop resulted in higher Maize stover yield which was also significantly different from other treatment. The lowest stover yield resulted under treatment MS which was not significantly different from treatment MD 2:4. In 2015; generally, there were improvement in Grain Yield (GY), Stover Yield (SY) and Cob weight. Grain Yield under sole maize was not significantly (P < 0.05) different from grain yield under treatment

MD.However, Sole maize (M) was not significantly higher in grain weight than Maize *Desmodium* intercrop (MD). Treatment MS 2:4 resulted in least grain yield in both years.Some of the selected cropping systems had higher grain yield than the average of 2.0 t ha^{-1} normally obtained in farmer' fields in the Guinea Savanna of Nigeria. This suggests that planting of *Desmodium* intercropping with maize could increase maize grain yield in the Northern Guinea Savanna Alfisol.

Amount of SOC sequestered under treatment maize soybean intercrop was significantly higher when compared with other cropping systems and the least was under maize *Desmodium* intercropping. This suggests that treatment under MS was able to sequester SOC to the soil through deposition of plant biomass from the legumes and maize. The SOC in macro aggregate were higher in relation to other aggregates. The total land equivalent ratio (LER) for intercropping and strip-cropping were 1.15 and 1.37 respectively showing 13 % and 27 % land saved in 2014 cropping seasons respectively; 1.21 and 1.37, showing 17 % and 27 % land saved in 2015 cropping seasons respectively.

6.2: Conclusions

Treatment under sole *Desmodium* and MD 2:4 best reduced soil BD, increased soil organic carbon by sequestering more carbon that may have contributed in reducing global warming, helped in stabilizing soil aggregates, enhanced sustainable maize yield and therefore recommended for sustainable soil productivity and environmental health. Treatment MD 2:4 reduced soil acidity which may have affected yield. It istherefore recommended that treatment MD 2:4 could be used to improve soil acidity and total nitrogen.

Recommendation

Further studies involving longer term research and evaluation of this cropping system as well as considering the socio-economics of the system is suggested. This would allow for better discernment of soil quality changes and cost benefits appreciation of the system.

REFERENCES

Abu, S.T. and Abubakar I.U. (2012).Evaluating the effects of tillage techniques on soil hydro-physical properties in Guinea Savanna of Nigeria. *Soil Tillage Research*126:159-68.

Acosta-Martinez,V., MikhaM. M. and Vigil M.F. (2007). Microbial communities and enzyme activities in soil under alternatives crop rotations compared to wheat- fallow for the central Great Plains. *Applied Soil Ecology*. 37:41-52.

Adepetu, J.A. (1983). Characteristics phosphorus sorption and its implication insoilsof Ondo State, Nigeria. *Beit Tropical LandwirlschVeterinaermed,* 19:291-300.

Adepetu, J.A. (1997). Soil and Nigeria food security. Inaugurallecturesseries 119. Obafemi Awolowo University, Ile-Ife, Nigeria. p.19.

Adepoju, A.Y. (1993). Evaluation of P sorption capacity of forest and savanna soils of Nigeria.Tropical Agriculture (Trinidad), 70: 127-130.

Adentuji, M.T.(1995).Equilibrium phosphate concentration as an estimate ofPhosphate needs of maize in some tropical Alfisols. *TropicalAgriculture.*(Trinidad), 70: 127-130.

Adeoye, K.B. (1984). Influence of Grass mulch on soiltemperature, Soil moisture,and Yield of maize and Gero millet in a savanna zone soil. *Samaru JournalAgricultural Research,*2:87-89.

Adjei-Nsiah, S., Kuyper, .T.W., Leeuwis, C., Abekoe, M., Cobbinah, J., Sakyi-Dawson, O., Giller, K.E (2008). Farmers agronomic and social evaluation of Productivity, yield and N_2-fixation in different cowpea varieties and their subsequent residual effects on a succeeding maize crop. *Nutrient Cycling inAgro ecosystem.* 80, 199-209.

Agbenin, J.O. (1995). Laboratory manual for soil and plant analysis (selected methodsand data analysis).

Agbenin, J.O. and Goladi, J.T. (1997). The cation exchange properties andmicrobial carbon,nitrogen and phosphorus in savanna Alfisols under continuouscultivation,*Journal ofScience, Food and Agriculture*, 75: 412-418

Agbenin, J.O. and Goladi, J.T. (1997).Cation exchange properties and carbon, nitrogen and phosphorus in savanna Alfisols under continuous cultivation.*Journal of Science, Food and Agriculture,*75: 412-418.

Aina, P.O. (1976). Soil and crop managementin relation to soil erosion in the rainforest region of western Nigeria. Symposium proceedings of the national soilerosion conference 25-26, May,1976, Lafayett, India.

Allmaras, R.R. and Nelson, W.W. (1971).Corn (Zea mays L) root configurations influenced by Some row inter-row variants of tillage and straw mulch arrangement Soil Science Society of America Proceedings, 35:974-980.

Andrew, C. and Robins, M. (1969). The effect of phosphorus on the growth and Chemical composition of some tropical pasture legumes. II, Nitrogen,Calcium, Magnesium, potassium and Sodium contents. *Crop and PastureScience*, 20(4): 675-685.

Andrew, S.S.,Karlen, D.L. and Carmbardella, C.A. (2004). The soil management assessment framework: A quantitative soil and quality evaluation method.*Soil Science Society of America Journal*, 68: 51-59.

Andrew, S.S and Caroll,C.R. (2011).Designing a soil quality assessment tool for Sustainable agro-ecosystem.*Ecological Applications*, 11: 1573-1585.

Anderson, J.M. and Ingram, J. I. S. (1993). Tropical Soil Biology and Fertility: A Hand book of Methods (2nd ed.) C.A.B. InternationalWallingford,U.K.p221.

Angers, D.A., Samson N. and Legege, A. (1993). Early changes in water stable aggregate by rotation and tillage on soil winter barley production.*Canadian Journal ofSoil Science,* 73: 51-59.

Angers, D.A, Giroux, M. (1996). Recently deposited organicmatter in soil water –stable Aggregates. *Soil Science Society of America Journal*, 60: 1547-1551.

Anikwe, M.A.N. (2006) Soil quality assessment and Monitoring: A review of currentresearch efforts. New Generation Books Enugu, Nigeria.p. 147-158.

Arshad, M.A. and Martin, S. (2002). Identifying critical limits for soil quality indicator in agro-ecosystems. *Agriculture, Ecosystems and Environment.*88(2): 153-16.

