SOIL QUALITY AND MAIZE YIELD AS INFLUENCED BY TILLAGE/LEGUME MANAGEMENT AND FERTILIZER RATES IN SAMARU ALFISOLS, NIGERIA

BY

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DEPARTMENT OF SOIL SCIENCE, FACULTY OF AGRICULTURE, AHMADU BELLO UNIVERSITY, ZARIA-NIGERIA.

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DECLARATION

I declare that the work in this thesis entitled **"Soil Quality and Maize Yield as Influenced by Tillage/Legume Management and Fertilizer Rates in Samaru Alfisols, Nigeria"** was performed by me in the Department of Soil Science, under the supervision of Professor A.C Odunze, Professor J.O. Ogunwole and Professor B.D. Tarfa.

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 a higher degree at the Ahmadu Bello University or any other institution.

_____ _____

EBIRERI, Onome Felicia (Candidate) Date

CERTIFICATION

This thesis entitled **"Soil Quality and Maize Yield as Influenced by Tillage/Legume Management and Fertilizer Rates in Samaru Alfisols, Nigeria"** by EBIRERI ONOME FELICIA, meets the regulations 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.

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DEDICATION

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ABSTRACT

This study was conducted in 2010 and 2011 cropping seasons at the Institute for Agricultural Research (IAR) farm, Ahmadu Bello University, Zaria to determine tillage/legume practice that affects soil quality most and also to develop strategies for efficient use of inorganic nitrogen (N) and phosphorus (P) fertilizers to improve maize productivity. The trial was established in 2010 and repeated in 2011 at the IAR meteorological site ($11^0$10'58"N, $7^0$37'0"E) in the Northern Guinea Savanna ecology of Nigeria. Soils in the experimental site were classified as Typic Haplustalf (USDA) and Acrisols (FAO/UNESCO). The experiment was laid out in a split plot design and replicated three times. The main plots ($255m^2$), consisted of three tillage practices {Conventional Tillage plus *Centrosema pascuorum* (CT+Cp), Conventional Tillage without *Centrosema pascuorum* (CT) and Permanent cover plus *Centrosema pascuorum* (PC+Cp)} and three Nitrogen fertilizer rates (NFR) (60, 80 and 100 kg N ha^{-1}) while the sub plots ($75m^2$) consisted of three Phosphorus fertilizer rates (PFR) (6.6, 13.2 and 26.4 kg P ha^{-1}). Results show that treatment CT+Cp had least bulk density which was significantly ($P \leq 0.05$) lower than the other tillage plots. Plots that received 100 kg N ha^{-1} and 13.2 kg P ha^{-1} had the least bulk density which was significantly ($P \leq 0.05$) better than other nitrogen (N) and phosphorus (P) rates at the end of the cropping season. Treatment CT+Cp resulted in a significantly ($P \leq 0.05$) higher mean weight diameter (MWD) of aggregates than the other tillage treatments. pH however decreased slightly under CT+Cp and CT and increased under PC+Cp. Differences in soil pH however, were not significant and decrease was not sufficient to hamper crop growth. Treatment CT+Cp had organic carbon content value that was significantly ($P \leq 0.05$) higher than other treatments. Plots with 100 kg N ha^{-1} and 26.4 kg P ha^{-1} gave better organic carbon contents statistically. CT had significantly ($P \leq 0.05$) higher content of available P at the

end of trial while CT+Cp had the least. Cation Exchange Capacity was better improved statistically under PC+Cp. Treatments with 60 kg N ha^{-1} and 6.6 kg P ha^{-1} had better CEC values statistically. CT+Cp showed significant ($P \leq 0.05$) increase in maize yield over the other treatments with yield of over 3.67 t ha^{-1} at the end of the 2011 cropping season. Effect of decreased bulk density, increased mean weight diameter, reduced exchange acidity and improved CEC and ECEC with years would imply that soil health/quality over the years had been positively impacted upon by the management practices. However, CT+Cp at 100 kg N ha^{-1} and 13.2 kg P ha^{-1} proved superior in improving both soil health and maize productivity with a percentage rise in yield of 2.51 % over CT and 70.6 % over PC+Cp and is therefore recommended for sustainable maize production in Samaru Alfisols, Nigeria.

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CHAPTER ONE

INTRODUCTION

Sub-Saharan Africa is the sub continent that suffered the second largest net loss of forests between 2000 and 2010 with about 3.4 million hectares (FAO, 2010). One major implication of converting forest to agricultural land is deforestation (FAO, 2010). Demography and income growth allied to vagaries of climate change place unrelenting demands on the natural resources to produce food in harmony with other societal and environmental needs. With decreasing per capita land area (currently < 0.1ha), the risk of degradation has greatly increased, posing a severe challenge to soil management for resource conservation, especially soil use and water conservation.

In the West African Savanna, traditional agricultural systems are dominated by low input-low output slash and burn agriculture (FAO, 1997). However, in the last few decades, cropping practices have changed in the West African Savanna, especially with continuous cropping instead of fallowing (Weber *et at*. 1995a). The West African Savanna is particularly fragile due to soil and climatic constraints. Soils of the sub-region are inherently low in nutrients, especially nitrogen (N; less than 2 g kg^{-1}), phosphorus (P; Bray 1 P less than 10 mg kg^{-1}) and soil organic matter (SOM; in the top soil averaging around 10 g kg^{-1} (Bationo and Mokwunye, 1991). To mitigate the negative impact of such intensification, various management practices have been developed. These practices hinge around rotations as an alternative to continuous cropping, conservation instead of conventional tillage (ECAF, 1999) and use of compost farm manure, excess straw and other organic residues (Ogunwole and Ogunleye, 2004).

Upland soils of the Northern Guinea Savanna zone of Nigeria were classified as Typic Haplustalf according to the USDA soil taxonomy (Ogunwole *et al*. 2001) and Acrisols based on 1994 FAO-UNESCO legend. The soils are low in inherent fertility, organic matter, cation exchange capacity, and dominated by low activity clays (Odunze, 2003). They also support production of crops such as maize, sorghum, millet, cowpea, groundnut, soya beans and cotton, and are cultivated continuously and intensively. This continuous and intense cultivation of soils in the zone has resultant effect of accelerated soil erosion, soil nutrient depletion and soil degradation (Bationo *et al*. 2003). This is because continuous cultivation alters soil structure and increases loss of soil organic matter (Mrabet, 2002) which leads to soil degradation. Increasing incidence of soil degradation and the consequent impoverishment of soils have generated interest in the need for proper understanding of soil characteristics, and adoption of suitable conservation practices by farmers for sustained crop production in the zone.

Maize (*Zea mays* L), which is a major staple cereal produced both for cash returns and for food in the Savanna agro-ecology of Nigeria has high yield potential and occupies about 40% of the total area covered by arable crops (Smith *et al*. 1994; Badu-Apraku *et al*. 1997). Enhanced maize production, therefore, has a strong potential for improving livelihood of smallholder farmers in Nigeria. Continuous cropping of this major staple cereal crop in Nigeria has adversely affected soil quality; especially under mono cropping system prevalent in Savanna ecologies.

Nitrogen (N) on the other hand is the most important mineral nutrient limiting maize (*Zea mays* L) production in Nigeria savanna (Uyovbisere *et al*. 1997; Carsky and Iwuafor, 1999; Sanginga *et al*. 2001; Yusuf *et al*. 2003). In spite of its low inherent supply in soils, N deficiency is further exacerbated by its continual depletion from the soil pool through removal of N-containing crop residues from the farmer's fields (Yusuf

et al. 2009). Grain legumes are good sources of food, fodder and cash for farmers. It is an excellent component for a good quality soil in any farming system because it provides residual N and reduces the need for mineral N fertilizer by associated non-legumes (Yusuf *et al*. 2009). Integration of legumes into the cropping systems of the Northern Guinea Savanna of Nigeria has been considered a vital resource management technique for reduction of energy use, cost and pollution potential of inorganic fertilizer usage (Yusuf *et al*. 2009).

Therefore, in an attempt to alleviate soil degradation orchestrated by inappropriate management practices under continuous cultivation in the Guinea Savanna of Nigeria, it became imperative to test the contribution of *Centrosema pascuorum,* N and P rates to soil quality improvement and yield increase in maize under conventional and conservation tillage.

The specific objectives of the study therefore were to;

- assess soil quality changes due to tillage/legume treatments.
- determine fertilizer (N and P) requirements for sustainable maize production.

CHAPTER TWO

LITERATURE REVIEW

2.1 Agricultural and Environmental Sustainability

Food security depends on an abundance of food, even distribution and ability to purchase food, as well as political stability. Unfortunately, in the world today about 3 billion out of the 6.3 billion (PRB, 2003) are malnourished because of shortages of calories, protein, several vitamins, iron and iodine (WHO, 2000). Based on current rate of increase, the world population is projected to double to more than 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, providing adequate food becomes an increasingly severe 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, food production only increases linearly. Furthermore, degradation of land, water, energy and biological resources vital to agricultural sustainability continues unabated (Pimental and Pimental, 2003). 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, fresh water, 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 cropland 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 favourable 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 and foremost on sustainable conservation and management of the land, water, energy, and all biological resources required for food production. The basic needs of a people must be brought into balance with life sustaining natural resources. The conservation of these resources will require coordinated efforts of all individuals and countries. Along with this, more efficient and environmentally friendly agricultural technologies must be developed and put into practice to support continued productivity of Agriculture (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 and degradation, and environmental impacts. Soil resource management is one aspect of sustainable agriculture that is necessary to overcome limitations 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, Nigerian soils undergo about 30% loss in organic matter (Adepetu, 1997). The characteristic low organic matter content 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 decade, soil quality has been one of the topics of great interest in Soil Science, so much so that a database 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 and searching for reliable ways for assessing the quality of soils. In recent years, defining soil quality has put into consideration the key involvement of the soil in crop production, water and atmospheric purification and thus emphasis is laid on the role of the soil both for production and for environmental quality improvement. This has led to a profusion of definitions 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 and air quality, and support human health and habitation", is widely accepted. 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 the concept of soil quality from that of soil health. The limits of the two concepts are not particularly clear, but it is currently accepted that the term quality refers to the aptitude of the soil for carrying out a specific function, while health refers to its overall condition (Doran and Safley, 1997; Doran, 2002). In spite of the large number of scientific papers that choose soil quality as a keyword, less than 20% deal with the 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, and 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 the change in soil quality. Though soil quality is affected by a large number of properties, the 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 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 limits or threshold level), at different time intervals, for a specific use in 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. They observed that high yield, low labour requirement, low input cost, high profit, and stability are some features that are likely to enhance farmer satisfaction. Natural resource conservation is 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 systems of the Northern Guinea Savanna (NGS) are based mainly on cereals such as maize, sorghum, millet and rice which are well adapted to the 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 system. In other areas where there is good access to market,

availability of fertilizers and improved maize varieties, the production system is changing to maize-based system (Weber *et al*. 1995b). The most common non-cereal crops in the savanna system include cotton, groundnut, cowpea and soybean (Ogungbile *et al*. 1991). Cultivation of forage crop is rare, in spite of increasing animal husbandry.

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 has led to a decline in soil fertility, soil compaction, soil acidification resulting from misuse of chemical fertilizers, and a build-up of pest problems affecting productivity of the land (Weber *et al*. 1996).

There are some socio-economic constraints to expansion of the maize-based cropping system. The structural adjustment reforms introduced in the country in the mid-eighties has led to an increase in fertilizer/grain price ratios in spite of the 80 percent subsidy on fertilizers. Fertilizers have 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 the maize-based system, strategies are therefore required for efficient use of native nitrogen and for a judicious application of inorganic fertilizers.

2.4 Tillage and Tillage Systems

Lal (1979) defined tillage as physical, chemical or biological soil manipulation to optimize conditions for seed germination, emergence and seedling establishment. There are different forms of tillage systems practiced all over the world. Whichever type is practiced in any particular ecology is usually determined by soil condition, climate and type of crop to be grown.

Tillage and crop residue retention have been shown to retain more water in semi-arid Mediterranean soils, not only because of reduced evaporation (Lampurlane´ and Cantero-Martı´nez, 2006), but also because tillage often results in the development of a new and more extensive pore system that enhances soil water holding capacity (Bescansa *et al*. 2006a). Tillage is often justified for these soils because, as reported in other areas (Arrouays *et al*. 2002), producers are concerned that without it, compaction often results in higher bulk densities and increased penetration resistance, especially in the upper few centimeters (Schjønnning and Rasmussen, 2000; Bescansa *et al*. 2006b). Perhaps by developing criteria for assessing soil quality, producers will be able to understand all aspects of soil management and thus be more willing to adopt no-till practices and gain the water conservation, soil organic matter, and crop yield benefits of those practices (Bescansa *et al*. 2006b). The beneficial effects of tillage on aggregate stability, soil carbon sequestration, favorable distribution of carbon and nitrogen in aggregate size fractions and reduction in bulk density, have been widely reported (Madari *et al*. 2005; Jiao *et al*. 2006; Alan *et al*.2007). Land use and management practices affecting change in plant cover, intensive soil tillage and removal of plant biomass from the fields may decrease SOM concentration, thus deteriorating soil physical properties (Li *et al*. 2007). Because of a strong relationship between physical and chemical properties and crop growth, understanding how these properties are influenced by the interactive effects of subsurface drainage and tillage is crucial to sustainable management of these soils.

Tillage systems practiced in Nigeria include ridge tillage, which is labour intensive (Ogban *et al*. 2007). Ridge tillage and mound tillage techniques consist of heaping the surface soil for both root and non-root crops commonly grown. It can also be known as conventional tillage. Flat tillage on the other hand is either zero-tilled (no

till) or plough-tilled. These tillage systems are specifically used to enhance rain water infiltration and control noxious weeds that damage the potential of land and take more than 50% of time the farmers spend on the field (Ogban *et al*. 2007). However, Nye and Greenland (1960) have reported that simple as these tillage systems are in low-input agro ecosystems, they are associated with a decline in soil organic matter, especially as little or no agricultural residues are returned to the soil.

Two of these tillage practices are further explained below;

1. Conventional Tillage: This refers to the method of annual seed bed preparation that involves physical soil manipulation by commonly used farm implements such as disc plough, mould board plough, rotavator and harrow. It has been shown to cause undesirable side effects on soil properties (Stanford *et al*. 1973; Lal, 1976; Doran, 1980; Hargrove *et al*. 1982; Dick, 1983; Garji *et al*. 2002). It has also been proven that conventional tillage practices disrupt soil aggregates, exposing more organic matter to faster or more rapid microbial attack. Organic matter may be protected from microbial attack by adsorption (Ladd *et al*. 1985) and the formation of micro aggregate (Edwards and Bremmer, 1967; Gregorich *et al*. 1989), by isolation in micro pores (Adu and Oades, 1978; Foster, 1981) and by physical protection within stable macro aggregates (Elliot, 1986).
2. No-Tillage or Zero-Tillage: Philips *et al*. (1980) defined no-tillage system as one in which the crop is planted either entirely without tillage or with just sufficient tillage to allow crop seed to germinate and emerge. No till farming signifies a major shift in the conceptual basis of soil management for crop production. It signifies much more than another method of seed bed preparation and the elimination of ploughing (Lal *et al*. 2004). The concept challenges the scientific basis of ploughing as an original, universal method of soil preparation. It questions the wisdom of repeatedly disturbing the soil

ecosystem. Nothing in nature matches the drastic perturbation of surface soils resulting from frequent ploughing. The concept of no-till farming embodies ecological principles of minimal or no soil disturbance, continuous maintenance of vegetal/mulch cover on the soil surface, strengthening natural processes that improve soil structure and recycle nutrient elements through the activity and species diversity of soil micro flora and fauna, and maintaining/ enhancing soil organic matter content. Crop residue, mulch, minimal or no soil disturbance and rotations are principal components of no-till farming (Lal *et al*. 2004). They require development of specific techniques of sowing in an undisturbed seed bed with loose residues, controlling weeds and other pest and pathogen.

Lal (1975) had questioned the usefulness and feasibility of ridges and mound without mulch as a soil protecting device particularly for unstable soil of coarse texture. This is especially so because, despite the potential of crop/ plant residues to increase the resistance of soil to erosion, improve nutrient retention and storage (Woomer and Ingram, 1990), increase buffering capacity in low- activity clay soils (Lal, 1975; Swift and Sanchez, 1984) and increase their poor water holding capacity (Lal, 1986), as well as being available and inexpensive (Agboola, 1978), residue mulching is not commonly practiced in Nigeria. Residue mulch was reported to reduce soil particle detachment and transport (Iwuafor *et al*. 1990; Opara- Nadi, 1993), improve organic matter content and soil fertility, soil water storage capacity, and infiltration rate (Mbagwu, 1991; Obatolu and Agboola, 1993; Opara- Nadi, 1993; Owaiye, 1993; Ogban *et al*. 2001) and increase crop growth and yield (Owaiye, 1993; Ogban *et al*. 2001). Lal (1975) demonstrated that residue mulch on mounds or ridges improved infiltration characteristic, stability of aggregates, water storage capacity and crop yield on coarse textured soils. Hulugalle *et*

al. (1985) observed that tillage reduced soil bulk density, but that soil infiltration increases only when tillage and mulch were combined.

2.5 Tillage and Mulching

Tillage and mulching are two essential soil management practices for enhancing and sustaining productivity of soil in the tropics. While tillage is used in different intensities to reduce soil compaction and control weeds, mulching with plant residues serve to improve soil fertility, microbial activities, conserve soil water and moderate soil temperature (Borlaugh and Dowswell, 2004). Therefore, a proper combination of tillage and mulching is expected to improve soil productivity and crop yield, especially in case of maize which is highly sensitive to soil temperature. While the positive influence of mulch on soil and crop has been affirmed (Awodun and Ojeniyi, 1998; Falade and Ojeniyi, 1997) on Alfisols, the intensity and type of tillage necessary for different soil types and crops vary (Ojeniyi and Agboola, 1995). The utility of conservation tillage systems for soil and water conservation is generally recognized worldwide. Conservation tillage systems are based on the principle of mulch farming and they usually conserve soil and water simultaneously by controlling runoff. Past studies have shown that conservation tillage maintains the preservation of soil structure and other soil quality, productivity and biodiversity through three basic principles: minimum tillage, cover crops and crop rotation (Iwuafor *et al*. 1990; Obatolu and Agboola, 1993; ECAF, 1999; Ogban *et al*. 2007; Melero *et al*. 2009). There is a growing quest worldwide for the adoption of conservation tillage systems (no-till and reduced tillage), especially in tropical and semi-arid agro ecosystems (Baudoin *et al*. 2009). Conservation tillage has numerous positive effects on soil. It improves water holding capacity, nutrient retention, structural stability, slows down mineralization which in turn increases soil organic matter content, reduces run-off and erosion (Ogban *et al*. 2001).

Diur (2004) and Yen (2006) established that crop mixtures take up higher amount of nutrients per unit land area than sole crops. According to Diur (2004), one hectare of crop mixtures took up 40-60% more nutrients than 2.5 hectares of corresponding sole crops. In general, total uptake of nutrients in crop mixtures was reported to increase with increasing population of individual crops in the mixture (Kusimo, 2005; Cam, 2007). Adeyi (2003) and Bada (2005) reported decline in soil fertility and crop yields with increasing population of component crops in the mixture and ascribed the decline to depletion of soil organic matter. In contrast, Adenle (2004) and Crick (2007) noted an appreciable increase in soil fertility in crop mixtures, involving certain tropical legumes after cropping. They adduced the increase in soil fertility to the ability of legumes to fix large quantities of nitrogen in the soil. In Nigeria, legume/maize intercropping system is a very prominent traditional farming system. Benefits of the inclusion of legume in many crop mixtures had been reported to include improvement in N status of the soil through nitrogen fixation, its short lifespan, as well as its ability to cover the ground, with resultant decreases in the incidence of weed infestation and soil erosion (Aya, 2004; Gerh, 2007). The inclusion of certain tropical legumes in crop mixtures has also been reported to increase soil organic carbon, total nitrogen, available phosphorus and exchangeable potassium (Singh *et al*. 2006). In addition to the above, the inclusion of legume in crop associations minimizes the risk of crop failure and brings about higher total returns per unit area of land, which allows larger financial gains for farmers (Beader, 2004). In Nigeria, the literature reporting agricultural research on conservation tillage systems for the various agro-ecological zones is limited.

2.6 Effect of Tillage Systems on Soil Properties

Several studies have shown the 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. Furthermore improvement of soil structure allows better soil aeration and water infiltration, and the preservation of surface cover of residue 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*. (1977) 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) under no- tillage was lowered from 6.1 to 4.1 compared to 4.7 under conventional tillage when an annual rate of 336 N kg/ha was applied. Hargrove *et al*. (1982) also reported that in no- tillage, soil pH decreases more rapidly with depth than with conventional tillage and that Ca, Mg, P, Mn and Zn accumulated more on the surface in no- till than on tilled treatments. Dhiman *et al*. (2001) reported an increase in bulk density of the soil from 1.50g cm^{-3} in conventional to 1.58gcm^{-3} in no- tillage plots. And increase in the value of bearing capacity by about 50% under no- till plots.

Shear and Moscher (1969) reported that K availability was not affected by tillage and that P accumulated more in the upper 5cm surface in no- till soils. A similar result was reported by Nangyu (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) have data that show that the 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 and Cookson *et al*. 2008).

2.7 Effect of Tillage Systems on Crop Performance and Yield

Results of tillage systems on crop performance and yield have been quite variable. Lal and Dinkins (1979) reported that grain yield of maize and rice was significantly higher for no-till plot than conventionally 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.

Poor seedling emergence and establishment have been widely reported on no-till treatments and this has led to sparse crop stands in no-till treatment compared to conventionally tilled plots (Lal *et al*. 2004). The poor stand may be due to wide range of factors including unavailability of the proper equipment or seed drill, poor seed-soil contact, low soil moisture, unfavourable soil temperature, pest infestation and damage by birds and rodents. Mean seedling establishment by zero tillage method is reported to be about 20% less than 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 yields were equal and often significantly higher with reduced and no tillage systems than with conventional tillage (Fenster, 1977; Unger *et al*. 1977; Unger and Wiesse, 1979). The higher yields with reduced and no

tillage were generally attributed to increased soil water contents resulting from increased infiltration, decreased runoff and porosity, decreased evaporation.

Lal (1979) reported that tillage caused no significant differences in plant height in the initial stages but the differences in plant height between the no till and conventional tillage increased with time, with no till treatments having taller plants with higher leaf area index. Root elongation has been reported to be slower in 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 the lateral spread of the roots during the early stages of crop development. Baeumer (1981) reported that on sandy soil, shallow rooting persisted until harvest probably due to mechanical impedance on the soil to root penetration. Ehlers *et al*. (1983) reported that root growth was linearly related to penetration resistance.

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 the yields of cassava and maize were significantly affected by tillage, cowpea yield was not significantly affected.

