EFFECT OF TILLAGE, SORGHUM/*DESMODIUM* INTERCROP AND FERTILIZER RATES ON SOIL QUALITY IN THE NORTHERN GUINEA SAVANNA

BY

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OCTOBER, 2014

DECLARATION

I declare that the work in this thesis entitled ‘’Effect of Tillage, Sorghum/*Desmodium* intercrop and Fertilizer Rates on Soil Quality in the Northern Guinea Savanna’’ has been carried out by me in the Department of Soil Science. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of the thesis was previously presented for another degree or diploma in this or any other university.

______________________	______________________	______________________
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CERTIFICATION

This thesis entitled ‘’EFFECT OF TILLAGE, SORGHUM/*DESMODIUM* INTERCROP AND FERTILIZER RATES ON SOIL QUALITY IN THE NORTHERN GUINEA SAVANNA’’ by Majiyebo Joshua TSEJA, meets the regulations governing the award of the degree of Masters in soil science of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work to God the Father, God the Son, God the Holy Spirit for His Mighty Hand at every stage of this Programme. To you alone be all the Glory.

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ABSTRACT

Soils of the Northern Guinea Savanna of Nigeria are continuously and intensively cultivated resulting in soil quality degradation, accelerated soil erosion and soil nutrient depletion. This study on effect of tillage, sorghum/*Desmodium* intercrop and fertilizer rates on soil quality was conducted in order to investigate the extent to which it can alleviate the afore-mentioned problems in the zone. The study involved a forage legume (*Desmodium uncinatum*) subjected to different levels of N fertilizer rates (30kgN ha^{-1}, 40kgN ha$^{-1,}$ 50kgN ha^{-1} and 60kgN ha^{-1}) and P fertilizer rates of (6.6kgP ha^{-1}, 13.2kgP ha^{-1} and 26.4kgP ha^{-1}), intercropped with sorghum (SAMSORG 14) and planted under different tillage systems viz; (i) conservation tillage system which includes, sorghum/*Desmodium* incorporated (SDIC), sorghum/*Desmodium* on old ridge (SDOR) (ii) Zero tillage with sorghum/*Desmodium* under no tillage (SDNT) and (iii) conventional tillage with sorghum mono-cropped. Data obtained were evaluated on Randomized Complete Block Design for soil chemical properties (organic carbon/organic matter, available phosphorus, total nitrogen, soil pH, CEC, and C/N ratio). Crop phrenology (plant height, stover and sorghum grain yield were also measured. Results showed that one year *Desmodium uncinatum* planted fallow added significant amount of organic carbon (5.3g kg^{-1}), CEC (6.7cmol kg^{-1}), available phosphorus (8.5mg kg^{-1}) and total nitrogen (1.2g kg^{-1}) at the surface soils when compared with their value at the beginning of the Trial. In the second cropping season, conservation tillage systems (SDIC and SDOR) and Zero tillage (SDNT) proved to be significantly better land management practices than conventional tillage without *Desmodium* (SC). Sorghum/*Desmodium* under no tillage (SDNT) sequestered significantly ($P<0.05$) higher organic carbon (6.9gkg^{-1}), followed by SDIC (5.8g kg^{-1}), SDOR (4.9g kg^{-1}) and least in SC (3.6g kg^{-1}). Total nitrogen content of the soils significantly improved under SDIC (1.7g kg^{-1}), followed by SDOR (1.6g kg^{-1}), SC (1.5g kg^{-1}) and SDNT (1.3g kg^{-1}) that were significantly different between treatments. Sorghum/*Desmodium* incorporeted (SDIC) resulted in significantly ($P<0.05$) higher (1.48t ha^{-1}) sorghum grain yield followed by SDNT (1.32t ha^{-1}) that was significantly higher than SDOR (1.20t ha^{-1}) least in SC (1.17t ha^{-1}). P rate of 26.4kgP ha^{-1} resulted in the highest sorghum grain and stover while 50kgN ha^{-1} resulted in higher sorghum grain and significantly higher stover yield. Therefore, conservation tillage; particularly SDIC and Zero tillage with *Desmodium uncinatum* (SDNT) improved soil quality condition and were more superior to other land management practices in enhancing sorghum grain yield.

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CHAPTER ONE

INTRODUCTION

Influence of soil quality on crop production and the need to sustain soil quality are crucial to long term sustainability of life in soils. Soil quality is defined as the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health (Doran and Parkin, 1994). The concept of soil quality refers to more than just vigor of soil biota. It also considers chemical, physical and biological, as well as ecological properties of soils and the disturbance and ameliorative responses by land managers (Sanginga and Woomer, 2009).

Soil quality assessment is vital for proper maintenance and management of natural resources for sustainable and continuous crop production. Hence, the need to adopt good management and land use practices as well as appropriate soil protection strategy and policy. Protection of soil quality under intensive land use and fast economic development is a major challenge for sustainable resource use in the developing world such as Nigeria (Doran and Parkin, 1996). Therefore the basic assessment of soil quality is necessary to evaluate the degradation status and changing trends following different land use and small holder management interventions (Lal and Stewart, 1995). Development of such a strategy and policy require a careful knowledge of the soil quality status, extent and impact of soil degradation processes and land use management strategy in practice. Soil tillage is among the important practices affecting soil quality and crop yield. It contributes up to 20% of all crop production factors (Khurshid *et al.*, 2006).

Tillage method affects sustainable use of soil resources through its influence on soil quality (Hammel, 1989). Tillage systems; particularly conventional tillage system, adversely affect soil quality by damaging soil structure, decreasing soil moisture content, increasing soil bulk density and root penetration resistance (Rashidi and Keshavarzpour, 2007). Derpsch *et al.* (2009) reported that continuous cultivation under conventional or intensive tillage leaves soil bare and unprotected, thereby promoting soil structure deterioration and leading to excessive high soil temperature. However, No-tillage system improves the soil's moisture retention, aeration, infiltration and reduces run off and evaporation (Duiker and Myers, 2005). Also, annual disturbance and pulverization caused by conventional tillage produce a finer and loose soil structure as compared to conservation and no-tillage method which leaves the soil intact (Rashidi and Keshavarzpour, 2007).

Soils in the Northern Guinea Savanna of Nigeria are continuously and intensively cultivated, resulting in accelerated soil erosion, soil nutrient depletion and soil degradation (Bationo *et al.,* 2003). The soil supports production of cereal crops, mainly sorghum, maize, millet etc. and out of these crops sorghum is one of the most cultivated in the zone.

Sorghum is a major staple cereal crop grown mainly for food, fodder and production of alcoholic beverages (Kutama *et al.,* 2010). It is ranked first both in terms of production and total land area put to cultivation of the different staple cereal crops grown in Northern Nigeria (Purseglove, 1972; FAO, 2005; Daniel and Maria, 2009; Ngugi *et al.,* 2002). In 2004, Nigeria was the largest producer of sorghum in Africa and the third most important sorghum producer in the world after United States and India (FAO, 2005; Wikipedia 2008). According to Ofor *et al.* (2009), sorghum and maize are high-nutrient demanding crops compared with other cereals. These crops require both the major nutrients (N, P and K) and the secondary nutrients (Zn, S, Mg, Ca, B, Fe, Cl, Cu etc.) in adequate amount to ensure good root establishment, vigorous and healthy growth, and increased yield.

However, in Guinea Savanna zone of Nigeria, intensive cropping of this major staple cereal crop and frequent removal of crop residues year-in year-out have adversely affected soil quality and led to nitrogen and phosphorous deficiency in the soils. In view of the nutrient deficient status of the soil, *Desmodium,* a forage legume, integrated into sorghum cropping system was evaluated in this study. *Desmodiun uncinatum* is a forage legume capable of increasing the activities of beneficial soil organisms and improving the quality of soils by "fixing" nitrogen and through its incorporation as a residue into the soil. Khan *et al.* (2008) reported that *Desmodium* has proven to have beneficial effect on soil fertility, soil erosion control and soil moisture conservation through the returns of crop residues to soil, instead of feeding them to livestock, without necessarily adding inorganic fertilizer and pesticide.

The aim of this study therefore was to determine the contribution of *Desmodium uncinatum* under conservation tillage practices to the yield of sorghum. The study also measured changes in soil quality following sorghum-*Desmodium* intercropping in two-year cropping seasons in the Northern Guinea Savanna of Nigeria.

1.1 Justification of the Study

In Africa, three-quarters of farmland is severely degraded (Eswaran, 1997; Stocking, 2003). As a result, Africa (Nigeria inclusive) cannot produce enough food to keep pace with its food needs. Also, Africa's per capita food production is declining (Lal, 1997; Lal and Stewart, 1995) largely due to poor soil quality. Declining soil productivity due to poor soil quality has been a major limiting factor to food production in Nigeria and in the Guinea Savanna belt in particular (Sanginga *et al.,* 2001; Yusuf *et al.,* 2003). There is also the growing quest to protect soil quality under intensive land use and to adopt good management and land use practices. More so, inorganic fertilizer sources and chemicals are becoming increasingly unavailable to small scale famers due to poor economic policies and poor standard of living of the farmer. Kim *et al.* (1997) showed that farmers in the Northern Guinea Savanna of Nigeria apply low N-rates of 20 to 50KgNha^{-1} for sorghum which is too low to improve crop productivity. Hence, other fertility enhancement sources are needed to facilitate sustainable crop production. *Desmodium uncinatum,* a forage legume that has proven to have beneficial effect on soil fertility, soil erosion control and soil moisture conservation through the returns of crop residues and “fixing” nitrogen into the soil, without necessarily adding inorganic fertilizer (Khan *et al.*, 2008) was intercropped with sorghum in this study and evaluated. Therefore, in an effort to mitigate land degradation and soil nutrient depletion problems in the Northern Guinea Savanna Alfisols, the contributions of *Desmodium uncinatum* under conventional and conservation tillage practices in improving soil quality and yield of sorghum in the zone were investigated.

1.2 Objectives of the Study

The specific objectives of this study are therefore to determine;

1. Changes in soil quality following two year sorghum/*Desmodium uncinatum* intercrop, combined with different rates of nitrogen and phosphorus application under various tillage practices.
2. The effects of fertilizer (N & P) application on sorghum grain and stover yield under various tillage practices.
3. The effects of sorghum intercrop with *Desmodium uncinatum* on growth performance and yield of sorghum.

CHAPTER TWO

LITERATURE REVIEW

2.1 Concept of Soil Quality

Concept of soil quality emerged in the early 1990s (Doran and Safety, 1997; Wienhold *et al.*, 2004) and its first official application was approved by Soil Science Society of America AdHoc committee on soil quality and discussed by Karlen *et al.* (1997).

However, people have different ideas of what a quality or healthy soil is. For example;

1. For people active in production agriculture, it may mean highly productive land, sustaining or enhancing productivity, maximizing profits or maintaining the soil resource for future generations.
2. For consumers, it may mean plentiful, healthful and inexpensive food for present and future generations
3. For naturalist, it may mean soil in harmony with the landscape and its surroundings.
4. For the environmentalist, it may mean soil functioning at its potential in an ecosystem with respect to maintenance or enhancement of biodiversity, water quality, nutrient cycling and biomass production.

Furthermore, soil quality has been defined in different ways by different authors and/or researchers. According to United State Department of Agriculture (USDA) and National Remote Sensing Center (NRSC), soil quality refers to soil health. It is how well soil does over what we want it to do. More specifically, soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation. Soil quality is also defined as the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health (Doran and Parkin, 1994). Soil health is defined as the continued capacity of soil to function as a vital living system, by recognizing that it contains biological elements that are key to ecosystem function within land-use boundaries (Doran and Zeiss, 2000; Karlen *et al.,* 2001). Soil quality includes an inherent and a dynamic component (Carter, 2002). The former is an expression of soil forming factors, documented by soil surveys as expressed by land capability classification. Dynamic soil quality, however, refers to the condition of soil that is changeable in a short period of time largely due to human impact and management (Carter, 2002). Soil quality concept encompasses the chemical, physical and biological soil characteristics needed to support healthy plant growth, maintain environmental quality, and promote human and other animal health (Doran *et al.,* 1994). With farmer and lay audiences, the term “soil health” is often preferred when referring to this dynamic soil quality, concept as it suggests a holistic approach to soil management (Idowu *et al.,* 2008). Soil quality is therefore used interchangeably with soil health.

These functions are able to sustain biological productivity of soil, maintain the quality of surrounding air and water environments, as well as promote plant, animal and human health (Doran and Parkin, 1996). Although, it is important to distinguish that soil quality is related to soil function (Karlen *et al.,* 2003; Letey *et al.,* 2003), soil health presents the soil as a finite non-reversible and dynamic living resource (Doran and Zeiss, 2000).

2.1.1 Soil Quality Degradation and the Need for Standards

Declining soil quality is emerging as an environmental and economic issue of increasing global concern; as degraded soils are becoming more prevalent due to intensive use and poor management, often the result of over-population (Eswaran *et al.,* 2005). Pressing problems such as soil erosion, compaction, acidification, organic matter losses, nutrient losses and desertification reduce agricultural production capacity. Soil quality decline severely impacts the environment and agricultural viability, and thus ecosystems and the population's health, food security and livelihoods.

Tests to monitor air and water quality have been standardized and widely adopted internationally (Riley, 2001). However, though an estimated 65% of land area worldwide is degraded (FAO, 2005), no standardized soil quality tests exist currently, especially for use in the tropics (Winder, 2003). The World Soils Agenda developed by the International Union of Soil Science lists as the first two agenda items (1) assessment of status and trends of soil degradation at the global scale and (2) definition of impact indicators and tools for monitoring and evaluation (Hurni *et al.*,2006). There is clearly a need for international standards to measure soil quality. These could be useful for agricultural research and extension agencies, non-governmental organizations, governments and farmers to better understand, implement and monitor sustainable soil management practices.

2.1.2 Assessment of Soil Quality

Understanding soil quality means assessing and managing soil so that it functions optimally now and is not degraded for future use. By monitoring changes in soil quality, a land manager can determine if a set of practices is sustainable.

Soil quality assessment is a tool focused on dynamic soil properties and processes that are useful for assessing the sustainability of soil management practices (Anikwe, 2006). Soil quality is the foundation of sustainable crop production. While it is true that soil testing serves the purpose of monitoring soil, testing focuses mainly on the ability of soil to provide plant nutrients. It does not serve the purpose of measuring overall soil quality. Soil quality assessment helps to determine the status of soil functions and environment risks associated with production practices. To assess the status of a given soil, one needs to be aware of standard values for indicators of optimal soil quality as determined by available data.

Soil quality cannot be measured directly. But soil properties (also referred here as soil properties) that are sensitive to changes in management can be used as indicators (Andrew *et al.,* 2004). According to Kinyangi (2007), soil health indicators are needed to help smallholder farmers understand the chain of cause and effect that link farm decisions to ultimate productivity and health of plants and animals. Also, the soil health approach is better applied when specific goals are defined for a desired outcome from a set of decisions. Therefore we can think of soil quality as an evaluation process which consists of a series of actions;-

a. selection of soil quality indicators
b. determination of a minimum data set (MDS)
c. development of an interpretation scheme of indices
d. Assessment and validation of data generated, (Odunze *et al.*, 2012 and 2013)

2.1.3 Soil Quality Indicators

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

The following are some criteria to be considered when selecting soil health and soil quality indicators. Appropriate indicators should be;

a. easy to assess
b. able to measure changes in soil function both at plot and landscape scales
c. assessed in time to make management decisions
d. accessible to many farmers
e. sensitive to variations in agro-ecological zone
f. representative of physical, biological or chemical properties of soil
g. assessed by both qualitative and/or quantitative approaches (Kinyangi, 2007).

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

2.1.3.1 Biological Indicators

Identification of biological indicators of soil quality is reported as critically important by several authors (Doran and Parkin, 1994; Winder, 2003) because soil quality is strongly influenced by microbiologically mediated processes (nutrient cycling, nutrient capacity, aggregate stability). Biological indicators of soil quality that are commonly measured include soil organic matter; respiration, microbial biomass (total bacteria and fungi) and mineralizable nitrogen (Kinyangi, 2007). However, soil organic matter is selected as biological indicators under this study.

2.1.3.2 Chemical Indicators

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

2.1.3.3 Physical Indicators

Soil physical properties are estimated from the soil’s texture, bulk density (a measure of compaction), porosity, water-holding capacity (Hillel, 1982). According to (Kinyangi, 2007), the presence of hard pans usually presents barriers to rooting depth. These properties are all improved through addition of organic matter to soils. Therefore, the suitability of soil for sustaining plant growth and biological activity is a function of its physical properties (porosity, water-holding capacity, structure and tilt). (Anikwe, 2006) reported that, a decline of a soil physical quality has serious consequences for the chemical and biological condition of soil. Thus, for the first year of this experiment soil bulk density would be used as physical indicator to evaluate quality of soil in the study site.

2.1.4 Minimum Data Set: Concept and Application.

A minimum data set (MDS) was proposed to measure soil quality and its changes due to management practices through selection of key indicators such as soil texture, organic carbon, pH, nutrient status, bulk density, electrical conductivity and rooting depth (Larson *et al.,* 1994). Collecting a minimum data set helps to identify locally relevant soil indicators and to evaluate selected indicators and soil and plant properties (Arshad and Martin, 2002; Odunze *et al.,* 2012, 2013).

According to (Kinyangi, 2007), minimum data set is a minimum set of indicators required to obtain a comprehensive understanding of soil quality/health status. They are therefore important tools for screening the condition, quality and health of soil (Larson *et al.,* 1994; Doran and Parkin, 1994), For smallholder farmers these tools need to be simple measures of soil health and soil quality such as consistency, color and workability (Murage *et al.,* 2000; Mairura *et al.,* 2007). For extension and policy personnel, they provide basic information needed to arrive at management decisions (Barrios *et al.,* 2006) and variations in order to conduct meaningful assessment of soil status, often expressed as an index of soil quality (Kang *et al.,* 2005).

2.1.5 On-farm soil health assessment

On-farm assessment of soil quality and health is recommended to assist farmers evaluate the effects of their management decisions on soil productivity (Andrews and Carroll, 2001). Also, this approach permits interaction between researchers, extension and policy personnel when providing interpretation to link on-farm knowledge to soil health information. The main challenge is to develop soil quality and soil health standards to assess changes which are practical and useful to farmers (Barrios and Trejo, 2003). For instance, linking soil health measurements with farmer perceptions of soil quality can bridge the gap in interpretation of complex data sets. In Africa several studies (Murage *et al.*, 2000; Barrios *et al.*, 2006) show that by using local knowledge, smallholder farmers are able to accurately predict soil quality differences of productive and non-productive fields.