Baeumer, K. and Bakermens, W.A.P. (1973). Zero tillage. *Advance in Agronomy*, 25:77-125

Baeumer, K. (1981). Tillage effects on root growth and crop yield.In: Agricultural yield potentials in continental climates. 16th Proceedings collation.InternationalPotash Institute Bern, 55-75.

Badu-Apraku, B., Abamu, F.J., Menkir, A., Fakorede, M.A.B. and Obeng-Antwi, K.(2003). Genotype by environment interaction in the regional earlyvariety trials in West and Central.*Maydica*,48: 93-104.

Balasubramania, V. and Nnadi, L.A. (1980). Crop residue management and soil conservation in savanna areas. In FAO Soils Bulletin No. 43, Rome P. 15

Bationo, A.(2004).Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa. Academy Science Publishers.

Barrios, E., Delve*R.J.*,Bekunda, R.J., Mowo, J., Ramisch, J. and Thomas, R.J.(2006). Indicator of soil quality:a South-South development of a methodological guide for linking local and technical knowledge. *Geoderma,* 135: 248-259.

Barrios, E., and Trejo, M. T. (2003). Implication of local soil knowledge for integrated soil fertility management in Latin America. *Geoderma*, 111, 217-231

Bhagad, S. B., Chavan, S. A., Zagade, M. V.and Dahiphale, A. V.(2006). Intercropping groundnut and sweet cornat different fertility levels and row proportions.*Indian Journal of Crop Science*, *1*(1-2): 151-153.

Binford, G.D., Blackmer,A.M. and El-Hout, N. M. (1990). Tissue test for excess nitrogen during corn production. *Agronomy Journal,* 82: 124-129.

Blake, G.R. and Hartge, K.H. (1986).Bulk density methods of soil analysis, part 1physical and mineralogical method (Ed. A Klute). 2nd ed. *America Society of Agronomy,* Madison, WI. p. 363-375.

Blevins, R.L,. Thomas, G.W. and Cornelius, P.L. (1977). Influence of no-tillage and nitrogen fertilization on certain soil properties after five years of continuous corn. *AgronomyJournal*, 69:383-386.

Blevins, R.L, Thomas, G.W., Smith M.S., Frye. W.W. and CorneliusP.L. (1983). Changes in soil properties after 10 years continuous no-till and conventional tilled corn. *Soil andTillage Research,*3: 135-146.

Bouyoucos, G.J. (1951). A recalibration of the hydrometer method for makingmechanical analysis of soils. *Agronomy Journal*, 43: 434-438.

Brady, R.H. and Kurtz, L.T. (1945). Determination of total organic and available forms of phosphorus in Soils. *Soil Science*, 59: 36-45.

Brady, N.C. and Weil, R.R. (1999). The Nature and Properties of Soils, (12th edn.),pretice Hall, Inc, New Jersey.

Brady, N.C. (1975). Nature and Properties of Soils. 8th edition. MacMillan publishing Co. Inc. New York, p.639.

Bremner, J.M. and Mulvaney, C.S. (1982). Nitrogen total, in Methods of soilanalysis. Part II, Chemical and Microbiological Methods. Agronomy Monograph no.9 (2nded.). pp.595-624, *American Society of Agronomy andsoil Science Society of America*, *Madison* USA.

Burton J. W., Harlow, C. and Theil, E. C. (1998). Evidence for reutilization of nodule ironin soybean seed development. *Journal Plant Nutrition,* 21 913–920.

Canter-martinez, C., Angas P. and Lampurlanes, J. (2003). Growth, yield and water productivity of barley (Hordeum vulgare L.) affected by tillage and N fertilization in Mediterranean semi-arid, rain fed conditions of Spain, *FieldCrop Research*, 84:341-357.

Carpenter-Boggs, L., Kennedy, A.C., Reganold, J.P. (2000) Organic and biodynamicManagement: effects on soil biology. *Soil Science Society America Journal*54:1651–1659

Carlson, G. and Huss-Danell, K. (2003). Nitrogen fixation in perennial forage legumes in the field. *Plant and Soil*, 253: 352-372.

Carsky, R.J., Reid, W.S., Suhet A.R. and Lathwell, D.J. (1990). Screening crops III. The buried bag method. *Plant and Soil,* 128:275-282.

Carsky, R.J. and Iwuafor, E.N.O. (1999). Contribution of soil fertility research/maintenance to Improve maize production and productivity in sub-SaharanAfrica. In: Badu-Apraku B., Fakorede MAB, Ouedraogo M., Quin FM (eds)Strategy for Maize Production in West and Central Proceedings of regional maize workshop held at IITA-Cotonou, Republic of Benin, April 1997. P3-20

Chapman, H.D. (1965). Total exchangeablebases. In Black, C.A. (ed.). Methodsof Soil analysis, part II. *America Society of Agronomy,* 56: 902-904.

Chaudhary, M.R. and Prihar, S. S. (1974). Root development and growth responses of corn following mulching and cultivation or interrow compaction. *AgronomyJournal,* 66: 350-355.

Chen, T.H., Chiu, C.Y. and Tian, G.L. (2005). Seasonal dynamics of soil microbial bio-massincoastal sand dune forest. Performance in the Rift Valley Highlands of Kenya. *Africa Crop Science Journal*, (4): 667-676.

Cheruiyot, E. K., Mumera L.M., Nakhone L.N. and Mwongo,S.M. (2001).Rotationaleffects of grain legume on maize performance in the Rift Valley Highlands ofKenya. *Africa Crop ScienceJournal,* (4): 667-676.

Chude,V.O. (1996). Fertilizer in maize production. Department of Soil Science, ABU, Zaria,Nigeria. A paper presented at a national workshop on maize production in Nigeria held at Banquet Hall State House, Kano,Kaduna, July 22, 1996.

Cookson, W.R., Murphy, D.V. and Roper,M.M. (2008). Characterizing the relationship between Soil organic matter components and microbial function and composition along tillage disturbance gradient. *Soil Biology and Biochemistry,* 40: 763 -777.

Danso, S.K.A.(1992).Biological nitrogen fixation in tropical agrosystems: twenty years of biological nitrogen fixation research in Africa. In: Mulongoy, K; Gueye, M. and

Spencer, D.S.C. (eds). Biological Nitrogen Fixation and sustainability of Tropical Agriculture. A Wiley Saycc Co-Publ. UK. P488.