2.8 Effect of Soil Cover and Legume Green Manure on Soil and Crop Yield Improvement

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 the 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 and 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 *et al*. 2007). The reduction of moisture losses can be attributed to a combination of several factors (Shukla *et al*. 2004): (i) significant reduction in the rate of surface evaporation and surface runoff, and (ii) increases in infiltration rates and moisture retention capacity of the soil.

Biological nitrogen fixation (BNF) 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 *Mucuna pruriens*, *Macrotyloma uniflorum and Centrosema pascuorum* as green manure, can improve soil fertility and can help increase the 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 40 kg N for every 1000 kg of dry matter of shoots produced (Humphreys, 1995). Several reports have shown the use of accumulated N due to biological fixation to increase the yield of subsequent crops. For example, in their work to determine the contribution of five different legumes to soil nitrogen status and performance of succeeding maize in short fallow, Cheruiyot *et al*. (2001) reported improved soil N status and increased grain yield of maize following the legumes. Their result was also supported by Whitbread (2004) and Mulongoy and Akonbundu (1990) who reported that *Mucuna pruriens* significantly improved maize grain yield when planted as fallow.

Furthermore, some legumes have been found to facilitate the utilization of soil P in low P soils of northern Guinea 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.

2.9 Maize and Its Importance

Maize (Zea mays L.) is an annual plant of the grass Gramineae family. It is an out-pollinated plant which matures usually within 100-120 days, although some variation exists. The male flowers called tassels emerge 50-60 days after planting (DAP) at the apex of the plant. At about the same time, the female flowers are formed in the axils of the lower leaves. But the stigmatic surfaces of the female flower 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 the introduction of fertilizers, responsive improved cultivars and the adoption of fertilizer use, maize cropping has dramatically transformed agriculture in the Northern Guinea Savanna (NGS) from subsistence to 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 high yield potential and occupies about 40% of the area under arable crops in the savanna zones (Badu-Apraku *et al*. 2003).

2.10 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 range from 350-400 cal cm^{-2} day^{-1} in the north and averages about 250 cal cm^{-2}

day^{-1} in the south while the corresponding mean daily air temperatures are 27^{o}C and 25^{o}C (FAO, 1997). High temperature above 32^{o}C at tasseling and pollination speeds up differentiation process of the reproductive organs resulting in higher kernel abortion. When many kernels are aborted, the total sink size could limit yield (IITA, 1986).

Maize is grown on a wide range of soils. 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 higher susceptibility to moisture and nutrient stress. Maize does best on soils with pH of 5.5 - 7.0, and strongly acid soils with pH < 5.0 are unsuitable except when limed. It can also be grown in alkaline soils but deficiencies of iron and manganese must be corrected (William and Chew, 1980).

2.11 Legume Integration into Cereal-Based Systems

Legumes play a major role in farming system because in addition to being a source of protein, they provide an 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; COMBS, 1993). Legume can fulfill a major part of their N requirement through N_2 fixation, and contribute N to the soil and the companion or subsequent crops. Soil physical properties that are affected by incorporation of the green manure include the structure, moisture retention capacity, consistency and density. Other properties such as porosity, aeration, conductivity, hydraulics and infiltration are allied to the modifications 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 manure 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 *Centrosema pascuorum, Centosema brasilianum,*

Lablab purpureus and *Macrotyloma uniflorum* can be integrated into cropping systems of the Guinea Savanna (Iwuafor, 1986; Odunze *et al*. 2002) 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.

2.12 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 yields at different levels of N fertilization, and/or by determining the correlation between tissue N concentration or N content and maize yield performance. Often crops which provide 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 the N need of a given crop. Another important factor is the internal crop N requirement, defined as the N concentration in the total above ground 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 has proven N requirement of maize to be 120 kg N ha^{-1}(Chude, 1996).

2.13 Response of Maize to N Fertilization in Northern Guinea Savanna of Nigeria

Maize responds well to soil fertility especially to high N availability (Jones an wild, 1975), probably because of its shorter growth period and hence greater intensity of

nutrient demand. Early fertilizer work on maize gave a recommended rate of 66kgNha^{-1} as optimal for an expected average yield of about 2.0 – 2.8 t ha^{-1} grain (i.e. 30-42kg grain kg N^{-1}) in the Northern Guinea Savanna of Nigeria (Goldworthy, 1967). Jones (1972) tested three rates of N applied as Calcium Ammonium Nitrate (CAN) and found that the responses of maize were generally high and significant to rates of 56 kg and 112 kg N ha^{-1}; and on the average, these rates increased yield by 2.0 and 1.0t ha^{-1} respectively. Higher application rates resulted in further increase of only 0.6t grain ha^{-1}. With intensification of cultivation, development of improved varieties, improved management practices and skills over the years, greater responses to N fertilizers and much higher yields than hitherto have been achieved. The current N fertilizer recommendation for the Northern Guinea Savanna therefore, is 120 kg N ha^{-1}for open pollinated (OP) maize and 150 kg N ha^{-1}for hybrid (Chude, 1996) with grain yields ranging from 3.5-5.0 t ha^{-1} for OP and an average of 5.0 t ha^{-1} for hybrid, under adequate Phosphorus (P) and Potassium (K) content in the soil (Enwezor *et al*. 1989).

In general, maize response to nitrogen fertilizer shows that grain yield at first increase linearly with N and further additional increase in N gives only a smaller increase in yield (declining rate of return) until a maximum yield is attained, beyond which yield declines.

2.14 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 the soils are responsible for the continuous downward spiral in

soil and crop productivity within the ecology; as continuous cultivation without soil fertility programme leads to soil structural degradation and loss of soil organic matter (Mrabet, 2002). Further, 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 the 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 yields of cereal crops. Maize is known to tolerate high rate of nitrogen fertilizer without any depression in yields (Samuel and Aldrich, 1980). However, in a cropping situation where stress related to other nutrients 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 portions 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 fertilizers is now a contentious issue. In the USA, research has shown that continuous nitrogen fertilizer use in maize production can result in a wide spread of nitrate pollution of ground water and economic loss to farmers.

Fast population growth as well as increased industrialization and urbanization has greatly increased 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 land fertility and maintain good soil structure have to be put in place.

2.15 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 and Kuikman, 1990). Soil aggregates are the basic units of soil structure, and composed of primary particles and binding agents that stabilizes 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 the soil 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 where tillage and other cultural practices disturb the land.

In the Savanna, Agbenin and Goladi (1997) reported changes of carbon (C), nitrogen (N) and phosphorus (P) of Alfisols under continuous cultivation complimented with farmyard manure and inorganic fertilization for forty-five years. Their result shows that, continuous cultivation 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 1mm diameter. Their results show that these treatments were better aggregated to withstand wind erosion.

2.16 Phosphorus Requirements of Maize and Legume to P Applied to Soils of Northern Guinea Savanna

Phosphorus which is an essential nutrient element to crop growth and productivity is added generally to soils and specifically to tropical soils to take care of deficiencies that normally occur due to their acidic nature which range between pH 4 to 6.5 and variable charged minerals rich in Fe and Al oxyhydroxides with high affinity for P (Abdu, 2009). Significant response to phosphorus applied through water sources have been observed for arable crops (Adetunji, 1997, 1995). Some studies (Adepetu, 1983; Adepoju, 1993) show that P sorption measurements influence the phosphorus requirements of crops in Nigerian soils. It has been proven from studies also that some legumes have been found to facilitate the utilization of soil P by crops in the low P soils of Northern Guinea Savanna of Nigeria (Kahm *et al*. 2002).

2.17 Soil Microbial and Biochemical Changes Associated with Cropping Systems and Soil Depth

Contemporary concerns for sustainable agricultural production underpin the need to develop appropriate crop management practices that are able to improve soil quality (Harris and Bezdicek, 1994). Soil microbial biomass represents the active fraction of the soil organic matter pool, which is responsible for organic matter decomposition and, thus, soil nutrient content (Gregorich *et al*. 2000; Haney *et al*.

2001). Generally, soil microbial biomass depends on soil organic matter as substrate; therefore, the decrease of SOM will cause the reduction of soil microbial biomass (Chen *et al.* 2005). Changes in soil organic matter stock occur very slowly and it may take many years before any demonstrable changes due to disturbance or restoration become discernable (Garcia and Hernandez, 1996). There is however, growing evidence that soil biological properties could serve as early and sensitive indicators of soil ecological stress or restoration (Dick and Tabatabai, 1993). Indeed, soil microbial population and biomass have been used in conjunction with enzyme activities as indicators of soil quality under various cropping systems (Ndiaye *et al*. 2002; Monkiedje *et al*. 2006; Franchini *et al*. 2007). These microbiological parameters respond to management practices such as fertilizer application, crop residue management and crop rotation.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site Description and Climate

The trial was conducted for two cropping seasons (2010 and 2011) at the experimental farm of the Institute for Agricultural Research (IAR), Samaru, Zaria. The experiment was established in 2010 at the IAR meteorological site ($11^0$10'58"N, $7^0$37'0"E) in the Northern Guinea Savanna ecology of Nigeria. Long term mean annual rainfall (1928-2008) in the zone is 986.5mm and is received mainly between the months of May and September with peak rainfall received in August (Odunze, 2011). Mean daily temperature of the area is 24^0C with an altitude of 686m above sea level (Oluwasemire and Alabi, 2004). Soils in the experimental area were classified as Typic Haplustalf {USDA Soil Taxonomy (USDA, 1975; Ogunwole et al., 2001)} and Acrisols {FAO-UNESCO legend (1994).

3.2 Experimental Materials

Maize and *Centrosema pascuorum* were the planting materials used in the trial and they were obtained from Seed Production Unit of the Institute for Agricultural Research (IAR), Samaru. *Centrosema pascuorum* was selected because of its high seed dissemination, availability and ability to subdue striga (*Striga hermanthica*) attack. The maize variety used was early maturing SAMAZ-14 (Quality Protein Maize and early maturing).

3.3 Experimental Methods

3.3.1 Design of Experiment, Treatment and Plot Layout

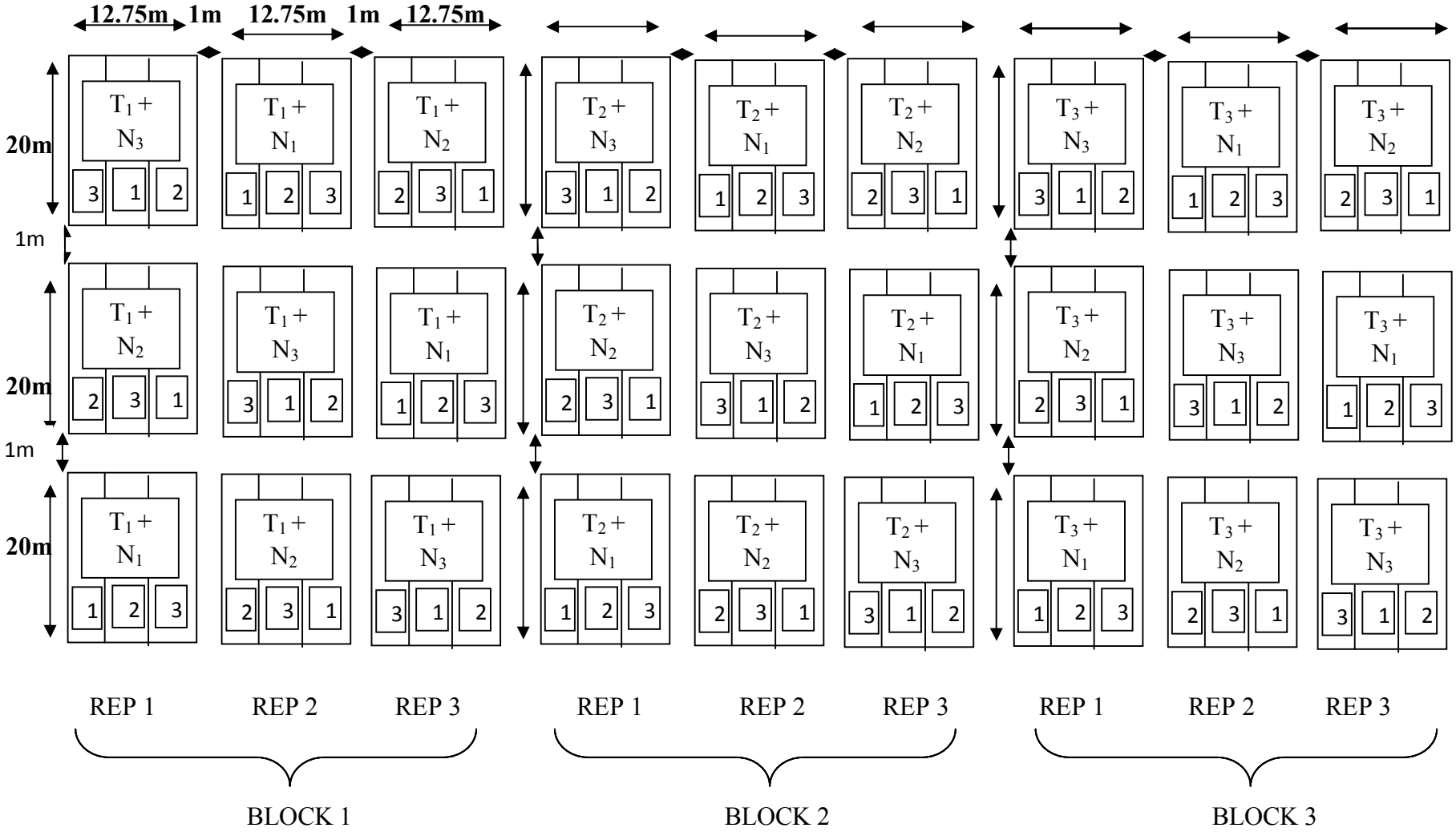
The experiment was laid out in a split plot design and replicated three times. The main plots (255m^2), consisted of three tillage practices {Conventional Tillage plus *Centrosema pascuorum* (CT+Cp), Conventional Tillage without *Centrosema*

pascuorum (CT) and Permanent cover plus *Centrosema pascuorum* (PC+Cp)} and three nitrogen (N) fertilizer rates and the sub plots ($75m^2$) consisted of three phosphorus (P) rates. The N rates (60, 80 and 100 kg N ha^{-1}) were applied in two equal split doses at 2 weeks after planting (crop establishment) and 6weeks after planting (tasseling) respectively, while the P rates (6.6, 13.2 and 26.4 kg P ha^{-1}) were applied only once at 2 weeks after planting. Nitrogen fertilizer source was urea (46% N) and phosphorus fertilizer source was single super phosphate (18% P).

Lower rates of both fertilizers (N and P) were selected to determine if maize will yield as much as with recommended dosage of 120 kg N ha^{-1} and 60 kg P ha^{-1} in the ecological zone (Chude, 1996) since *C. pascourum* was relayed along the maize on some treatments. N was applied in two equal splits to reduce leaching.

The experimental layout is shown below;

Experimental Layout



Where;

T_1 = Conventional tillage plus *Centrosema pascuorum* (CT+Cp).

T_2 = Conventional tillage (CT).

T_3 = Permanent cover plus *Centrosema pascuorum* (PC+Cp).

N_1 = 60 kg N ha^{-1} 1 = 6.6 kg P ha^{-1}

N_2 = 80 kg N ha^{-1} 2 = 13.2 kg P ha^{-1}

N_3 = 100 kg N ha^{-1} 3 = 26.4 kg P ha^{-1}

Each block was made up of three replications and each replicate was made up of three plots making 9 plots per block. This gave a total of twenty seven (27) plots in the experimental layout.

3.3.2 Land Preparation and Planting Methods

After the land was cleared of bush re-growth, the conventionally tilled plots were disc ploughed and harrowed once after which ridges were made to give a ridged seed-bed. The no-till plots were cultivated with *Centrosema pascuorum* prior to experimentation to give it permanent cover and so were not ploughed or harrowed. It was only sprayed two weeks before planting with gramazon (Paraqat, Syngenta Ltd., Switzerland) to suppress weed. Thereafter, it was cultivated with maize intercropped with *C. pascuorum* drilled beside the maize to give the plot permanent cover throughout each cropping season. Both crops were planted simultaneously on 24th July and 30th June in 2010 and 2011 respectively. Maize (SAMAZ-14) {quality protein maize (QPM) and early maturing} was planted on the peak of

the ridge at a spacing of 25 cm apart giving a plant population of about 53,333 stands per hectare. Two seeds were planted per hole and thinned to one, two weeks after planting (WAP). The legume (*C. pascuorum)* was drilled on the ridge slope for the treatment that involved legume/maize intercrop while the treatment involving maize monocrop was left with only maize. Both maize and *C. pascuorum* were planted on the same day in both years.

3.3.3 Cultural Management

Herbicide {Gramazon (Paraqat, Syngenta Ltd., Switzerland)} was applied on the Permanent Cover (PC) plots two weeks before planting so as to suppress weeds since it was a no-till plot. Subsequently weed control for this treatment was through herbicide application and hand pulling. Plots in the other treatments were kept free of weeds with hoe and re-moulding (earthen-up) with traditional big hoe**.** Fertilizer (nitrogen and phosphorus) were applied at rates of 60, 80 and 100 kg N ha^{-1} and 6.6, 13.2 and 24.6 kg P ha^{-1} respectively as described in the experimental layout. Fertilizers were applied at about 5 cm depth and 5cm away from the plant and covered. The experiment was repeated in 2011 cropping season using the same plots and the same experimental design as described in 3.3.2.

3.3.4 Treatments

Treatment 1 - Conventional Tillage + *Centrosema pascuorum* (CT +Cp): Planted with maize at 25 cm apart on ridge peak, drilled with legume *(Centrosema pascuorum)* on the ridge slope to give it permanent soil cover and tilled annually. Previous year residue was incorporated in soils.

Conventional Tillage (CT): No cover crop; planted with maize only at 25 cm apart on ridge peak, but annually tilled (ploughed, harrowed and ridged)

Permanent Cover (PC): Permanently covered with residue; planted with maize at 25 cm apart and drilled with legume (*C. pascuorum*) by the side.

Treatment 2 – Nitrogen Fertilizer Rates (NFR): 60, 80, and 100 kg N ha^{-1} applied at 2 and 6WAP

Treatment 3 – Phosphorus Fertilizer Rates (PFR): 6.6, 13.2 and 26.4 kg P ha^{-1} applied at 2WAP

3.3.5 Observations and Soil Sampling

Maize height measurement taken from the soil level to the tip of the tallest leaf was done at 4, 6, and 8 weeks after planting (WAP). Measurements were made on four tagged plant stands within the net-subplot ($75m^2$) and the average computed per sub-plot.

Maize shoot dry matter yields was obtained by cutting shoot at the soil surface level at harvest and oven-drying before weighing for each net sub-plot of the treatments.

Phenological observations taken on maize included number of days to tasseling, and harvesting.

3.3.6 Harvesting

The maize crop was harvested after maturity and some level of drying in the field. The ears were harvested and de-husked, oven-dried and yield (cob weight, maize grain yield, 1000 grain weight) computed and reported.

3.3.7 Soil Analysis

Soil samples taken with soil auger were air-dried, crushed with porcelain pestle and mortar and screened through a 2mm sieve. The fine earth portions were stored in clean polythene bags and analysed for the following;

3.3.7.1 Chemical Analysis

1. Particle Size Distribution: Particle size distribution of soils less than 2 mm fine earth was determined by hydrometer method as described by Gee and Bauder (1986).
2. Soil pH: Soil pH was determined directly using the Pye unican pH meter in water and 0.01M $CaCl_2$ solutions as described by Agbenin (1995).
3. Soil Organic Carbon: Soil organic carbon was determined by the Walkley Black wet oxidation method (Nelson and Sommers, 1982).
4. Available Phosphorus: Available phosphorus was determined by Bray No.1 method as described by Nelson and Sommers (1982).
5. Total Nitrogen: Total nitrogen was analysed by Kjeldahl digestion method described by Bremner and Mulvaney (1982).
6. Exchangeable Acidity (H^+ and Al^{3+}): Exchangeable acidity was determined by shaking the soil in 0.01M KCl and titrating the filtrate with 0.1M of NaOH (Agbenin, 1995).
7. Exchangeable Bases (Ca, Mg, K and Na): Exchangeable Ca, Mg, K and Na were extracted in ammonium acetate (1N NH_4OAC) solution using 1:10 soil to solution ratio according to Chapman (1965). Calcium (Ca) and Magnesium (Mg) were determined by EDTA titration method (Agbenin, 1995). Potassium (K) and Sodium (Na) were determined using flame photometry (Anderson and Ingram, 1993).

8. Micronutrients (Fe, Mn, Zn, and B): Micronutrients content of the soil were determined by method describe by Juo (1979) and Page et al. (1982).

9. Soil Cation Exchange Capacity: Cation exchange capacity of the soil samples was determined using the 1N Neutral Ammonium Acetate (1N NH_4OAC) method (Rhoades, 1987).

3.3.7.2 Physical analysis

1. Bulk Density: Bulk densities of the soil were determined using cores (Anderson and Ingram, 1993).

2. Aggregate Stability: Aggregate stability was determined by dry sieving method as described by van Bavel (1950). Bulk sample was sieved with 5 mm sieve.

3.3.7.3 Microbial Biomass Assessment:

1. Microbial Biomass Nitrogen: The soil microbial biomass nitrogen (SMBN) was estimated using the chloroform incubation method of Jenkinson and Powlson (1976).

II. Microbial Biomass Phosphorus

The soil microbial phosphorus (SMBP) was determined by the method described by Hedley and Stewart (1982) except that there was no removal of resin extractable P prior to $CHCl_3$ fumigation because of low amounts of resin P in these soils (Agbenin and Goladi, 1997).

III. Microbial Biomass Carbon

3.4 Weather Report

Rainfall and temperature data for the period of the experiment (2010 and 2011) was obtained from the meteorological station of the Institute for Agricultural Research (IAR).

3.5 Statistical Analysis

Data collected during the trial were subjected to analysis of variance and mean values were separated using Tukey's Honestly Significant Difference test (HSD). The relationship between crop performance and soil parameters were determined by correlation analysis (SAS, 1993).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Samaru Weather Report for year 2010 and 2011

Tables 1 and 2 and provide weather data in Samaru for year 2010 and 2011 (trial period). Data show that in 2010, mean annual air temperature ranged between 22.22^{O}C in December to 30.63 ^{O}C in April. Air temperature fluctuated within the year but data show that the highest air temperature was observed in the early months of the year (February to May). It was generally observed that the highest amount of air temperature was in April (Table 1). Earth temperature fluctuated throughout the year as mean earth temperature ranged between 23.53 ^{O}C in December to 31.79 ^{O}C in April.