2.2 ***Desmodium uncinatum***

Desmodium uncinatum also known as Silver leaf is a perennial forage legume with cylindrical or angular stems densely covered with short, hooked hairs which make the stem adhere to hands, clothing e. t. c. The leaflets are dark green on the upper side with an area of white shiny surface near the central vein, often surrounded by a dark shiny area. Lower side of the leave is lighter green and uniform in colour and both sides hairy. The flowers are pinkish in colour and later become bluish.

The pods are sickle-shaped, light brown at maturity and densely covered with minute hooked hairs so that the segments adhere to clothing and coat of animal; hence making it easy to spread widely. *Desmodium uncinatum* originated from Deodora, Brazil and was later introduced to Kenya.

2.2.1 Soil and Rainfall Requirement;

Desmodium uncinatum has been shown to require annual rainfall amount of about 900m. It is adapted to a wide range of soils from sand to clay loam, though; it is not as successful on sand as *Desmodiun intortum*. It does well on soils with an open texture and not so well on compact heavy clays. It grows at pH 5.5 to 6.5 up to pH 7.0. It does not tolerate salinity (Andrew and Robins, 1969). It performs best in well-prepared cultivated seed bed.

2.2.2 Sowing Method and flowering date;

Desmodium uncinatum is usually sown by drilling, ground broadcasting, aerial seeding or sod seeding. (Whiteman and Lulhan, 1970) found that *Desmodium uncinatum* flowered in 181days when planted in October and in 132 days when planted in September in South-east Queensland Australia.

2.2.3 Economic Importance of *Desmodium;*

- It is highly palatable and nutritious to dairy cows
- It is capable of repelling insects such as stemborer, thereby reducing the cost of buying pesticide which may be harmful to the environment.
- They are also capable of reducing drastically the devastating effects of parasitic weed, such as, *Striga hemonthica* by releasing chemicals from their roots which is capable of undermining growth of the weed.

2.2.4 Impacts of *Desmodium* on Soil Quality;

Research has shown that *Desmodium* is able to increase significantly more beneficial soil organism in Cereal-*Desmodium* field. Also, *Desmodium* could act as cover crop to control soil erosion and retain soil moisture (Khan *et al.,* 2008).

Desmodium enhances quality of the soils by fixing nitrogen and through the incorporation of the fodder, increases the soil organic matter content which in turn improves the soil quality (Khan *et al.,* 2008).

2.3 LAND MANAGEMENT

2.3.1 Tillage practices

Tillage is physical, chemical or biological soil manipulation to optimize conditions for germination, seedling establishment and crop growth (Lal, 1984); Lal and Greenland, 1979), or any physical loosening of the soil carried out in a range of cultivation operations, either by hand or mechanized (Ahn and Hintze, 1990). Also soil tillage includes all mechanical measures/operation to loosen, turn or mix the soil, such as ploughing, digging, hoeing, harrowing etc (IIRR, 2005). (Boone and Cromack, 1988) saw tillage as the soil- related actions necessary for crop production. (Antapa and Angen, 1990) defined tillage as any operation or practice taken to prepare soil surface for the purpose of crop production.

Tillage practices/system can be categorized into two major systems;

1. Conservation tillage 2. Conventional tillage.

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

Conservation tillage and cover crops alter the physical and chemical properties of soil. In conservation tillage systems, bulk density is decreased and available concentrations of nitrate and phosphorus are increased. Soil manipulation can change fertility status markedly and the changes may be manifested in good or poor performance of crop (Ohiri and Ezumah, 1990). In addition, tillage operations loosen, granulate, crush or compact soil structure; changing soil properties such as bulk density, pore size distribution and the composition of the soil atmosphere that affect plant growth.

Tillage is an essential aspect of farm management and has become a standard practice in agricultural production systems. Intensive tillage practices are contributing to declining air, water and soil quality in Northern Guinea Savanna of Nigeria (Iwuafor, 1986). Reducing soil disturbance by implementing conservation tillage practices and planting forage legumes such as *Desmodium uncinatum* may improve this situation. Conservation tillage is defined as any tillage system that leaves 30% or more of the soil surface covered with crop residue after planting (Veenstra., 2006). Conservation tillage reduces dust emissions from agricultural fields by decreasing the frequency and intensity of tillage operations. Limiting soil disturbance has been shown to improve soil's tilt, and fertility, water infiltration, organic matter storage and reduce erosion (Holland, 2004). However, these benefits may be dependent upon cropping system, climate and soil type. It is therefore important to determine conservation tillage effect on Alfisols in the Northern Guinea savanna and on the yield of sorghum.

Conservation tillage is seldom practiced in Nigeria. Thus, the impact of different land management practices such as no-till, reduced tillage and conventional tillage plus cover cropping would be studied and evaluated in the Northern Guinea Savanna Alfisols of Nigeria. Conventional tillage operations consume considerable energy and increase equipment and labour needs, so there may be an economic benefit for reverting to conservation tillage.

Conservation tillage crop production practices may help reduce the environmental impacts and production costs of farming.

2.3.2 Effects of land management systems on physical properties

2.3.2.1 Soil organic matter (SOM) and land management practices

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

Frequent tillage can reduce the amount of organic matter in soil, an important aspect of its quality. Tillage results in loss of SOM primarily through three mechanisms: 1) mineralization of organic matter due to breakdown of soil aggregates and changes in temperature and moisture regimes, 2) leaching of organic carbon, and 3) accelerated rates of erosion (Lal, 2002). Even in cropping systems that return almost none of the above ground residue to soil, such as silage corn production and some biofuel systems, reducing tillage intensity can result in maintaining or increasing soil organic fraction that is most readily decomposable (Angers *et al.*, 1993). Additionally, reduced tillage has been shown to result in increased soil microbial biomass levels before measurable changes in total soil carbon occurs (Angers *et al*., 1993, Cartar, 1992, Doran, 1987).

Tillage is responsible for substantial loss of carbon from the soil. As carbon is released from soil as a result of tillage, it leaves in the form of carbon dioxide (CO_2). The deeper and more aggressive the tillage, the more CO_2 is released to the atmosphere. Soil organic matter refers to all organic material in soils, including decaying plant material, soil microbes and humified substances. Organic matter improves the biological, chemical and physical properties of soil and provides readily available nutrients for plant and microbial uptake. Properly managed soil organic matter can increase nutrient availability to plants, which may allow farmers to reduce fertilizer use (Reeves, 1997). Through interactions with minerals, organic matter can improve the physical properties of soil, including aggregate stability, aeration, water holding capacity and water infiltration. By disrupting soil aggregates, intensive tillage exposes protected organic matter to increased microbial activity, which leads to its loss as carbon dioxide. In contrast, by decreasing soil disturbance, conservation tillage systems have the potential to accumulate organic matter in some geographic regions. In other regions, conservation tillage redistributes organic matter to the soil surface while decreasing organic matter in the subsurface. Adding organic matter as a cover crop can also benefit crop growth and improve soil quality. Cover crops can be legumes such as vetches or clovers, which fix nitrogen, or non legumes such as ryegrass or sudan grass, which immobilize nitrogen prone to leaching.

Legume cover crops can add up to 89 pounds nitrogen per acre (100 kilograms nitrogen per hectare) through biological nitrogen fixation (Poudel *et al.*, 2001). Cover crops also increase organic matter by increasing the amount of biomass added to soil. The additional biomass of cover crops can be incorporated into soil as green manure in standard tillage systems or left on surface as mulch in conservation tillage systems. When left on the surface, cover crop residues effectively control weeds, reduce soil erosion and conserve soil moisture by reducing evaporation (Hartwig and Ammon, 2002; Lu *et al.*, 2000).

2.3.2.2 Bulk density and land management practices

Bulk density is a measure of soil's weight or mass per unit volume; soil with lower bulk density has more pore space and allows for more water infiltration and space for roots to grow than soil with higher bulk density. In a research conducted by Veenstra *et al.* (2006), they found that after 4 years of conservation tillage and cover cropping, soil bulk density was lowest with conservation tillage and highest with conventional tillage. Bulk density was higher in the 6- to 12-inch depth than in the surface 0 to 6 inches for all treatments.

Changes in bulk density can usually be correlated to changes in the soil organic matter. Organic matter binds soil mineral particles into structural units that improve porosity, thereby decreasing bulk density (Veenstra *et al.,* 2006).

2.3.3 Effects of land management systems on chemical properties

2.3.3.1 Soil pH and land management practices

Soil pH has a profound influence on plant growth. It affects the quantity, activity and types of micro organisms in soil which in turn influence decomposition of crop residues, manures, sludge's and other organics. It also affects other nutrient transformations and solubility, or plant availability of many plant nutrients. However, tillage practices have influence on soil pH. For instance, continuous no- tillage results in rapid decrease of soil pH with depth while conventional tillage resulted in more homogenous soil with respect to soil fertility (Ismail *et al.,* 1994; Hargrove *et al.,* 1982; Ike, 1986). Veenstra *et al.,* (2006) reported that there was no significant change in soil pH across the surface and sub surface soil. However, Tarkalson *et al.* (2006) showed that there was no difference in pH between No-till and conventional tillage at depth greater than 10cm. This is in line with the work of Odunze *et al.* (2013) and Mahlar and Harder (1984) that reported greatest acidification with No- till at depth 0-7 cm whereas for conventional tillage it occurred at 7.5-15cm depth. They however, concluded that placement of N fertilizer under tillage systems and subsequent nitrification resulted in these differences.

2.3.3.2 Soil carbon and land management practices

Total soil carbon is used to estimate soil organic matter, which is made up primarily of carbon. Soil carbon increases with decrease in tillage, however, Veenstra *et al.* (2006)

reported a great loss in total carbon in the top 12 inches of soil under conservation tillage due to change in land use. This overall decrease was attributed to change in land use.

Although, research have found increases in total carbon with decreasing tillage, but most of this research was conducted in the temperate, humid regions. Researchers in Texas United State of America (U.S.A) found that soil carbon accumulation is inversely related to mean annual temperature, and that hot dry conditions create a challenging environment for increasing soil carbon (Potter *et al.,* 1998).

According to Veenstra *et al.* (2006), the addition of cover crop residues increased soil carbon regardless of tillage practice. Cover crops, by adding more biomass to the system, increase carbon inputs to the soil. Veenstra *et al.,* (2006), noted that more carbon was found in the upper 6 inches, and there was no change in total carbon in the 6- to 12-inch depth under the conservation tillage. Carbon accumulates in the upper 6 inches in conservation tillage because crop residues are left on the surface and not tilled into the soil. Conversely, with conventional tillage, total carbon increased in both depths because the residues were incorporated and mixed into the soil.

Other studies showed that carbon increases in no-till systems in similar hot, semiarid climates after 10 years (Zibilske *et al.,* 2002; Mrabet *et al.,* 2001). Others found increases in total carbon at the surface after 10 years, but no overall carbon accumulation because of losses from lower depths (Hernanz *et al.,* 2002).

2.3.3.3 Nitrogen and land management practices

Nitrogen in soil is the most important element for plant development. It is required in large amounts and must be added to the soil to avoid a deficiency. Nitrogen is a major part of chlorophyll and the green colour of plants. It is responsible for lush, vigorous growth and the development of a dense, attractive lawn (Veenstra *et al.,* 2006). Although nitrogen is the most abundant element in our atmosphere, plants cannot use it until it is naturally processed in the soil, or added as fertilizer. Sawyer (2008) reported that if no N is applied for many years (fertilizer or manure), the soil's ability to supply plant available nitrogen becomes depleted. Sawyer (2008) also reported that apart from N – fertilization, nitrogen could also come from fixed ammonia released from clay minerals as well as mineralization caused by microbial activities on crop residues and soil organic matter.

Soil nitrogen is an important nutrient for plants and microbes; large amounts of nitrogen are needed to form amino acids, proteins and enzymes (Veenstra *et al.*, 2006). Therefore proper management of soil in terms of method of tillage adopted is very important in determining amount of N in the soil. For instance, Veentra *et al.* (2006) showed increased total nitrogen for conservation and conventional tillage. According to them the increases in total nitrogen in both conservation and conventional tillage systems were linked to increase input of organic matter associated with cover crop. Celik *et al. (*2011), observed total nitrogen to be higher only at surface 0-10cm depth under no-tillage and lowest for conventional tillage with cover cropping. However, conventional tillage was reported not to have any effect on total nitrogen at 10 -30cm depth for each of 3 years. They concluded that higher total organic carbon content caused high total N content in reduced and no- tillage plots compared to conventional tillage. Also there was no significant effect of different tillage methods on total nitrogen at 10-30cm and no difference in total nitrogen concentration between tillage methods in the first year of treatment (Mc Carty *et al.,*1998), but had significant difference after 3 years (Aon *et al.*, 2001). Heenam *et al.* (2004) also showed that No–tillage and Reduced tillage practices increased the total nitrogen content of the soil when compared to conventional tillage.

2.3.3.4 Phosphorus and land management practices

Phosphorus is an essential component of DNA and RNA, making it another important plant nutrient (Veenstra *et al.,* 2006). Conservation tillage usually improves the availability of surface phosphorus by converting it into organic phosphorus (Veenstra *et al.,* 2006). Crops take up phosphorus from below, “mining” and depositing it on the surface. In conventional tillage systems this phosphorus would be remixed into the soil profile, whereas in conservation tillage it accumulates at the surface (Robbins and Voss, 1991; Zibilske, 2002).

2.3.3.5 Grain yields and tillage practices

Research by Tarkalson *et al.* (2006) showed that no-till increased long-term average grain sorghum yields compared with conventional Tillage. Numerous studies have demonstrated increased crop yields from no- till attributed to greater soil moisture storage due to residue cover in cropping systems in arid and semiarid environments (Bordovsky *et al.,* 1998; Bonfil *et al.,* 1999; Halvorson *et al.,* 2001). Researchers have found increased crop yield after several years of conservation tillage (Hill, 1990). Some of this effect was related to increased continuity of pore space, more favourable soil water relationships, and maintenance of soil organic matter (Karlen *et al.,* 1990).

CHAPTER THREE

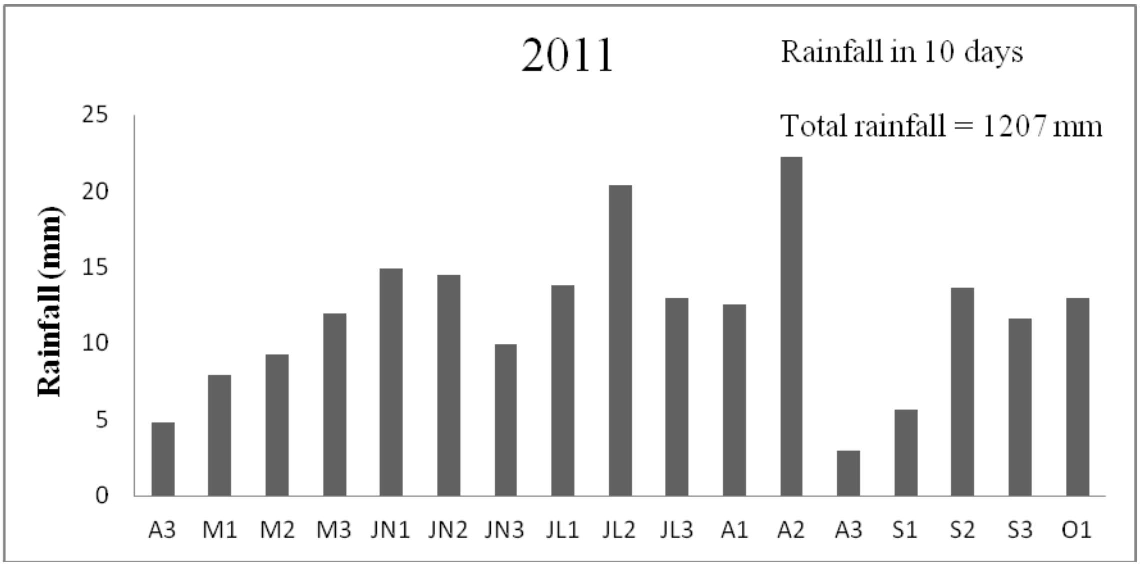
MATERIALS AND METHODS

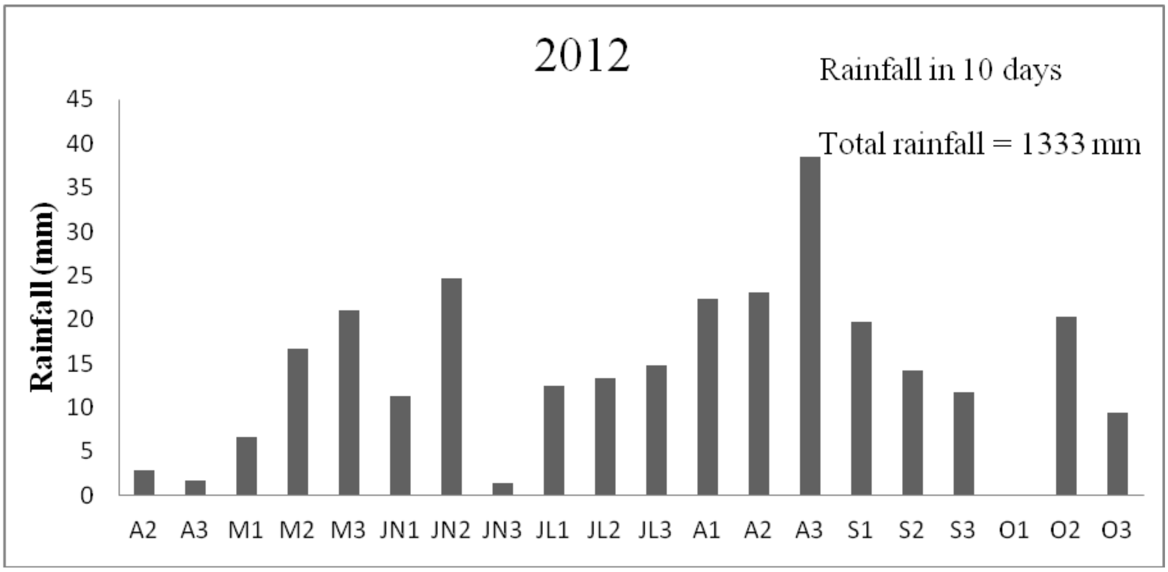
3.1 Site Description

This study was conducted at the Institute for Agricultural Research (IAR) experimental farm Samaru, Zaria. The experimental field (W6) is located between longitude 7^{o}37.497` and 7$^{o}$37.520` E and latitude 11^{o}10.751`and 11$^{o}$ 10.3765`N with an altitude of 694m above sea level in the Guinea Savanna ecology of Nigeria. Soils of the study area were classified as Typic Haplustalf according to USDA Soil Taxonomy (1999) as cited by Ogunwole, *et al.* (2000) and Acrisol in the FAO-UNESCO legend (Valette and Ibanga, 1984; Uyovbisere *et al.,* 2000). The soil is low in inherent fertility, organic matter, cation exchange capacity, and dominated by low activity clays (Jones and Wild, 1975; Odunze, 2003). The clay is predominantly kaolinitic (Gallez *et al.,* 1976; Ojanuga, 1979; Agbenin, 1996), typically high in iron (Fe) and aluminium (Al) oxides (Moberg and Esu, 1991) and the soil is of major agricultural importance in the Zone (Agbenin, 1996).