Dariush, M. Ahad, M.andMeysam, O. (2006). Assessingtheland equivalent ratio (LER). Of two corn (Zea maysL.) varieties intercropping at various Nitrogen Levels in KARAJ, IRAN.*Journal of Central European Agriculture.* 7(2) 359- 364.

Delgado M. J., Bedmar E. J., Downie J. A. (1998). Genes involved in the formation andassembly of rhizobial cytochromes and their role in symbioticnitrogen fixation," in *Advances in Microbial Physiology* Vol. 40 ed. Poole R. K., editor191–231.

de Ridder, N. and van Keulen, H. (1990). Some aspects of the role of organic matter in sustainable intensified arable farming system in West African semiarid tropics (SAT).*Fertilizer Research,* 26:299-3010.

Dhiman, S.D., Om H and Kumar H. (2001).Advantagesandlimitations of no-tillage in wheat. Indian Farming, 51(6): 8-10.

Dick, W.A. and Tabatabai M.A (1993).Significant and potentialuses of soil enzymes. In:Meeting, F.B. (Ed). Soil microbial ecology: Applications in agricultural and environmental management. Marcel Dekker, New York. P95-127.

Dixon, R.and Kahn, D. (2004). Genetic regulation of biological nitrogenfixation.*Natu*reReviews Micobiology. 2: 621–631.

Doran, J.W. Varvel G.E. and Culley, J.B.L. (1994). Tillage and residue management effect on soil quality on sustainable land management. In: Wood, R.C and Dumanski, J. (Eds). Sustainable land management for the 21st century vol. 2 plenary papers, University of Lethbridge, Canada p59-74.

Doran, J. W. and Parkin,T.B.(1994).Defining and Assessing Soil Quality for Sustainable Environment.SoilScienceSociety.Publ.35,SSSA,ASA,

Doran, J.W. and Safley, M. (1997). Defining and assessing soils health and sustainable Productivity, in pankhurst, C.E., Doube, Gupta, V.V.S.R. (Eds.), Biological indicators of Soil Health. CAB International, Wallingford, p1-28.Dumanski, J. (Eds) Sustainable land management for 21stcentury vol. 2 plenary papers, University of Lethbridge, Canada p56-74.

Doran, J.W. and Parkin,T.B. (1994). Defining and assessing soil quality. Defining soil quality for a sustainable environment. *Soil Science Society of America.* Special Publication 35, SSSA, pp. 3-21.

Doran, J.W, and Zeiss M. R. (2000). Soil health and sustainability: managing the biotic component of soil quality. *Applied Soil Ecology,* 15: 3-11

Doran, J.W., (2002). Soil health and global sustainability: translating science into practice. *Agriculture, Ecosystem and Environment,* 88: 119-127.

Ewansiha, S.U., Tarawali S.A., Odunze, A.C. and Iwuafor E.N.O. (2008). Potential contribution of Lablab Residues toMaize Production in MoistSavanna ofWest Africa.*Journal of Sustainble Agriculture*, 32(3): 394.

Elliott, E.T. (1986). Aggregate structure and carbon, nitrogen and phosphorus in Natural and cultivated soils. *Soil Society of America Journal, 50:627-633*

Eswaran, H., Almaraz, R., Van den Berg, E. and Reich, P. (2005).An assessment of soil resources of Africa in relation to productivity. World Soil Resources, Soil Survey division USDA, Natural Resource Conservation Service, Washington, DC.

FAO, (1995). Planning for sustainable use of land resources towards a new approach:In:Sombroek, W.G., Sims,D. (eds), Land and Water Bulletin No.2.FAO.Rome.

FAO (1997).Quarterly Bulletin of Statistics. Food and Agricultural Organization.UnitedNations. Rome Italy

FAO, (2005). Compendium on post-harvest operations. Food and agricultural Organization bulletin pp 43-46

Flores-Sanchez, D., Pastor, A., Janssen, B. H., Lantinga, E. A., Rossing, W. A. H. andKropff, M. J. (2013).Exploring Maize-Legume intercropping systems in South West MexicoAgroecology and Sustainable FoodSystems.

Franchini, J.C., Crispino C.C., Souzee R.A.,Torres E. and Hungria M. (2000). Microbio logical Parameters as indicators of soil quality under various soil management and crop rotation systems in southern Brazil. *Soil and Tillage Research*, 92: 18-29.

Francis, C. A. (1986). *Multiple cropping systems*. Macmillan, Newyork.

Franke, A., Ellis-Jones,J., Tarawali, G., Schulz, S., Hussaini, M., Kureh, I., White, R,Chikoye,D., Douthwaite, B., Oyewole, B., Olarenwaju, A. (2006). Evaluating and scaling-up integrated *Striga hermontica*control technologies among farmers in northern Nigeria. *Crop protection*. 25: 865-878.

Gachene, C.K.K. and Kimaru, G. (2003). Soil Fertility and Land productivity - A guide for extension workers in the eastern Africa region. Technical Handbook No.30. Regional Land Management Unit (RELMA)/ Swedish International Development Cooperation.

Garcia, C. and Hernandez, T. (1996).Biological and Biochemistry indicators in derelictsoil subject to erosion. *Soil Biology and Biochemistry,* 28: 171-177.

Gee, G. W. and Bauder, J.W. (1986). Particle-size Analysis. In Methods of Soil Analysis:Physical and Mineralogical Methods (Klute*et al*., eds.). AgronomyNumber 9 Part 1.*American Society of Agronomy, Soil Science Society of America*Inc.Madison, Wisconsin. p383-411

Giller, K.E. (2001).Nitrogen Fixation in Tropical Cropping Systems. CAB International Wallingford, UK

Goldsworthy, P.R.(1967). Responses of cereals to fertilizer in northern Nigeria. *Maize IIExperimental Agriculture,* 3: 263-273.

Gomez, A.A., Sewete Kelly D.E., Syer, K.K. and Coughlan, K.J. (1996). Measuring Sustainability of agricultural systems at the farm level. .*In*: Methods for Assessing Soil Quality, Doran J.W., and Jones A.J. (Eds); Special publication no. 49. Soil Science Society of America, Madison, USA.P401-409

Gregorich, E.G., Liang, B.C., Drury C.F., Mackenzie A.F and McGill, W.B (2000).Elucidation of The source and turnover of water soluble microbial on in agricultural soils. *SoilBiology and Biochemistry,* 32: 581-587.

Guerinot M. L. (1991). Iron uptake and metabolism in the rhizobia legumesymbiosis *PlantSoil* 130 199–209.