Total rainfall amount recorded in Samaru in 2010 was 1122.15mm with the highest amount of rainfall recorded in the month of August (313.4mm). The first rain recorded in Samaru in 2010 was on April 16th amounting to 3.3mm. It rained only five (5) days in April that year and the total rainfall amount in the month amounted to 52.4mm (Table 1) which was not sufficient to sustain crop production. In May, rainfall was recorded for seven (7) days amounting to 92.9mm, June recorded 11 days amounting to 158.3mm and in July, 13 days of rainfall was recorded which spread within the month and was sufficient to sustain crop production. The total amount of rainfall in July was 211.65mm. August recorded the highest rainfall amount of 313.4mm in 19 days and there was a drop in the amount of rainfall in September recording a total rainfall of 211.2mm in 16 days. Rainfall amount dropped sharply in October with a total rainfall of 82.3mm in 10 days. The last rain in Samaru in year 2010 was recorded on October 28th with a rainfall amount of 1.2mm.

In 2011 also, Samaru mean air temperature ranged between 21.61 ^{O}C in January to 30.19 ^{O}C in April. Air temperature fluctuated within the year but data show that the highest air temperature was observed in the early months of the year (February to May). It was generally observed that the highest amount of air temperature was in April (Table 2). Earth temperature fluctuated throughout the year as mean earth temperature ranged between 22.94 ^{O}C in January to 31.19 ^{O}C in April.

Total rainfall amount recorded in Samaru in 2011 was 866.2mm with the highest amount of rainfall recorded in the month of August (239.9mm). The first rain recorded in Samaru in 2011 was on April 17th amounting to 4.3mm and thereafter, there was political crisis in Samaru that lasted for Five (5) days so rainfall amount could not be collected for those number of days since it was done manually and there was curfew. Rainfall data was therefore collected for only three (3) days in April that year and the total rainfall amount in the month amounted to 13.9mm which was not sufficient to sustain crop production. In May, rainfall was recorded for eleven (11) days amounting to 123.3mm, June recorded 12 days amounting to 162.5mm spread evenly and in July, 14 days of rainfall was recorded which also spread within the month and was sufficient to sustain crop production. The total amount of rainfall in July was 223.9mm. Like in 2010, August also recorded the highest rainfall amount of 239.99mm in 16 days and there was a drop in the amount of rainfall in September recording a total rainfall of 102.7mm in 11 days. The last rain in Samaru in year 2011 was recorded on September 29th with a rainfall amount of 7.2mm.

Generally, in both years, days without rainfall were more than days with rainfall. 2010 recorded 133 days without rainfall and 81 days with rainfall and 2011 recorded 116

days without rainfall and 67 days with rainfall within the months of April to October in 2010 and April to September in 2011 that rainfall was observed in the trial area.

Table 1 Samaru Mean Monthly Weather Report for Year 2010

MONTH	AIR TEMP(^{O}C)	EARTH TEMP(^{O}C)	RAINFALL(mm)		
			Days with rain	Days without rain	Total Rainfall
JAN	23.63	24.28	-	-	-
FEB	27.285	27.525	-	-	-
MAR	29.18	30.055	-	-	-
APR	30.62	31.785	5	25	52.4
MAY	29.045	29.94	7	24	92.9
JUNE	26.6	27.905	11	19	158.3
JULY	24.84	26.32	13	18	211.65
AUG	24.915	25.98	19	12	313.4
SEPT	26.035	26.195	16	14	211.2
OCT	26.63	26.675	10	21	82.3
NOV	24.95	24.79	-	-	-
DEC	22.225	23.53	-	-	-
TOTAL			81	133	1122.15

Table 2: Samaru Mean Monthly Weather Report for Year 2011

MONTH	AIR TEMP(^{O}C)	EARTH TEMP(^{O}C)	RAINFALL(mm)		
			Days with rain	Days without rain	Total Rainfall
JAN	21.61	22.935	-	-	-
FEB	27.355	27.39	-	-	-
MAR	29.13	29.62	-	-	-
APR	30.185	31.19	3	27	13.9
MAY	28.675	29.88	11	20	123.3
JUNE	26.6	26.825	12	18	162.5
JULY	25.45	26.185	14	17	223.9
AUG	24.95	26.025	16	15	239.9
SEPT	23.75	26.85	11	19	102.7
OCT	-	-	-	-	-
NOV	-	-	-	-	-
DEC	-	-	-	-	-
TOTAL			67	116	866.2

4.2 Pre-Experiment Soil Condition

4.2.1 Soil Physical Properties

Physical properties of soils of the trial site prior to experimentation are presented in Tables 3-6. Bulk density of the soils ranged between 1.23 Mg m^{-3} to 1.47 Mg m^{-3} at the surface layer (0-5 cm) and 0.97 to 1.56 Mg m^{-3} in the subsurface depths (10-15 cm) in areas put under conventional tillage while the areas under permanent cover had bulk density of 1.40 Mg m^{-3} to 1.49 Mg m^{-3} at the surface and 1.42 to 1.51 Mg m^{-3} at the subsurface. This suggests that the sub-soils were more compacted than the surface soils in the permanent cover plots. The higher bulk density at the permanent cover plots areas could have resulted from soil crusting, binding actions of ion and organic matter and lack of tillage on that plot which caused soil particles to bind and harden to increase bulk density. However, surface soils at the conventionally tilled plot areas had fairly high bulk density values and this could have resulted from effects of crusting and compaction due to previous years' cultivation activities using tractorized equipment. The pre-experimental bulk density of both 2010 and 2011 showed the same trend (Table 3).

Tables 4 and 5 show that sand fractions dominate the soil separates. Sand values range between 56 and 59 percent in the surface layers (0-15 cm) and 55 to 59 percent in the subsoil (15-30 cm) for both conventionally tilled plots and permanent cover plots. Silt fractions were almost the same for both surface and subsurface layers. The range was between 25 and 28 percent. Clay values ranged from 14 to 17 percent and the textural class according to the USDA classification for both the surface and subsurface horizon was sandy loam for both years.

Table 3: Pre-experimental bulk densities of soils of the experimental site; 2010 and 2011

Treatment	Depth (cm)	Bulk Density 2010	Bulk Density 2011
		Mg m^{-3}	
Conventional Tillage(CT)	0-5	1.47	1.23
	5-10	1.46	1.56
	10-15	1.47	0.97
Permanent Cover(PC)	0-5	1.49	1.40
	5-10	1.48	1.51
	10-15	1.46	1.42

Table 4: Pre-experimental particle size distribution of soils at the experimental site; 2010

Treatment	Depth (cm)	Clay (<2)	Silt (20-50)	Sand (50-2000)	Textural Class USDA
	<----------%---------->				
Conventional Tillage(CT)	0-15	16.00	28.00	56.00	SL
	15-30	17.00	27.00	55.00	SL
Permanent Cover(PC)	0-15	17.00	27.00	56.00	SL
	15-30	17.00	28.00	57.00	SL

SL ---> Sandy Loam

Table 5: Pre-experimental particle size distribution of soils at the experimental site; 2011

Treatment	Depth (cm)	Clay (<2)	Silt (20-50)	Sand (50-2000)	Textural Class USDA
	<----------%---------->				
Conventional Tillage(CT)	0-15	14.00	28.00	58.00	SL
	15-30	14.00	26.00	59.00	SL
Permanent Cover(PC)	0-15	14.00	25.00	59.00	SL
	15-30	14.00	27.00	59.00	SL

SL ---> Sandy Loam

Table 6 shows also, mean weight diameter of the soils prior to experimentation. Dry mean weight diameter at the surface soil (0-15 cm) ranged from 1.31 mm to 1.34 mm and was lower than for the sub soil (15-30 cm) which ranged from 1.33 mm to 1.38 mm. This shows that the sub-soils had relatively higher aggregate stability than the surface soils and implies that the 15-30 cm subsoil could withstand more wind erosive forces than the 0-15 cm surface soil. The pre-experimental mean weight diameter of soils followed the same trend for both 2010 and 2011. The higher values for aggregates at the subsoil (15-30 cm) could be due to the fact that aggregates are formed by chemical and physical binding agents (Angers *et al*. 1993) and because there was no disturbance at the sub-soils, these binding agents were intact and bound soil particles together while the surface soil (0-15 cm) was less aggregated because of cultivation, environmental and tractorized activities (Agbenin and Goladi, 1997).

Table 6 : Pre-experimental mean weight diameter of soils of the experimental site; 2010 and 2011

		MWD	
		2010	2011
Treatment	Depth(cm)	Dry sieving	Dry sieving
Conventional Tillage(CT)	0-15	1.31	1.32
	15-30	1.36	1.34
Permanent Cover(PC)	0-15	1.34	1.31
	15-30	1.38	1.33

4.2.2 SOIL CHEMICAL PROPERTIES

Tables 7, 8, 9 and 10 present data on pre-experiment chemical properties of the soils. Tables 7 and 8 show that soil pH varied between 5.50 and 5.60 in water and 4.60 to 4.75 in $CaCl_2$ at the surface soil and 5.55 to 5.75 in water and 4.55 to 5.20 in $CaCl_2$ at the sub soil for conventionally tilled plot areas, while for permanent cover area, pH ranges were between 5.60 and 6.15 in water and 4.50 to 5.70 in $CaCl_2$ at the surface layer (0-15 cm) and 5.55 to 5.90 in water and 4.55 to 5.25 in $CaCl_2$ at the subsurface layer. This shows that pH values were higher at the surface soils than at the subsurface layer, which implies that soils at the subsoil layer (15-30 cm) were more acid than at the surface (0-15cm) layer.

Organic carbon values were lower at the surface layer ranging from 5.5 to 6.4 g kg^{-1} and 7.4 to 8.3 g kg^{-1} at the sub-soil (15-30 cm layer) for year 2010, while in 2011, organic carbon was slightly higher at the surface horizon (6.0 to 6.1 g kg^{-1}) than at the subsurface layer (5.4 to 5.5 g kg^{-1}). This implies that soils at the 0-15 cm layer were lower in inherent fertility compared to soils at the sub-soil (15-30 cm layer).

Total nitrogen of the soils were very low; 0.5 to 0.7 g kg^{-1} in the surface layers (0-15 cm) and 0.6 to 0.8 g kg^{-1} in the subsoil (15-30 cm) depths. These confirm earlier studies (Lal, 1975; Jones and Wild, 1975; Uyovbisere *et al*. 1997; Carsky and Iwuafor, 1999; Sanginga *et al*. 2001; Odunze, 2003 and Yusuf *et al*. 2009) showing that soils of the Northern Guinea Savanna of Nigeria are low in fertility status.

Available phosphorus of the surface layers (0-15 cm) ranged from 5.25 mg kg^{-1} to 7.00 mg kg^{-1} and 5.25 mg kg^{-1} to 9.19 mg kg^{-1} at the subsurface layers (15-30 cm). Exchangeable calcium values in the surface layers ranged from 3.30 cmol kg^{-1} to

4.60cmolkg^{-1} and 3.10 to 4.40 cmol kg^{-1} at the subsurface layers. Exchangeable Mg of the soils also ranged between 0.83 and 1.25 cmol kg^{-1} at the surface horizon and 0.71 to 0.98 cmol kg^{-1} at the subsurface layers. Exchangeable K of the soils were low (0.17 and 0.26 cmol kg^{-1}) in both surface and subsurface depths. Also, exchangeable Na in the soils were generally low (0.11 and 0.13 cmol kg^{-1}) at both surface and subsoil depths.

Exchangeable acidity values of the soils were less than 1.0 cmol kg^{-1} and this suggest that the soils have no exchangeable acidity problems (Odunze, 1997). Cation exchange capacity (CEC) of the soils ranged from 6.90 to 9.75 cmol kg^{-1} at the surface (0-15 cm) layer and 7.90 to 9.85 cmol kg^{-1} at the sub surface (15-30 cm) depths. This implies that there were more cation exchange activities in the subsoil (15-30 cm) than the surface soil (0-15 cm).

Tables 9 and 10 present data on pre-experimental microbial biomass assessment and cationic micronutrients. Cu^{2+} ranged between 0.0016 to 0.0029 mg kg^{-1}, Fe^{2+} ranged between 0.007 to 0.0085 mg kg^{-1}, Mn^{2+} ranged between 0.0032 to 0.0051 mg kg^{-1} and Zn^{2+} ranged between 0.0035 to 0.0081 mg kg^{-1}.

Microbial biomass assessment shows that the soils were low in microbial biomass C, N and P. Microbial biomass carbon values ranged between 0.03 to 0.07 mg kg^{-1}, microbial biomass nitrogen values ranged between 0.005 to 0.1 mg kg^{-1} and microbial biomass phosphorus values ranged between 0.004 to 0.03 mg kg^{-1}. These confirm the view of Odunze, 2003 that upland soils of the Northern Guinea Savanna zone of Nigeria are low in inherent fertility and organic matter.

Table 7: Pre-experimental chemical properties of the soil at the site; 2010

Treatment	Depth (cm)	pH H_2O (1:2.5)	pH 0.01M $CaCl_2$	Org.C	Total N	Avail. P	Exchangeable Cation				Exchangeable Acidity	CEC
							Ca	Mg	K	Na		
				<---g kg^{-1}---- - ->		(mg kg^{-1})	<----------cmol kg^{-1}---------->				(H^++Al^{3+})	
CT	0-15	5.50a	4.75a	5.5b	0.5a	5.25a	4.60a	1.23a	0.26a	0.11a	0.40b	6.90b
	15-30	5.75a	5.20a	7.4a	0.6a	7.44a	4.40a	0.96a	0.17a	0.11a	0.50a	7.90a
PC	0-15	6.15a	5.70a	6.4b	0.7a	7.00a	3.30a	1.25a	0.27a	0.11a	0.50a	8.60a
	15-30	5.90a	5.25a	8.3a	0.8a	9.19a	3.10a	0.98a	0.17a	0.11a	0.60a	9.60a

Means with the same letters are not significantly different ($P \leq 0.05$)

CT - Conventional Tillage

PC - Permanent Cover

Table 8: Pre-experimental chemical properties of the soil at the site; 2011

Treatment	Depth (cm)	pH H_2O (1:2.5)	pH 0.01M $CaCl_2$	Org.C	Total N	Avail. P	Exchangeable Cation				Exchangeable Acidity (H^++Al^{3+})	CEC
							Ca	Mg	K	Na		
				<---------g kg^{-1}--------->		(mg kg^{-1})	<----------cmol kg^{-1}---------->					
CT	0-15	5.60	4.60	6.0	0.7	5.25	4.50	0.83	0.20	0.13	0.50	9.15
	15-30	5.55	4.55	5.4	0.6	5.25	3.40	0.71	0.17	0.12	0.40	9.25
PC	0-15	5.60	4.50	6.1	0.7	5.25	4.30	0.84	0.19	0.13	0.50	9.75
	15-30	5.55	4.55	5.5	0.6	5.25	3.20	0.72	0.17	0.13	0.40	9.85

CT - Conventional Tillage

PC - Permanent Cover

Table 9: Pre-experimental Microbial Biomass C, N, & P and Micronutrients; 2010

Treatment	Depth (cm)	Microbial Biomass			Micronutrients			
		C	N	P	Cu	Fe	Mn	Zn
		<----------mg kg^{-1}---------->			<----------mg kg^{-1}---------->			
CT	0-15	0.04	0.05	0.01	0.0021	0.0085	0.0047	0.0068
	15-30	0.03	0.04	0.01	0.0025	0.0074	0.005	0.0050
PC	0-15	0.07	0.10	0.03	0.0025	0.0081	0.0048	0.0081
	15-30	0.06	0.08	0.02	0.0030	0.007	0.0051	0.0063

CT – Conventional Tillage

PC – Permanent Cover

Table 10: Pre-experimental Microbial Biomass C, N, & P and Micronutrients; 2011

Treatment	Depth (cm)	Microbial Biomass			Micronutrients			
		C	N	P	Cu	Fe	Mn	Zn
		<---------mg kg^{-1}---------->			<----------mg kg^{-1}---------->			
CT	0-15	0.05	0.03	0.009	0.0016	0.0084	0.0032	0.0036
	15-30	0.03	0.005	0.008	0.0016	0.0082	0.0034	0.004
PC	0-15	0.05	0.03	0.005	0.002	0.0081	0.0038	0.0035
	15-30	0.04	0.005	0.004	0.002	0.0079	0.004	0.0036

CT – Conventional Tillage

PC – Permanent Cover

4.3 Soil Physical Properties

4.3.1 Soil Particle Size Distribution

Table11 presents the particle size distribution under tillage, N and P level treatments. Soil texture of the experimental site was predominantly sandy loam in 2010 and 2011. Clay fractions generally ranged from 15.74 to 16.85 % in both 2010 and 2011. Silt fractions ranged from 25.48 to 26.33 % in both years while, sand fractions which were dominant ranged from 56.63 to 58.07 %. Generally values for % clay, % silt and % sand were not significantly ($P \leq 0.05$) changed by the treatments. No regular pattern was also observed for particle size distribution under all the treatments as fluctuating values were observed. This may be due to heterogeneity on seemingly similar soils as observed by Wuddivira (1998).

Results showed that interactions between tillage and N, and N and P were not significant on clay content in 2010 and silt in 2011. Tillage and N interacted significantly on sand fraction in both years but generally, particle size was not affected by treatments since there were no changes recorded within treatments. This is in line with the fact that soil particle sizes are not easily changed with management practices, at least not within a short period of two years.

Table 11: Effects of tillage, N and P on soil particle size distribution; 2010 and 2011

	Particle size distribution corrected to 20°C							
	2010				2011			
	Clay	Silt	Sand	Textural class	Clay	Silt	Sand	Textural class
Treatment	<----------(%)---------->				<----------(%)---------->			
Tillage								
CT+Cp	16.69a	25.78a	57.15ab	SL	16.46a	25.96a	57.26a	SL
CT	15.96a	25.93a	58.07a	SL	16.07a	26.27a	57.67a	SL
PC+Cp	16.37a	26.33a	56.70b	SL	16.74a	25.59a	57.22a	SL
Mean	16.34	26.01	57.31		16.43	25.95	57.38	
SE±	0.29	0.26	0.29		0.26	0.25	0.31	
N level(kg/ha)								
60	16.85a	25.82a	56.74b	SL	15.98b	25.52a	58.48a	SL
80	15.69b	26.15a	57.96a	SL	16.39ab	26.04a	57.11b	SL
100	16.48ab	26.07a	57.22ab	SL	16.91a	26.30a	56.56b	SL
Mean	16.34	26.01	57.31		16.43	25.95	57.38	
SE±	0.29	0.26	0.29		0.26	0.25	0.31	
P level(kg/ha)								
6.6	16.44ab	26.11a	57.26ab	SL	16.67a	26.22a	56.67b	SL
13.2	16.83a	25.96a	56.63b	SL	16.85a	25.48a	57.59ab	SL
26.4	15.74b	25.96a	58.04a	SL	15.76a	26.15a	57.89a	SL
Mean	16.34	26.01	57.31		16.43	25.95	57.38	
SE±	0.29	0.26	0.29		0.26	0.25	0.31	
Interaction								
T*N	NS	**	**		*	NS	**	
T*P	**	NS	**		*	**	*	
N*P	NS	NS	NS		NS	NS	**	
T*N*P	*	**	**		*	NS	**	

Means with the same letter are not significantly different at 5% level of probability using Tukey's Honesty Significant Difference (HSD)

* = significant at 5% level of probability, SE = standard error

** = significant at 1% level of probability

NS = not significant

SL = Sandy Loam

4.3.2 Bulk Density

Table 12 shows that in 2010, treatment CT+Cp resulted in least bulk density at 6WAP, which was significantly ($P \leq 0.05$) lower than CT and PC+Cp. The values however, generally increased at 12WAP with CT+Cp resulting in significantly lower bulk density value than CT, which in turn was significantly lower than PC+Cp. It has been proven that bulk density values above 1.49 Mg m^{-3} are high and could hamper crop growth and root ramification (Richard et al., 2001)

Nitrogen rates application in 2010 also shows that 80 kg N ha^{-1} resulted in significantly lower bulk density compared with 60 kg N ha^{-1} and 100 kg N ha^{-1}. Bulk density value of plots with 80 kg N ha^{-1} at 12WAP, however, decreased (1.27 Mg m^{-3}), suggesting further soil improvement that was significantly lower than 100 kg N ha^{-1}. The 60 kg N ha^{-1} application rate, however, resulted in increased bulk density value of 1.61 Mg m^{-3} that indicates soil compaction that could impair crop performance and yield as observed by Richard et al., 2001.

Phosphorus rates of 6.6 kg P ha^{-1} resulted in low bulk density of 1.3 Mg m^{-3} that was not significantly ($P \leq 0.05$) different from 26.4 kg P ha^{-1} (1.41 Mg m^{-3}), but were both significantly better than 13.2 kg P ha^{-1} (1.48 Mg m^{-3}) at 6WAP. Rates of phosphorus application had no significant effect on bulk density at 12WAP (Table 4.11)

In 2010 and 2011, interactions between all factors on soil bulk density were significant at 6WAP. However, at 12WAP, only the interaction between tillage and N; and that between N and P were significant on soil bulk density. This is in line with findings by Hullugalle et al., 1985 that tillage reduced bulk density (Table 12).

Table 12: Effect of tillage, N and P on bulk density of soils at harvest in 2010 and 2011

	Bulk density (Mg m^{-3})			
	2010		2011	
Treatment	6WAP	12WAP	6WAP	12WAP
Tillage				
CT+Cp	1.05b	1.18c	1.47b	1.46a
CT	1.56a	1.49b	1.46b	1.34b
PC+Cp	1.58a	1.62a	1.60a	1.24b
Mean	1.4	1.43	1.51	1.35
SE±	0.03	0.03	0.03	0.03
N level(kg/ha)				
60	1.43a	1.61a	1.46b	1.45a
80	1.30b	1.27a	1.60a	1.34ab
100	1.45a	1.41a	1.48ab	1.25b
Mean	1.4	1.43	1.51	1.35
SE±	0.03	0.03	0.03	0.03
P level(kg/ha)				
6.6	1.30b	1.44a	1.52a	1.35a
13.2	1.48a	1.45a	1.52a	1.31a
26.4	1.41b	1.41a	1.49a	1.38a
Mean	1.4	1.43	1.51	1.35
SE±	0.03	0.03	0.03	0.03
Interaction				
T*N	**	**	**	**
T*P	**	NS	NS	NS
N*P	*	*	NS	**
T*N*P	**	NS	NS	**

Means with the same letter are not significantly different at 5% level of probability using Tukey's Honesty Significant Difference (HSD)

* = significant at 5% level of probability, SE = standard error

** = significant at 1% level of probability

NS = not significant

4.3.3 Mean weight Diameter (MWD)

Table 13 shows that conventional tillage (CT) resulted in a significantly ($P \leq 0.05$) higher mean weight diameter (MWD) aggregates than the other tillage treatments in 2010. MWD value under CT was significantly higher than that under PC+Cp which in turn was significantly higher than CT+Cp in 2010. Also, the application of 80 kg N ha^{-1} resulted in significantly ($P \leq 0.05$) higher mean weight diameter than the other tillage treatments (Table 13). Application of 13.2 kg P ha^{-1} resulted in a higher MWD of 1.53 that was not significantly different from 26.4 kg P ha^{-1} and 6.6 kg P ha. This information suggests that with conventional tillage, the use of 80 kg N ha^{-1} and 13.2 kg P ha^{-1} would result in significantly higher MWD than the other treatments' combination. Also, tillage interacted significantly with N and P rates to influence soil aggregate stability in the study area (Table 13).