3.2 Climate Condition

The northern Guinea savanna has a unimodal rainfall pattern with an annual precipitation of 900-1300mm and a growing period of 150-180 days with effect from June to October. The derived savanna has a bimodal rainfall pattern with an annual precipitation of 1000 to 1800mm, allowing 210 – 270 days of crop growth (from April to November). The southern Guinea savanna is in the transition area between the unimodal and bimodal pattern with total annual precipitation of 1100 to 1500mm with a growing period of 180 to 210 days (Tian *et al*., 1995)

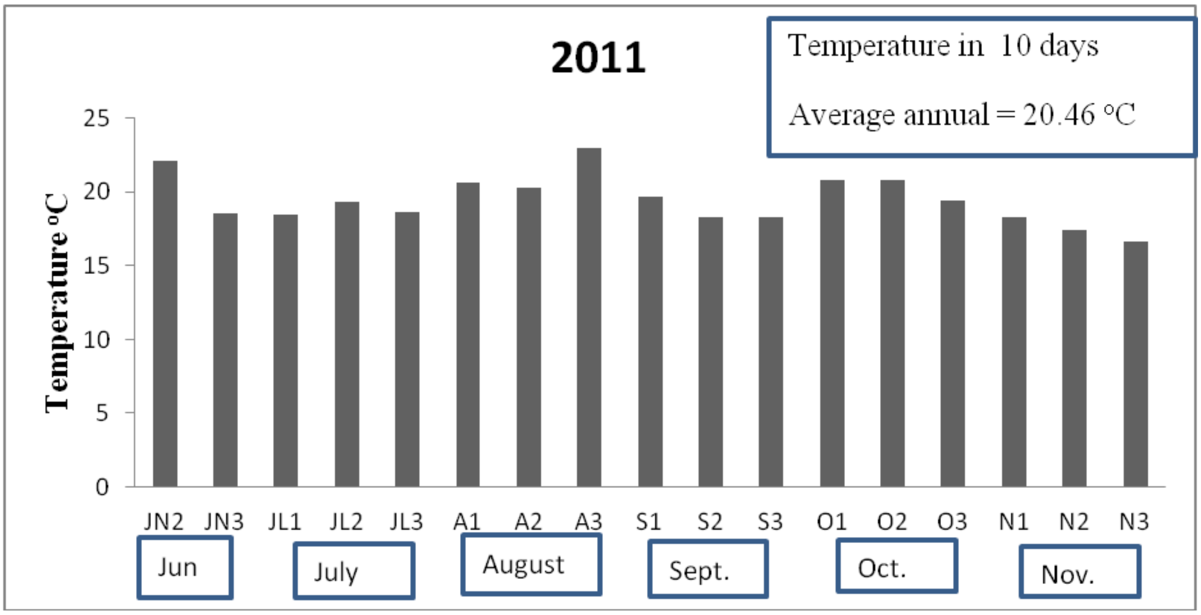


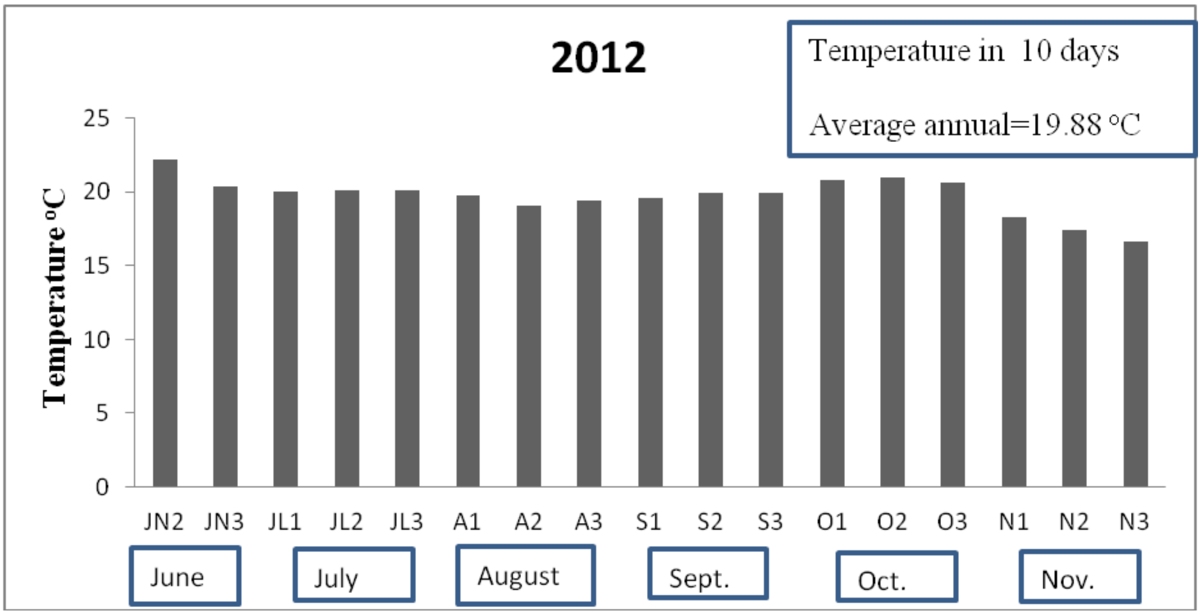


Source: Meteorological Unit, Institute for Agriculture Research Ahmadu Bello University, Zaria

Fig 3.1. Rainfall monthly dekadal (10days) distribution patterns in Samaru (Study site) during 2011 and 2012 cropping seasons.

From left to right; A3= 3rd 10days rainfall in April, **M1**=1st 10days rainfall in May, **M2**= 2nd 10days rainfall in May, **M3**= 3rd 10days rainfall in May**, JN1**= 1st 10days rainfall in June, **JN2**= 3rd 10days rainfall in June, **JN3**= 3rd 10days rainfall in June, **JL1**=1st 10days rainfall in July, **JL2**= 2nd 10days rainfall in July, **JL3**= 3rd 10days rainfall in July, **A1**= 1st 10days rainfall in August, **A2**= 2nd 10days rainfall in August, **A3**=3rd 10days rainfall in August, **S1**= 1st 10days rainfall in September, **S2**= 2nd 10days rainfall in September, **S3**= 3rd 10days rainfall in September **O1**= 1st 10days rainfall in October.





Source: Meteorological Unit, Institute for Agriculture Research Ahmadu Bello University, Zaria.

Fig 3.2 Monthly dekadal (10days) temperature distribution patterns in Samaru (Study site) during 2011 and 2012 cropping seasons.

From left to right; JN2= 2nd 10days temperature in June, **JN3**=3rd 10days temperature in June, **JL1**= 1st 10days temperature in July, **JL3**= 3rd 10days temperature in July**, A1**= 1st 10days temperature in August, **A2**= 2nd 10days temperature in August, **A3**= 3rd 10days temperature in August, **S1**=1st 10days temperature in September, **S2**= 2nd days temperature in September, **S3**= 3rd 10days temperature in September, **O1**= 1st 10days temperature in October, **O2**= 2nd 10days temperature in October, **O3**=3rd 10days temperature in October, **N1**= 1st 10days temperature in November, **N2**= 2nd 10days temperature in November, **N3**= 3rd 10days temperature in November.

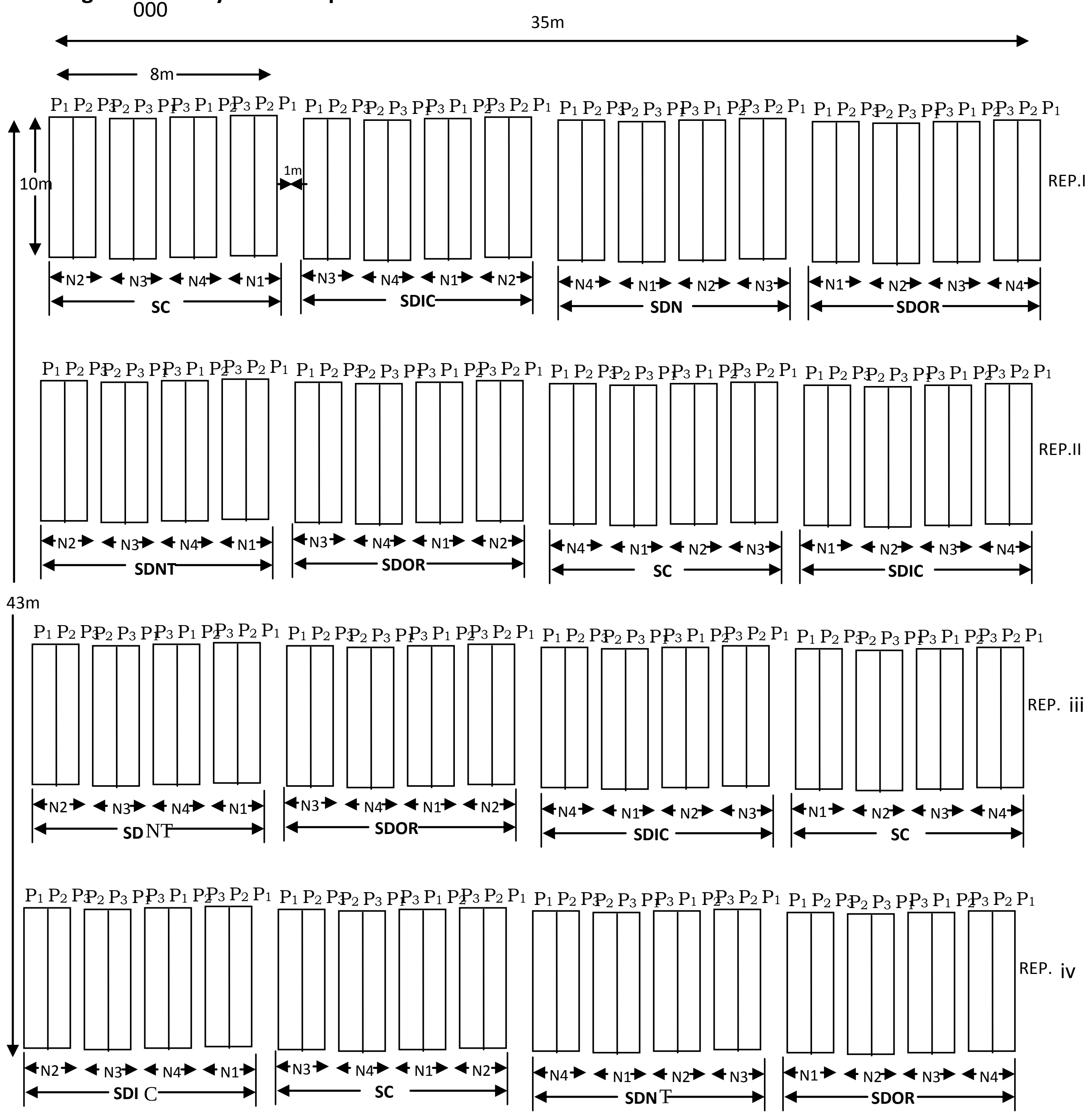
3.3 Field lay-out and Experimental Design:

In the first year (2011), land was cleared and thereafter ploughed, harrowed, and ridged by disc harrow and disc ridger respectively and planted with *Desmodium uncinatum* cover for a period of one year; hence, referred to as conservation tillage plus *Desmodium uncinatum* (CT+D). However, two portions of the field; hereafter referred to as sorghum/*Desmodium* under No-till (SDNT), were left un-tilled but planted with Desmodium *uncinatum* while the other portion of the field hereafter refer to as sorghum monocrop under conventional tillage (SC), was ploughed but left bare (without *Desmodium uncinatum* and sorghum). *Desmodium uncinatum* was planted on ridge slopes of every ridge in the plot of (CT+D).

In the second year (2012), the experiment was laid out using a split plot Randomized Complete Block Design (RCBD). The main plot, Conservation tillage plus *Desmodium* (CT+D) including the bare plots of the field were divided into four sub plots sole sorghum alone under conventional tillage, sorghum/*Desmodium* incorporated, sorghum/*Desmodium* on old ridge (SC, SDIC, SDOR and SDNT) measuring 10m by 32m and replicated four times and each sub plot measured 10m by 8m with twelve ridges.

Ridges of sub plot SC and SDIC were remoulded at the beginning of 2012 using oxen while SDNT remained unploughed and ridges of SDOR were left unploughed in the second year. Thereafter Sorghum (Samsorg 14) was planted on ridge peaks of SC, SDIC, SDNT and SDOR.

Fig 3.3 Field Lay-Out of Experimental Plots



Keys

P- Phosphorous rates P1=6.6kg, P2=13.2kg, P3=26.2kg

N- Nitrogen rates N1=30kg, N2=40kg, N3=50kg, N4=60kg

SC – Sorghum + Conventional Tillage

SDIC- sorghum + *Desmodium* incorporated

SDNT – Sorghum + No- Tillage

SDOR – Sorghum + *Desmodium* on Old Ridge

Area of Sub Plot = 10m x 8 = 80m^2 (0.008ha)

Area of Main plot = 10m x 35m = 350m^2 (0.035ha)

Area of Entire land = 43m x 35m = 1505m^2(0.1505ha)

3.4 Experimental Treatments:

The experimental treatments include the following;

The main treatments include tillage and N-rates as follows;

1. Sorghum mono crop under Conventional tillage (SC) i.e. plough the soil once, harrow thrice and ridge, then plant with sorghum alone without *Desmodiun uncinatum*

2. Sorghum with *Desmodium uncinatum* live-mluch under No-till (SDNT) i.e., zero tilled in both 2011 and 2012 but planted only with *D. uncinatum* without sorghum in 2011 and in 2012 sorghum was intercropped with *D.uncinatum*.

3. Sorghum intercrop with *Desmodium uncinatum* on old ridge (SDOR) i.e., plough and harrow once, planted *D. uncinatum* only in the first year; plant sorghum and re-plant *D. uncinatum* in the second year while the ridge remain un-remoulded.

4. Intercrop of Sorghum and *Desmodium uncinatum* under conservation tillage (SDIC) i.e., plough, harrow once and ridge then plant only *D. uncinatum,* in 2011 and in 2012 one year fallow *D.uncinatum* was incorporated into the soil and drill *D. uncinatum* again on the ridge slope and intercropped with sorghum.

The N-treatments include;

Nitrogen rates of (30, 40, 50 and 60kgN ha^{-1}), (Kim *et al.,* 1997). Each nitrogen rate was applied in three contiguous ridges/plot/treatment randomized in all the plots of the main treatments.

The sub plot treatments include;

Three Phosphorous rates of (6.6, 13.2 and 26.4kgP ha^{-1}), (Odunze *et al*., 2013). Each phosphorous rate was applied in one ridge/N rate and randomized in all the nitrogen plots.

3.5 Soil quality and changing trends:

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

i). Data on total nitrogen, organic carbon, available phosphorus and pH of soils after crop harvest.

ii). Data on sorghum grain yield for study period

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

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

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

3.6 Soil Sampling and Analysis.

Initial soil samples were collected in the first year (2011) with auger from the experimental field at two depths; 0-15cm and 15-30cm, at five points (three from one diagonal transect and two from the next diagonal transect) prior to planting, so as to determine nutrient status of the field. The samples were homogenized by depth and composite samples obtained for analysis at each sampling depth. The soil samples were then air dried, ground, sieved through 2mm sieve mesh for determination of physicochemical properties. Parameters such as particle size distribution, pH, organic carbon, total nitrogen, available phosphorous and exchangeable acidity cation exchange capacity of the soils were determined.

Core samples from depth 0-5, 5-10 and 10-15cm were also taken using core sampler (5 by 5 cm diameter) during the first year for the determination of bulk density, and soil moisture content.

The second soil samples were collected in the second year to determine status of the soil following establishment of *Desmodium uncinatum* in the first year. This was done before planting sorghum. The final soil samples were taken at harvest of sorghum from all sub plots to assess changes in soil quality. Thereafter, samples collected were prepared and taken to the laboratory to be analyzed for (total nitrogen, organic carbon/organic matter, available phosphorous, and pH).

3.7 Cultural Practices

i. **Planting**: *Desmodium uncinatum* (silver leaf) was planted by drilling method on the ridge slope in all plots except for SC and was maintained one year round *Desmodium* soil cover. Sorghum (SAMSORG 14) was planted on ridge peaks with *Desmodium* during the second year cropping season in all plots. Four sorghum seeds were planted per hole and at a spacing of 25 cm apart. *Desmodium* live-mulch following one year fallow was incorporated into the soil of plots with Conservation tillage + *Desmodium* i.e SDIC in all main plots at the beginning of second year.

ii. **Thinning/ Supplying**: Sorghum was thinned to one plant per stand two (2) weeks after planting and those that did not germinate were supplied.

iii. **Fertilizer Application**: Nitrogen in form of urea was applied in a split dose. The first half dose was applied at 2 weeks after planting (WAP) with Single Super Phosphate (SSP) while the second half doses of urea fertilizer was applied at 6WAP.

iv. **Weeding**: This was done manually by handpicking and use of hoe at 3, 4, 6 and 8 WAP.

v. **Harvesting**: The harvesting of *Desmodium* was done twice. The first harvest was done during the second season shortly before planting sorghum. This was done by cutting back the *Desmodium* shoot while the second harvest was done along side with sorghum when the two plants reached maturity.

3.8 Plant Observations

i. **Plant height**: Five Sorghum stands / plot / treatment were tagged and monitored for plant height and Leaf Area Index (LAI). The measurement was done at 6, 8, 10 and 16 weeks after planting (WAP).

ii. **Leaf Area Index**: This was done by using the method described by Stickler *et al.* (1961). Average Lengths and widths of the leaf area measured were multiplied and their products were then multiplied by a factor 0.75. This was done at 6, 10 and 16 WAP.

iii. **Grain yield of sorghum at harvest**: This was done by harvesting and weighing grains in the sub plots measuring 10 m x 8 m and converted in tha^{-1}.

iv. **Ground cover assessment for *Desmodium***: The total area of ground covered by *desmodium* was determined using 1 m x 1 m quadrant at 6, 8, 10 and 16 WAP.