Haney, R.I.,Frenzlubbars A.J., Hons F.M., Hosser L.R. and Zuberer, D.A. (2001). Molar concentration of K_2SO_4 and soil pH effect estimation of extractable with chloroform fumigation extraction, *Soil Biology and Biochemistry*, 133: 1501- 1507.

Harris, R.F. and Bezdicek,D. F.(1994). Descriptive aspect of soil quality/health. In: Doran. J.W., Coleman, D.C and Stewart, B.A. (eds.) Defining soil quality for sustainable environment, SSSA special publication No 35. Madison. WI.p23-35

Hargrove, W.L., Reid J.T., Touchton J.T.andGallahar, R. W. (1982). Influence of Tillage practices on the fertility status of an acid soil double cropped toWheat and soyabeans. *Agronomy Journal,* 74: 684-687

Hedlund, A.,Witter, E. and An, B.X. (2003). Assessment of N, P andK managementby nutrientbalances and flows on peri-urban smallholderfarmsin SouthernVietnam.*European Journal of Agronomy,* 20: 71-87.

Henderson, W.H., Laland, H. and Duquette, M. (1993). Soil reaction and Exchangeable In: Soil Sampling and Methods of analysis. Carter, M.R (Ed.). Can. Society of Soil Science, Lewis Publishers London. 141-145.

Herrick, J.E. (2000).Soil quality: an indicator of sustainable land management? *AppliedSoil Ecology*,15(1): 75-83.

Hillel, D. (1982). Introduction to soil physics.Academic Press, San Diego.

Horst, W. J. (1995). Mineral nutrition of higher plants. Second edition. Academic Press New York. P. 889

Humphreys, L.R. (1995). Diversity ofproductivity of tropical legumes. In D' Mello, J.P.E. and Davendra (Eds). Tropical legumes in animal nutrition.CAB International, Wallingfood, UK. P1-21

Hurni, H., Giger, M and Meyer, K. (2006). Soils of the global agenda. Developing international mechanisms for sustainable land management. Prepared with the support of an international group of specialists of the IASUS Working Groupof the International Union of Soil Sciences (IUSS). Center for Development and Environment,Bern.

Idowu, O.J., van Es, H. M., Abawi, G.S., Wolfe, D. W., Ball, J.I., Gugino,B.K andBilgiili, A.V. (2008). Farmer-oriented assessment of soil quality using field, laboratory, and VNIR spectroscopy methods. *Plant and Soil*, 307(1-2): 243-253.

Igwe, C.A. (2000). Nutrient losses in runoff and eroded sediments from soils of central south eastern Nigeria. *Polish Journal Soil Science*, 33: 67-75.

IITA (1986).Maize Production Manual Vol.1.Manual series No.8. International institute of Tropical, Ibadan, Nigeria. P218

Ike, I..F. (1985). Soil and crop responds to difference tillage practices in a ferruginous soil in Nigeria savanna, *Soil and Tillage Research*, 6: 261-272.

Ike, I.F.(1987). An evaluation of soil compaction and soil crusting strength under different Tillage practices in Sandy loam soil. 15th Annual Conference of Soil Science Society of Nigeria, Kaduna 20-24th September, 1987, p. 16.

Iwuafor, E.N.O. (1986). The effect of tillage and crop residue management practices on soil Properties and crop performance in the Southern Guinea Savanna zone of Nigeria. Ph.D. thesis (unpublished). Dept. of Soil Science.Ahmadu BelloUniversity, Zaria. p13.

Jackson, M.L. (1962). Soil Chemical Analysis Pergamon Press. Prentice Hall of Englewood cliffs, New Jersey, USA, 1962

Jekinson, M.L. and Powlson, D.S. (1976). The effect of biocidal Treatments on metabolism in Soils:a method for measuring biomass. *Soil Biology and Biochemistry*, 8:203-213.

Jones, M. J. and Wild, W.(1975). Soils of the West African Savanna. Technical communications No. 55.Commonwealth Bureau of Soils. CAB Harpenden. P 240

Juo, A.S.R. (1997).Selected Methods of Soil andPlant Analysis. IITA manual series Pp70

Kahm, M., Avdou M., Chude V. Wiesler F. and Horst, W. J. (2002). Mobilization of phosphorus contributes to positive rotational effects of leguminous cover crops on maize grown on soils from northern Nigeria. *Journal of Plant Nutrition and Soil Science,* 165: 566-572.

Kang, B.T. (1992). Potentials of Legumes for soil fertilityimprovement in humid and Sub-humid tropics. In Collaborative group of maize-based systems research (COMBS (1992). Report of the second workshop, Kumasi, Ghana, June 1990. West African farming systems Research Network (WAFSRN/RESPAO), Ouagadougou, Burkina Faso, and InternationalInstitute Tropical Agriculture (IITA), Ibadan, Nigeria.

Kang, G.S., Beri, V., Sidhu, B.S. and Rupela, O.P.(2005). Anew index to access soil quality and sustainability of wheat-based cropping systems. *Biology and Fertility of Soils,* 41: 389-398.

Karlen, D. L., Mausbach, M. J., Doran, J.W., Cline, R. G., Harris, R. F., and Schuman,G.E. (1997). Soil Quality and Sustainability a concept, definition and frame work for Evaluation. *Soil Science Society of America Journal*, 61, 4-10.

Kemper, W.D.andRosenau, R.C. (1986).Aggregate stability and size distribution. In:Method of soil Analysis. Part 1.Physical and Mineralogical Method (Klute A, ed), pp.425- 442 (2nded). Soil Science Society of America Agronomy monograph No.9.

Khan, Z.R., Hassanali A,. Overholt W. (2002). Control of witchweed *Striga hermonthica* by intrcropping with *Desmodium* spp.,and mechanism defined basallelopathic. *Journal of Chemical Ecology* 28, 1871-1885

Khan, Z.R,Midega, C.A.O., Njuguna, E.M, Amudayi, D.M, Hassanali, A. and Pickett, J.A .(2008).On farm evaluation of the ‘push pull’ technology for the control of and striga weed on maize on Western Kenya *Field Crop Research* 106: 224-233.

Kinyangi, J. (2007) Soil health and soil quality: A Review worldaginfo.org/files/Soil%20Health%20Review.pdf.Dec 8,2010.

Kirchhof, G. andSalako,F.K. (2000). Residual tillage and bush fallow effects onsoilproperties and maize inter-cropped with legumes on a tropicalAlfisols. *Soil Use Management,* 16: 183-188.

Klute, A. (1986). Water retention laboratory methods (Klute A, ed), pp 425-442 (2nded)Soil Science of America Agronomy monograph No 9.