In 2011 however, CT+Cp resulted in a significantly ($P \leq 0.05$) higher MWD than the other tillage treatments. MWD under CT and PC+Cp were not significantly different. MWD under nitrogen and phosphorus treatments were not significantly different, however, 100 kg N ha^{-1} and 6.6 kg P ha^{-1} resulted in higher MWD. This implies that a combination of CT at 80 kg N ha^{-1} and 13.2 kg P ha^{-1} in 2010 and CT+Cp at 100 kg N ha^{-1} and 6.6 kg P ha^{-1} impacted positively on mean weight diameter of soils and have the tendency to withstand wind erosion compared to the other treatments. These results agree with the findings of McRae and Mehuys (1988) that legumes increase soil organic matter which in turn improves soil physical properties by increasing the distribution and stability of soil aggregates decreasing soil bulk density.

Table 13: Effect of tillage, N and P on mean weight diameter of soils at harvest in 2010 and 2011

	2010	2011
	Mean Weight Diameter	
Treatment	12WAP	12WAP
Tillage		
CT+Cp	1.34c	1.46a
CT	1.62a	1.27b
PC+Cp	1.54b	1.32b
Mean	1.5	1.35
SE±	0.02	0.02
N level(kg/ha)		
60	1.48a	1.35a
80	1.54a	1.34a
100	1.48a	1.36a
Mean	1.5	1.35
SE±	0.02	0.02
P level(kg/ha)		
6.6	1.48a	1.38a
13.2	1.53a	1.37a
26.4	1.48a	1.30a
Mean	1.5	1.35
SE±	0.02	0.02
Interaction		
T*N	*	**
T*P	**	**
N*P	**	NS
T*N*P	**	NS

Means with the same letter are not significantly different at 5% level of probability using Tukey's Honesty Significant Difference (HSD)

* = significant at 5% level of probability, SE = standard error

** = significant at 1% level of probability

NS = not significant

4.4 Soil Chemical Properties

Data on soil reactions of the study site following tillage, N and P applications in 2010 and 2011 are presented in Tables 14 - 19.

4.4.1 Soil pH

Table 14 contains data on effect of tillage, N and P on soil pH in 2010 and 2011 and shows that CT+Cp significantly increased soil pH in water and $CaCl_2$ compared with CT and PC+Cp that had similar pH values in both 2010 and 2011 (Table 14).

Soil pH values of were not significantly affected by N rates. However, in $CaCl_2$, 80 kg N ha^{-1} resulted in less acidity that was significantly improved over 60 kg N ha^{-1} and 100 kg N ha^{-1} in both 2010 and 2011.

Phosphorus application rates did not show any significant effect on soil pH values in water and $CaCl_2$ solution. These findings imply that conventional tillage + cover crop (*Centrosema pascuorum*; incorporated and relayed) (CT+Cp) at 60 kg N ha^{-1} modified soil acidity to slightly acid range at which most nutrients are readily available for crop roots uptake and falls within the best pH range (5.5 – 7.0) for maize cultivation (William and Chew, 1980) .

In 2010 therefore, tillage (T), nitrogen (N), and phosphorus (P) rates interacted significantly to reduce soil acidity. Results in 2011 also followed the same trend.

Table 14: Effects of tillage, N and P on soil pH at harvest in 2010 and 2011

	pH			
	2010		2011	
Treatment	H_2O(1:2.5)	$CaCl_2$(0.01M)	H_2O(1:2.5)	$CaCl_2$(0.01M)
Tillage				
CT+Cp	5.75a	4.87a	5.59a	4.71a
CT	4.92b	4.09b	4.91b	4.13b
PC+Cp	4.86b	4.10b	5.68a	4.82a
Mean	5.17	4.35	5.4	4.56
SE±	0.03	0.03	0.03	0.03
N level(kg/ha)				
60	5.24a	4.32b	5.43a	4.61a
80	5.1a	4.44a	5.49a	4.67a
100	5.15a	4.30b	5.26b	4.39b
Mean	5.17	4.35	5.4	4.56
SE±	0.03	0.03	0.03	0.03
P level(kg/ha)				
6.6	5.19a	4.38a	5.33a	4.46b
13.2	5.19a	4.35a	5.42a	4.61a
26.4	1.15a	4.33a	5.44a	4.60a
Mean	5.17	4.35	5.4	4.56
SE±	0.03	0.03	0.03	0.03
Interaction				
T*N	**	**	**	**
T*P	NS	NS	NS	**
N*P	**	**	**	**
T*N*P	**	**	**	**

Means with the same letter are not significantly different at 5% level of probability using Tukey's Honesty Significant Difference (HSD)

* = significant at 5% level of probability, SE = standard error

** = significant at 1% level of probability

NS = not significant

4.4.2 Soil Organic Carbon, Total Nitrogen and Available Phosphorus

Table 15 shows that CT+Cp treatment resulted in a 5.6 g kg^{-1} organic carbon content which was significantly higher than CT and PC+Cp in 2010 at harvest period. The application of 100 kg N ha^{-1} resulted in significantly ($P \leq 0.05$) higher organic carbon than 80 kg N ha^{-1} and 60 kg N ha^{-1}. The 26.4 kg P ha^{-1} and 6.6 kg P ha^{-1} treatments had statistically similar organic carbon (Table 15) values but organic carbon value at 26.4 kg P ha^{-1} was significantly higher than that at 13.2 kg P ha^{-1} in 2010. Only the interaction between nitrogen and phosphorus rates on organic carbon content was significant in 2010. In 2011, however, organic carbon contents were statistically similar across treatments.

Table 15 also contains data on effect of tillage, N and P on soil total nitrogen in 2010 and 2011 and shows that total nitrogen values for all treatments were not significantly different. The only exception was P level in 2010, when the application of 26.4 kg P ha^{-1} resulted in a significantly lower soil total nitrogen compared with 6.6 and 13.2 kg P ha^{-1} that were at par. This implies that treatments did not have any significant ($P \leq 0.05$) effect on soil total nitrogen content (Table 15).

Table 15 also presents data on soil available phosphorus. PC+Cp and CT had similar but significantly higher available phosphorus than CT+Cp in 2010. In 2011, however, CT resulted in significantly higher available phosphorus than CT+Cp and PC+Cp which were statistically similar. The application of 60 kg N ha^{-1} resulted in the highest available phosphorus value, which was only significantly ($P \leq 0.05$) different from 80 kg N ha^{-1} in 2010. In 2011, 60 and 100 kg N ha^{-1} had similar but significantly higher available phosphorus than 80 kg N ha^{-1}. Application of 13.2 kg P ha^{-1} resulted in significantly

($P \leq 0.05$) higher available phosphorus value than 26.4 kg P ha^{-1} only. The difference in the available phosphorus content of 6.6 kg P ha^{-1} and 26.4 kg P ha^{-1} was not significant in 2010. In 2011, application of 26.4 kg P ha^{-1} resulted in significantly higher available phosphorus content than 6.6 and 13.2 kg P ha^{-1}. The difference in the available phosphorus content of 6.6 kg P ha^{-1} and 26.4 kg P ha^{-1} was not significant. A research by Kahm *et al*. (2002) showed that legumes facilitate the utilization of soil phosphorus in the northern Guinea savanna of Nigeria, therefore the high available P content found on CT plots may be as a result of the absence of legume on that plot since P is not very mobile in soils and there was no legume to facilitate its utilization.

These findings imply that CT+Cp combined with 100 kg N ha^{-1} and 6.6 kg P ha^{-1} improved soil organic carbon. Also, PC+Cp combined with 60 kg N ha^{-1} and 13.2 kg P ha^{-1} effectively improved soil available phosphorus (Table 15).

Table 15: Effects of tillage, N and P on soil organic carbon, total N and available P at harvest in 2010 and 2011

	2010			2011		
	Org. C	Total N	Avail. P	Org. C	Total N	Avail. P
Treatment	<--------gkg^{-1}------->		$mgkg^{-1}$	<-------gkg^{-1}-------->		$mgkg^{-1}$
Tillage						
CT+Cp	5.6a	0.4a	2.72b	5.7a	0.4a	2.92b
CT	4.9b	0.4a	4.50a	5.5a	0.4a	4.85a
PC+Cp	5.2ab	0.4a	4.73a	5.6a	0.4a	2.93b
Mean	5.3	0.4	3.98	5.6	0.4	3.57
SE±	0.01	0.02	0.15	0.01	0.02	0.15
N level(kg/ha)						
60	5.0b	0.4a	4.24a	5.4a	0.4a	3.63a
80	5.2ab	0.4a	3.71b	5.6a	0.4a	3.09b
100	5.6a	0.4a	4.00ab	5.8a	0.4a	3.99a
Mean	5.3	0.4	3.98	5.6	0.4	3.57
SE±	0.01	0.02	0.15	0.01	0.02	0.15
P level(kg/ha)						
6.6	5.4ab	0.4a	4.04ab	5.7a	0.4a	3.24b
13.2	4.9b	0.4a	4.35a	5.3a	0.4a	3.35b
26.4	0.54a	0.3b	3.56b	5.7a	0.4a	4.10a
Mean	5.3	0.4	3.98	5.6	0.4	3.57
SE±	0.01	0.02	0.15	0.01	0.02	0.15
Interaction						
T*N	NS	**	**	*	**	**
T*P	NS	NS	NS	NS	*	NS
N*P	**	NS	**	*	**	**
T*N*P	NS	*	*	**	*	*

Means with the same letter are not significantly different at 5% level of probability using Tukey's Honesty Significant Difference (HSD)

* = significant at 5% level of probability, SE = standard error

** = significant at 1% level of probability

NS = not significant

4.4.3 Exchangeable Acidity (EA)

Table 16 presents information on exchangeable acidity of the soils. Treatments showed non significantly ($P \leq 0.05$) different exchangeable acidity values in both 2010 and 2011 but values ranged between 0.45 and 0.51 cmol kg^{-1} which is below the threshold limit of 1.0 cmol kg^{-1} for acid soils (Table 16). However, P application at the rate of 26.4 kg P ha^{-1} reduced exchangeable acidity of the soil significantly compared with 6.6 kg P ha^{-1} in 2010. Treatments applied in 2011 showed no significant difference. The values of exchangeable acidity obtained in this study were similar to those obtained by Odunze (1997) in the ecological zone and suggest that soils of the study site had no acidity problems.

Table 16: Effects of tillage, N and P on exchangeable acidity at harvest in 2010 and 2011

	2010	2011
	Exchangeable acidity	
	$(H^+ + Al^{3+})$	$(H^+ + Al^{3+})$
Treatment	<----------cmol kg^{-1}---------->	
Tillage		
CT+Cp	0.48a	0.48a
CT	0.48a	0.49a
PC+Cp	0.47a	0.47a
Mean	0.48	0.48
SE±	0.01	0.02
N level(kg/ha)		
60	0.50a	0.46a
80	0.45a	0.48a
100	0.49a	0.51a
Mean	0.48	0.48
SE±	0.01	0.02
P level(kg/ha)		
6.6	0.51a	0.47a
13.2	0.47ab	0.50a
26.4	0.46b	0.47a
Mean	0.48	0.48
SE±	0.01	0.02
Interaction		
T*N	NS	NS
T*P	*	**
N*P	NS	NS
T*N*P	**	*

Means with the same letter are not significantly different at 5% level of probability using Tukey's Honesty Significant Difference (HSD)

* = significant at 5% level of probability, SE = standard error

** = significant at 1% level of probability

NS = not significant

4.4.4 Exchangeable Cation and Cation Exchange Capacity

Tables 17 and 18 present data on soil exchangeable cation (Ca, Mg, K and Na), Cation Exchange Capacity (CEC), and percentage base saturation (%BS). They show that CT+Cp resulted in calcium (Ca^{2+}) content in soils that was not significantly different from contents under CT and PC+Cp. Also, application of 80 kg N ha^{-1} resulted in Ca^{2+} content that was not significantly different from 100 kg N ha^{-1} and 60 kg N ha^{-1}. Application of 13.2 kg P ha^{-1} resulted in Ca^{2+} content that was not significantly different from 6.6 kg P ha^{-1} and 26.4 kg P ha^{-1}. This implies that tillage practices, nitrogen levels and phosphorus rates had no significant effect on Ca^{2+} concentration of the soils in 2010. In 2011 also, CT+Cp resulted in higher Ca^{2+} content of soils that was not significantly different from PC+Cp and CT. Application of 60, 80 and 100 kg N ha^{-1} also resulted in non-significantly different Ca^{2+} content of the soils. 6.6 kg P ha^{-1} resulted in higher Ca^{2+} content that was not significantly different from 26.4 and 13.2 kg P ha^{-1}.

Tables 17 and 18 also show that CT resulted in magnesium (Mg^{2+}) content in soils that was not statistically different from Mg^{2+} content under PC+Cp and CT+Cp. Also, application of 100 kg N ha^{-1} resulted in Mg^{2+} content that was significantly ($P \leq 0.05$) different from 80 kg N ha^{-1} and 60 kg N ha^{-1} which were statistically the same. Application of 26.4 kg P ha^{-1} resulted in Mg^{2+} content that was not significantly different from 6.6 kg P ha^{-1} and 13.2 kg P ha^{-1}. This implies that tillage practices, nitrogen levels and phosphorus rates had no significant effect on Mg^{2+} concentration of the soils in 2010. In 2011, however, CT resulted in significantly ($P \leq 0.05$) higher Mg^{2+} content than CT+Cp and PC+Cp which were statistically the same. Also, application of 80 kg N ha^{-1} resulted in higher Mg^{2+} content of the soils that was significantly ($P \leq 0.05$) higher than 100 kg N ha^{-1} and 60 kg N ha^{-1}.

Application of 26.4 kg P ha^{-1} resulted in higher Mg^{2+} content of soil that was not significantly different from 13.2 kg P ha^{-1} and 6.6 kg P ha^{-1}.

Tables 17 and 18 show also that CT+Cp resulted in potassium (K^{+}) content which was not statistically different from PC+Cp and CT. Application of 60 kg N ha^{-1} resulted in K^{+} content that was not significantly different from 100 kg N ha^{-1} and 80 kg N ha^{-1}. Application of 6.6 kg P ha^{-1} resulted in K content that was not significantly different from 26.4 kg P ha^{-1} and 13.2 kg P ha^{-1}. This implies that tillage practices, nitrogen levels and phosphorus rates had no significant effect on K^{+} concentration of the soils in 2010. In 2011 also, CT+Cp and PC+Cp resulted in higher K^{+} content of soils that was not significantly different from CT. Application of 80 and 100 kg N ha^{-1} also resulted in non-significantly different but higher K^{+} content of the soils than 60 kg N ha^{-1}. Application of 26.4 kg P ha^{-1} resulted in higher K^{+} content that was not significantly different from 6.6 and 13.2 kg P ha^{-1}.

Tables 17 and 18 show also that CT resulted in sodium (Na^{2+}) content in soils that was not statistically different from PC+Cp and CT+Cp. Also, application of 80 kg N ha^{-1} resulted in Na^{2+} content that was not significantly different from 100 and 80 kg N ha^{-1}. Application of 13.2 and 26.4 kg P ha^{-1} resulted in similar Na^{2+} content in soil that was not significantly different from 6.6 kg P ha^{-1}. This implies that tillage practices, nitrogen levels and phosphorus rates had no significant effect on Na concentration of the soils in 2010. In 2011 also, treatment CT resulted in higher Na^{2+} content of soils that was not significantly different from CT+Cp and PC+Cp. Application of 60 kg N ha^{-1} also resulted in non-significantly different but higher Na^{2+} content of the soils than 80 and 100 kg N ha^{-1}. Application of 6.6 kg P ha^{-1} resulted in higher Na^{2+} content that was not significantly different from 26.4 and 13.2 kg P ha^{-1}.

Tables 17 and 18 also present data on soil cation exchange capacity (CEC). It shows that treatment CT+Cp resulted in significantly ($P \leq 0.05$) higher CEC value better than PC+Cp and CT which were statistically the same. Application of 60 and 80 kg N ha^{-1} resulted in significantly ($P \leq 0.05$) higher CEC value than 100 kg N ha^{-1}. Application of 13.2 kg P ha^{-1} resulted in significantly ($P \leq 0.05$) higher CEC value than 6.6 kg P ha^{-1} and 26.4 kg P ha^{-1}. In 2011, PC+Cp resulted in significantly higher CEC vale followed by CT+Cp and lest by CT. application of 60 kg N ha^{-1} resulted in significantly higher CEC value of soil followed by 100 kg N ha^{-1} and least by 80 kg N ha^{-1}. Application of phosphorus had no significant effect on soil CEC in 2011 (Table 18). Treatment CT resulted in higher effective cation exchange capacity (ECEC) followed by CT+Cp and least by PC+Cp. Also, application of 100 kg N ha^{-1} resulted in higher ECEC value of soils followed by 80 kg N ha^{-1} and least by 60 kg N ha^{-1}. The application of 13.2 kg P ha^{-1} resulted in higher ECEC value of the soils followed by 6.6 kg P ha^{-1} and least by 26.4 kg P ha^{-1}. These findings suggest that a combination of CT at 100 kg N ha^{-1} and 13.2 kg P ha^{-1} significantly enhanced soil ECEC in 2010. In 2011 however, CT+Cp resulted in higher ECEC value of the soils followed by CT and least by PC+Cp. Application of 80 kg N ha^{-1} resulted in higher ECEC value followed by 100 kg N ha^{-1} and least by 60 kg N ha^{-1}. Application of 6.6 kg P ha^{-1} resulted in higher ECEC value of soils followed by 26.4 kg P ha^{-1} and 13.2 kg P ha^{-1} recorded the least value for ECEC. These findings suggest that a combination of CT+Cp at 80 kg N ha^{-1} and 6.6 kg P ha^{-1} enhanced ECEC of soils (Table 17 and 18).

Base saturation (BS) of soils in 2010 ranged from 56.41 to 83.15 percent but in 2011, the values were from 55.74 to 67.12 percent. The high percent base saturation of soils

indicates that the soils have potential to exchange cations sufficient for crop use (Odunze, 1997).

Table 17: Effects of tillage, N and P on exchangeable cation and CEC at harvest in 2010

	Exch. Cation						
	Ca	Mg	K	Na	CEC	ECEC	% BS
Treatment	<----------cmol kg^{-1}---------->						
Tillage							
CT+Cp	3.62a	0.85a	0.24a	0.12a	8.54a	5.31	56.56
CT	3.57a	1.01a	0.21a	0.13a	7.39b	5.4	66.58
PC+Cp	3.39a	0.93a	0.23a	0.12a	7.42b	5.14	62.94
Mean	3.52	0.93	0.23	0.13	7.78	5.29	61.83
SE±	0.15	0.05	0.01	0.006	0.11	0.23	
N level(kg/ha)							
60	3.45a	0.72b	0.24a	0.12a	8.03a	5.03	56.41
80	3.62a	0.89b	0.21a	0.13a	7.95a	5.3	61.01
100	3.49a	1.19a	0.23a	0.12a	7.37b	5.52	68.25
Mean	3.52	0.93	0.23	0.13	7.78	5.29	61.83
SE±	0.15	0.05	0.01	0.006	0.11	0.23	
P level(kg/ha)							
6.6	3.70a	0.94a	0.25a	0.12a	7.70b	5.52	65.06
13.2	5.52a	0.86a	0.20a	0.13a	8.07a	7.18	83.15
26.4	3.34a	1.00a	0.23a	0.13a	7.58b	5.16	62.01
Mean	3.52	0.93	0.23	0.13	7.78	5.29	61.83
SE±	0.15	0.05	0.01	0.006	0.11	0.23	
Interaction							
T*N	*	**	**	NS	**		
T*P	NS	NS	*	*	NS		
N*P	NS	NS	NS	NS	NS		
T*N*P	NS	**	NS	NS	**		

Means with the same letter are not significantly different at 5% level of probability using Tukey's Honesty Significant Difference (HSD)

* = significant at 5% level of probability, SE = standard error

** = significant at 1% level of probability

NS = not significant

Table 18: Effects of tillage, N and P on exchangeable cation and CEC at harvest in 2011

	Exch. Cation						
	Ca	Mg	K	Na	CEC	ECEC	% BS
Treatment	<----------cmol kg^{-1}---------->						
Tillage							
CT+Cp	3.78a	0.93b	0.24a	0.12a	8.10b	5.55	62.59
CT	3.49a	1.13a	0.21a	0.13a	7.39c	5.45	67.12
PC+Cp	3.59a	0.81b	0.24a	0.12a	8.54a	5.23	55.74
Mean	3.62	0.95	0.23	0.12	8.01	5.4	61.42
±SE	0.15	0.06	0.01	0.005	0.13	0.245	
N level(kg/ha)							
60	3.74a	0.75b	0.22a	0.13a	8.40a	5.3	57.62
80	3.57a	1.15a	0.23a	0.12a	7.64b	5.55	66.36
100	3.54a	0.96a	0.23a	0.12a	7.99ab	5.36	60.7
Mean	3.62	0.95	0.23	0.12	8.01	5.4	61.42
±SE	0.15	0.06	0.01	0.005	0.13	0.245	
P level(kg/ha)							
6.6	3.79a	0.89a	0.22a	0.13a	8.16a	5.5	61.64
13.2	3.51a	0.93a	0.22a	0.12a	8.02a	5.28	59.6
26.4	3.57a	1.05a	0.24a	0.12a	7.86a	5.45	63.36
Mean	3.62	0.95	0.23	0.12	8.01	5.4	61.42
±SE	0.15	0.06	0.01	0.005	0.13	0.245	
Interaction							
T*N	NS	NS	*	NS	*		
T*P	NS	NS	NS	*	NS		
N*P	NS	NS	NS	NS	**		
T*N*P	NS	*	NS	NS	**		

Means with the same letter are not significantly different at 5% level of probability using Tukey's Honesty Significant Difference (HSD)

* = significant at 5% level of probability, SE = standard error

** = significant at 1% level of probability

NS = not significant

4.5 Cationic Micronutrients

Table 19 shows that CT+Cp and CT resulted in copper (Cu^{2+}) content in soils that was not statistically similar, but were significantly ($P \leq 0.05$) higher than Cu^{2+} content obtained under PC+Cp. Also, the application of 100 kg N ha^{-1} resulted in Cu^{2+} that was significantly ($P \leq 0.05$) higher than values obtained under 80 kg N ha^{-1} and 60 kg N ha^{-1}. Application of 6.6 kg P ha^{-1} resulted in Cu^{2+} content that was not significantly different from plots under 26.4 kg P ha^{-1} and 13.2 kg P ha^{-1}. This implies that P rates application had no significant effect on copper concentration of the soils. Also, the application of CT+Cp at 100 kg N ha^{-1} best enhanced soil copper content in the soils in 2010. In 2011, CT+Cp resulted in significantly higher Cu^{2+} content than CT and PC+Cp which were at par. Nitrogen and phosphorus treatments had no significant effect on Cu^{2+} content of soil in 2011. Generally, tillage, nitrogen and phosphorus rates interacted significantly to influence Cu^{2+} concentration of the soil (Table 19).