3.9 Soil Analysis

3.9.1 Soil physical properties:

i. **Particle size distribution**: This was determined using the hydrometer method as described by Gee and Bauder (1986) using water and calgon (sodium hexametaphosphate solution) as dispersing agents. While textural classes were determined from the USDA textural triangle.

ii. **Bulk density**: It was obtained using core (5cm by 5cm) sampler. The core sampler was driven into the soil to the desired depth and carefully removed. The sample was then dried in an oven at 105ºC, weighed and determined in accordance with the (Blake and Harte, 1998).

3.9.2 Soil chemical properties

(i) Soil pH: A representative's test portion of at least 5mL from the soil sample was taking and five volumes of water and calcium chloride solution was added. The solution was shaken and mixed properly using mechanical shaker and was measured electrometrically in duplicates both in distilled water and calcium chloride solution. A soil solution of 1:2.5 was used and read from Beckman Zermetic pH meter (Hendershot *et al.*, 1993)

(ii) Organic carbon: This was measured by wet oxidation method of Walkley and Black as described by Nelson *et al.* (1982).

(iii) Available phosphorous: Samples collected was weighed, air dried into 50mL centrifuge tube and then 20mL of extracting solution was added. The solution was mixed properly, decanted and then determined using Bray No. 1 method as described by (Olsen and Sommers, 1982).

(iv)Total nitrogen: This was determined by the regular micro-Kjeldahl digestion method (Bremner and Mulvaney, 1982)

(v) Cation Exchange Capacity (CEC): This was determined by the 1N Neutral Ammonium acetate (1N NH_4OAc) method as described by Rhoades (1982).

(vi) Moisture Content: This was obtained gravimetrically. The moist soil sample was weighed and dried in an oven at 105^oc until constant dried weight is obtained. The values obtained were then calculated using this formula;

$$M.C= \frac{MW \square \square \square DW}{DW} \times 100$$

M.C = Moisture Content
MW = Moist Wet
DW = Dry weight

N.B, The above physical and chemical analysis were determined as routine analysis during the first year, (2011) while selected physical and chemical properties hereafter refer to as soil quality indicators (Soil pH, Organic carbon/Organic matter, Available Phosphorus, and Total Nitrogen) were determined during the second year after harvest of sorghum in 2012 for soil quality changes.

3.10 Statistical Analysis; The Data obtained were subjected to analysis of variance (ANOVA) using statistical computer package of (SAS, 2002) and the means were separated using Ducan Multiple Regression Test (DMRT).

CHARPTER FOUR

RESULTS AND DISCUSSION

4.1 Pre-experimental Site Condition

4.2 Climatic Condition

4.2.1 Rainfall.

In 2011, there was consistent increase in rainfall between 4mm up to 16mm from 3rd dekadal of April through 1st, 2nd , 3rd dekadal of May and 1st dekadal of June. Rainfall amount was received between <10mm and 14mm in 3rd dekadal of June, 1st, 2nd, 3rd dekadal of July and 1st dekadal of August. Much of the rainfall for the year was received in 2nd dekadal of July (22mm) as well as 2nd dekadal of August (24mm). There was reduction in rainfall amount to as low as <8mm in 3rd and 1st dekadal of August and September respectively but picked-up again in 2nd dekadal of September and ended in the first dekadal of October (Fig 3.1). Therefore, in 2011, rainfall amount was well distributed throughout the year hence, implying sufficient moisture for plant growth and development.

In 2012, between 10 and 25mm rainfall amounts were received from 2nd dekadal of May to 2nd dekadal of June, with trace amounts in 3rd dekadal of June. This suggests sufficient availability of soil moisture to support planting for the year. Trace amounts of rainfall (<5mm) were received in 2nd, 3rd dekadal of April and 3rd dekadal of June in 2012. However, rainfall amounts increased to attained a peak in the 3rd dekadal of August (>35mm), decreased to less than 15mm in 3rd dekadal of September. The 2nd dekadal of October witnessed over 20mm rainfall amounts, but ceased finally in 3rd dekadal with less than 10mm rainfall amount (Fig 1). Rainfall in 2102 would therefore benefit lately planted crops, but was fairly well distributed within the crop growth periods of June to September.

4.2.2 Temperature

Average annual air temperature of the study site in 2011 and 2012 were 20.46ºC and 19.88ºC respectively (Fig. 3.2) signifying higher intensity of temperature in 2011 than in 2012. Figure 3.2 shows that within the year 2011, monthly air temperature was higher (23ºC) in 2nd dekadal of June, decreased below 20ºC in 3rd dekadal of June as well as 2nd and 3rd dekadal of July. Temperature rises in the 1st dekadal of August, attained its maximum (24ºC) at 3rd dekadal of August but decreased below 20ºC throughout the month of September. Month of October recorded temperature greater than 20ºC, however, temperature decreased consistently from 3rd dekadal of October through the month of November to as low as 17ºC.

In 2012, higher intensity of temperature (23ºC) was received in 2nd dekadal of June. Temperature range of 18ºC and 22ºC was received between 3rd dekadal of June and September. However, greater than 22ºC was received throughout the month of October. In November, temperature decreased gradually from 17ºC in 1st dekadal of November to as low as 16ºC in the 3rd dekadal of November. The reduced temperature recorded in November for both 2011 and 2012 could be due to cloud cover and harmattan.

Generally, it can be concluded that 2011 and 2012 witnessed moderate temperature distribution; sufficient for carbon accumulation (Porter *et al.*, 1998), plant growth and microbial activities.

4.3. Physical properties of soil before field establishment.

The bulk density (Bd), soil moisture content (SMC) and particular size distribution values of the soils before trial establishment are presented in (Table 4.1). Both Bd and SMC values of the soil were higher at the sub surface 15-30 cm depth than at the surface (0-5 cm) depth, signifying increase in Bd and SMC with increase in depth (Veenstra *et al.,* 2006). However, Bd was generally low at the surface and subsurface of the study site, though, not significantly different between Bd at the surface (1.54Mg/m^3) and at the subsurface (1.57Mg/m^3).

Silt fractions dominate soil separates of the experimental field than the other fractions, both at the 0-15cm and 15-30 cm (563g kg^{-1} and 583g kg^{-1} respectively with a mean of 573g kg^{-1}) followed by sand (354g kg^{-1} and 254g kg^{-1} at respective depths) with a mean value of 294g kg^{-1} while clay separates was the least (83g kg^{-1} and 183g kg^{-1} at respective depths) of the experimental field. The textural class of the study area was generally Silt loam.

4.4 Chemical properties of the soil before field establishment.

Some chemical properties of 0-15 cm and 15- 30 cm depth of the experimental site before planting are shown in Table 4.1 The soil was slightly acidic with pH (H_20) of 5.8 while pH ($CaCl_2$) was 5.1

The mean value of organic carbon content was lower at 0-5 cm (2.3g kg^{-1}) than at 15-30 cm (2.5g kg^{-1}). This shows increase in organic carbon content down the soil profile. However, it was generally observed to be low (2.4g kg^{-1}).

The available phosphorus was higher at (0-5 cm depth 8.3mgkg^{-1} and 8.7mg kg^{-1} at 5-15 cm) than at (15-30 cm depth 7.1mg kg^{-1}). However, the mean available phosphorus of the experimental site was 8.03mg kg^{-1}.

The Cation Exchange Capacity CEC was 4.6cmol kg^{-1} at 0-5cm, 5.2cmol kg^{-1} at 5-15 cm and 5.3cmol kg^{-1} at 15-30 cm depth. Generally the CEC of the experimental area was generally low (<10cmol kg^{-1}). This could earlier suggest that the soils are dominated by low activity clays; kaolinites and sesquioxides as reported by (Odunze *et al.*, 2013) and are low in organic matter content. However, this increased in CEC down the profile perhaps due to decomposed plant roots in sub surface of the trial field. Total Nitrogen of the experimental soil is 0.5 both at the 0-15 cm and 15- 30 cm depth.

Table 4.1; Initial nutrient status of the experimental field in 2011

Physico/Chemical Properties	**Depth (cm)**			**MEAN**
	0-5	5-15	15-30	
BD (Mg/m^3)	1.54	1.57	1.57	1.56
SMC (g/g)	17.95	19.12	19.12	18.53
Sand (g kg^{-1})	354	ND	254	294
Silt (g kg^{-1})	563	ND	583	573
Clay (g kg^{-1})	83	ND	183	133
OM (g kg^{-1})	4.0	4.1	4.3	4.1
pH(H_20)	5.9	6	5.6	5.8
pH($CaCl_2$)	5.2	5	5	5.1
Av.P (mg kg^{-1})	8.3	8.7	7.1	8.03
CEC (cmol kg^{-1})	4.6	5.2	5.3	5.03
OC (g kg^{-1})	2.3	2.4	2.5	2.4
TN (g kg^{-1})	0.5	0.5	0.5	0.5
TEXTURAL CLASS	SILT LOAM		SILT LOAM	

ND= Not Determined at 5- 15 cm depth

4.2 Soil chemical properties of the experimental field after one year of *Desmodium uncinatum* fallow

Table 4.2 shows that the mean value of soil pH in H_20 and $CaCl_2$ was observed to have increased by 0.1 at the surface (0-5 cm) signifying less acidity as compared with the initial soil status. This suggests that *Desmodium uncinatum* fallow could be effective in improving the soil acidic condition if left for several years. This findings is in line with the work of Odunze *et al.* (2013) who observed increased in pH of soil after one year fallow of another forage legume *Centrosema pascuorum* under conservation tillage . However, there is no significant difference in soil pH mean value compared with the initial soil nutrient status; hence pH status of the soil remained at slightly acidic.

The mean values of organic carbon content of the soil after one year showed a significant ($P<0.05$) increase (3.1g kg^{-1}) when compared with the initial mean organic carbon content of the soil (2.4g kg^{-1}). Also, organic carbon content was higher at the 0-5cm (5.3g kg^{-1}) and decreased down the soil profile as compared with the initial organic carbon content of the soil which was lower at the 0-5 cm (2.3g kg^{-1}) and increased down the soil profile. This information revealed that *Desmodium uncinatum* could sequester more carbon into soil after one year *Desmodium* fallow than plot where *Desmodium uncinatum* was not planted. This finding is in harmony with Odunze *et al.* (2013) that showed that natural fallow sequestered less organic carbon than plot where forage legume was planted.

Although, the mean value of available phosphorus obtained after one year of *Desmodium uncinatum* fallow was lower (7.9mg kg^{-1}) compared with the initial (8.03mg kg^{-1}), available phosphorus increased slightly from 8.3mg kg^{-1} to 8.5mgkg^{-1} at the 0-5 cm depth of the soil. This information revealed a build up of available phosphorus content at the surface soil of the trial field after one year *Desmodium uncinatum* fallow to support optimal root uptake of phosphorus. This finding is in agreement with Odunze *et al.* (2013). And the increase in available phosphorus under soils planted with *Desmodium uncinatum* could be attributed to increase nodulation of the root of *Desmodium uncinatum* live-mulch in the soil (Ogola *et al.*, 2012) as well as *Desmodium uncinatum* biomass (above and below ground) contributions to the soil (Odunze *et al.*, 2013).

Cation exchange capacity (CEC) of the soils were low (<10cmol kg^{-1}). However, Table 4.2 shows that mean value of the trial soil after one year *Desmodium uncinatum* fallow increased from 4.6cmol kg^{-1} to 6.7cmol kg^{-1} at 0-5 cm depth compared with initial CEC status of the soil, suggesting improvement in capacity of the trial soils; particularly the surface (0-5 cm) soil, to exchange nutrients. CEC was also observed to decrease with soil depth as compared with the initial CEC status that increased with depth. But generally, mean value of CEC after one year *Desmodium uncinatum* fallow was still low (<10cmol kg^{-1}) though increased (5.53cmol kg^{-1}) compared with initial status (5.03cmol kg^{-1}). This increase in CEC could be attributed to effect of *Desmodium uncinatum* in sequestering higher organic matter and organic carbon after one year (Odunze *et al.,* 2013).

Mean total nitrogen content of the experimental soil increased after one year *Desmodium uncinatum* fallow by 50%, and by 58.3% at the surface 0-5cm compared with the initial soil status (Table 4.2). This increase in nitrogen content could be due to N-Fixation by activities of rhizobium present in the root nodules. This signifies that *D. uncinatum* could better improve nitrogen content of the soil.

Table 4.2 Soil Nutrient status of the experimental field after one-year of *Desmodium uncinatum* fallow (Tillage with *Desmodium* live mulch).

Soil Properties	**Depth (cm)**			**MEAN**
	0-5	**5-15**	**15 -30**	
SMC (g/g)	17.95	19.12	ND	18.54
Organic Matter (g kg^{-1})	9.1	3.6	3.3	5.3
pH (H_2O)	6	5.8	5.7	5.8
pH ($CaCl_2$)	5.3	5.3	5.2	5.3
Av.P (mg kg^{-1})	8.5	8.5	6.7	7.9
CEC (cmol kg^{-1})	6.7	5.1	4.8	5.53
Organic Carbon (g kg^{-1})	5.3	2.1	1.9	3.1
Total Nitrogen (g kg^{-1})	1.2	1.2	0.5	1.0

ND= Not Determined at 15-3 0cm, SMC= Soil Moisture Content, CEC= Cation Exchange Capacity.

4.3 Effect of land management practices and fertilizer rates on selected soil chemical properties of the study site.

There were no significant differences ($P>0.05$) among the land management practices (SDOR, SDIC, SDNT and SC) in soil pH values measured in water; while there was a significant difference ($P<0.05$) between SDOR, (pH 4.80) and SC (pH 4.69) in pH values measured in $CaCl_2$ (Table 4.3). However, in both water and $CaCl_2$ solution, soil acidity was less under SDOR (pH 5.54 and pH 4.80) followed by SDIC (pH 5.53 and pH4.75), SDNT (pH 5.46 and pH 4.72) at respective solutions while SC had the highest acidity value of pH 5.38 and pH 4.6 (Table 4.3).This results showed that conventional tillage without *Desmodium uncinatum* (SC) could drastically increase soil acidity after 2 years cropping more than other treatments while, under split old ridge and conservation tillage with *Desmodium uncinatum* and zero tillage with *Desmodium uncinatum* (SDOR, SDIC and SDNT respectively) could help mitigate incidence of increasing soil acidity. However, all the treatments resulted in general reduction of pH of the soils compared with the initial values (Odunze *et al.,*2013).

Generally, there were no significant differences ($P>0.05$) among all values of P rates in both pH in water and $CaCl_2$. However, application of 13.2kgP ha^{-1} produced highest pH values in water (pH 5.50) followed by 6.6kgP ha^{-1} (pH 5.47) and the least is 26.4kgP ha^{-1} (5.46). In $CaCl_2$ solution, the application of 6.6kgP ha^{-1} produced the highest value (pH 4.74) followed by 26.4kgP ha^{-1} and 13.2kgP ha^{-1} that gave the least value (pH 4.72).

Both N rates of 30kgN ha^{-1} and 50kgN ha^{-1} did not show any significant difference ($P>0.05$) in soil pH in water. However, N rate of 40kgN ha^{-1} significantly caused higher acidity (pH 5.1) in water followed by 60kgN ha^{-1}. Meanwhile, N rates treatments did not show any significant different among one another in $CaCl_2$ solution. Generally, the result showed increase in pH values in $CaCl_2$ with increase in N rates and decrease at N rate of 60kgN ha^{-1}.

Therefore, it can be inferred that beyond 50kgN ha^{-1}, the soil pH values would decrease. This finding agree with Odunze *et al.,* (2013) and (Caddel, 2011) who stated that soil pH usually decreases with time due to nitrogen fertilization etc.

Total nitrogen under SDIC was significantly the highest (1.7g kg^{-1}) followed by SDOR (1.6g kg^{-1}), SC (1.5g kg^{-1}) and SDNT (1.3g kg^{-1}) at harvest. It could be inferred therefore that SDIC contributed higher total nitrogen to the soil than the other land management practices after 2 years of land management. This increase in total nitrogen under SDIC and SDOR could be as a result of the incorporation of *Desmodium uncinatum*. This result conforms to Nwaogu *et al.* (2013) who showed that inclusion of short duration grain legume had the capacity to improve not only total N, but also organic matter. N rate of 30kgN ha^{-1} and 50kgN ha^{-1} significantly affected total nitrogen compared to both 60kgN ha^{-1} and 40kgN ha^{-1} (1.5g kg^{-1} and 1.4g kg^{-1}) respectively.

Available phosphorus content was significantly ($P<0.05$) the highest (10.19mg kg^{-1}) in SDNT followed by SDIC (9.48mg kg^{-1}) and least in SDOR (8.14mg kg^{-1}). The higher available phosphorus in SDNT could be attributed to *Desmodium uncinatum* biomass (above and below ground) contributions to the soil (Odunze *et al*., 2013) and no tillage effect would keep phosphorus in place against loss by soil erosion. Also, the P rate of 13.2kgP ha^{-1} significantly resulted in the highest available phosphorus (9.21mg kg^{-1}) of the trial soil compared to other P rates. N rates did not significantly affect available phosphorus. However, N rate of 40kgN ha^{-1} resulted in the highest (9.35mg kg^{-1}) available phosphorus.

Organic carbon content of the soil was highest (6.9g kg^{-1}) in SDNT, followed by (5.8g kg^{-1}) in SDIC, (4.9g kg^{-1}) in SDOR and least in SC (3.6g kg^{-1}). This suggests that SDNT could sequester more organic carbon into soil than the other land management practices. This could be attributed to the absence of tillage effect on soil and also as a result of the effect of

Desmodium uncinatum being able to sequester more organic carbon into the soil. However the lower organic carbon in SC could be due to absence of *Desmodium uncinatum* and effect of tillage in the soil and this practice could hasten soil degradation for sustainable agricultural production and increase greenhouse gas emission to impact adversely on global warming (Lal and Stewart, 1995; Larson *et al.,* 1994; Odunze *et al.,* 2012).

Also, organic carbon content was higher at both 50kgN ha^{-1} and13.2kgP ha^{-1} than other N and P rates. Hence, 50kgN ha^{-1} and/or 13.2kgP ha^{-1} would be a better option in crediting more organic carbon content in SDNT, SDIC and SDOR for sustainable soil health and environmental management, as well as reduction in inorganic N fertilizer use by farmers.