Kowal, J.M. and Knabe, D.T. (1972). An Agro climatological Atlas of Northern States Of Nigeria with Explanatory Notes. Ahmadu Bello University press, Zaria, p.111

Kowal, J .M. (1972). Study of the surface crusts in the loess plain soils of Northern Nigeria. *Nigeria Journal of Sciences,* 6(1) : 93-100

Kowal, J .M. and Kassam,A. H. (1976). Energy load and instantaneous intensity of rainstorms at Samaru, Northern Nigeria. *Tropical Agriculture,* (Trinidad) 53(3): 185 -197

Laflen, J. M., Amemiya, M. and Hintz,E.A. (1981). Measuring Crop Residue Cover.*Journalof Soil and Water conservation* p.341-343.

Lal, R. and Okigbo, B.N. (1990)**.** Assessment of soil Degradation in the Southern States of Nigeria. The World Bank Sector Poilcy and Research staff. Environment working paper No. 39, p.58.

Lal, R., Peter, R.H., Uphoff, N and David, O.H. (2004). Reconciling food security withEnvironmental Quality through no-till farming. In: Sustainable Agricultureand the international Rice-Wheat system. Marcel Dekker, Inc. New York. P495-511.

Lal, R. and Dinkins, E.L. (1979).Tillage systems and crop production in an Ultisols in Liberia. In Lal, R. (Eds). Soil Tillage and Crop Production, p221-234.IITA Proceedings Series 2

Lal, R. (1979). Physical characteristics of Soils of the Tropics. Determination and Management. In: Lal R and Greenland D.J.(eds). Soil Physical Properties and Crop production in the tropics. Willey J and Sons, Chichester, UK, 7- 44.

Lal, R. and Stewart, B.A. (1995).Soil Management: Experimental Basis for Sustainability and Environmental Quality. *Advances in Soil Science CRC Press*, Boca Raton,Florida.

Lal, R., Hansen, D. Uphoff,N.and Slack, S. (2002). Food Security and Environmental Quality in the Developing World.CRC press. Boca Raton, FL.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science*, 304: 1623-27

Larson, W. E. and Pierce F. J. (1994). The dynamic of soil quality as a measure of sustainable Management. Pages 37- 51 in Doran J. W., Coleman D. C., Bezdicek

D. F., and Stewart B. A., eds. Defining soil quality for a sustainable environment.SSSA-Special Publication 35. *Soil Science Society of America*, Madison, WI, USA.

Lawal, H.F.M (2015). Tillage and cover crop effects on soil quality and maize growth at Samaru, Northern Nigeria. Unpublished Ph. D. Thesis. Ahmadu Bello University, Zaria, Nigeria.

Liu, D. (1991).Efficient use of nitrogen in crop production. Extension bulletin No.340. Food and Fertilizer Technolgycentre, Taipei, ROC. Taiwan. p1-10.

Li L. T., Chen O. S.,Ward D. M. and Kaplan, J. (2001). CCC1 is a transporter that mediates vacuolar iron storage in yeast. *Journal of Biology and Chemistry*.276:29515–29519 Mairura, F., Mugendi, D., Mwanje, J., Ramisch, J.,Mbugua, P. and Chianu, J.(2007).Integrating scientific and farmers' evaluation of soil quality indicators in Central Kenya.*Geoderma*, 139 (1): 134-143.

Malik, R. K.,Yadav, A., Singh, S., Malik, R.S., Banga R.S., Sardana, P.K., Jaipal, S., Hobbs. ,P. R.,Gill G., Gupta R.K. and Bellinder R. (2002) Herbicide resitance management and evolution of no-tillage: A success story. Research bulletin. Haryana Agricultural University, Hisar, india.

Marschner, H. (1998). Mineral Nutrition of Higher plants. Second edition. Academic press. p889

Matusso, J. M. M., Mugwe, J. N., and Mucheru-Muna, M. (2012). Potential role of cereal legume intercroppingsystems in integrated soil fertility management in smallholder farming systems of sub-Saharan AfricaResearch Application Summary. *Third RUFORUM Biennial Meeting 24-28 September 2012, Entebbe,Uganda.*

Mayer, J., Buegger F., Jensen E.S., and Shloter, M., (2003). Residual nitrogen contribution from grain legumes to succeeding wheat and rape and related microbial process. Plant and Soil, 255, %41- 554.

Meyer, R. (2010). Low-input intensification in agriculture chances for small-scale farmers in developing countries. *GAIA-EcologicalPerspectives for Science and Society, 19*, 263-268.

Mazaheri, D and Overysi, M. (2004). Effects of intercroppingof two corn varieties at various nitrogen levels. *Iranian Journal of Agronomy* 9:71-76.

McRae, R.J and Mehuys, G.R. (1988). The effect of green manuring on the Physical Properties of the temperate-area soils. *Advances in Soil Science*, 3: 71-94

Melero , S., Lopez-Garrido R., Madejon E., Murillo J.M.,vanderlinden K., Ordonez R. R. and Moreno, F. (2009). Long term effects of conservation tillage on organic fractions in two soils in southeast of Spain.*Agriculture, Ecosystem and Environment*,133:68-74.

Moebius, B.N., Idowu, O.J., Schindelbeck, R.R., Van Es, H., Wolfe, D.W., Abawi.,G.S. andGugino, B.K (2007). Developing standard protocols for Soil Quality Mornitorinaccessment.http://www.hort.cornell.edu/soilhealth/research/papers/Develo ping standard Protocols.pdf 20/10/2010. Accessed in June, 2012.

Monkiedje, A., Spiteller M., Fotio D. and Sukul, P. (2006). Theeffect of land use on soil health indicators in pri-urban agriculture in the humid forest zone of southern Cameroon. Journal of Environmental Quality, 35: 2402-2409.

Moreno,F. Pelegin, F., Fern J.Eand Murillo J.M. (1997). Soil Physical properties, waterdepletion and crop development under traditional and conversation tillage in southern Spain. *Soil and Tillage Research,* 41: 25-42.

Moreira, F.M.S, (2008) Nitrogen-Fixing LeguminosaenodulatingBacteria (pp.107-108). In:Moreira F.M.S., Huising E.J and D.E. Bignell. (2008). A hand book of Tropical Soil Biology.Sampling and Characterization of Below-ground Biodiversity.Earthan Dunstan House London.

Mrabet, R. (2002). Stratification of soil aggregation and organic matter under conservation tillage systems in Africa. *Soil and Tillage Research,* 66:119-128.