Table 19 also shows that tillage, nitrogen and phosphorus treatments had no significant effect on soil Fe^{2+} content in both 2010 and 2011. This implies that tillage practices, nitrogen and phosphorus application had no significant effect on Fe^{2+} concentration of the soils.

Results presented on Table 19 also show that tillage, nitrogen and phosphorus treatments had no significant effect on soil Mn^{2+} content in both 2010 and 2011.

Table 19 shows also that CT resulted in zinc (Zn^{2+}) content in soils that was significantly ($P \leq 0.05$) different from Zn^{2+} content obtained under PC+Cp and CT+Cp which were at par. Application of 80 kg N ha^{-1} resulted in Zn^{2+} content that was significantly higher

than 60 kg N ha^{-1} and 100 kg N ha^{-1} which were statistically the same. Application of 6.6 kg P ha^{-1} and 26.4 kg P ha^{-1} resulted in a Zn^{2+} content of which were statistically the same but significantly ($P \leq 0.05$) different from 13.2 kg P ha^{-1}. In 2011, CT+Cp and CT resulted in significantly higher Zn^{2+} content in soil than PC+Cp. Application of 60 kg N ha^{-1} and 80 kg N ha^{-1} also resulted in significantly higher Zn^{2+} content in soil than plots under 100 kg N ha^{-1}. Application of phosphorus had no significant effect on soil Zn^{2+} content. This implies that application of CT at 80 kg N ha^{-1} and 6.6 kg P ha^{-1} best enhanced soil Zn^{2+} content in 2010. However, tillage, nitrogen and phosphorus rates interacted significantly to influence Zn^{2+} content of the soil.

Table 19: Effects of tillage, N and P on soil micronutrients at harvest in 2010 and 2011

	2010 Micronutrients				2011			
	Cu^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}
Treatment	<---------- mg kg^{-1} ---------->							
Tillage								
CT+Cp	0.0033a	0.0089a	0.0043a	0.0054b	0.0034a	0.0085a	0.0046a	0.0061a
CT	0.0031a	0.022a	0.0045a	0.0060a	0.0029b	0.022a	0.0044a	0.0061a
PC+Cp	0.0027b	0.0090a	0.0045a	0.0056b	0.0031b	0.0088a	0.0043a	0.0050b
Mean	0.003	0.013	0.0044	0.0057	0.0031	0.0145	0.0044	0.0057
SE±	0.00012	0.0081	0.00009	0.0017	0.00014	0.0081	0.0001	0.00019
N level(kg/ha)								
60	0.0029b	0.0090a	0.0044a	0.0055b	0.0031a	0.023a	0.0044a	0.0061a
80	0.0029b	0.023a	0.0044a	0.0064a	0.0033a	0.0088a	0.0046a	0.0059a
100	0.0033a	0.0085a	0.0045a	0.0052b	0.0030a	0.0083a	0.0043a	0.0052b
Mean	0.003	0.013	0.0044	0.0057	0.0031	0.014	0.0044	0.0057
SE±	0.00012	0.0081	0.000009	0.00017	0.00014	0.0081	0.0001	0.00019
P level(kg/ha)								
6.6	0.0032a	0.0089a	0.0046a	0.0060a	0.0033a	0.022a	0.0043a	0.0056a
13.2	0.0028a	0.023a	0.0044a	0.0050b	0.0030a	0.0088a	0.0044a	0.0056a
26.4	0.0030a	0.0091a	0.0044a	0.0060a	0.0031a	0.0087a	0.0043a	0.0060a
Mean	0.0030	0.013	0.0045	0.0057	0.0031	0.014	0.0044	0.0057
SE±	0.0012	0.0081	0.000009	0.00017	0.00014	0.0081	0.0001	0.00019

Means with the same letter are not significantly different at 5% level of probability using Tukey's Honesty Significant Difference (HSD)

4.6 Crop Performance

4.6.1 Crop Height (2010 and 2011)

Table 20 shows that at 4, 6 and 8 weeks after planting (WAP), treatment PC+Cp resulted in taller maize plants compared with the other tillage treatments in 2010. This treatment was significantly ($P \leq 0.05$) taller than CT at the 4, 6 and 8 WAP in 2010. However, at 8 WAP in 2010, maize height was not statistically different using PC+Cp and CT+Cp. Also, at 6 WAP, in 2010, CT+Cp enhanced maize height significantly ($P \leq 0.05$) than CT. In 2011, PC+Cp and CT+Cp enhanced maize plant height significantly ($P \leq 0.05$) better than CT at 4 WAP. However, CT and CT+Cp at 6 WAP and CT+Cp at 8 WAP increased maize height significantly than the other treatments (Table 21). These results suggest that PC+Cp treatment would result in significantly taller plants at 4 WAP than the other treatments. However, at 8 WAP, CT+Cp would result in significantly taller plants than the other treatments

Table 20 shows also that at all sampling date in 2010, maize plant height increased significantly with increase in N rate. In 2011, on the other hand, N had no effect on maize plant height, except at 8WAP when maize plants were shorter using 80 kg N ha^{-1} compared with 60 kg N ha^{-1} and 100 kg N ha^{-1} that were at par (Table 20).

Phosphorus application had no influence on maize plant height in both years except at 6WApwhen the application of 13.2 and 26.4 kg P ha^{-1} resulted in similar but taller maize plants than 6.6 kg P ha^{-1}

These results imply that at 4 WAP, a combination of PC+Cp, 100 kg N ha^{-1} and 6.6 kg P ha^{-1}would enhance maize height significantly (Table 20). Also, results show

that application of CT+Cp at 100 kg N ha^{-1} and 26.4 kg P ha^{-1} will significantly enhance maize plant height. Results also show that tillage and nitrogen interacted significantly to improve maize height at 4 and 6 WAP in 2010 and tillage, nitrogen and phosphorus interacted significantly also at 6 and 8 WAP in 2010 to enhance maize plant height (Table 20).

Table 20: Effects of Main Treatments, N and P on maize height (cm); 2010 and 2011

	2010			2011		
	Maize Height (cm)					
Treatment	4	6	8	4	6	8
	<----------WAP---------->					
Tillage						
PC+Cp	66.99a	158.17a	213.39a	70.89a	161.11b	200.37b
CT	62.20b	131.18c	186.53b	58.59b	175.54a	193.22c
CT+Cp	64.19b	149.48b	217.17a	73.93a	173.48a	223.69a
Mean	64.46	146.28	205.7	67.83	170.04	205.76
SE±	1.07	0.72	1.14	1.08	2.78	1.54
N level(kg/ha)						
60	58.93c	139.25c	195.19c	68.35a	170.11a	206.63a
80	64.90b	144.72b	202.52b	67.04a	168.20a	199.75b
100	69.54a	154.86a	219.38a	68.11a	171.82a	210.91a
Mean	64.46	146.28	205.7	67.83	170.04	205.76
SE±	1.07	0.72	1.14	1.08	2.78	1.54
P level(kg/ha)						
6.6	64.97a	143.06b	195.73a	69.22a	169.07a	205.52a
13.2	63.51a	148.20a	208.76a	67.80a	170.43a	203.70a
26.4	64.90a	147.57a	212.60a	66.48a	170.63a	208.06a
Mean	64.46	146.28	205.7	67.83	170.04	205.76
SE±	1.07	0.72	1.14	1.08	2.78	1.54
Interaction						
T*N	**	**	NS	**	NS	**
T*P	NS	**	**	NS	NS	NS
N*P	NS	NS	**	NS	NS	**
T*N*P	NS	**	**	*	NS	*

Means with the same letter are not significantly different at 5% level of probability using Tukey's Honesty Significant Difference (HSD)

WAP = Weeks after planting

* = significant at 5% level of probability, SE = standard error

** = significant at 1% level of probability

NS = not significant

4.6.2 Maize Yield (2010 and 2011)

Table 21 presents data on yield of maize as influenced by tillage, N and P rates in 2010 and 2011 growing seasons. It shows that in both years, CT+Cp treatment produced significantly ($P \leq 0.05$) higher grain yield than CT, which in turn yielded significantly higher than PC+Cp. Also, grain yield increased significantly with each increase in N rate up to the highest rate of 100 kg N ha^{-1} used in this study (Table 21). The application of 26.4 kg P ha^{-1} resulted in significantly ($P \leq 0.05$) higher maize grain yield followed by 13.2 kg P ha^{-1} and least by 6.6 kg P ha^{-1}. These results suggest that the combined treatments of CT+Cp at 100 kg N ha^{-1} and 26.4 kg P ha^{-1} enhanced significant ($P \leq 0.05$) maize grain yield better than the other treatments. The table also shows that in both years, tillage interacted with nitrogen and phosphorus rates positively to influence higher maize grain yield than the average of 2.0 t ha^{-1} normally obtained in farmers' fields in the Guinea Savanna of Nigeria (Goldsworthy, 1967; Jones, 1972; Chude, 1996).

Table 21 shows also that in 2010, CT and CT+Cp had similar but significantly ($P \leq 0.05$) higher cob weight compared to PC+Cp. However, in 2011, CT+Cp resulted in significantly higher cob weight than CT which in turn was significantly higher than PC+Cp. Also, significantly ($P \leq 0.05$) higher maize cob was obtained under 100 kg N ha^{-1} followed by 80 kg N ha^{-1} and least by 60 kg N ha^{-1} in both years. Application of 26.4 kg P ha^{-1} resulted in significantly ($P \leq 0.05$) higher maize cob weight than 13.2 kg P ha^{-1} which in turn was significantly higher than 6.6 kg P ha^{-1} in both years. These results suggest that the combination of CT+Cp at 100 kg N ha^{-1} and 26.4 kg P ha^{-1} enhanced maize cob weight significantly ($P \leq 0.05$) better than the other treatments. Results show

also that tillage, nitrogen and phosphorus rates interacted positively in both years to enhance cob weight of maize (Table 21).

Data on stover yield show that in 2010, tillage treatment, nitrogen and phosphorus had no significant effect on maize stover yield (Table 21). The interaction factors were also not significant on maize stover yield in 2010. However, in 2011, treatment CT produced significantly higher stover yield than CT+Cp which in turn was significantly higher than PC+Cp. Also, maize stover yield increased significantly with each increase in N and P rate up to the highest rate of 100 kg N ha^{-1} and 26.4 kg P ha^{-1} used in this study (Table 21).

Percentage difference between treatments with years using CT (control) as a baseline is presented in Table 22. It shows that in 2010, CT+Cp had a 6.61 % increase in yield over CT while PC+Cp had a yield decrease of 37.6 % compared with CT. Also, in 2011, CT+Cp had a 2.51 % yield increase over CT and PC+Cp had a yield decrease of 41.90 % relative to CT. This suggests that CT+Cp yielded better than the other treatments in both years and is therefore superior to the other treatments. Normally, yield decreases with years, but results from this study showed increase in yield of maize. Perhaps, the treatments/management practice has enhanced soil quality to support yield increase with continued in-situ cultivation with same crop.

Table 21: Effects of tillage, N and P on maize yield(t ha^{-1}) at harvest in 2010 and 2011 with percentage difference between years

Treatment	2010			2011			% Difference Between Years		
	GY	CW	SY	GY	CW	SY	GW	CW	SY
	<----------t ha-1---------->								
Tillage									
PC+Cp	1.51c	0.35b	0.97a	2.08c	0.47c	1.37c	37.7	34.3	41.2
CT	2.42b	0.7a	4.65a	3.58b	1.19b	5.54a	51.7	70	19.1
CT+Cp	2.58a	0.7a	2.12a	3.67a	1.23a	4.65b	38.8	75.7	119.3
Mean	2.17	0.59	2.58	3.11	0.99	3.85	-	-	-
SE±	0.08	0.01	0.77	0.97	0.09	0.36	-	-	-
N level(kg/ha)									
60	1.62c	0.45c	1.16a	2.57c	0.88c	3.32c	58.6	95.6	186.2
80	2.03b	0.57b	1.53a	2.99b	0.91b	4.00b	47.3	59.6	161.4
100	2.87a	0.74a	4.69a	3.77a	1.17a	4.23a	31.4	58.1	-9.8
Mean	2.17	0.59	2.58	3.11	0.99	3.85	-	-	-
SE±	0.08	0.01	0.77	0.97	0.09	0.36	-	-	-
Plevel(kg/ha)							-	-	-
6.6	1.87c	0.5c	1.42a	2.86c	0.92c	3.51c	52.9	84	147.2
13.2	2.14b	0.58b	4.62a	3.17b	0.99b	3.83b	48.1	70.7	-17.1
26.4	2.50a	0.68a	1.42a	3.30a	1.06a	4.21a	32	55.9	196.5
Mean	2.17	0.59	2.58	3.11	0.99	3.85	-	-	-
SE±	0.08	0.01	0.77	0.97	0.09	0.36	-	-	-
Interaction									
T*N	**	**	NS	**	**	**			
T*P	**	**	NS	**	**	**			
N*P	**	**	NS	**	**	**			
T*N*P	**	**	NS	**	**	**			

Means with the same letter are not significantly different at 5% level of probability using Tukey's Honesty Significant Difference (HSD)

WAP = Weeks After Planting
GW = Grain weight
CW = Cob weight (ha)
SY = Stover Yield (ha)

* = significant at 5% level of probability, SE = standard error

** = significant at 1% level of probability, NS = not significant

Table 22: Grain Yield as % of CT in 2010 and 2011

	Yield (t ha^{-1})		Yield as % of CT	
	2010	2011	2010	2011
Treatment				
PC+Cp	1.51	2.0	-37.6	-41.90
CT	2.42	3.58	-	-
CT+Cp	2.58	3.67	6.61	2.51

PC+Cp – Permanent cover plus *Centrosema pascuorum*

CT – Conventional tillage

CT+Cp – Conventional tillage plus *Centrosema pascuorum*

4.6.3 Interactions between treatments (2011)

Figures 3 and 4 show yield obtained when tillage interacted with nitrogen and phosphorus rates in the study area. They shows that, with treatment CT, what is required is for optimum maize yield is 60 kg N ha^{-1} and 6.6 kg P ha^{-1}. They show also that with treatment PC+Cp, N and P requirements for optimum maize productivity is 100 kg N ha^{-1} and 26.4 kg P ha^{-1} and with treatment CT+Cp, what is required for optimum maize productivity is 100 kg N ha^{-1} and 13.2 kg P ha^{-1}

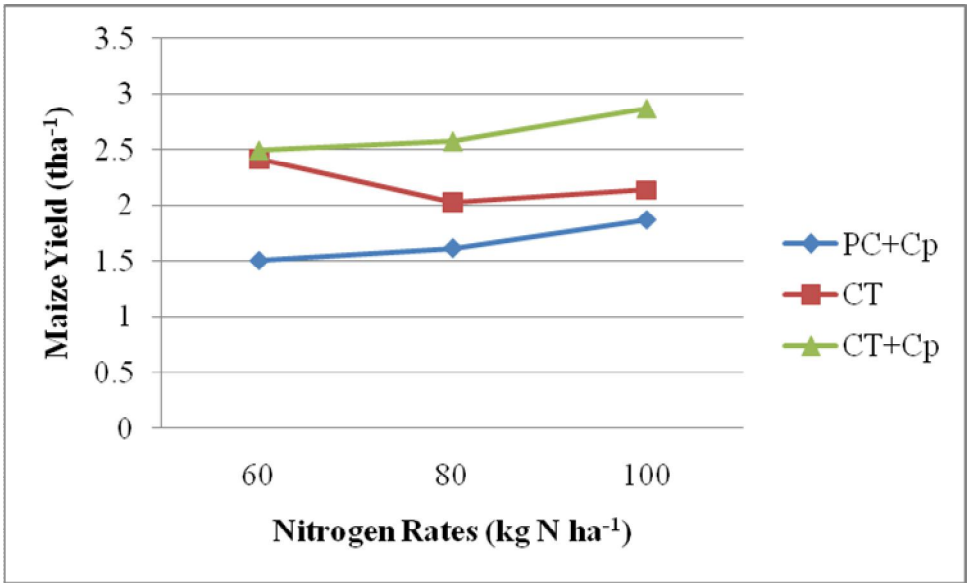


Figure 1: Maize grain yield as influenced by interaction of tillage and nitrogen fertilizer rates at Samaru (2011)

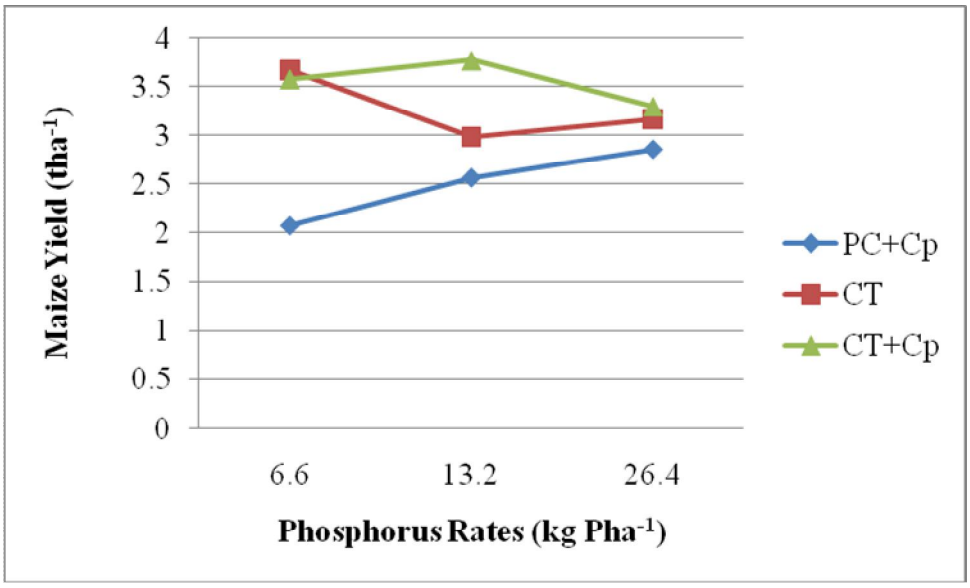


Figure 2: Maize grain yield as influenced by interaction of tillage and phosphorus fertilizer rates at Samaru (2011).

4.6.4 Effects of tillage, N and P on 1000GW and Days to tasseling (DTT) (2010 and 2011).

Table 23 presents data on 1000-grain weight (1000 GW) and days to 50% tasseling (DTT) of maize. It shows that in 2010, CT+Cp and CT treatments resulted in similar but significantly higher 1000-grain weight than PC+Cp in 2010. Also, significantly ($P \leq 0.05$) higher weight of 1000 maize grain was obtained under 100 kg N ha^{-1} followed by 80 kg N ha^{-1} and least by 60 kg N ha^{-1}. Application of 13.2 P ha^{-1} resulted in significantly ($P \leq 0.05$) higher weight of 1000 maize grain compared with 26.4 kg P ha^{-1} and 6.6 kg P ha^{-1} that were statistically similar.

Table 23 also show that CT+Cp plants reached 50 % tasseling stage earlier than those in PC+Cp while CT further delayed tasseling. Plants under 60 and 80 kg N ha^{-1} significantly reached 50 % tasseling stage earlier than 100 kg N ha^{-1}. Also, application of 6.6 and 13.2 kg P ha^{-1} tasseled later than plants under 26.4 kg P ha^{-1} (Table 23). These findings suggest that a combination of treatment CT+Cp at 100 kg N ha^{-1} and 26.4 kg N ha^{-1} enhanced days to 50% tasseling of maize.

In 2011, results show that CT+Cp resulted in significantly ($P \leq 0.05$) higher 1000 maize grain weight followed by CT and least by PC+Cp. Also, application of 100 kg N ha^{-1} resulted in higher 1000 maize grain weight and which was significantly ($P \leq 0.05$) higher than 80 kg N ha^{-1} and 60 kg N ha^{-1}. Application of 26.4 and 13.2 kg P ha^{-1} resulted in significantly ($P \leq 0.05$) higher maize 1000 grain weight than 6.6 kg P ha^{-1}. These results suggest that the combination of CT+Cp at 100 kg N ha^{-1} and 26.4 kg P ha^{-1} enhanced 1000 grain weight of maize.

Results on DTT in 2011 show that CT+Cp treatment took the least number of days to attain 50 % tasseling followed by PC+Cp while CT took the highest number of days to attain 50 % tasseling. Also, application of 100 kg N ha^{-1} resulted in lower days to attain 50 % tasseling followed by 60 kg N ha^{-1} and 80 kg N ha^{-1} took the highest number of days to attain 50 % tasseling. Application of 26.4 kg P ha^{-1} resulted in lower number of days to attain 50 % tasseling and was significantly different from 6.6 and 13.2 kg P ha^{-1} which were statistically the same.

These findings suggest that combination of CT+Cp at 100 kg N ha^{-1} and 26.4 kg P ha^{-1} improved days to 50 % tasseling. Results also show that tillage, nitrogen and phosphorus interacted significantly to enhance 100 grain weight and days to attain 50 % tasseling (Table 23).

Table 23: Effects of tillage, N and P on 1000 GW and DTT; 2010 and 2011

	2010		2011	
Treatment	1000GW(g)	Days to 50% taselling	1000GW(g)	Days to 50% tasseling
Tillage				
PC+Cp	211.25b	49.48b	162.41c	55.78b
CT	242.84a	59.52a	290.36b	58.37a
CT+Cp	244.90a	45.11c	346.77a	55.37b
Mean	232.99	51.37	266.51	56.51
SE±	1.09	0.2	1.08	0.22
N level(kg/ha)				
60	217.59c	51.71a	245.14c	56.59a
80	231.01b	51.74a	260.24b	56.74a
100	250.39a	50.67b	294.16a	56.19a
Mean	232.99	51.37	266.51	56.51
SE±	1.09	0.2	1.08	0.22
P level(kg/ha)				
6.6	229.37b	51.89a	255.99b	56.81a
13.2	236.86a	51.67a	270.59a	56.81a
26.4	232.76b	50.56b	272.96a	55.89b
Mean	232.99	51.37	266.51	56.51
SE±	1.09	0.2	1.08	0.22
Interaction				
T*N	**	**	**	**
T*P	**	**	**	NS
N*P	**	**	**	NS
T*N*P	**	NS	**	NS

Means with the same letter are not significantly different at 5% level of probability using Tukey's Honesty Significant Difference (HSD)

GW – Grain weight (g)

* = significant at 5% level of probability, SE = standard error

** = significant at 1% level of probability

NS = not significant

4.7 Criteria for Soil Quality Monitoring and Evaluation in Samaru, Nigeria

To monitor soil quality, treatment means for bulk density, mean weight diameter, pH in H_2O and $CaCl_2$, organic carbon, total nitrogen, available phosphorus, cation exchange capacity and maize grain yield were matched graphically as shown in the Appendices.