Table 4.3 Effect of land management practices and fertilizer rate on selected chemical properties of experimental site after Harvest in Dec, 2012

TREATMENTS	H_2O	$CaCl_2$	OC $(g\ kg^{-1})$	Av.P (mg/kg)	OM (g kg)	TN $(g\ kg^{-1})$
Land management (LMGT)						
SDOR	5.54a	4.80a	4.9a	8.14c	8.5a	1.6b
SDIC	5.53a	4.75ab	5.8a	9.48b	10.0a	1.7b
SDNT	5.46a	4.72ab	6.9a	10.19a	11.9a	1.3c
SC	5.38a	4.69b	3.6a	8.21c	6.2a	1.5b
SE ±	0.031	0.024	0.19	0.27	3.5	0.05
Phosphorus (P) rates $(kgha^{-1})$						
6.6	5.47a	4.74a	5.1a	8.84a	8.8a	1.5a
13.2	5.50a	4.72a	5.5a	9.21a	9.5a	1.6a
26.4	5.46a	4.73a	5.4a	8.95a	9.3a	1.5a
SE±	0.027	0.021	0.17	0.234	3.1	0.04
Nitrogen (N) rates $(kgha^{-1})$						
30	5.50ab	4.71a	4.5c	8.83a	7.8c	1.6a
40	5.1a	4.74a	4.8c	9.35a	8.3c	1.4c
50	5.50ab	4.75a	6.8a	8.81a	11.7a	1.6a
60	5.41b	4.72a	5.5b	9.01a	9.5b	1.5b
SE±	0.031	0.024	0.190	0.270	3.5	0.05
Depth (D) (cm)						
0 -5	5.48a	4.77a	6.0a	9.02a	10.4a	1.6a
5- 15	5.47a	4.72ab	5.3b	9.00a	9.1b	1.6a
15 -30	5.50a	4.70a	4.7c	8.98a	8.1b	1.3b
SE±	0.027	0.021	0.17	0.234	3.1	0.04
Interaction effect						
P ×LMGT	NS	NS	NS	NS	NS	**
N×LMGT	NS	NS	***	NS	***	***
D×LMGT	NS	NS	**	NS	**	**
P×N	NS	NS	***	NS	**	NS
D×P	NS	NS	*	NS	**	*
D×N	NS	NS	**	NS	**	NS
P×N×LMGT	NS	NS	**	NS	**	***
D×N×LMGT	NS	NS	**	NS	**	NS
D×P×LMGT	NS	NS	NS	NS	NS	NS
D×P×N	NS	NS	*	*	NS	**
D×P×N×LMGT	NS	NS	*	*	*	NS

*= significant, **= highly significant at ($P<0.05$), ***= highly significant at ($P<0.01$), NS= Not significant

4.4 P rates and soil depth interaction effect on organic carbon

Surface soil (0-5 cm) depth of the experimental field contained highest organic carbon content (6.2g kg^{-1}) when 6.6kgP ha^{-1} and 26.4kgP ha^{-1} were applied. At each application of P-fertilizer, Organic Carbon content decreased down the profile; except for 13.2kgP ha^{-1} which increased and decreased, implying inconsistency and poor interaction with soil depth (Fig 4.1). The interaction was statistically significant ($P<0.05$), however, the organic carbon content was found to be lower at 15-30 cm depth for each P rates.

The 6.6kgP ha^{-1} rate therefore, could be a better option in contributing higher Organic carbon content into the surface soil.

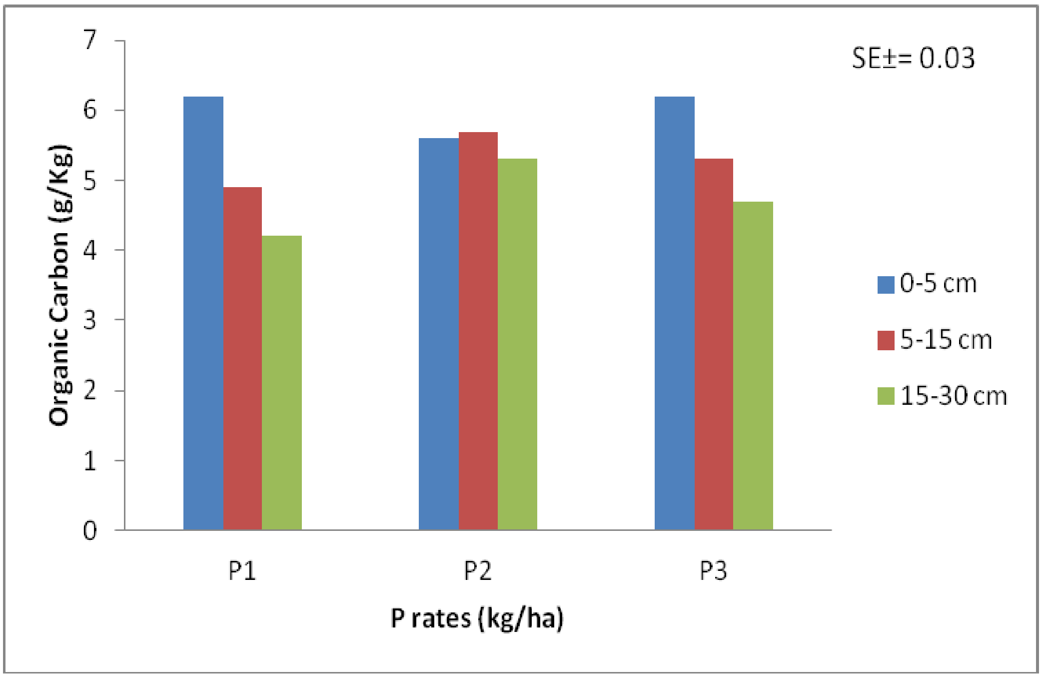


Fig. 4.1 P rates and soil depth interaction effect on soil organic carbon

P=Phosphorus Fertilizer (SSP) Where; P1=6.6kgP ha^{-1}, P2 =13.2kgP ha^{-1}, P3=26.4kgP ha^{-1}.

4.4.1 N and P rates interaction effect on soil organic carbon

A significant interaction ($P<0.001$) effect was observed between N and P rate on organic carbon content of the soil (Fig. 4.2). The interaction effect between (N and P rates) showed that organic carbon content increased with increase in N rates: 30kgN ha^{-1}, 40kgN ha^{-1} and 50kgN ha^{-1} application with a P rate of (26.4kgP ha^{-1}) and then dropped at the highest N rate of 60kgN ha^{-1}) as shown in Fig 5.

Similar trend was also observed when different N rates were applied with P rate of (6.6kgP ha^{-1}) but there was no drop at 60kgN ha^{-1}. Generally, application of different N rates with 26.4kgP ha^{-1} gave higher organic carbon content than 6.6kgP ha^{-1}; except for 60kgN ha^{-1} and 26.4kgP ha^{-1}. This would suggest that as higher N rates interacting with low P rates of 6.6kgP ha^{-1}, higher organic carbon amount would be sequestered into the soils. Greater than 50kgN ha^{-1} interact with 26.4kgP ha^{-1} would result in organic carbon content decrease.

However, interaction between nitrogen and phosphorus rates of 50kgN ha^{-1} and 13.2kgP ha^{-1} produced highest organic carbon content (7.5g kg^{-1}) followed by interaction between 50kgN ha^{-1} and 26.4kgP ha^{-1}.

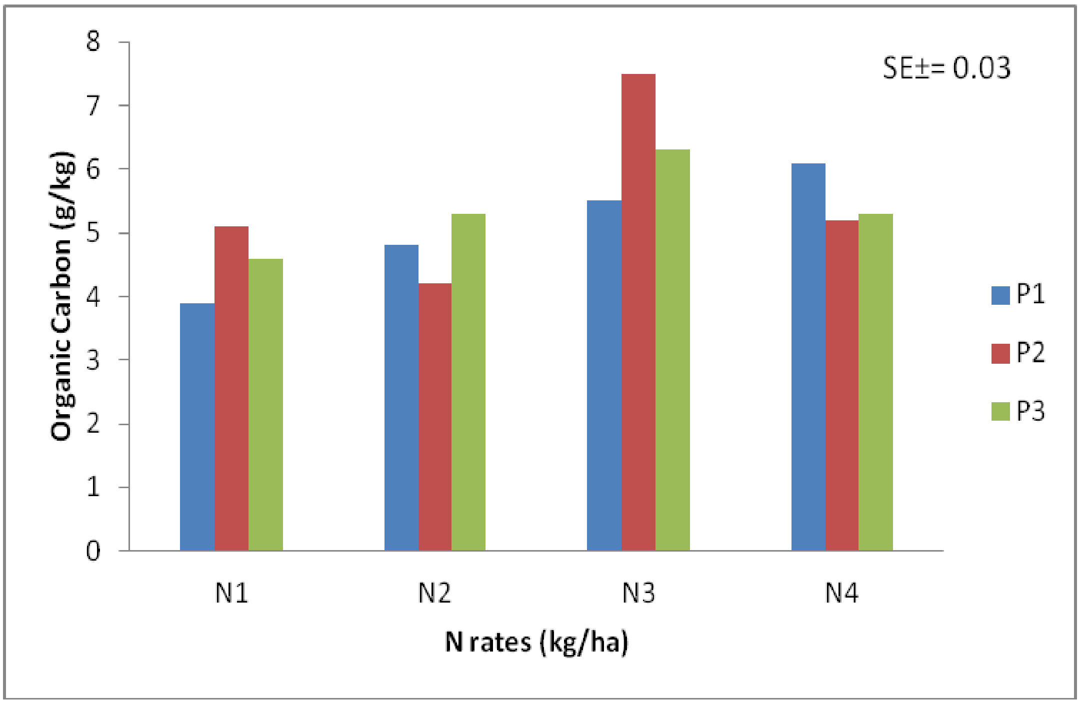


Fig: 4.2 N and P rates interaction effect on soil organic carbon

N= Nitrogen Fertilizer (Urea) Where; N1=30kgN ha^{-1}, N2=40kgN ha^{-1}, N3=50kgN ha^{-1}, N4=60kgN ha^{-1}.
P= Phosphorus Fertilizer (SSP) Where; P1=6.6kgP ha^{-1}, P2=13.2kgP ha^{-1}, P3=26.4kgP ha^{-1}.

4.4.2 Land management and N rates interaction effect on soil organic carbon

Organic carbon content was higher (9.4g kg^{-1}) in soils of SDNT at 50kgN ha^{-1} followed by soils of SDIC (8.3g kg^{-1}) also at 50kgN ha^{-1}.

At both SDNT and SDIC, organic carbon content increased with increase in N rates and decreased at the highest rate of 60kgN ha^{-1} (Fig 4.3). This suggests that 50kgN ha^{-1} could result in better organic carbon sequestration under both Land Management Practices (SDNT and SDIC). However, the lowest organic carbon content (3.1g kg^{-1}) was observed in soils of SC when 50kgN ha^{-1} was applied. Therefore, it can be inferred that both soils of SDNT and SDIC would respond better with 50kgN ha^{-1} in terms of organic carbon sequestration than other Land Management practices. The interaction was generally statistically significant ($P<0.001$).

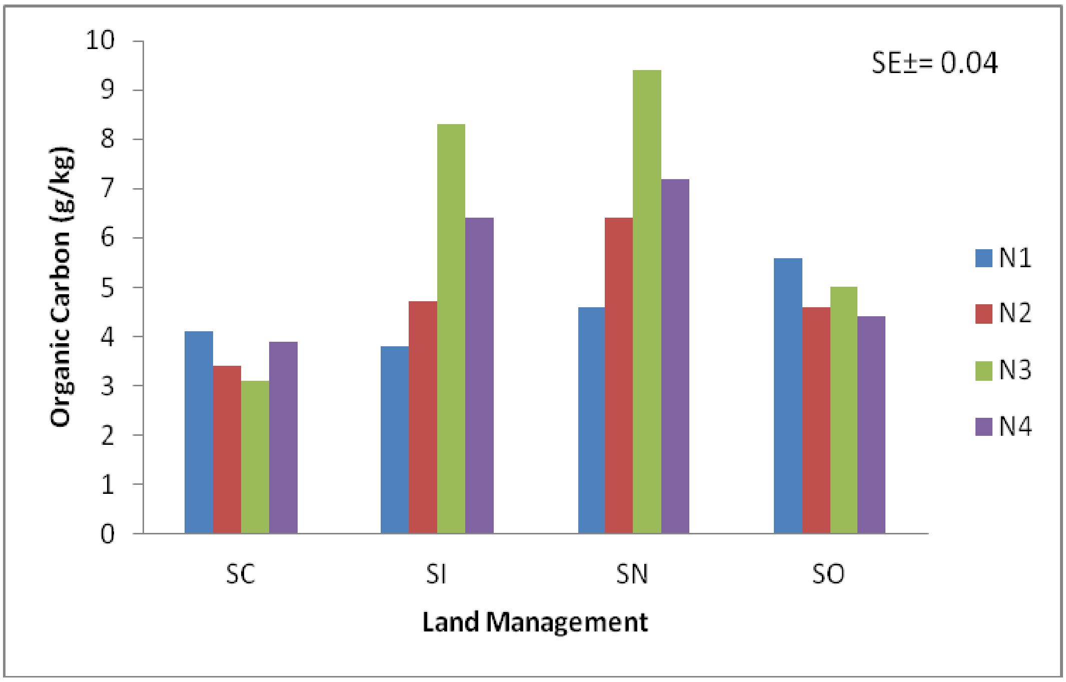


Fig: 4.3 Land Management and N rates interaction effect on soil organic carbon.

SC= Sorghum alone under Conventional Tillage; SI= SDIC=Sorghum/*Desmodium*-Incorporated under Conservation Tillage; SN= SDNT=Sorghum/*Desmodium* under No-Tillage, SO= SDOR=Sorghum/*Desmodium* on Ridge.
N= Nitrogen Fertilizer (Urea) Where; N1= 30kgN ha^{-1}, N2= 40kgNha^{-1}, N3= 50kgN ha^{-1}, N4= 60kgN ha^{-1}.

4.4.3 Land management and soil depth interaction effect on soil organic carbon.

Organic carbon content was high at (0-5cm) depth for both SDNT and SDIC land management practices with the exception of SDOR and SC which were highest at 5-15 cm depth (Fig 4.4). Organic carbon decreased down the profile in SDNT compared to others, where there were no consistency to elicit trend deductions.

Though interaction was statistically significant ($p \leq 0.01$), highest organic carbon content (8.3g kg^{-1}) was found in soils of SDNT at a depth of 0-5 cm. The lowest organic carbon content (3.8g kg^{-1}, 3.9gkg^{-1} and 3.1g kg^{-1}) was obtained in soils of SC at the depths 0-5 cm, 5-15 cm and 15-30 cm respectively.

Hence, SDNT would be a better land management practices for rapid organic carbon sequestration than others.

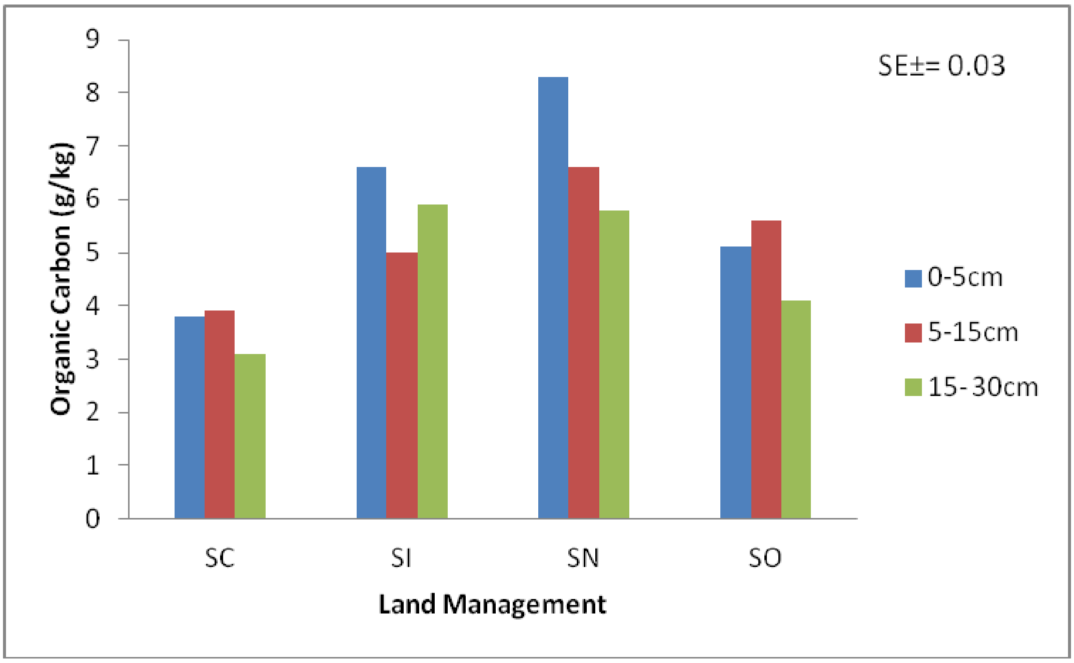


Fig. 4.4 Land Management and soil depth interaction effect on soil organic carbon.

SC=Sorghum alone under Conventional Tillage; SI= SDIC=Sorghum/*Desmodium*-Incorporated under Conservation Tillage; SN=SDNT= Sorghum/*Desmodium* under No-Tillage; SO= SDOR=Sorghum/*Desmodium* on old Ridge.

4.4.4 N rates and soil depth interaction effect on soil organic carbon.

Figure 4.5 reveals that organic carbon was higher (6.2g kg^{-1}, 6.9g kg^{-1} and 6.2g kg^{-1}) at the surface layer 0-5cm depth when 40kgN ha^{-1}, 50kgN ha^{-1} and 60kgN ha^{-1} respectively were applied. However, the highest organic carbon content (6.9g kg^{-1}) resulted when 50kgNha^{-1} was applied. Although, organic carbon content of the experimental field increased with increase in N rates and decreased at highest N rate of 60kgN ha^{-1}, yet 60kgN ha^{-1} resulted in higher organic carbon content (6.2g kg^{-1}) than 30kgN ha^{-1} which gave an organic carbon content of 4.6g kg^{-1} . Thus, 50kgN ha^{-1} gave the highest organic carbon content (6.9g kg^{-1}) and is a better N rate to sequester more organic carbon content than 40kgN ha^{-1} and 60kgN ha^{-1} which gave (6.2g kg^{-1} each). The interaction was generally statistically significant ($P<0.001$).