Mulongoy K. and Akonbudu, I.O. (1990) Agronomic and Economic benefits of nitrogen contributed by legumes in Live-much and alley cropping systems. In Nitrogen Fixation. Achievement and object. EdsGresshof P.M., RothL.E., Stacey G and Newton W.E. p625-632. Chapman and Hall, New York.

Murage, E. W., Karanja, N.K., Smithson, P.C., andWoomer, P.L. (2000).Diagnostic indicators of soil quality in productive and non-productive small holders' field of Kenya's Central Highlands. *Agriculture, Ecosystem and Environment,* 79(1): 1-8.

Murphy, J. and Rilly, J.P. (1962). A modified single solution method for Determination of Phosphates in natural waters.*Analytical ChemicalActa* 27:31-36

Muyinda K., Karamanos R.E. and Haloran I.P.O. Haloran (1988). Yields of wheat inrotation with maize and soyabeans in Zambia. *Canadian Journal of Soil Science,* 6: 47-753.

Nambia,K.K.M., Gupta, A.P., Fu, Q.L. and Li, S. (2001). Biophysical, Chemical and socio-economic indicators for assessing agricultural Sustainability in the Chinese Coastal zone Agriculture, Ecosystem and Environment. 87: 209-214.

Nangyu, D.(1979). Effect of tillage methods on growth and yields of cowpea and soybean. In: Lal, R. (Ed) Soil tillage and Crop Production.P93-108.

Natural Research Conservation Servic (2011). Soil quality management Key Strategies for agricultural land.

Ndiaye, E.I., Sandeno, J.M., McGrath D and Dick R.P. (2002). Integrative biological indicators for detecting change in soil quality. *American Journal of Soil Science,* 6:747-753.

Nielson, D.W and Vigil M.F (2005). Legume green fallow effect on soil water content at wheat planting and wheat yield. *Agronomy Journal*. 97: 684-689.

Nortcliff, S. (2002). Standardisation of soil quality attributes.*Agriculture, Ecosystems andEnvironment,* 88:161-168

Natural Resource Conservation Service (2013). Soil Quality Indicators. USDA Natural Resource Conservation Service. Washinton DC.

Odunze, A.C. (1997). Effects of different legumes covers on soil properties, erosion and yield of maize (Zea mays L) at Samaru, Nigeria. Ph.D.dissertation (unpublished). Dept. of Soil Science, Ahmadu Bello University, Zaria. P93-95.

Odunze, A.C. Iwuafor, E.N.O. and Chude, V.O. (2002). Maize/Herbaceous Legume Inter - Crop and Soil Properties in the Northern Guinea Savvana Zone, Nigeria. *Journal of Sustainable Agriculture*, 20(1): 10-15.

Odunze, A. C. (2003).Northern Guinea Savanna of Nigeria and Rainfall Properties for Erosion Control. *African Soil Journal*, 33: 73-81

Odunze, A.C. (2006). Soil properties and Management Strategies for some sub humid Savanna zone Alfisols in Kaduna State, Nigeria. Samaru*Journal Agriculture Research*.,22:3-14

Odunze, A. C. (2011). Use of meteorological data in Agriculture. Training Manual: Trainig of monitoring and evaluation staff handling weather data collectionof Kaduna State Agricultural Development Project. Farming Systems Research Programme (FSRP),Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria. Special Publication No. 1. 3rd & 4thFebruary,2011.P 1-6

Odunze, A.C, Jinshul, W, Shoulong, L., Hanhua, Z., Tida. G.,Wang, T. and Qiao, l. (20 12). Soil Quality Changes and quality status: a case study of the subtropical China region Ultisol.*British Journal of Environment and Climate Change* 2(1): 37-57.

Odunze, A. C. Ebireri, O. F. Ogunwole, J. O., Tarfa, B.D, and Eche, N.M. (2013). Effect ofTillage and Fertilizer on Soil Quality and Yield of Maize in an Alfisols of aNorthern Guinea Savanna ofNigeria. *Journal of Agriculture and Biodiversity Research.* 2 (8): 167-177.

Ogunsola, O. E (2016). Contribuion of conservation Agriculture to improvement of soil quality and maize (Zea mays) yield in Samaru, Northern Guinea Savanna of Nigeria. Unpublished M.Sc. Dissertation. Ahmadu Bello University, Zaria, Nigeria

Ogunwole, J. O.Babalola,A.O.Onyinlola,E.Y and Raji, B. A. (2001). A pedological Characterization of soils in the Samaru area of Nigeria.*Samaru Journal of Agricultural Research*, 17: 71-77

Ogunwole, J.O. and Ogunleye, P.O (2004). Surface aggregation, trace, and heavy metalenvironment under long-term application of farm yard manure and mineral fertilizer contamination in soil. *Soil Science and Plant Analysis*, 36(11 &12): 1506-1516.

O'Hara,G. W.(2001).Nutritional constraints on root nodule bacteria affecting Symbiotic nitrogen fixation: a review. *Aust. Journal. Exp. Agric.* 41 417–433

Onweremadu, E.U, Onyia VN, Anikwe, M.A.N (2007). Carbon and nitrogen distributionin water -stable aggregates under two tillage techniquesin fluvisols of Owerre area, Southeastern Nigeria. Soil Tillage Research, 97: 195-206.

Onweremadu, E., Osuji G., Eshett, T. Unamba-Oparah, I. and Onwuliri, C. (2010). Soil carbon Sequestration in Aggregate Size of a Forested Isohyperthermic ArenicKandiudult. *Thai Journal of Agricultural Science,* 43(1):9-15.

Oluwasemire, K.O. and Alabi,S.O. (2004).Ecological Impact of Changing Rainfall Pattern, Soil process and Environmental Pollution in Nigeria Sudan and Northern Guinea Savanna Agro-Ecological Zones. *Nigeria Journal of Soil Research,* 5: 23-31

Papendick, R.I. and Parr, J. (1992). Soil quality-the key to sustainable agriculture.*AmericaJournal of Agriculture*. 7,2-3

Parr, J.F, Papendick RI, Hornck S.B and Meyer R.E.(1992) Soil quality: attributes and relationship to alternative and sustainable agriculture. *America Journal. Alternative Agriculture*. 1992;7:5-11

Peters, J. W., Szilagyi,R. K. (2006). Exploring new frontiers of nitrogenase structure and mechanism. *Current Opinion Chemical. Biology,* 10: 101–108

Pimental, D., Bailey O.,Kim P., Mullaney E., Calabrese J., Walman F., Nelson F. and Yao X. (1999). Will the limits of the Earth's resources control human populations?*Environment,Development and Substainability,* 1: 19-39.