Figure 3 shows that CT+Cp had the least bulk density in both 2010 and 2011 while PC+Cp had the highest bulk density in 2010 and dropped tremendously at the end of the 2011 cropping season to become the least bulked soil. 100 kg N ha^{-1} and 13.2 kg P ha^{-1} had the least bulk density at the end of the 2011 cropping season.

Figure 4 shows that CT+Cp increased in diameter of mean weight and had the highest mean weight diameter in 2011 while CT had a decrease in mean weight diameter. PC+Cp also had decrease in mean weight diameter but the decrease was less than that of CT. 80 kg N ha^{-1} and 6.6 kg P ha^{-1} gave the best values for mean weight diameter at the end of the 2011 cropping season.

Figures 5 and 6 shows pH in H_2O and $CaCl_2$ respectively. It shows that pH decreased slightly under CT+Cp and CT and increased under PC+Cp. Also, 60 kg N ha^{-1} increased in pH with 80 kg N ha^{-1} having the highest increase in soil pH. Decrease in soil pH however, was not sufficient to hamper crop growth. Both pH in H_2O and $CaCl_2$ followed the same trend.

Figure 7 shows that there was increase in organic carbon contents under all treatments with CT+Cp having the highest organic carbon content. 100 kg N ha^{-1} and

26.4 kg P ha^{-1} gave the highest content of organic carbon at the end of the 2011 cropping season.

Figure 8 shows that a flat total N content of 0.4 g kg^{-1} was observed across treatments. It shows also that there was an increase in 26.4 kg P ha^{-1} from 0.3 g kg^{-1} in 2010 to 0.4 g kg^{-1} in 2011.

Figure 9 shows that CT had the highest content of available P at the end of both 2010 and 2011 cropping seasons. CT+Cp had the least and this could be attributed to crop uptake of phosphorus since it has been proven that legumes use up phosphorus more and the presence of legume facilitates the utilization of soil phosphorus by crops in the low P soil of Northern Guinea Savanna of Nigeria (Kalm et al. 2002).

Figure 10 shows that CEC decreased slightly under CT+Cp, remained constant under CT and increased tremendously under PC+Cp. 60 kg N ha^{-1} and 6.6 kg P ha^{-1} increased in 2011 and had the highest CEC value.

Figure 11 shows general increase in maize yield. CT+Cp increased tremendously over the other treatments with yields of over3.5 t ha^{-1} at the end of the 2011 cropping season. CT increased slightly and PC+Cp also increased in yield better than CT. 100 kg N ha^{-1} and 26.4 kg P ha^{-1} gave the highest yield also. Yields were improved at the end of 2011 cropping season.

Effect of decreasing bulk density, increasing mean weight diameter/aggregate stability reduced EA and improved CEC and ECEC with years would imply that soil health/quality over the years had been positively impacted upon by the management practices (McRae and Mehuys, 1988; Carlson and Huss-Danell, 2003). The negative

changes however, confirm the opinion of Bationo *et al.* (2003) on nutrient depletion following continuous cropping in the zone.

Management practices which were superior by improving soil quality and yielding better were ascertained from results and a summary of the threshold limits using soil and crop parameters that were superior as a baseline is presented in Tables 24 and 25.

Table 24: Results obtained from interaction of treatments at harvest in 2011 as baseline for threshold limits for soil quality assessment in Samaru Alfisols.

Soil/Crop Parameter	CT+Cp at 100 kg N and 13.2 kg P ha^{-1}	CT at 60 kg N and 6.6 kg P ha^{-1}	PC+Cp at 100 kg N and 26.4 kg P ha^{-1}
Bulk Density (Mg m^{-3})	1.46	1.3	1.24
Organic Carbon (g kg^{-1})	5.7	5.5	5.6
Total Nitrogen (g kg^{-1})	0.4	0.4	0.4
Available Phosphorus (mg kg^{-1})	2.92	4.85	2.93
Cation Exchange Capacity (cmol kg^{-1})	8.10	7.39	8.54
Mean Weight Diameter	1.46	1.27	1.32
pH (H_2O)(1:2.5)	5.59	4.91	5.68
pH ($CaCl_2$(0.01M)	4.71	4.13	4.82
Yield (t ha^{-1})	3.67	3.58	2.08

PC+Cp – Permanent cover plus *Centrosema pascuorum*

CT – Conventional tillage

CT+Cp – Conventional tillage plus *Centrosema pascuorum*

Table 25: Summary of Criteria for Soil Quality Monitoring and Evaluation in Samaru, Nigeria

Nutrients/Grain Yield	Soils in Samaru		
	High	Medium	Low
Bulk Density (Mg m^{-3})	≥ 1.4	1.2– 1.4	< 1.2
Organic Carbon (g kg^{-1})	≥ 5.0	4.0 - 5.0	< 4.0
Total Nitrogen (g kg^{-1})	>0.3	0.2 – 0.3	< 0.2
Available Phosphorus (mg kg^{-1})	≥ 4.0	2.5 – 4.0	< 2.5
Cation Exchange Capacity (cmol kg^{-1})	≥ 8.0	7.0 – 8.0	< 7.0
Mean Weight Diameter	≥1.5	1.3 – 1.5	< 1.3
pH (H_2O)(1:2.5)	>5.5	4.8 – 5.5	< 4.8
pH ($CaCl_2$(0.01M)	>4.5	4.0 – 4.5	< 4.0
Yield (t ha^{-1})	>2.5	1.5 – 2.5	< 1.5

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

The study was conducted for two planting seasons (2010 and 2011) at the experimental farm of the Institute for Agricultural Research (IAR), Samaru, Zaria. The experiment was established in 2010 and repeated in 2011 at the IAR meteorological site ($11^0$10'58"N, $7^0$37'0"E) in the Northern Guinea Savanna ecology of Nigeria to determine soil quality changes arising from tillage/legume treatments, and fertilizer (N and P) application for maize production. The legume evaluated was *Centrosema pascuorum* which was intercropped with maize on both tilled and no-till plots. Another plot was also tilled and mono cropped with maize. Inorganic nitrogen and phosphorus were applied to the treatments at three levels (60, 80 and 100 kg N ha^{-1} and 6.6, 13.2 and 26.4 kg P ha^{-1} respectively) to determine the level that will give the best maize yield production. Performance of these treatments in relation to soil physical and chemical conditions was compared using split plot design (SPD) procedure. Dry matter production and maize yield under the treatments were compared. These were done to aid selection of the most suitable tillage/legume practice, N and P rates for improvement in soil physical and chemical properties for sustainable maize production.

Soils of the study site at the Institute for Agricultural Research (IAR) farm, Ahmadu Bello University in Zaria, were classified as Typic Haplustalf according to the USDA soil taxonomy and Acrisols according to FAO/UNESCO soil classification systems.

Following results obtained, these are inferred;

i. In both years, bulk density value under *Centrosema pascuorum* + Conventional tillage (CT + Cp) was significantly lower than the rest treatments at 6 WAP. Bulk density was significantly lower under treatments with leguminous cover than those without leguminous cover, suggesting that CT+Cp best improved soil bulk density in both years. Also, 80 kg N ha^{-1} and 6.6 kg P ha^{-1} resulted in reduced bulk density. This suggests that a combination of CT+Cp at 80 kg N ha^{-1} and 6.6 kg P ha^{-1} will significantly reduce soil bulk density of Samaru area Alfisols.

ii. Dry mean weight diameter (MWD) under conventional tillage (CT) was significantly higher followed by permanent cover + *Centrosema pascuorum* (PC+Cp) and CT+Cp gave the least. It is inferred from this result that CT would reduce wind erosion effect more than the other treatments.

iii. Organic carbon content obtained under the treatments showed significant differences with CT+Cp giving the highest organic carbon content of 5.7 g kg^{-1} followed by PC+Cp while CT gave the lowest organic carbon value of 5.5 g kg^{-1}. This implies that CT+Cp treatment could credit higher organic carbon into soils of the experimental site, than the other treatments at 100 kg N ha^{-1} and 26.4 kg P ha^{-1} thus sequestering more carbon and may have contributed in mitigating global warming better than the other treatments.

iv. In 2010 and 2011, CT+Cp resulted in significantly higher maize grain yield (2.6 t ha^{-1} and 3.6 t ha^{-1} respectively) followed by CT (2.4 and 3.7 t ha^{-1} respectively) while PC+Cp (1.5 and 2.08 t ha^{-1}) gave the least maize grain yield. Nitrogen levels applied at 100 kg N ha^{-1} gave the highest maize grain yield (2.9 t ha^{-1} and 3.8 t ha^{-1}) followed by 80 kg N ha^{-1}(2.0 and 3.0 t ha^{-1} respectively) while 60 kg N ha^{-1} gave the

least maize grain yield of 1.6 t ha^{-1} and 2.6 t ha^{-1} respectively for 2010 and 2011. Phosphorus levels also showed significant differences in maize grain yield with 26.4 kg P ha^{-1} (3.3 t ha^{-1}) yielding the highest followed by 13.2 kg P ha^{-1} (3.2 t ha^{-1}) while the least maize grain yield was obtained under 6.6 kg P ha^{-1} (2.9 t ha^{-1}). Maize cob weight also followed the same trend as maize grain yield. For maize dry matter however, CT (5.5 t ha^{-1}) gave the highest value followed by CT+Cp (4.6 t ha^{-1}) while PC+Cp (1.4 t ha^{-1}) gave the least value. Dry matter yield value under N increased with increasing N rates while P rates had 26.4 kg P ha^{-1} giving the highest value of maize dry matter yield of 4.2 t ha^{-1} followed by 13.2 kg P ha^{-1} (3.8 t ha^{-1}) and 6.6 kg P ha^{-1} gave the least value of 3.5 t ha^{-1}. It is therefore inferred that CT+Cp treatment could result in higher maize grain weight and cob weight. However, since maize grain yield increased with increase in N application rates, optimal N rate may not have been attained. But CT+Cp at 100 kg N ha^{-1} and 26.4 kg P ha^{-1} proved superior in improving soil quality and maize yield. The treatments however exceeded the 2.0tha^{-1} maize yield obtainable at farmers' fields in the zone, thus confirming sustainable management practice.

v. Days to tasseling also showed significant differences. CT+Cp reached 50 % tasseling stage earlier than the other treatments. It was followed by PC+Cp, while CT took the highest number of days to attain 50% tasseling. It can be inferred that plants under CT+Cp treatment had the tendency to mature earlier and save time.

Effect of decreased bulk density, increased mean weight diameter, reduced exchange acidity and improved CEC and ECEC with years would imply that soil health/quality over the years had been positively impacted upon by the management

practices. However, CT+Cp at 100 kg N ha^{-1} and 13.2 kg P ha^{-1} proved superior in improving both soil health and maize productivity with a percentage rise in yield of 2.51 % over CT and 70.6 % over PC+Cp and is therefore recommended for sustainable maize production in Samaru Alfisols, Nigeria.

RECOMMENDATION

Following the summary and conclusion above, the following recommendations are made;

i. CT+Cp treatment reduced soil bulk density, increased soil organic carbon by sequestering more carbon and may have contributed in reducing global warming, relatively helped in stabilizing soil aggregates, enhanced sustainable maize yield and is therefore recommended for sustainable soil productivity and environmental health.

ii. It is also recommended that CT+Cp treatment combined with the application of 100 kg N ha^{-1} and 26.4 kg P ha^{-1} could be applied to enhance maize production in Samaru.

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

REFERENCES

Abdu, N. (2009). Effects of soil properties on the kinetics of desorption of phosphorus from Alfisols by anion exchange resins. *Journal of Plant Nutrition and Soil Science*, **172: 101-107**

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

Adenle, M.O. (2004). Effects of inter-planted legumes with maize on major soil nutrients and yield of maize. *Plant and Soil Sciences*, **3(3): 521-526**.

Adepetu, J.A. (1983). Characteristics phosphorus sorption and its implication in soils of Ondo State, Nigeria. *Beit Tropical Landwirlsch Veterinaermed*, **19: 291-300.**

Adepetu, J.A. (1997). Soil and Nigerian food security. Inaugural lecture series 119. OAU.

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

Adetunji, M.T. (1995). Equilibrium Phosphate concentration as an estimate of phosphate needs of maize in some tropical Alfisols. *Tropical Agriculture*. (Trinidad), **72: 285-289**.

Adetunji, M.T. (1997). Phpsophate adsorption capacity of low activity clay soils of southwestern Nigeria and its usefulness in evaluating P requirement of rice. Nutrient Cycling in Agro Ecosystem, **47: 181-188**.

Adeyi, S.O. (2003). Effect of increasing maize population in cassava/maize mixture on soil nutrients and performance of cassava. *Crop science*, **6(5): 771-776**.

Adu, J.K. and J.M. Oades (1978). Physical factors influencing decomposition of organic materials in soil aggregates. *Soil Boiogy and Biochemistry,* **10: 109-115**.

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

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

Agboola, A.A. (1978). Influence of soil organic matter on cowpea response to N Fertilizers. *Agronomy Journal*, **70(1): 25-28**.

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

Alan, L.W., F. Dou, and F.M. Hons (2007). Soil organic C and N distribution for wheat cropping systems after 20 years of conservation tillage in central Texas. *Agriculture Ecosystem and Environment*, **121: 376–382**.

Allmaras, R.R. and W.W. Nelson (1971). Corn (Zea mays L.) root configuration as influenced by some row inter-row variants of tillage and straw mulch arrangement. *Soil Science Society of America Proceedings*, **35: 974-990**.

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

Andrews, S.S., D.L. Karlen and C.A.Cambardella (2004). The soil management assessment framework: A quantitative soil quality evaluation method. *Soil Science Society of America Journal,* **68: 1945-1962**.

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

Arrouays, D., J. Balesdent, G.C. Germon,, P.A. Jayet, J.F. Soussana and P. Stengel (Eds.) (2002). Contribution a` la lutte contre l'effet de serre. Stocker du carbone dans les sols agricoles de France? Expertise Scientifique Collective, Synthe` sedu rapport. INRA, Paris, France, **p12–14**.

Arshad, M. A. and S. Martin (2002). Identifying critical limits for soil quality indicators in agro-ecosystems. *Agriculture, Ecosystems & Environment*, **88(2): 153-160**

Awodun, M.A. and S.O. Ojeniyi (1998). Use of weed mulches for improving soil fertility and maize performance. *Applied Tropical Agriculture*, **3: 26-30**.

Aya, K.O. (2004). Effects of increasing maize population in a soybean maize mixture on soil nutrients and performance of soybean. *Agricultural Science Journal*, **5(3): 405-409**.

Bada, K.T. (2005). Influence of increasing maize population in a yam/maize mixture on major soil nutrients and yield of yam. *Journal of Plant Nutrition Research*, **7(5): 803-808**.

Badu-Apraku, B., M.A.B. Fakorede, M. Ouedraogo and F.M. Quin (1997). Strategy for maize production in West and Central Africa. Proceedings of a regional maize workshop held at IITA-Cotonou, Republic of Benin, April 1997. **p 3-20**.

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

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

Baeumer, K. and W.A.P. Bakermens (1973). Zero tillage. Advances in Agronomy. **25: 77-123**.

Bationo, A. and A.U. Mokwunye (1991). Alleviating soil fertility constraints to increased crop production in West Africa: the experience in the Sahel. **p195-215**. In: A.U. Mokwunye (ed.) Alleviating soil fertility constraints to increased crop production in West Africa. Kluwer Academic Publishers, Netherlands.

Bationo, A., U. Mokwunye, P.L.G. Vlek, S. Koata and B.I. Shapiro (2003). Soil fertility management for sustainable land use in the West Africa Sudano- Sahelian zone. In soil fertility management in Africa: A regional perspective (M.P. Gichuru, A. Bationo, M.A., Bekunda, H.C., Goma, P.L., Mafongoya, D.N.. Mugendi, H.M., Murwira, S.M., Nandwa, P., Nyathi & M.J. Swift, eds.), **p255-292**. Tropical Soil Biology and Fertility Institute of CIAT; Nairobi, Kenya.

Baudoin, E., L. Philippot, D. Cheneby, L. Chapuis-Lardy, N. Fromin, D. Bru, B. Rabury and A. Brauman (2009). Direct seeding mulch-based cropping increases both the activity and the abundance of denitrifier communities in a tropical soil. *Soil Biology and Biochemistry,* **41: 1703-1709**.

Beader, F.M. (2004). Biological and economic appraisal of the productivity of cowpea based intercropping systems. *Crop Ecology*, **3(1): 176-181**.

Bescansa, P., M.J. Imaz, I. Virto, A. Enrique and W.B. Hoogmoed (2006a). Soil water retention capacity as affected by tillage systems under semiarid conditions in Navarra (NE Spain). *Soil Tillage Research*, **87: 19–27**.

Bescansa, P., M.J. Imaz, I. Virto, A. Enrique, J.J. Pe´ rez de Ciriza, Delgado, I. Iran˜ eta and E. Dı´az (2006b). Laboreo de conservacio´n y calidad de suelos. Navarra Agraria **157: 15–22**.

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

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

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

Borlaug, N.E. and C.R.C. Dowswell (2004). Prospects for world Agriculture in the twenty-first century. In: Lal, R., P.R. Hobbs, N. Uphoff and D.O. Hansen (Eds.). Sustainable Agriculture and the International Rice-Wheat System. Marcel Dekker, Inc. New York. Basel. **p1-18**.

Bremmer, J.M. and C.S. Mulvaney (1982). Nitrogen total in: Page, A.L. (ed) Part 2 A.S.A., Madison, W.I **p595-624**.

Cam, F.K.N (2007). Studies on the effects of different crop mixtures on soil fertility in the humid tropics. *Soil Fertility Research*, **6(4): 588-593**.

Canter-martinez, C., P. Angas and J. Lampurlanes (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, *Field Crops Research*, **84: 341-357**.

Carlson, G., and K. Huss-Danell (2003). Nitrogen fixation in perennial forage legumes in the field. *Plant Soil*, **253**: **353- 372**.

Carsky, R.J. and E.N.O. Iwuafor (1999). Contribution of soil fertility research/maintenance to improved maize production and productivity in sub-Saharan Africa. In: Badu-Apraku B, Fakorede MAB, Ouedraogo M, Quin FM (eds) Strategy for maize production in West and Central Africa. Proceedings of a regional maize workshop held at IITA-Cotonou, Republic of Benin, April 1997. **p3-20**.

Chapman, H.D. (1965). Total exchangeable bases. In: Black, C.A. (ed.). Methods of soil analyses, part II. *American Society of Agronomy*, **56: 902-904**.

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

Chen, T.H., C.Y. Chiu and G.L. Tian (2005). Seasonal dynamics of soil microbial biomass in coastal sand dune forest. *Pedobiologia,* **49: 645-653**.

Cheruiyot, E. K., L. M. Mumera, L. N. Nakhone and S.M. Mwongo (2001).Rotational effects of grain legumes on maize performance in the Rift Vally Highlands of Kenya. *Africa Crop Science Journal,* **(4): 667-676**

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

Collaborative Group on Maize-based systems (COMBS) Research (1993). Improvement in soil fertility and weed suppression thorugh legume-based technologies. 11TA Research Guide 48. Training programme, International Institute of Tropical Agriculture (11TA), Ibadan, Nigeria. **p42**.

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

Crick, A.O. (2007). Effects of the inclusion of certain tropical legumes in crop mixtures on soil fertility. *Soil Science*, **4: 411-415**.

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 Sayce Co-Publ. UK. **p488**.

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

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

Dick, W.A. (1983). Organic carbon, nitrogen and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. *Soil Science Society of American Journal,* **47: 102-107**.

Dick, W.A. and M.A. Tabatabai (1993). Significant and potential uses of soil enzymes. In: Metting, F.B. (Ed). Soil microbial ecology: Applications in agricultural and environmental management. Marcel Dekker, New York. **p95-127**.

Diur, F.A. (2004). Effects of different crop associations on major soil nutrients. *Global Journal of Agricultural Research*, **4(3): 318-323**.

Doran, J.W. (1980). Soil microbial and biochemical changes associated with reduced tillage. *Soil Science Society of American Journal,* **44:765-771**.

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

Doran, J.W. and M. Safley (1997). Defining and assessing soils health and sustainable productivity, in: Pankhurst, C.E., Doube, B.M., Gupta, V.V.S.R. (Eds.), Biological Indicators of Soil Health. CAB International, Wallingford, **p1–28**.

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

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

Doran, J.W., M. Sarrantoni and M.A. Liebig (1997). Soil Health and Sustainability. *Advances in Agronomy,* **56: 1–54**

Edwards, A.D and J.M. Bremmer (1967). Microaggregates in Soil. *Journal of Soil Science,* **18: 64-73**.

Ehlers, W., U. Kopke, F. Hesse and W. Bohnm (1983). Penetration resistance and root growth of oats in tilled and untilled loess soil. *Soil and Tillage Research,* **2: 261-275**.

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

Enwezor, W.O., E.J. Udo, N.J. Usoroh, K.A. Ayotade, J.A. Adepetu, V.O. Chude and C.I. Udegbe (1989). Fertilizer Use and Management Practices for Crops in Nigeira (series No. 2). Fertilizer Procurement and Distribution Division, Federal Ministry of agriculture, Water Resources and Rural Development, Lagos, Nigeria. **p163**.

European Conservation Agricultural and Federation (ECAF) (1999). Conservation agriculture in Europe: environmental, economic and EU policy perspectives, ECAF (European Conservation Agricultural and Federation), Brussels. **p23**.

Ewansiha, S.U., S.A. Tarawali, A.C. Odunze and E.N.O. Iwuafor (2008). Potential Contribution of Lablab Residues to Maize Production in Moist Savanna of West Africa. *Journal of Sustainable Agriculture,* **32(3): 394**.

Falade, I.O. and S.O. Ojeniyi (1997). Effect of siam weed mulch on soil nutrient contents of maize. *Applied Tropical Agriculture*, **2: 110-113**.

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: United Nations. Rome Italy.

FAO-UNESCO. (1994). Soil map of the world. Revised legend. Tech. Paper No. 20. FAO/Rome and ISRIC/Wageningen, the Netherlands.

FAO (2010). Global Forest Resource Assessment 2010, main report.

Fenster, C.R. (1977). Conservation Tillage in the Northern Plains. *Journal of soil water conservation,* **32: 37-42**.

Foster, R.C. (1981). Polysaccharides in Soil Fabrics. Science (Washington, DC) **214: 655-667**.