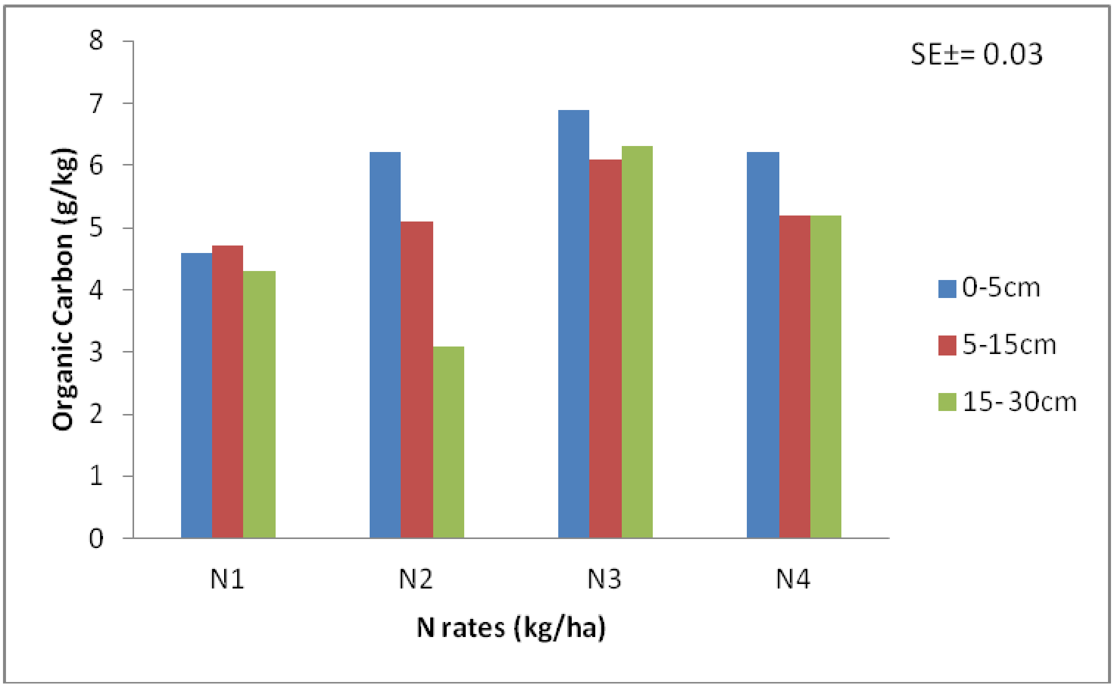


Fig. 4.5 N rates and Soil depth interaction effect on soil organic carbon.

N= Nitrogen Fertilizer (Urea) Where; N1= 30kgN ha^{-1}, N2= 40kgN ha^{-1}, N3=50kgN ha^{-1} , N4= 60kgN ha^{-1}.

4.4.5 Soil depth, N and P rates interaction effect on soil organic carbon.

Results in Fig. 4.6 show that there was an increase in organic carbon content with increase in P rates (6.6kgP ha^{-1}, 13.2kgP ha^{-1} and 26.4kgP ha^{-1}) when 50kgN ha^{-1} was applied with each P rates at the surface soil (0-5 cm). However, the treatments were not statistically different ($P>0.05$) and ($P>0.01$), interaction between N rate and P rate of 50kgN ha^{-1} and 13.2kgP ha^{-1} respectively sequestered more organic carbon content (7.9g kg^{-1}) at sub surface layer 5-15 cm depth, followed by 50kgN ha^{-1} and 13.2kgP ha^{-1} at 15-30 cm depth (7.8g kg^{-1}). This suggests that application of 50kgN ha^{-1} and 13.2kgP ha^{-1} would better enhance sequestration of organic carbon at the sub surface soils than other N and P rates interaction. Application of 50kgN ha^{-1} and 26.4kgP ha^{-1} would add more organic carbon content at surface soil of the experimental field.

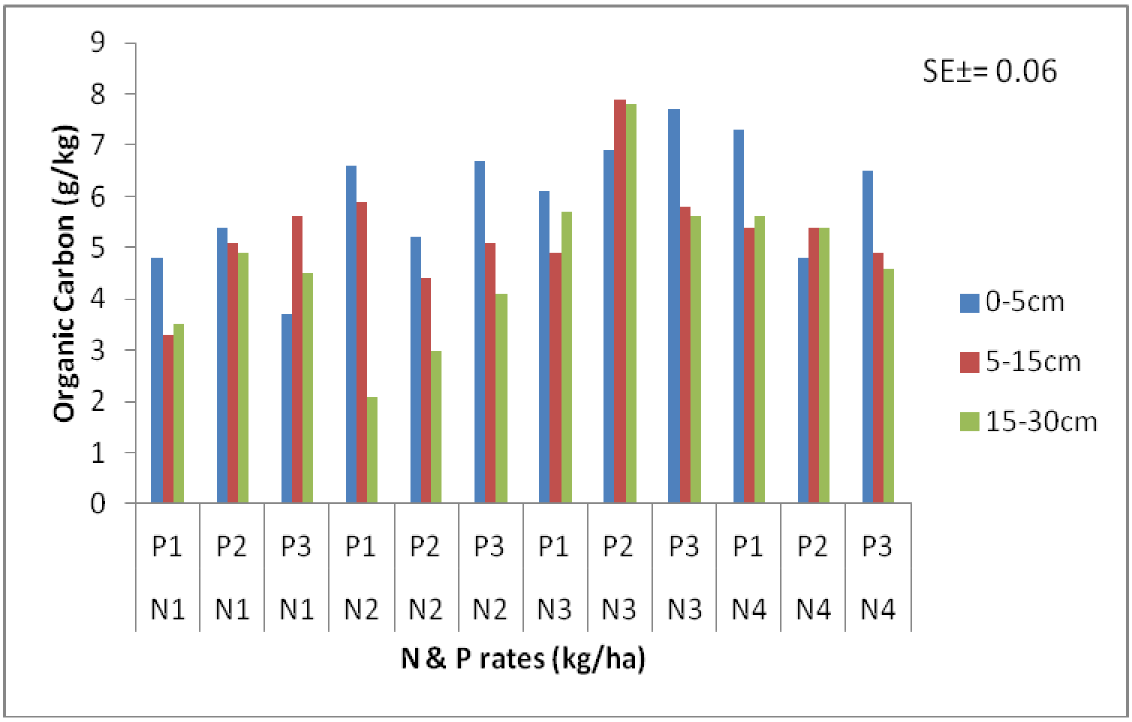


Fig. 4.6 Soil depth, N and P rates interaction effect on soil organic carbon.

N= Nitrogen Fertilizer (Urea) Where; N1= 30kgN ha^{-1}, N2= 40kgN ha^{-1}, N3= 50kgN ha^{-1} , N4=60kgN ha^{-1}. P= Phosphorus Fertilizer (SSP) Where; P1= 6.6kgP ha^{-1}, P2=13.2kgP ha^{-1}, P3=26.2kgP ha^{-1}.

4.4.6 Land management, N rates and Soil depth interaction effect on soil organic carbon.

The surface layer (0-5 cm) depth of SDNT contained highest organic carbon value (9.9g kg^{-1}) and (9.7g kg^{-1}) when 40kgN ha^{-1} and 50kgN ha^{-1} application were made respectively, followed by 50kgN ha^{-1} in the surface soils of SDIC (9.0g kg^{-1}) than other land managements (Fig.4.7). This would suggest that 40kgN ha^{-1} and 50kgN ha^{-1} would add more organic carbon at the surface layer (0-5 cm) depth of both SDNT and SDIC respectively than other N rates and other land management practices. The interaction was generally statistically significant ($P<0.01$).

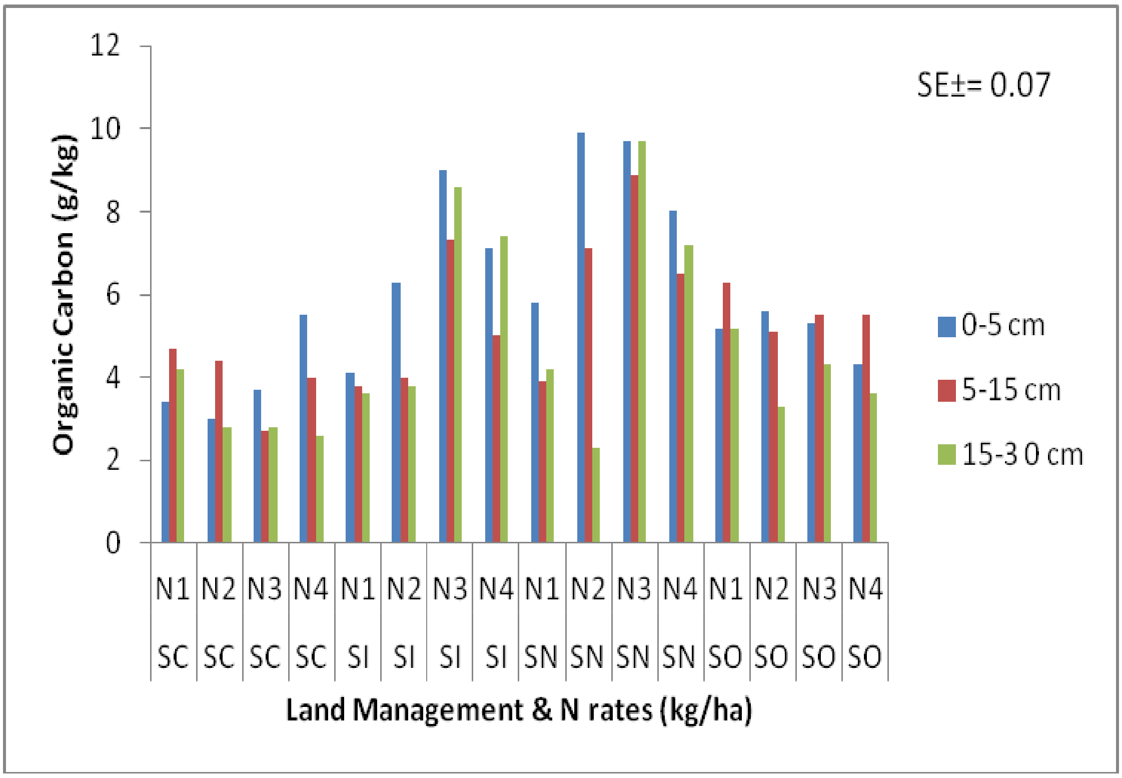


Fig.4.7 Land Management, N rates and soil dept interaction effect on soil organic carbon.

SC=Sorghum alone under Conventional Tillage, SI=SDIC=Sorghum/*Desmodium*-Incorporated under Conservation Tillage, SN=SDNT=Sorghum/*Desmodium* under No-Tillage, SO=SDOR=Sorghum/*Desmodium* on old Ridge.
N=Nitrogen Fertilizer (Urea) Where; N1= 30kgN ha^{-1}, N2= 40kgN ha^{-1}, N3= 50kgN ha^{-1}, N4= 60kgN ha^{-1}.

4.4.7 Land management, N and P rates interaction effect on soil organic carbon

The interaction between N and P rates of 50kgN ha^{-1} and 13.2kgP ha^{-1} resulted in significantly higher organic carbon content of 9.6g kg^{-1} and 12.3g kg^{-1} in both soils of SDIC and SDNT respectively than other land management practices. The organic carbon content was generally low for SC, with N and P rates application (Fig.4.8). This information revealed that both SDNT and SDIC would respond better in crediting soil organic carbon than other land management practices when 50kgN ha^{-1} and 13.2kgP ha^{-1} are applied. Generally, the interaction was statistically significant ($P \leq 0.01$).

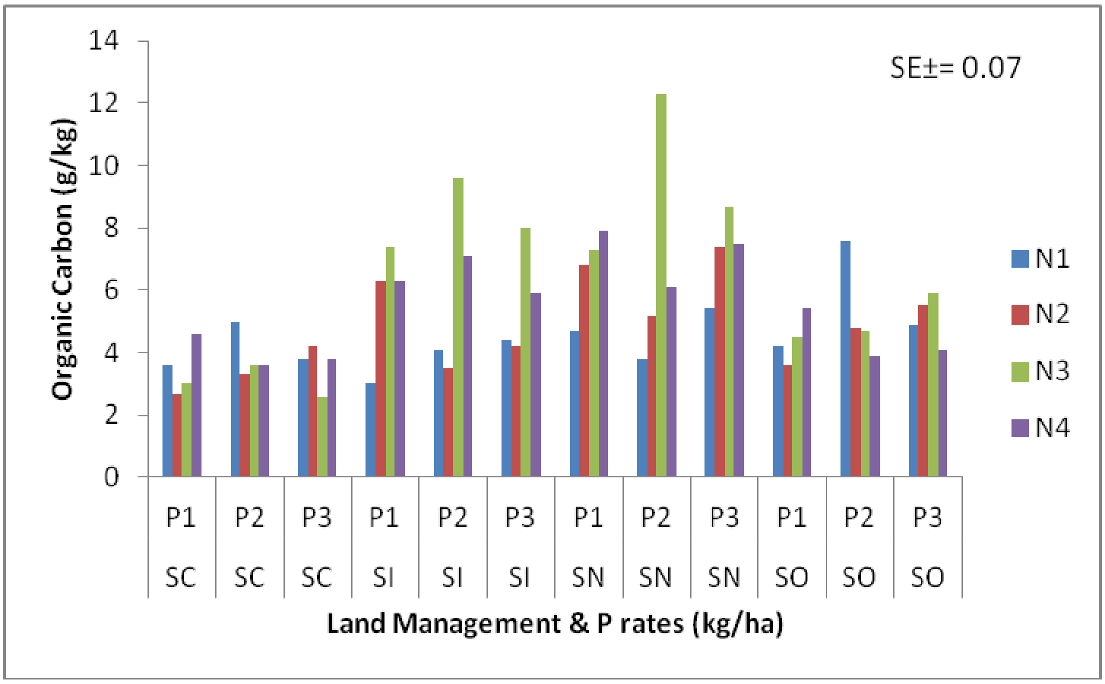


Fig. 4.8 Land Management, N and P rates interaction effect on soil organic carbon

SC= Sorghum alone under Conventional Tillage, SI=SDIC=Sorghum/*Desmodium*-Incorporated under Conservation Tillage, SN=SDNT=Sorghum/*Desmodium* under No-Tillage, SO= SDOR=Sorghum/*Desmodium* on old Ridge.
P= Phosphorus Fertilizer (SSP) Where; P1= 6.6kgP ha^{-1}, P2= 13.2kgP ha^{-1}, P3= 26.4kgP ha^{-1}.
N= Nitrogen Fertilizer (Urea) Where; N1= 30kgN ha^{-1}, N2=40kgN ha^{-1}, N3=50kgN ha^{-1}, N4=60kgN ha^{-1}.

4.4.8 Land management, depth (cm), N and P rates interacton effects on organic carbon

The interaction between N and P rate of 60kgN ha^{-1} and 6.6kgPha^{-1} gave more (7.5g kg^{-1}) organic carbon at the surface soil (0-5cm) under SC than other N and P rates. At SDIC, 50kgNha^{-1} and 26.4kgP ha^{-1} resulted in more (9.6g kg^{-1}) organic carbon at the surface soil (0-5 cm), followed by 50kgN ha^{-1}+13.2kgP ha^{-1} and 40kgN ha^{-1}+6.6kgP ha^{-1} (9.5g kg^{-1}). Hence, it can be inferred that the application of 50kgN ha^{-1} and 26.4kgP ha^{-1} would be a better option in sequestering higher organic carbon in soils of SDIC than other N and P rates interaction.

At SDNT, 40kgNha^{-1} and 6.6kgP ha^{-1} gave more (11.6g kg^{-1}) organic carbon at the surface followed by 40kgN ha^{-1} and 26.4kaP ha^{-1} (10.8g kg^{-1}). And at SDOR, 50kgN ha^{-1} and 26.4kgP ha^{-1} gave more (7.8g kg^{-1}) organic carbon into the surface soil followed by 40kgNha^{-1} and P rates of (13.2kgP ha^{-1} and 26.4kgP ha^{-1}) (6.0g kg^{-1}). Generally, it can be inferred that under conservation tillage (SDIC) and zero tillage systems incorporated or relayed with *Desmodium uncinatum* (SDIC and SDNT) the interaction between 40kgN ha^{-1} and 6.6kgN ha^{-1} resulted in more organic carbon sequestration. Under conventional tillage without *Desmodium uncinatum*, a higher N rates than 60kgN ha^{-1} would be required to sequester as much organic carbon as was obtained in SDIC and SDNT (Fig. 4.9). The interaction was statistically significant (P<0.05). Thus, presence of *Desmodium uncinatum* could reduce application rate of inorganic N-fertilizer and give more organic carbon into the soil.

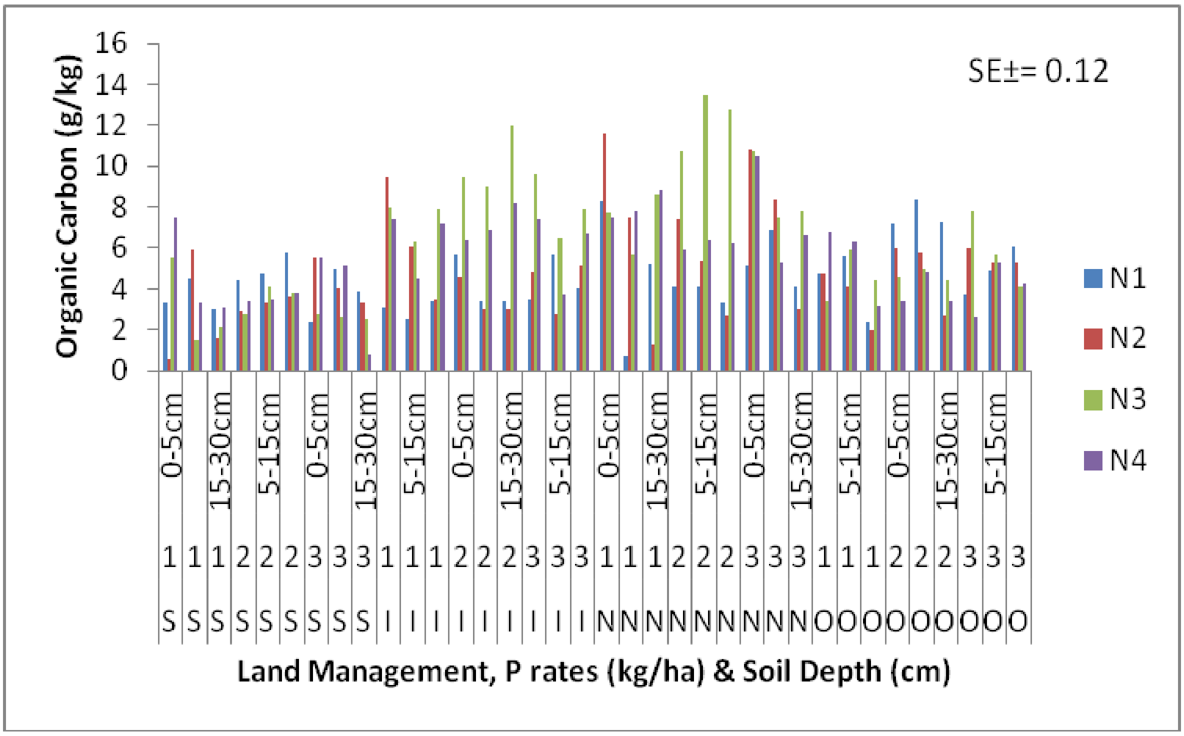


Fig.4.9 Land Management, Depth, N and P rates interacton effects on organic carbon

S=SC=Sorghum alone under Conventional Tillage, I=SDIC=Sorghum/*Desmodium*-incorporated under Conservation Tillage, N=SDNT=Sorghum/*Desmodium* under No-Tillage, O=SDOR=Sorghum/*Desmodium* on old Ridge. 1, 2, 3= Phosphorus Fertilizer (SSP) Where; 1=P1= 6.6kgP ha^{-1}, 2=P2= 13.2kgP ha^{-1}, 3=P3= 26.4kgP ha^{-1}.
N= Nitrogen Fertilizer (Urea) Where; N1= 30kgP ha^{-1}, N2=40kgP ha^{-1}, N3=50kgP ha^{-1}, N4=60kgN ha^{-1}.