Pimental, D., (2004).Food Security and Environmental Substainability. In: Ratten, L., Peter, R.H.; Norman, U. and David O.H. (Eds.). Sustainable Agriculture and the International Rice-Wheat System. Marcel Dekker, Inc. p37-53.

Pimental, D.and Pimental, M. (1996). Food, Energy and Society: Colorado Press. Niwet,Co.Reginald, E. M.,Pramod, K.C. Dhyan,S.andAshokk,P. (2007).Soil Quality Responds to Long-Term Nutrient and crop management ona Semi-arid inceptisol.*Agriculture, Ecosystems, and Environment,* 118(1-4), 130-142(Jan 2007).

PRB.(2003). World Population Data Sheet. Population Reference Bureau. Washing to DC. Science. 1995. Cities as disease vectors. Science 270 (edition)

Reginald, E. M., Pramod, K.C. Dhyan, S and Ashokk, P. (2007). Soil Quality Responds to Long-term Nutrient and crop management on a semi-arid inceptisol. *Agriculture,Ecosystems and Environment,* 118(1-4): 130-142

Rhoades, J.D. (1982). Cation exchange capacity. In: Page A.L., Miller R.H., Keeney D.R.(eds.) Methods of Soil Analysis,Chemical and Microbiological Properties, part 2, 2nd edn.ASA-SSSA Madison Wisconsin, pp. 1490-1589.

Riley, J. (2001). The indicator explosion: local needs and international challenges.*Agriculture,Ecosystems and Environment* 87, 119-120.

Russel, E.W. (1973).Soil *Conditions and Plant Growth.*The English Language Book Society and Longman London. P.849.

Rusinamhodzi, L. Corbeels, M., Nyamangara. and Giller K. E. (2012). Maize-grain legume intercropping is an an attractive option for Ecological Intensification that reduces climatic risk for a smallholder farmers in central Mozambique. *Field Crop Reserch.* 136.12-22.

Samuel, R. and Aldich, K. (1980).Nitrogen in relation to food, environment and energy.Illinois Agricultural Experimental station, USA.

Sanginga, N, Ibewiro, Houngnandan,Valawe B, Okogun J.A, Akobundu I.O, and Versteeg M. (1996). Evaluation of Symbiotic properties and nitrogen contribution of Mucuna to maizegrown in the derived savanna of West Africa. *Plant and Soil Journal*, 179: 119-129.

Sanginga, N., J. A. Okogun, B. Vanlauwe, J. Diels, R.J. Carsky and K. Dashiell (2001).Nitrogencontribution of promiscuous soybeans in maize-based croppingsystems.SSSA.SpecialPublication 58, Madison, USA, p157-177.

Sanginga, N. (2003). Role of biological nitrogen fixation in legumes based cropping systems. A case study of West Africa farming systems: *Plant and Soil*, 252: 25-39.

Salako, F.K., Hauser, S. Babalola,O. and Tian, G. (2001). Improvement of the physical ferttility of a degraded Alfisol with planted and natural fallows humid tropical conditions.*Soil Use Management*, 17:42-47

Seran, T. H., and Brintha, I. (2010). Review on maizebased intercropping.*Journal of Agronomy, 9*(3), 135-145.

Shear, G.M. and Moschler,W.W. (1969). Continous corn by no-tillage and conventional tilled methods. *Agronomy Journal,* 61:524-526.

Shukla, M., Lal,R. and Ebinger, M. (2006). Determining soil quality indicators by factor Analysis.*Soil and Tillage Research, 87(2): 194-204.*

SAS Software version 9.3 (2011). *Statistical Analysis System InstituteIncorporation*, Cary, NC, USA.

Sauerborn, J., Sprich H. and Mereer-Quarshie, H. (2000). Crop rotation to improve Agricultural production in sub-Saharan Africa. *Journal of Agronomy Crop Science, 184:67-72.*

Shiralipour, A., Mc Connell,W. and Smith, W. H. (1992) Physical and chemical properties of soil as affected by municipal solid waste compost application. *Biomass Bioenergy* 3:195–211.

Six, J., Elliot, E.T and Paulstain, K. (2000). Soil micro aggregate turnover and micro aggregate formation: A mechanism for C sequestration under no tillage agriculture. *Soil Biology and Biochemistry.* 32: 2099-2103.

Six, J., Feller, C., Denef K., Ogle S.M., de Moraes , J. F.L. and Albrecht, A .(2002). Soil organic matter. Biota and aggression in temperate and tropical soils effects of no tillage. *Agronomy*, 22: 755-775.

Smith, M.J. (1988). Soil Mechanics, (4th edn.), Longman Scientific & Technical, Essex.Smith,J., Barau, A.D., Goldsman, A. and Mareck (1994). The role of technology in Agricultural intensification: the evolution of maize production in the Northern Guinea Savanna of Nigeria. *Economic Development Cultural Change,*.42: 537-554.

Soil Management CRSP (1992). Legume Green Manures Dry season survival and their effects and succeeding maize crops. Soil Management collaborative Research support program (CRSP) North Carolina state University Raleigh p.35.

Soil Survey Staff, USDA Soil Taxonomy (1999). Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. Washington D.C. P. 745.

Stern, W. R. (1993).Nitrogen fixation and transfer in intercrop systems. *Field Crop Research, 34:335*-356.

Steer, A. (1998). Making development sustainable. *Advance.Geo-Ecology*., 31: 857-865. Stocking, M. (2003). Tropical soils and food security: the next 50 years. *Science* 302(5649): 1356-1359.

Sultani, M.I., Gill M.A., Anwar, M.M. and Athar, M. (2007). Evaluation of soil physicalProperties as influenced by various green manuring legumes phosphorusfertilization under rain-fed conditions. *Int. Journal ofEnvironment, Science andTechnology,* 4(1): 109-118.

Syers, J., Pushparajah, E. and Hamblin, A. (1995). Indicators and thresholds for the evaluation of sustainable land management. *Canadian Journal of Soil Science*,75(4),423-428

Tanimu, J.,Iwuafor, E.N.O., Odunze, A.C. and Tian, G. (2007). Effect ofincorporation of leguminous cover crops yield compositions of maize. *World Journal of Agricultural Science.3*(2):243-249.