Franchini, J.C., C.C. Crispino, R.A. Souze, E. Torres and M. Hungria (2007). Microbiological parameters as indicators of soil quality under various soil management and crop rotation systems in southern Brazil. *Soil and Tillage Research*, **92: 18-29**.

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

Garji, P.R., V.K. Arora and S.S. Prihar (2002). Tillage management for efficient water and nitrogen use in wheat following rice. *Soil Tillage Research*, **24: 167-182**.

Gee, G.W. and J.W. Bauder (1986). Particle Size Analysis. In: Klute, A. (ed). Methods of Soil Analysis (2nd ed.). No. 9 ASA Inc. SSSA Inc. Madison, Wisconsin USA. **p383-409**.

Gerh, S.S. (2007). The role of certain tropical legumes in improving and maintaining soil organic matter. *Soil Science Research*, **3(3): 666-671**.

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

Goldsworthy, P.R. (1967). Responses of cereals to fertilizers in northern Nigeria 11: Maize. *Experimental Agriculture,* **3: 263-273**.

Gomez, A.A., D.E. Swete Kelly, K.K. Syer and K.J. Coughlan (1996). Measuring sustainability of agricultural systems at the farm level. **p401-409**. *In*: Methods for Assessing Soil Quality, J.W. Doran and A.J. Jones (Eds); Special publication no. 49, Soil Science Society of America, Madison, USA.

Greenland, D.J. (1960). Nitrate fluctuation in tropical soils. *Journal of Agricultural Sciience,* **50:82-91**

Gregorich, E.G., R.G. Kachanoski, and R.P. Voroney (1989). Carbon mineralization in soil size fractions after various amounts of aggregate disruption. *Journal of Soil Sci*ience, **40: 649-659**.

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

Haney, R.I., A.J. Frenzlubbars, F.M. Hons, L.R. Hossner and D.A. Zuberer (2001). Molar concentration of K_2S0_4 and soil pH effect estimation of extractable C with chloroform fumigation extraction. *Soil Biology and Biochemistry*, **133: 1501-1507**.

Hargrove, W.L., J.T. Reid, J.T. Touchton and R.W. Gallahar (1982). Influence of tillage practices on the fertility status of an acid soil double cropped to wheat and soybeans. *Agronomy Journal,* **74: 684-687**.

Harris, R.F. and D.F. Bezdicek (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, **p23-35**, SSSA special publication No 35. Madison. WI.

Hedley, M.J., J.W.B. Stewart and B.S. Chauhan (1982). Changes in inorganic and organic soil phosphorus fractions induced by cultivation practices and by laboratory incubations. *Soil Science Society of America Proceedings,* **46:970–976**.

Hedlund, A., E. Witter and B.X. An (2003). Assessment of N, P and K management by nutrient balances and flows on peri-urban smallholder farms in southern Vietnam. *Eur. Journal of Agronomy,* **20: 71–87**.

http://foris.fao.org/state/data/fra2010-Report-1oct.pdf (assessed November, 2010).

http://www.fao.org/ag/agl/aglw/equastatwater/wateruse/index5.stem (assessed January, 2012)

Hulugalle, N.R., R. Lal and O.A. Opara-Nadi (1985). Effect of tillage systems and mulch on soil properties and growth of yam (Diascorea rotundanta) and cocoyam (Xanthosoma Sagitifolium) on an Ultisol. *Journal of Root Crops,* **11:9-22**.

Humphreys, L.R. (1995). Diversity of productivity of tropical legumes. In. D' Mello, J. P. E. and C. Devendra (Eds.) tropical legumes in animal nutrition. CAB International,Wallingfood,Uk. **p1-21**

IITA (1986). Maize Production Manual Vol. 1. Manual series No. 8. International Institute of Tropical agriculture, Ibadan, Nigeria. **p218**.

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

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 Bello University, Zaria. **p13**.

Iwuafor, E.N.O., Y. Dantagwa and V.O. Chude (1990). Potentials of Millet thresh Waste as a Soil Amendment. Paper presented at 11th Annual Conference of the soil science society of Nigeira. Maiduguri, Nigeria.

Jenkinson, D.S. and D.S. Powlson (1976). The Effects of biocidal treatments on metabolism in soil. A method for measuring soil biomass. *Soil Biology and Biochemistry,* **8:209-213**.

Jiao, Y., J.K. Whalen and W.H. Hendershot (2006). No-tillage and manure applications increase aggregation and improve nutrient retention in a sandy loam soil.

Jones, A.S.R., and A. Wild (1975). Soils of the West Africa Savanna. Tech. Comm. No. 55: CAB Harpenden.

Jones, M. J. (1972). Time of application of nitrogen fertilizer to grain at Samaru, Nigeria. *Experimental Agriculture,* **10: 273-279**.

Juo, A.S.R. (1979). Selected Methods of Soil and Plant Analysis. IITA manual series, **p70.**

Kahm, M., M. Avdou, V. Chude, F. Wiesler and W.J. Horst (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 fertility improvement in humid and sub-humid tropics. In: Collaborative group of maize-based systems research (COMBS) (1992). Report of the 2nd workshop, Kumasi, Ghana, June 1990. West African farming systems Research Network (WAFSRN/RESPAO), Ouagadougou, Burkina Faso, and International Institute of Tropical Agriculture (11TA), Ibadan, Nigeria. Geoderma, **134: 24–33**.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F., Harris and G.E. Schuman (1997). Soil quality: a concept, definition, and framework for evaluation. *Soil Science Society of America Journal,* **61: 4–10**.

Kirchhof and F.K. Salako (2000). Residual tillage and bush fallow affects on soil properties and maize inter-cropped with legumes on a tropical Alfisol. *Soil Use Management*, **16: 183-188**.

Kusimo, A.K. (2005). Effects of different crop association on soil nutrient dynamics. *Soil Fertility and Crop Husbandry Research*, **7(5): 693-699**.

Ladd, J.N., M. Amato and J.M. Oades (1985). Decomposition of plant material in Australian soils. 111: Residual organic and microbial biomass C. and N from isotope labeled plant material and organic matter decomposing under field conditions. *Australian Journal of Soil Research*, **23: 603-611**.

Lal, R. (1975). Role of mulching techniques in tropical soil and water management. Tech.Bull. No. 1. Int-Inst. Trop. Agric. (11TA), Ibadan,Nigeria. **p38**.

Lal, R. (1979). Physical characteristics of soils of the tropics. Determination and management. Soil Physical Properties and Crop Productin in the Tropics. **p7- 44**.

Lal, R. (1986). Conservation of tropical rainforest. Agronomic potentials and ecological consequences. *Advances in Agronomy*, **39: 173-363**.

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

Lal, R. and E.L. Dinkins (1979). Tillage systems and crop production in an Ultisol in Liberia. In: Lal, R. (Ed). *Soil Tillage and Crop Production*, **p221-225**.

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

Lal, R., R.H. Peter, N. Uphoff and O.H. David (2004). Reconciling food security with Environmental Quality through no-till farming. In: Sustainable Agriculture and the International Rice-Wheat system. Marcel Dekker, Inc. New York. **p495-511**.

Lal. R. (1976). Soil erosion problems on an Alfisol in western Nigeria and their control. 11TA monograph. **p208**.

Lampurlane´ S. J. and C. Cantero-Martı´nez (2006). Hydraulic conductivity, residue cover and soil surface roughness under different tillage systems in semiarid conditions. *Soil Tillage Research*, **85: 13–26**.

Larson, W. E. and F. J. Pierce (1994). The dynamics of soil quality as a measure of sustainable management. Pages 37 - 51 in J. W. Doran, D. C. Coleman, D. F. Bezdicek and B. A. Stewart, eds. Defining soil quality for a sustainable environment. SSSA- Special Publication 35. Soil Science Society of America, Madison , WI, USA.

Li, X.G., F.M. Li, R. Zed, Z.Y. Zhan and B. Singh (2007). Soil physical properties and theirrelations to organic carbon pools as affected by land use in an alpine pastureland.Geoderma, **15: 98–105**.

Liu, D. (1991). Efficient use of nitrogen in crop production. Extension Billetin No. 340. Food and fertilizer Technology centre, Taipei, ROC. Taiwan. **p1-10**.

Madari, B., L. Pedro, O.A. Machado and E. Torres (2005). No tillage and crop rotation effects on soil aggregation and organic carbon in a Rhodic Ferralsol from southern Brazil. *Soil Tillage Research,* **80: 1985–2000**.

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

Mayer, J., Buegger, F., Jensen, E.S., Schloter, M., (2003). Residual nitrogen contribution from grain legumes to succeeding wheat and rape and related microbial process. *Plant Soil*, **255, 541-554**.

Mbagwu, J.S.C., A. Piccolo and P.Spallace (1991). Effects of field application of inorganic wastes from different sources on chemical rheological and structural properties of some Italian surface soils. *Biology Research Technology,* **37: 71-78**.

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

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

Monkiedje, A., M. Spiteller, D. Fotio and P. Sukul (2006). The effect 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**.

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

Moreno, F., F. Pelegin, J. E. Fern and J.M. Murillo (1997). Soil physical properties, water depletion and crop development under traditional and conservation tillage in southern Spain. *Soil Tillage Research*, **41: 25-42**.

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

Mulongoy K. and I.O. Akonbundu (1990) Agronomic and Economic benefits of nitrogen contributed by legumes in live-much and alley cropping systems. In Nitrogen Fixation. Achievement and object. Eds. P.M Gresshoff, L.E. Roth, G. Stacey and, W.E. Newton. **p625-632**. Chapman and Hall, New York.

Muyinda K., R.E. Karamanos and I.P.O. Haloran (1988). Yields of wheat in rotation with maize and soybeans in Zambia. *Canadian Journal of Soil Science,* **6: 747-753**.

Nangyu, D. (1979). Effect of tillage methods on growth and yield of cowpea and soybean. In: Lal, R. (Ed) Soil tillage and Crop Production. **p93-108**.

Ndiaye, E.I., J.M. Sandeno, D. McGrath and R.P. Dick (2002). Integrative biological indicators for detecting change in soil quality. *American Journal of Alternative Agriculture*, **15:1-10**.

Nelson, D.W. and L.E. Sommers (1982). Total carbon, organic carbon and organic matter. In: AL. Page et al. (ed.). Methods of Soil Analysis, Part 2, 2nd ed. Agron. Mongr. 9, ASA and SSSA, Madison, W1. **p539-577**.

Nielsen, D.C. and M.F. Vigil (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 and Environment,* **88: 161–168**.

Nye, P.H. and D.J. Greenland (1960). Soil under shifting cultivation. Tech. Comm. 51. Harpenden. UK.: Commonwealth Bureau of Soils.

Obatolu, C.R. and A.A. Agboola (1993) the Potential of Siam Weed (Chromolaena odorata) as a source of organic matter for Soils in the humid Tropics **p89-100** in: K. Mulongoy and R. Merckx (eds.) Soil organic matter Dynamics and Sustainability of Tropical Agriculture. John Wiley and Sons.

Obatolu, C.R. and A.A. Agboola (1993) the Potential of Siam Weed (Chromolaena odorata) as a source of organic matter for Soils in the humid Tropics **p89-100** in: K. Mulongoy and R. Merckx (eds.) Soil organic matter Dynamics and Sustainability of Tropical Agriculture. John Wiley and Sons.

Odunze, A.C. (1997). Effects of different legume 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. (2003). Effect of forage legume incorporation on selected soil chemical properties in the Northern Guinea Savanna of Nigeria. *Journal of Sustainable Agriculture,* **22(1): 5-10**.

Odunze, A.C. (2011). Use of meteorological data in Agriculture. Training Manual: Training of monitoring and evaluation staff handling weather data collection of Kaduna state Agricultural Development Project. Farming Systems Research Programme (FSRP), Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria Special Publication 1. 3rd and 4th February 2011. **p1-6**.

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

Odunze, A.C., J. Wu, S. Liu, H. Zhu, T. Ge, Y. Wang, and Q. Luo (2012). Soil quality changes and quality status: A case study of the subtropical China Region Ultisols. *British Journal of Environment and Climate Change* **2(1): 37-57**. Science Domain International.

Ogban, P.I., T.P. Ekanem and E.A. Etim (2001). Effect of mulching methods on soil properties and growth and yield of maize in southeastern Nigeria. *Tropical Agriculture* (Trinidad), **78(2): 82-89**.

Ogban, P.I., W.N. Ogunewe, R.I. Dike, A.C. Ajaelo, N.I. Ikeata, U.E. Achumba and E.E. Nyong (2007). Effect of tillage and mulching practices on soil properties and growth and yield of cowpea (*Vigna unguiculata* (L), Walp) in Southeastern Nigeria. Proceedintgs of the 31st Annual Conference of The soil science society of Nigeira (SSSN), 13th-17th Novemebr, 2006, Ahmadu Bello University, Zaria. **p199-204.**

Ogungbile, O.A., J.O. Olukosi and K. Elemo (1991). Characterization of target zone and technology adaption for the northern Guinea Savanna of Nigeria. In: Weber, G.; Smith, J. and J. Olukosi (eds.). Characterization of target zones and technology targeting. WAFSRN, Ouagadougou Burkina Faso. **p76-83.**

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

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

Ojeniyi, S.O. and A.A. Agboola (1995). A review of tillage requirement of food crops in African soils, **28: 259-266**.

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

Opara-Nadi, A.O. (1993). Effect of elephant grass and Plastic Mulches on Soil properties and cowpea Yield on an Ultisol in southeastern Nigeria. **p351-260**. In: K. Mulongoy and R. (Merckx (eds.) Soil Orgnaic Matter Dynamics and sustainability of Tropical Agriculture John Wiley and sons.

Owaiye, A.R. (1993). Effect of Residence Mulch on Characteristics and productivity of two soil classes under coffee in Nigeria **p339-344**. In: mulongoy and R. Merekx (eds) Soil organic Matter Dynamics and sustainability of Tropical Agriculture. John Wiley and sons.

Page, A.L., R.H. Miller and D.R. Keeney (1982). Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. American Society of Agronomy and Soil Science Society America. Madison, Wisconsin.

Phillips, R.E., R.L. Blevins, G.W. Thomas, W.W. Frye and S.H. Phillips (1980). No-tillage Agriculture. *Science,* **208 (4448): 1108-1113**.

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

Pimental, D. and M. Pimental (1996). Food, Energy and Society: Colorado Press. Niwet, Co.

Pimental, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurtz, M. McNair, S. Crist, L. Sphpritz, L. Fitton, R. Saffouri and R. Blair (1995). Environmental and economic costs of soil erosion and conservation benefits. *Science,* **267: 1117-1123.**

Pimentel, D. and M. Pimentel (2003). World Population, food, natural resources, and survival: World Futures (in press).

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

PRB. (2003). World Population Data Sheet. Population Reference bureau. Washington DC. Science. 1995. Cities as disease vectors. Science 270 (editorial).

Reginald E.M., K.C. Pramod, D. Singh and A. Patra (2007). Soil quality response to long-term nutrient and crop management on a semi-arid Inceptisol. *Agriculture, Ecosystems & Environment*, **118 Issues 1-4: 130-142**.

Rhoades, J.D. (1987). Cation exchange capacity. In: Page A.L., R.H. Miller, Keeney D.R. (eds). Methods of Soil Analysis, Chemical and Microbiological Properties, part 2, 2nd edn. ASA-SSSA Madison Wisconsin, **p1490 – 1589**.

Richard, G., I. Cousin, J.F. Sillon, A. Bruand and J. Gue´rif (2001). Effect of compaction on the porosity of a silty soil: influence on unsaturated hydraulic properties. *European Journal of Soil Science*, **52: 49– 58**.

Salako, F.K., S. Hauser, O. Babalola and G. Tian (2001). Improvement of the physical fertility of a degraded Alfisol with planted and natural fallows under humid tropical conditions. *Soil Use Management*, **17: 41-47.**

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

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

Sanginga, N., J.A. Okogun, B. Vanlauwe, J. Diels, R.J. Carsky and K. Dashiell (2001). Nitrogen contribution of promiscuous soybeans in maize-based cropping systems. SSSA Special Publication 58, Madison, USA, **p157-177**.

SAS Institute (1993). SAS/ETS User's Guide, Version 6, second Edition SAS Institute Inc., Cary, NC.

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

Schjønnning, P. and K.J. Rasmussen (2000). Soil strength and soil pore characteristics for direct drilled and ploughed soils. *Soil Tillage Research*, **57: 69–82.**

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

Shukla, M.K., R. Lal and M. Ebinger (2004). Soil quality indicators for reclaimed minesoils in southeastern Ohio. *Soil Science*, **169: 133–142**.

Singh, T.F., S.M. Laur and C.O. Ait (2006). Effects of inter-planted legumes with cassava on soil nutrients and performance of cassava. *Soil Science*, **4: 683-688**.

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

Smith J., A.D. Barau, A. Goldsman and H.J. Mareck (1994). The role of technology in agricultural intensification: the evolution of maize production in the northern guinea savanna of Nigeria. Econ. Dev. *Cultural Change,* **42: 537-554**.

Stanford, G., O.L. Bennett and J. F. Power (1973). Conservation tillage practices and nutrient availability. In: Conservation tillage proc. Natl conf. conserv. Services of America. **p54-62.**

Sultani, M.I., M.A. Gill, M.M. Anwar and M. Athar (2007). Evaluation of soil physical properties as influenced by various green manuring legumes and phosphorus fertilization under rain fed conditions. *Int. Journal of Environment, Science and Technology*, **4(1): 109-118**.

Swift, M.J. and P.A. Sanchez (1984). Biological management of tropical soil fertility for sustainable productivity. *Nature and Resources*, **20(4): 1-10.**

Thippayarugs, S., B. Toomsan, P. Vityakon, V. Limpinuntana, A. Patanothai and G. Cadisch (2008). Interactions in decomposition and N mineralization between tropical legume residue components. *Agroforest Systems*. **72: 137 – 148.**

U.S.D.A. (1975). Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. Washington D.C. **p745**.

Unger P.W., A.F. Wiese and R.R. Allen (1977). Conservation tillage in the southern plains. *Journal of Soil Water Conservation,* **32:43-48**.

Unger, P.W. and A.F. Wiese (1979).Managing irrigated winter wheat residues for water storage and subsequent dryland grain sorghum production. *Soil Science Society of American Journal,* **43: 582-588**.

Uyovbisere, E.O., V.O. Chude, and A. Bationo (1997). Promising nutrient ratios in fertilizer formations for optimal performance of maize in the Nigerian Savanna: The need for a review of current recommendations. In: Badu-Apraku B, Fakorede MAB, Ouedraogo M, Quin FM (eds) Strategy for maize production in West and Central Africa. Proceedings of a regional maize workshop held at IITA-Cotonou, Republic of Benin, April 1997. **p262-272**

van Bavel, C.H.M. (1950). Mean weight diameter of soil aggregates as a statistical index of aggregation. Soil Science of America Proceedings 14: 892-898.

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

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

Weber G., F. Smith and V.M. Manyoung (1995a). System dynamics and definition of research domains for the northern Guinea Savanna of West Africa. Agriculture Ecosystem and Environment (In press)

Weber, G.K., P.S. Chindo, K.A. Elemo and S. Oikeh (1995b). Nematodes as production constraints in intensifying cereal-based cropping systems of the northern Guinea Savanna. Resource and Crop Management research Monography No. 17. 11TA, Ibadan, Nigeria.

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

Whitbread, A.M. (2004). Soil organic matter: its formation and role in soil structure, In: Lefroy, R.D.B.; Blair, G.J. and Craswell, E.T. (eds.). soil organic matter management for sustainable Agriculture, ACIAR Workshop, Lisbon, Thailand. August, 20-24. **p124-131**.

Williams, C.N. and W.Y. Chew (1980). Tree and Field Crops of the Wetter Regions of the Tropics. Intermediate Tropical agriculture series. Longman Group. Ltd., London. **p262**.

Woomer, P.L. and J.S.I. Ingram (1990). The Biology and Fertility of Soils. TSBF Report Nairobi, Kenya: TSBF.

World Resources Institute WRI. (1994). World Resources 1994-95: Washington, DC.

World Health Organisation (WHO) (2000). Malnutrition Worldwide: http://www.who.int/nut/malnutrition_worldwide.htm

Wuddivira, H.N. (1998). Variabvility of infiltration in a savanna Alfisol. Unpublished M.Sc Thesis, ABU, Zaria p3.

Yen, A.E. (2006). Studies on soil fertility. *Journal of Soil Management*, **8(6): 777-782**.

Yusuf, A.A., B.H. Janssen and V.O. Chude (2003). Substitution rate of N, P and K in a farmyard manure on an Alfisol in Northern Guinea Savanna of Nigeria. J*ournal of Agriculture, Environment and International Development,* **97 (1/2): 93-105**.