4.5 N and P rates and soil depths interaction effect on available phosphorus

Though interaction was statistically significant ($P<0.05$), available phosphorus decreased with increase in P rates at the 0-5cm of the soil when 40kgNha^{-1} was applied along each P rates. When both 50kgNha^{-1} and 60kgNha^{-1} were applied along each P rate, available phosphorus increased and decreased, implying inconsistency and poor interaction with soil depth. There was also inconsistency and poor interaction with soil depth, resulting in decrease and increase in available phosphorus when 30kgNha^{-1} was applied along each P rates. Generally, highest available phosphorus at the 0-5cm depth of experimental soil was obtained when 40kgNha^{-1} was applied along with 6.6kgPha^{-1} (Fig.4.10). Moreso, 40kgNha^{-1} and 6.6kgPha^{-1} resulted in higher available phosphorus (10.17mgkg^{-1}) at 5-15cm than the other N and P rates' interaction. However, at 15-30cm depth, 30kgNha^{-1} and 26.4kgPha^{-1} yielded the highest (10.56 mgkg^{-1}) available phosphorus. This would suggest that at 0-5cm depth of soil, 40kgNha^{-1} and 6.6kg Pha^{-1} would be better in enhancing available phosphorus content of the soil than other N and P rates' interaction.

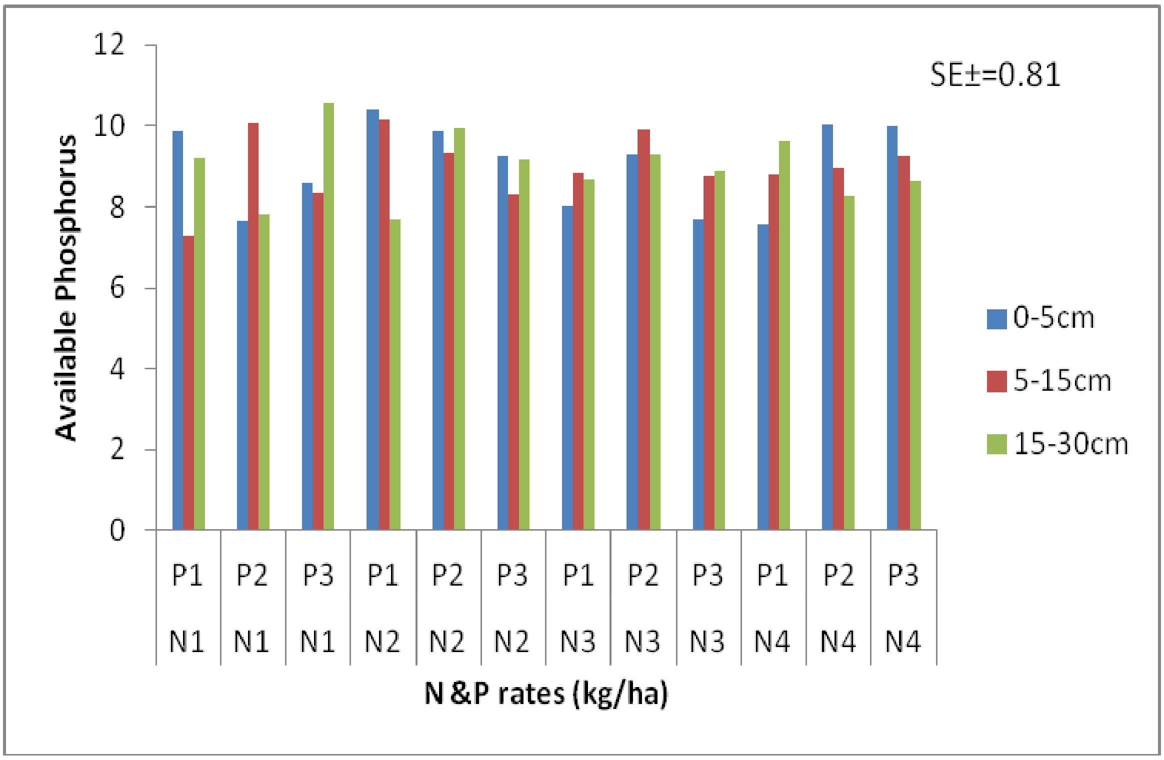


Fig.4.10 N and P rates and Soil Depths interaction effects on Available Phosphorus

N= Nitrogen Fertilizer (Urea) Where; N1= 30kgN ha^{-1}, N2= 40kgN ha^{-1}, N3= 50kgN ha^{-1}, N4=60kgN ha^{-1}.
P= Phosphorus Fertilizer (SSP) Where; P1= 6.6kgP ha^{-1}, P2=13.2kgP ha^{-1}, P3=26.2kgP ha^{-1}.

4.5.1 Land management, soil depth, N and P rates interacton effects on available phosphorus

At SC, 60kgN ha^{-1} and 26.4kgP ha^{-1} gave more (12.51mgkg^{-1}) available phosphorus at 0-5 cm of the trial soil than other fertilizer rate. At SDIC, 40kgN ha^{-1} and 6.6kgP ha^{-1} sequestered more available phosphorus (12.13mg kg^{-1}) (Fig 4.11). At SDNT, 40kgN ha^{-1} and 13.2kgP ha^{-1} gave more available phosphorus (11.46mg kg^{-1}) than other fertilizer rates.

At SDOR, 30kgN ha^{-1} and 6.6kgP ha^{-1} resulted in the highest (12.34mg kg^{-1}) available phosphorus. Thus, it can be inferred that interaction between 40kgN ha^{-1} and 6.6kgP ha^{-1} would result in more available phosphorus under conservation tillage with *Desmodium uncinatum* (SDIC and SDNT) compared with conventional tillage without *Desmodium uncinatum* (SC). And also that plot without *Desmodium uncinatum* (SC) would require higher N application rate. Generally, the interaction was statistically significant ($P<0.05$).

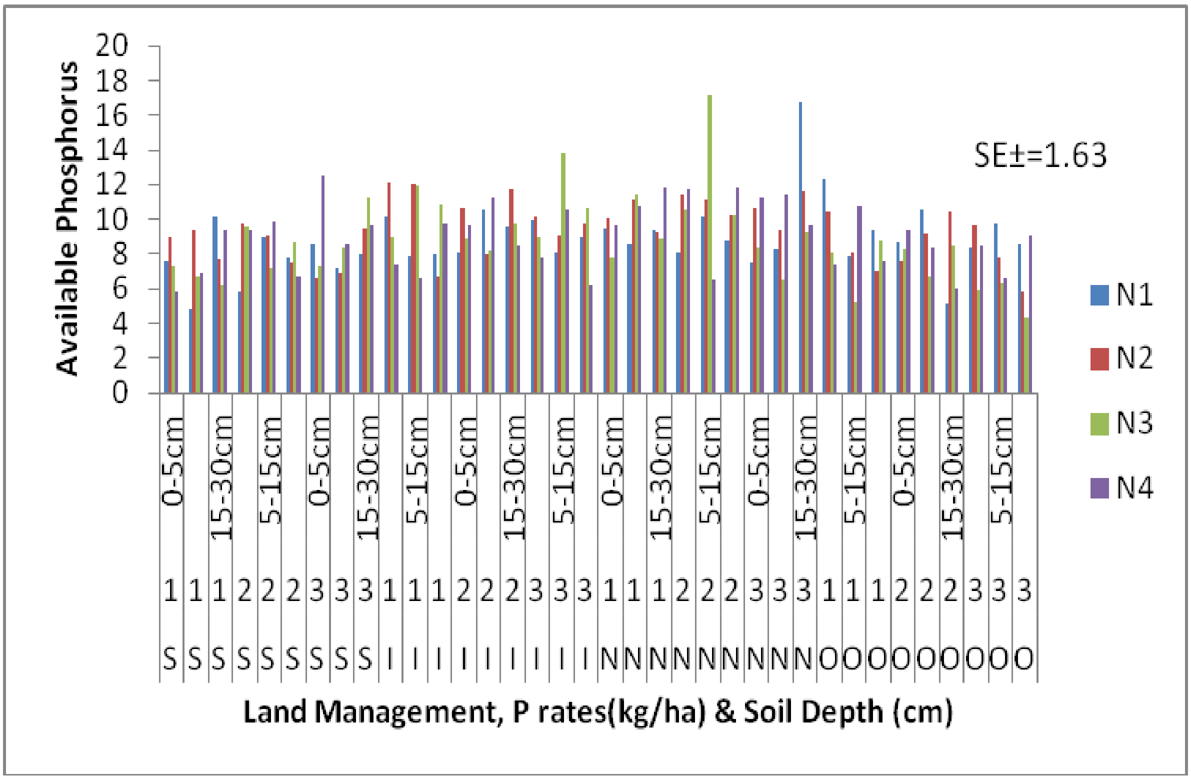


Fig. 4.11 Land Management, Soil depth, N and P rates interacton effects on available Phosphorus

S=SC= Sorghum alone under Conventional Tillage, I=SDIC=Sorghum/*Desmodium*-Incorporated under Conservation Tillage, N=SDNT=Sorghum/*Desmodium* under No-Tillage, O=SDOR=Sorghum/*Desmodium* on old Ridge.
1, 2, 3=P= Phosphorus Fertilizer (SSP) Where; 1=P1= 6.6kgP ha$^{-1,}$ 2=P2= 13.2kgP ha^{-1}, 3=P3= 26.4kgP ha^{-1}.
N= Nitrogen Fertilizer (Urea) Where; N1= 30kgN ha^{-1}, N2=40kgN ha^{-1}, N3=50kgN ha^{-1}, N4=60kgN ha^{-1}.

4.6 Land management and P rates interaction effect on total nitrogen

P rate of 13.2kgP ha^{-1} resulted in higher total nitrogen content (1.9g kg^{-1}) in soils of SDIC followed by 6.6kgP ha^{-1} and 26.4kgP ha^{-1} respectively. Similar result was obtained in soils of SC with 13.2kgP ha^{-1}, resulting in higher total nitrogen (1.6g kg^{-1}). This was followed by 26.4kgP ha^{-1} and 6.6kgP ha^{-1}, having the least total nitrogen (1.3g kg^{-1} each). This implies that 13.2kgP ha^{-1} will enhance total nitrogen in SDIC than other P rates in different land management practices. In SDOR there was a consistent decrease in total nitrogen as P rates increased. Total nitrogen content of SDNT was generally low when compared to other land management (Fig 4.12). Thus, SDIC could be suggested to better enhance total nitrogen with P rate of 13.2kgP ha^{-1} than other land management and P rates. The interaction was generally statistically significant ($P<0.001$).

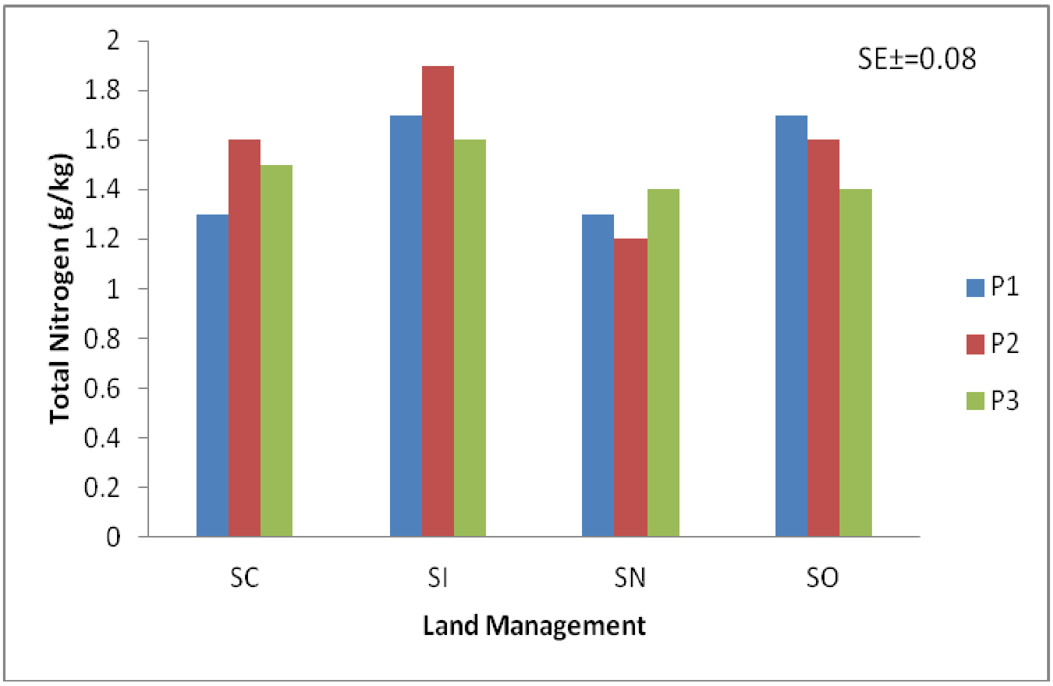


Fig: 4.12 Land Management and P rates interaction effect on total nitrogen.

SC= Sorghum alone under Conventional Tillage; SI=SDIC=Sorghum/*Desmodium*-incorporated under Conservation Tillage; SN=SDNT=Sorghum/*Desmodium* under No-Tillage, SO= SDOR=Sorghum/*Desmodium* on old Ridge.
P= Phosphorus Fertilizer (SSP) Where; P1= 6.6kgP ha^{-1}, P2=13.2kgP ha^{-1}, P3=26.4kgP ha^{-1}.

4.6.1 Land management and N rates interaction effect on total nitrogen

SDIC contained highest amount of total nitrogen (2.5g kg^{-1}) than the other land management practices when 50kgN ha^{-1} was applied compared to the other N rates (Fig.4.13). This implies that SDIC would perform better in increasing amount of total nitrogen in soils more than the rest Land Management practices with the application of 50kgN ha^{-1}. However, the interaction between land management and N rates was highly significant ($P \leq 0.001$).

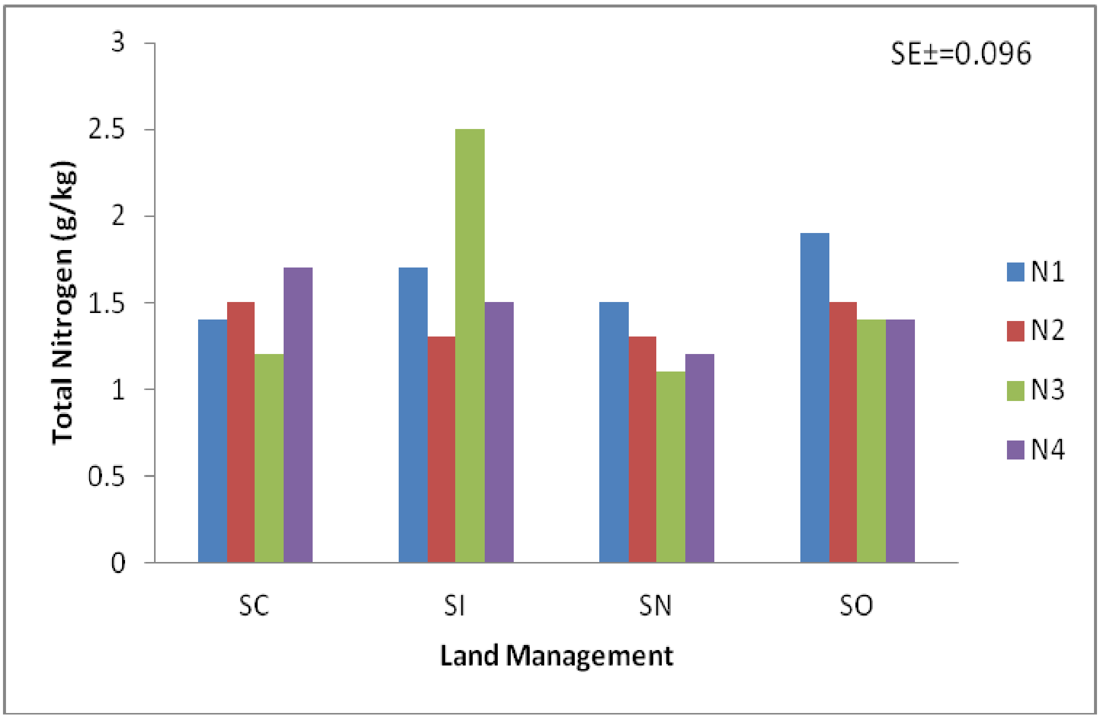


Fig. 4.13 Land Management and N rates interaction effect on total nitrogen

SC= Sorghum alone under Conventional Tillage; SI=SDIC=Sorghum/*Desmodium*-Incorporated under Conservation Tillage; SN=SDNT=Sorghum/*Desmodium* under No-Tillage, SO=SDOR=Sorghum/*Desmodium* on Ridge.
N= Nitrogen Fertilizer (Urea) Where; N1= 30kgN ha^{-1}, N2= 40kgN ha^{-1}, N3= 50kgN ha^{-1}, N4= 60kgN ha^{-1}.

4.6.2 Land management and soil depth interaction effect on total nitrogen

Amount of total nitrogen was higher at surface (0-5 cm) depth of all land management practices; except for SC, where the amount of total nitrogen at 0-5 cm depth was at par with total nitrogen at 5-15 cm depth but lowest in SDOR. More so, total nitrogen decreased down the soil profile for all land management practices, except for SDOR (Fig.4.14).

Generally, surface layer (0-5 cm) depth of SDIC contained the highest (2.0g kg^{-1}) amount of total nitrogen. This could be attributed to high rate of decomposition (i.e. mineralization) of *Desmodium uncinatum* and N-fixation potentials of *Desmodium uncinatum*. The interaction was generally statistically significant ($P<0.001$).