Tang, C. X., Robson A. D. and Dilworth, M. J. (1990). The role of iron in nodulation and nitrogen-fixation in *Lupinus angustifolius* L. *New Phytologist.* 114: 173–182

Tarawali, S. A.,Keatinge,J. D. H., Powell,J. M. Hiernaux,P. Lyasse, O. and Sang, N.(2001). Integrated natural resource management in West African crop- Livestock systems. In. Sustainable crop-livestock production for improved Livelihoods and natural resource management in West Africa (Williams,T. O. Tarawali,S. A. Hiernaux, P., and Fernandez- Rivera, S.eds.). Pp. 349-370.

Thayamini, H. S., and Brintha, I. (2010). Review on Maize based intercropping. *Journal of Agronomy*, *9*(3), 135-145.

Tripathi, R., Nayak, A. K., Bhattacharyya, P., Shukla, A. K., Shahid, M., Raja, R.,Panda, B. B, Mohanty, S., Kumar, A., Thilagam, V. K., (2014) Soil aggregation and distribution of carbon and nitrogen in different fractions after 41 years long-term fertilizer experiment in tropical rice–rice system. *Geoderma* 213 :280–286

Trujilo, W., Amezquita, E., Fisher, M .J, Lal, R. (1997). Soil organic carbon dynamics and Land use in the Colombian Savannas: I. Aggregate size distribution. p. 267–280. InR. Lal *et al*. (ed.) Soil processes and the carbon cycle. CRC Press, Boca Raton, FL.

USDA, (1975).Soil Taxonomy. A basic System of soil Classification for making and Interpreting soil Surveys. Washington D.C.p.745.

USDA – NRCS (2013) United State Department of Agriculture – Natural Resource Conservation Service Soil Quality kit, Guide for educators

Uyovbisere, E.O., Chude V.O and Bationo, A. (1997). Promising nutrient ratios in Fertilizer formations for optimal performance of maize in the NigeriaSavanna: The need for the review of current recommendations. In: Badu-Apraku B,Fakorede

M.A.B, Ouedraogo M,Quin F.M (eds) Strategy for Maize production in West and Central Africa. Proceedings of a reginal maize Workshop held at IITA-Cotonou, Republic of Benin, April 1997. P262-272.

Uyovbisere, E.O. Chude, V.O. and Bationo, A. (2000). Promising nutrient ratio fertilizer formulations for optimal performance of maize in Nigeria Savannah. The need for review of current recommendations. *Nigeria Journal of Soil Research*,1:29-34.

Van Bavel, C.H.M. (1950). Mean weight diameter of soil aggregates as a statistical index of Aggregation, *Soil Science society of America Journal*, 14:20-21.

Van Veen, J.A. and Kuikman, J. (1990). Soil structure aspects of decomposition of organicmatter by microorganisms. *Biogeochemistry,* 11:213-223.

Vandermeer, J.(1989). *The ecology of intercropping*. New York: Cambridge University press.http://dx.doi.org/10.1017/CBO9780511623523.

Valette, J. A., and Ibanga, I. J. (1984).The detailed soil survey of the experimental farm of the Institute for Agricultural Research Farm, Samaru, Zaria, Nigeria.Soil Survey Bull. Ahmadu Bello University, Zaria, Nigeria

Wani, S.P., Rupela, O.P. and Lee K.K (1995). Sustainable agriculture in the Semi-aid *Tropics through Biological nitrogen fixation in grain legumes. Plant and Soil*, 174: 29-49.

Weber, G., Smith F. and Manyoung, V.M. (1995a). Systems dynamics anddefiniftion of research domains for the northern Guinea Savanna of west AfricaAgriculture, Ecosystem and Environment. (in press).Cropping systems of the northern GuineaSavanna. Resource and Crop Management research Monography No. 17. IITA, Ibadan, Nigeria.

Weber, G.K.,Chindo P.S., Elemo K.A. and Oikeh, S. (1995b). Nematodes production constraints in intensifying cereal-based cropping systems of the northern Guinea savanna. Resource and Crop Management Research Monograph No.17. IITA, Ibadan, Nigeri

Weber, G.K., Elemo S.T.O., Lagoke A. and Oikeh, S. (1996). Population dynamic and determinants of strigahermonthica on maize and sorghum in savanna farming systems. *Crop Protection*,14(4): 283-290.

Whiteman, P. and Lulhan, A. (1971). Seasonal Changes in growth and nodulation of perennial tropical pasture legumes in the field. I. The influence of planting date and grazing a cutting on*Desmodium* uncinatum and phaseolus atropurpureus. *Crop and Pasture Science, 21* (2): 195-206.

Whitebead, A.M. (2004) Soil organic matter: its formation and role in soilstructure, In: Lefroys, R.D.B., Blair G.J. and Craswell E.T. (Eds.) Soil organic matter management for sustainable Agriculture, ACIAR August, 20 24.p124-131.

Willey, R. W. (1985). Evaluation and presentation of intercropping advantages. *Journal ofExperimental Agriculture*. 21:119-133

Winder, J. (2003). Soil Monitoring Programms: A literature Review. Alberta Environmentally Sustainable Agriculture Soil Quality Monitoring Program, Edmonton, Canada.

Williams, C.N. and Chew W.Y.(1980). Tree and Field crops of the wetter regions of the Tropics. Intermediate Tropical Agriculture series. Longman Group Ltd., London. P262.

World Health Organization (WHO) (2000). Malnutrition Worldwide: htt://www.who.int/nut/malnutrition world wide.htm

World Resource Institute WRI. (1994). World Resources 1994- 95: Washington,DC.World HealthOrganization(WHO)(2000).MalnutritionWorldwide:http://www.who.int/nut/malnutritionworldwide.htm

Yusuf, A.A.JanssenB.H. andChude,V.O. (2003). Substitution rate of N, P and K in Farm yardmanure on an Alfisol in Northern Guinea Savanna of Nigeria.*Journal ofAgriculture, Environment and International Development*, 97 (1/2): 93-105.

Yusuf, A.A., E.N.O. Iwuafor, R.C.Abaidoo, O.O. Olufajo and Sanginga, N. (2009) Grain legume Grain legume rotation benefits to maize in the Northern GuineaSavannaof Nigeria: Fixed- nitrogen vs other rotation effects. *Nutrient Cycling inAgroecosystems.* 84: 129-139.

Zhang, WL., Tian, Z.X., Zhang N., Li X.Q. (1996). Nitrate pollution of groundwater in northern China. *Agriculture,Ecosystem and Environment*, 59: 223-231.