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

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

Appendices

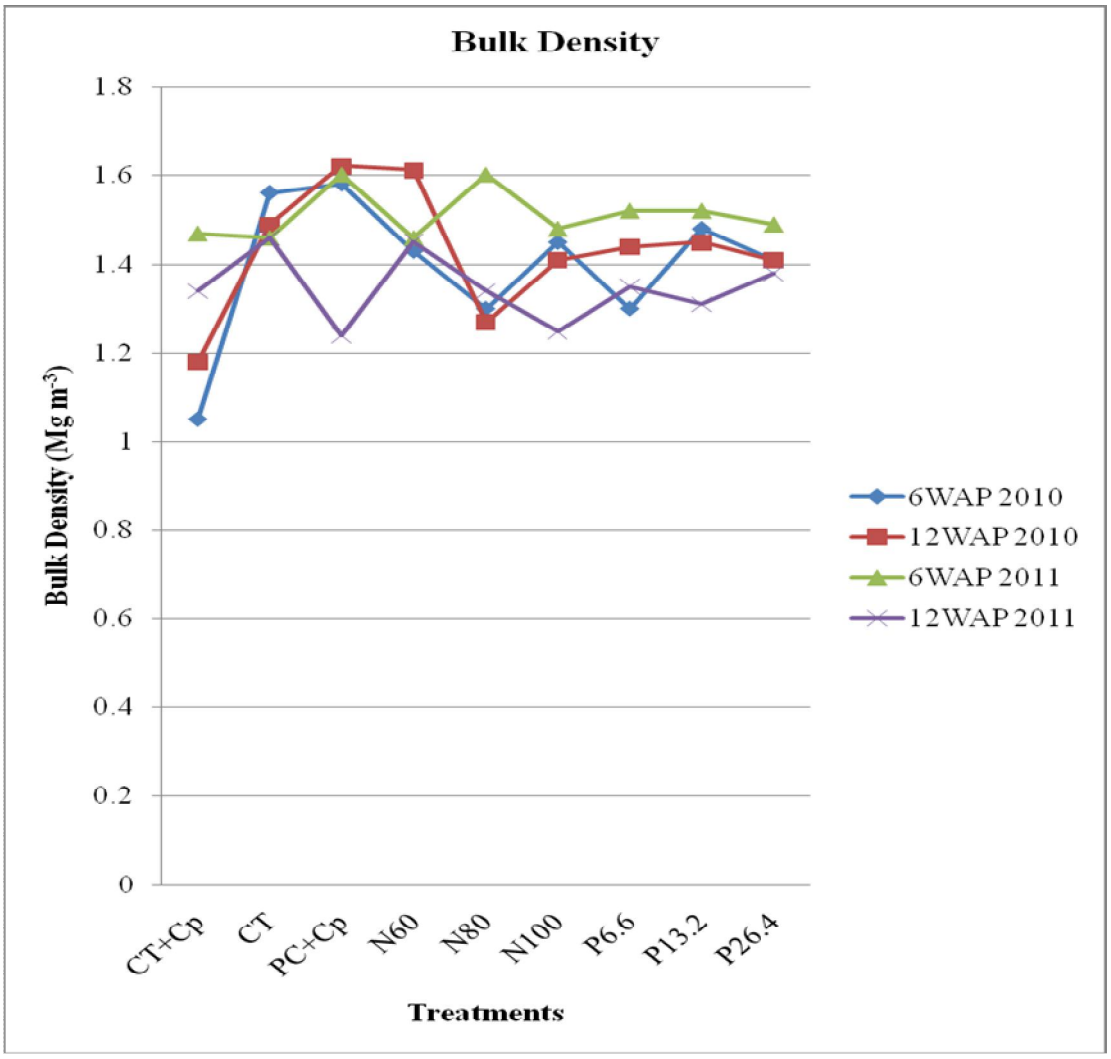


Fig. 3: Assessing Soil Bulk Density

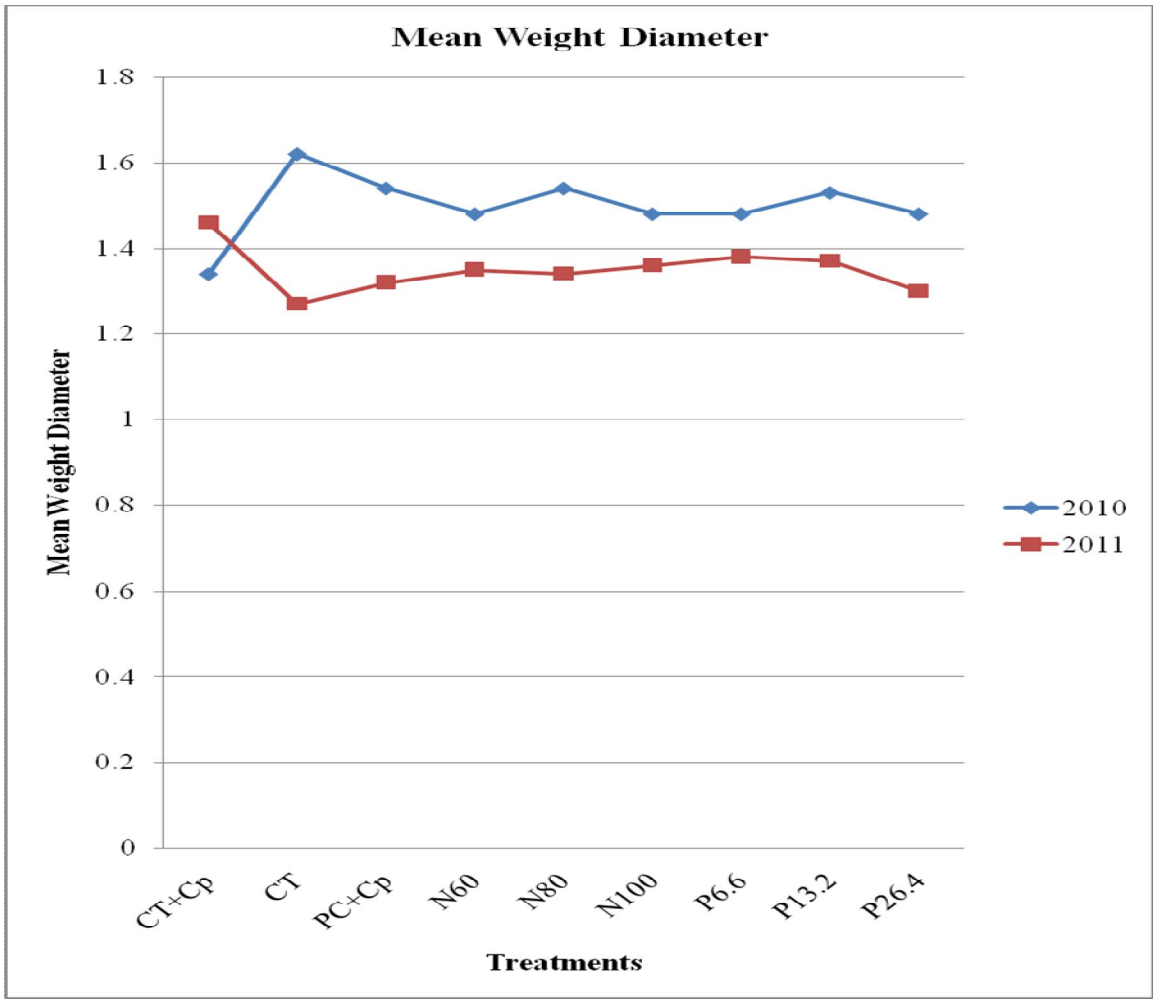
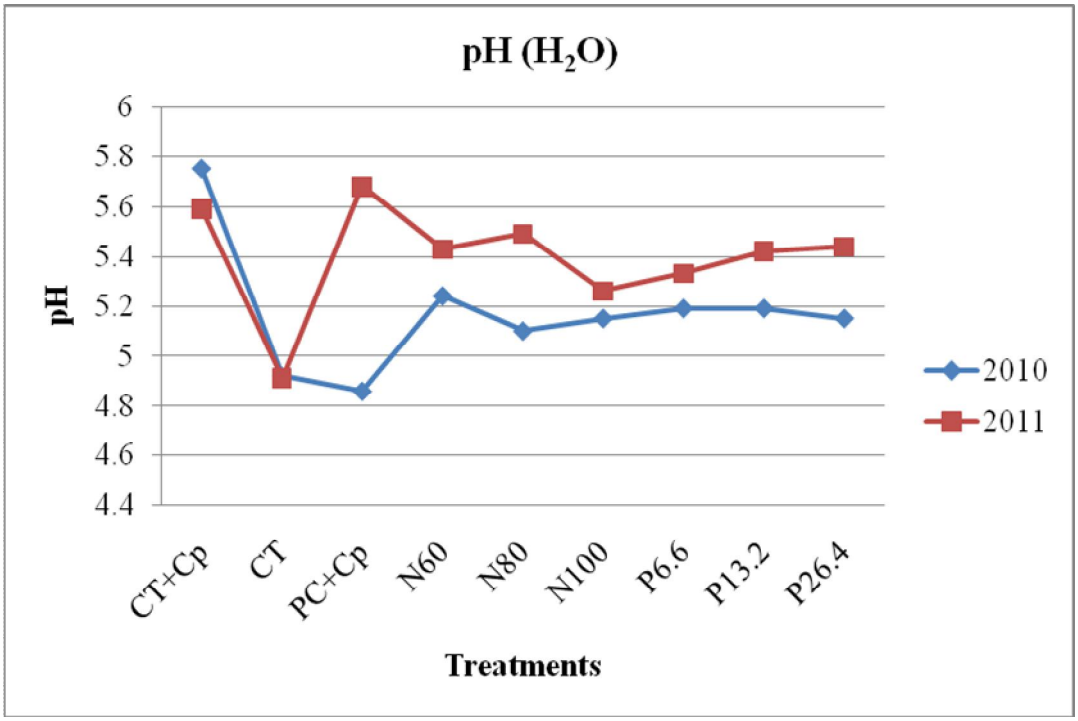


Fig. 4: Assessing Soil Mean Weight Diameter



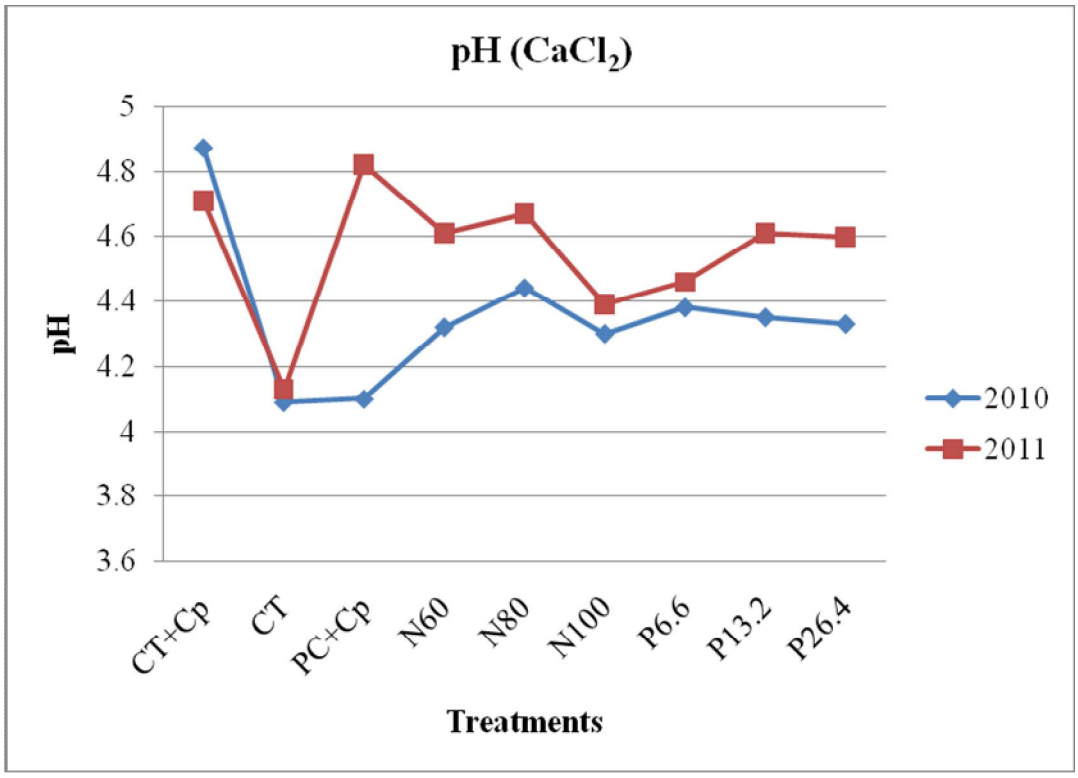
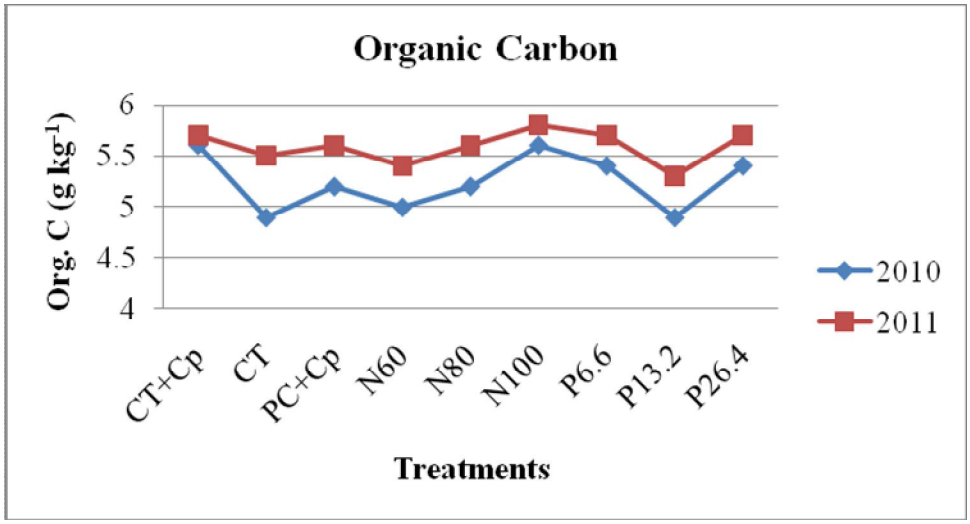
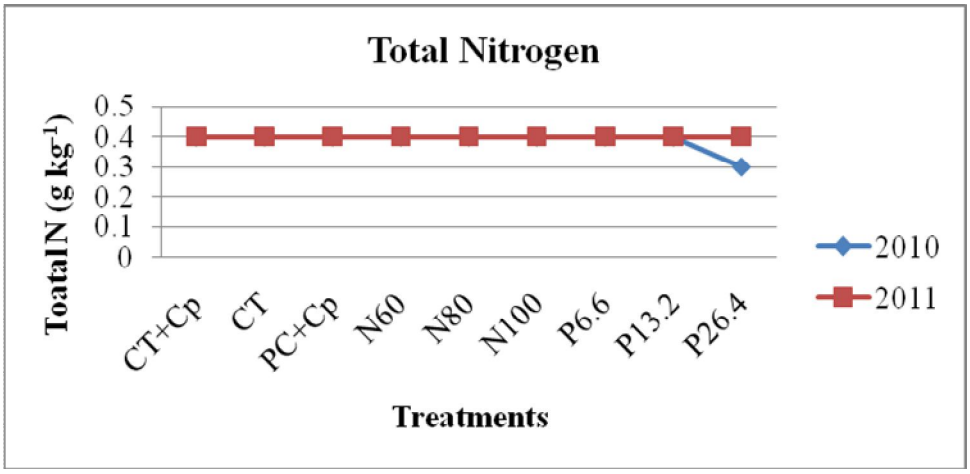


Fig. 5 and 6: Assessing Soil pH





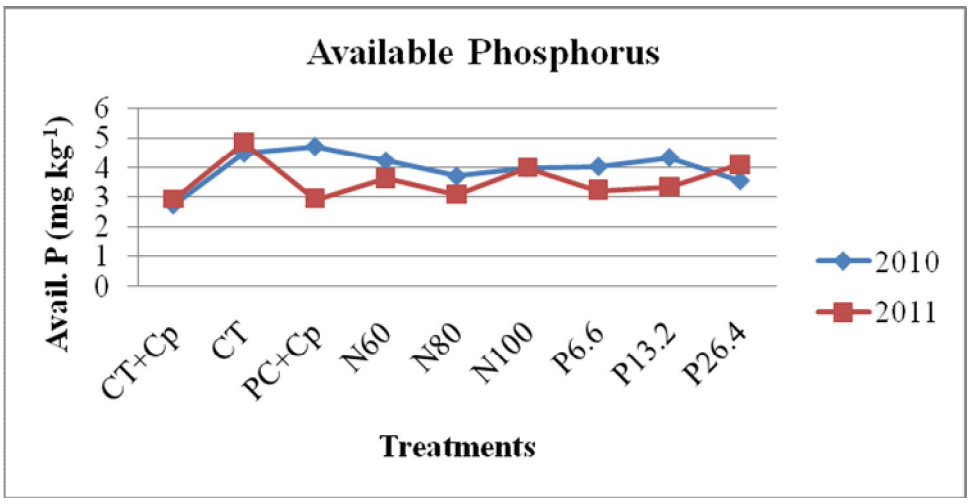


Fig. 7, 8 and 9: Assessing Soil Organic Carbon, Total Nitrogen and Available Phosphorus

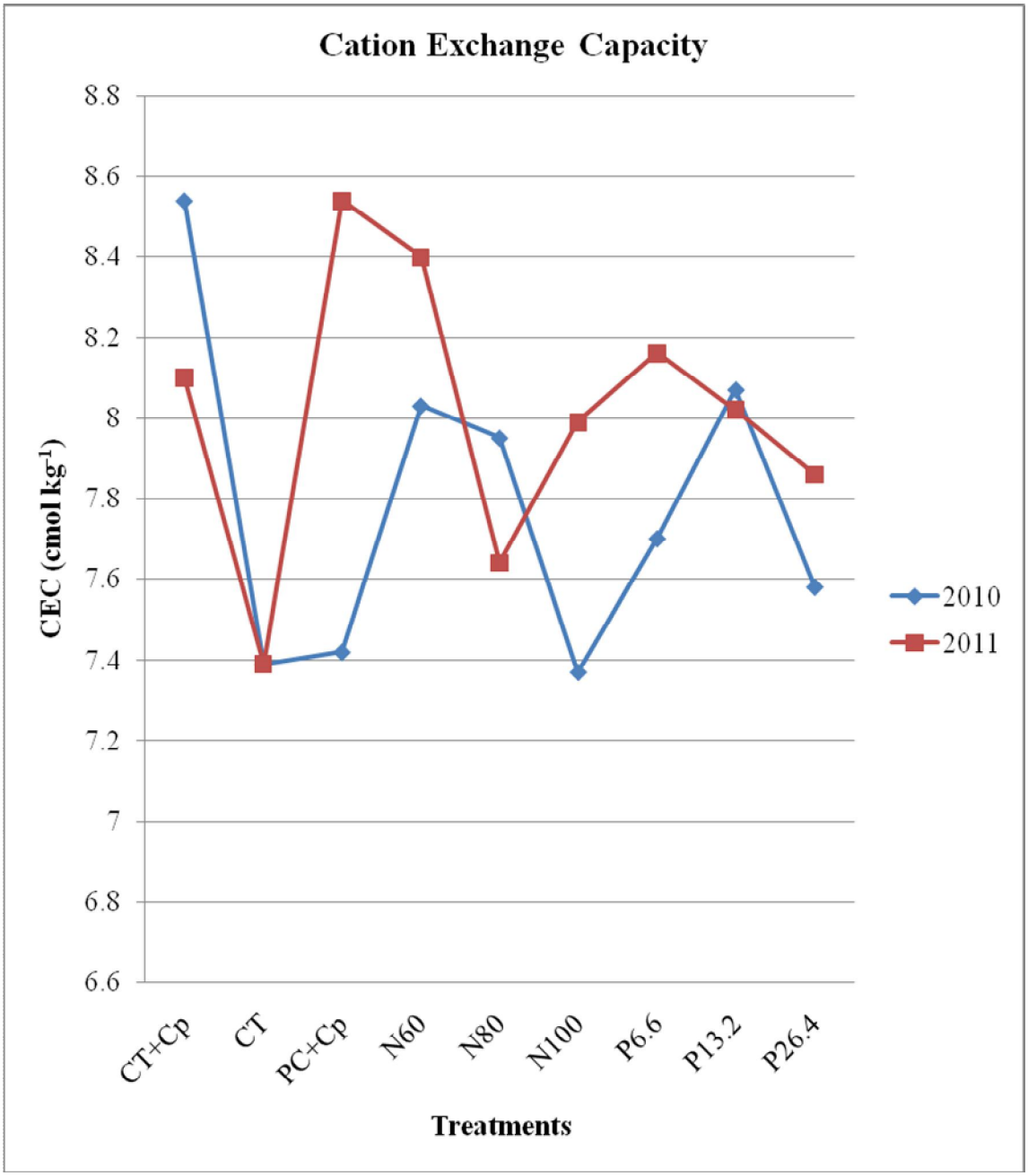


Fig. 10: Assessing Soil Cation Exchange Capacity (CEC)

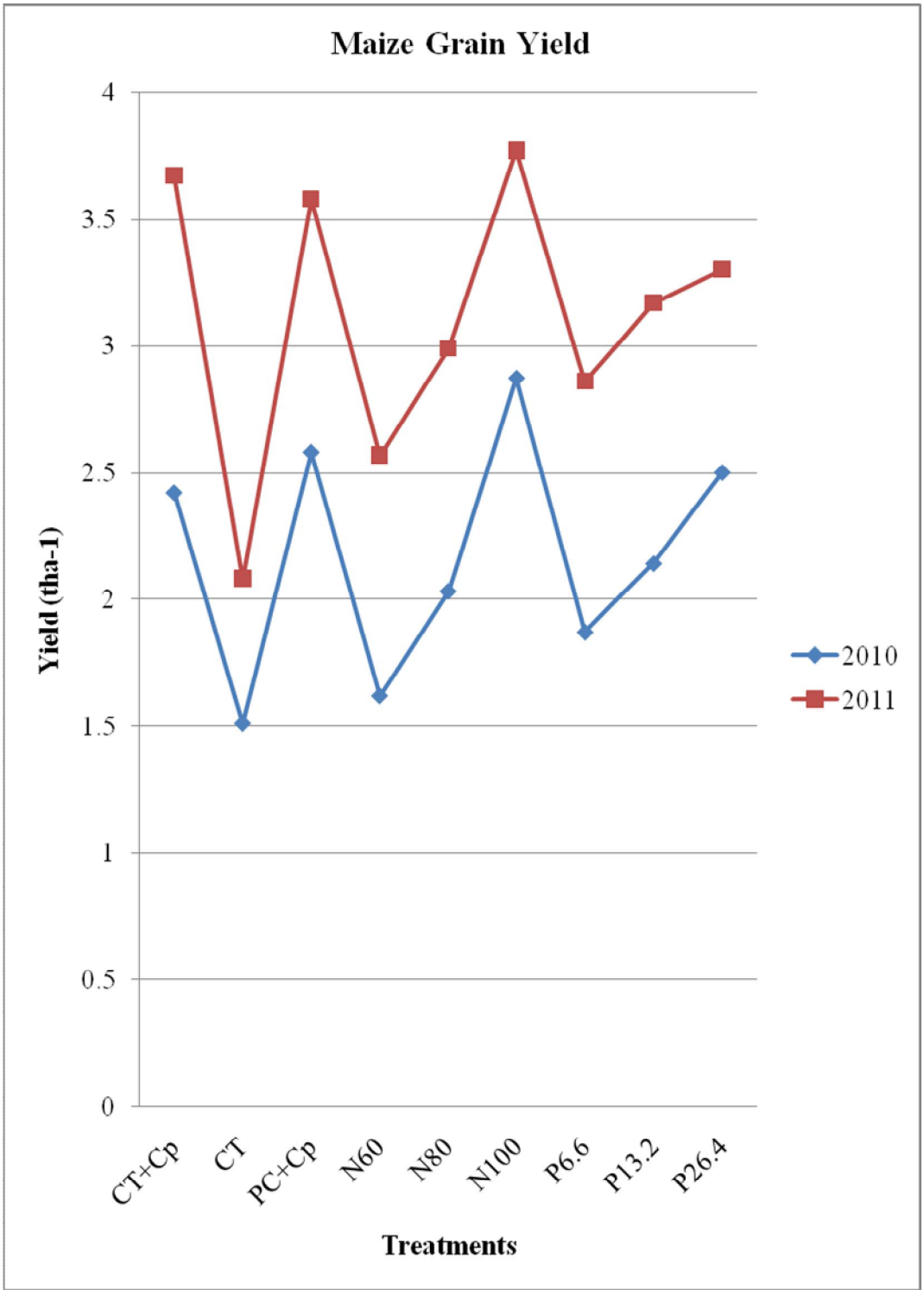


Fig. 11: Assessing Maize Grain Yield