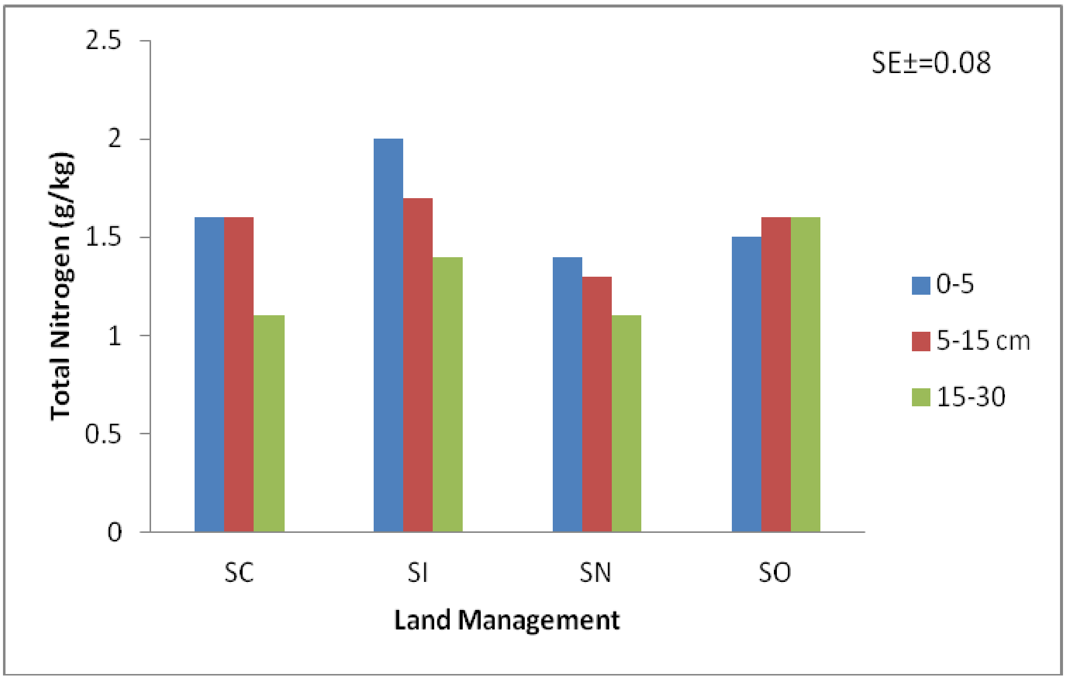


Fig. 4.14 Land Management and Soil depth interaction effect on total nitrogen.

SC=Sorghum alone under Conventional Tillage; SI=SDIC=Sorghum/*Desmodium*-incorporated under Conservation Tillage; SN=SDNT=Sorghum/*Desmodium* under No-Tillage; SO=SDOR=Sorghum/*Desmodium* on old Ridge.

4.6.3 P rates and Soil depth interaction effect on total nitrogen

Interaction between P rates and soil depth revealed that both 6.6kgP ha^{-1} and 26.4kgP ha^{-1} contributed more total nitrogen at the surface than 13.2kgP ha^{-1}. Both 6.6kgP ha^{-1} and 26.4kgP ha^{-1} were observed to contribute the same amount of total nitrogen (1.7g kg^{-1}) at the surface 0-5 cm depth (Fig.4.15). Though, the interaction was statistically significant ($P<0.05$). However the amount of total nitrogen decreased with depth when 6.6kgP ha^{-1} and 26.4kgP ha^{-1} were applied to the soil.

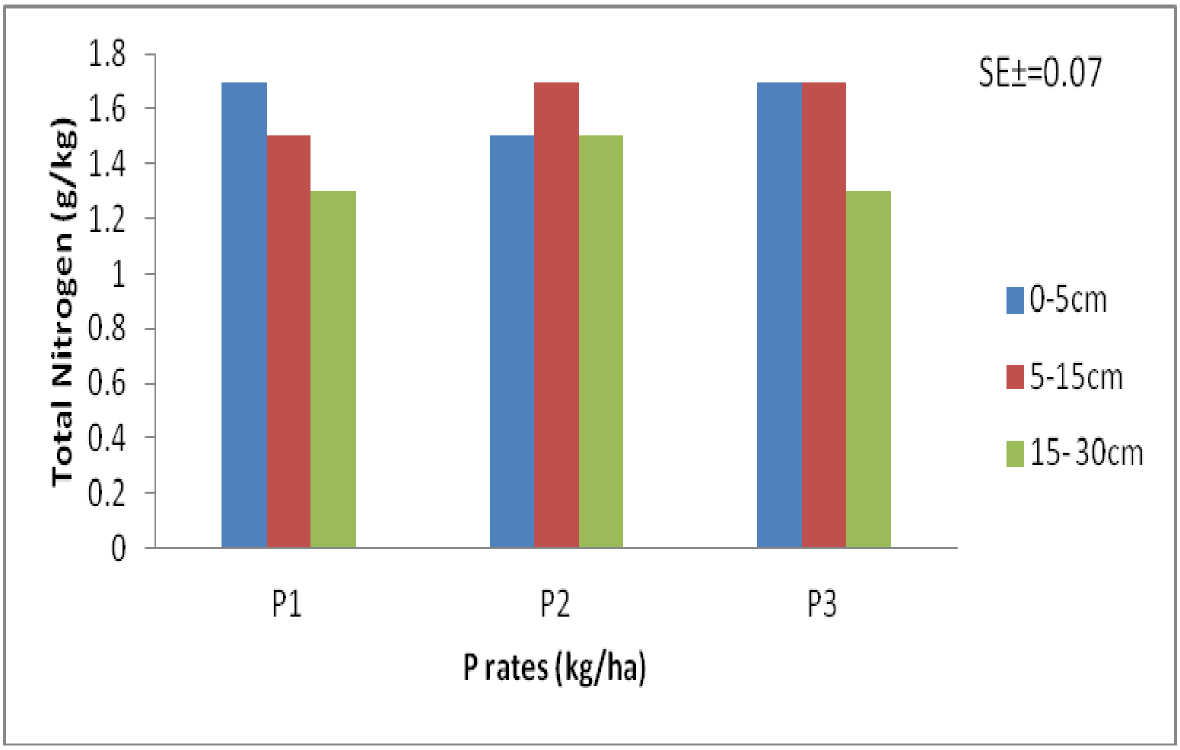


Fig. 4.15 P rates and soil depth interaction effect on total nitrogen

P=Phosphorus Fertilizer (SSP) Where; P1=6.6kgP ha^{-1}, P2 =13.2kgP ha^{-1} & P3=26.4kgP ha^{-1}.

4.6.4 Land management, N and P rates interaction effect on total nitrogen

In SDIC, the amount of total nitrogen was increased with increase in P rates of 6.6kgP ha^{-1} and 13.2kgP ha^{-1} and decreased at 26.4kgP ha^{-1} when 30kgN ha^{-1} was applied along each P rate. The same trend was observed when 40kgN ha^{-1} and 50kgN ha^{-1} were applied but the reverse was the case when 60kgNha^{-1} was applied. At SDNT, total nitrogen decreased with increase in P rates (13.2kgP ha^{-1}), and then increased at P rate of 26.4kgP ha^{-1} when 30kgN ha^{-1} was applied along with each of P rate. Similar trend was observed when 40kgN ha^{-1} and 50kgN ha^{-1} were applied along each P rate. But when 60kgN ha^{-1} was applied, the amount of total nitrogen increased with increase in P rates and decreased at the highest rate of 26.4kgP ha^{-1}.

In SC, total nitrogen content increased with P rates (6.6kgP ha^{-1}, 13.2kgP ha^{-1} and 26.4kgP ha^{-1}) when 60kgN ha^{-1} was applied along each P rate. Total nitrogen content also decreased with P rates at the lowest N rate of 30kgN ha^{-1}.

Generally, total nitrogen content was higher (3.0g kg^{-1}) and (2.4g kg^{-1}) when 50kgN ha^{-1}+13.2kgP ha^{-1} and 50kgN ha^{-1}+6.6kgP ha^{-1} respectively were applied, more than other rates of N and P (Fig. 4.16). This would suggest that 13.2kgP ha^{-1} and 50kgN ha^{-1} could better enhance total nitrogen content in SDIC. Also SDIC was a better land management practice than others. The interaction was generally statistically significant ($P<0.001$).

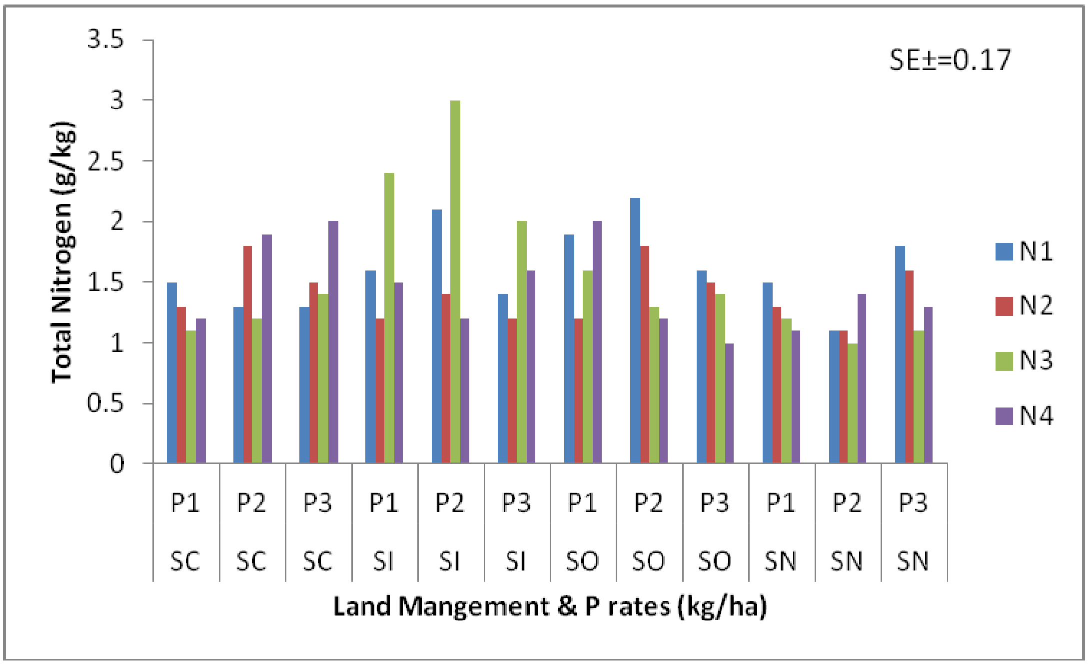


Fig. 4.16 Land management, N and P rates interaction effect on total nitrogen

SC= Sorghum alone under Conventional Tillage, SI=SDIC=Sorghum/*Desmodium*-incorporated under Conservation Tillage, SN=SDNT=Sorghum/*Desmodium* under No-Tillage & SO=SDOR=Sorghum/*Desmodium* on old Ridge.
P= Phosphorus Fertilizer (SSP) Where; P1= 6.6kgPha$^{-1,}$ P2= 13.2kgPha^{-1} & P3= 26.4kgPha^{-1}.
N= Nitrogen Fertilizer (Urea) Where; N1= 30kgNha^{-1}, N2=40kgNha^{-1}, N3=50kgNha^{-1}, N4=60kgNha^{-1}.

4.6.5 N and P rates and soil depths interaction effect on total nitrogen.

Total nitrogen content of experimental field was higher (2.0g kg^{-1}) at the surface (0-5 cm) depth when each of 30kgN ha^{-1} and 50kgN ha^{-1} was applied with 6.6kgP ha^{-1} than other N and P rate. Total nitrogen also decreased down the soil profile. Similar trend was observed for 26.4kgP ha^{-1} interacting with each 40kgN ha^{-1} and 50kgN ha^{-1} (Fig. 4.17).

Interaction between 6.6kgP ha^{-1} and each of 30kgN ha^{-1} and 50kgN ha^{-1} resulted in the same amount of total nitrogen; for reasons of reduced inorganic fertilizer use and optimum production, the interaction/ combination of 30kgN ha^{-1} +6.6kgP ha^{-1} could be applied.

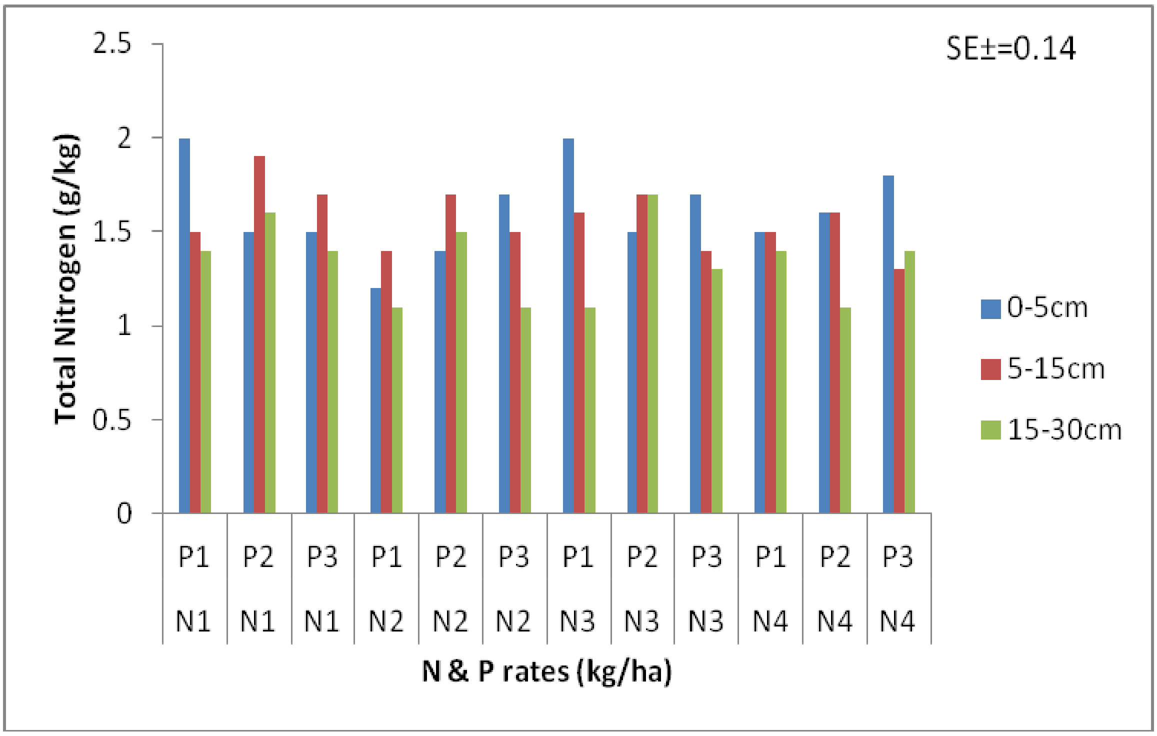


Fig. 4.17 N and P rates (Kgha^{-1}) and soil depths (cm) interaction effects on total nitrogen.

N= Nitrogen Fertilizer (Urea) Where; N1= 30kgN ha^{-1}, N2= 40kgN ha^{-1}, N3= 50kgN ha^{-1}, N4=60kgN ha^{-1}.

P= Phosphorus Fertilizer (SSP) Where; P1= 6.6kgP ha^{-1}, P2=13.2kgP ha^{-1}, P3=26.2kgP ha^{-1}.

4.8 Land management and N rates interaction effect on Plant height, 14 WAP

At (14 WAP), 40kgN ha^{-1} had the tallest plant height (206 cm, 254 cm and 250.08 cm) under the land management practices (SC, SDNT and SDOR respectively), except for SDIC where 60kgN ha^{-1} produced tallest plant height followed by 40kgN ha^{-1}. Generally, the interaction was not statistically significant (P>0.05), however, under the different land management practices, 50kgN ha^{-1} resulted in least sorghum plant height. The 30kgN ha^{-1} preceded 40kgN ha^{-1} in terms of plant height in all land management practices, (Fig. 4.18), except SC. Therefore, it can be inferred that 40kgN ha^{-1} would result in higher sorghum plant height in the land management practices; particularly, in SDNT.

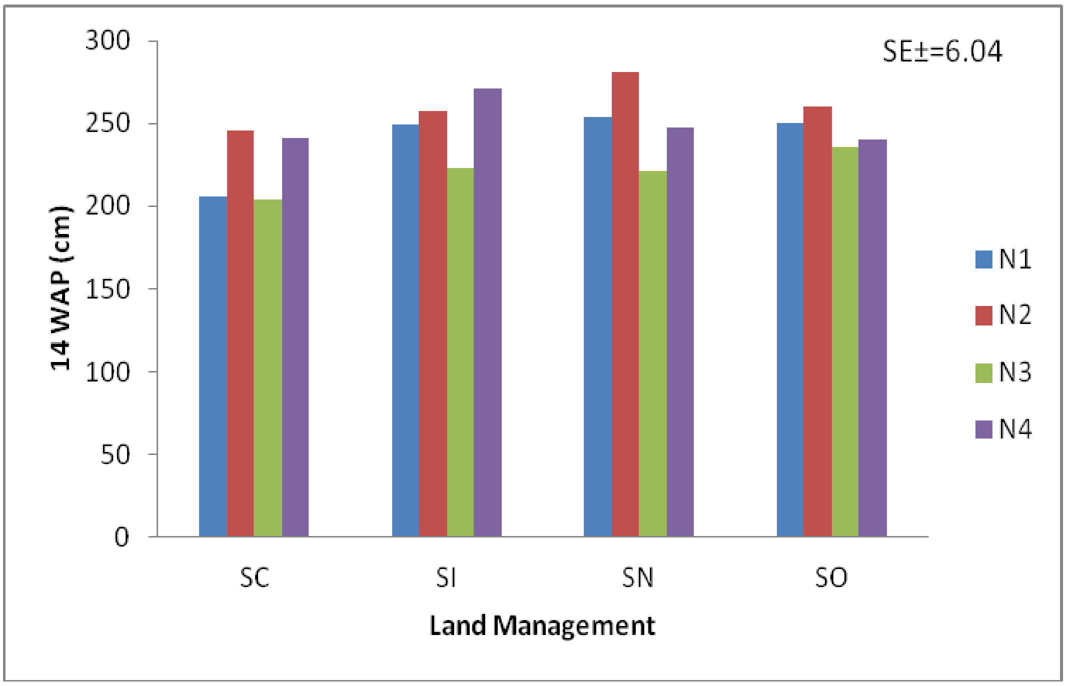


Fig. 4.18 Land management and N rates interaction effect on Plant height, 14 WAP

SC= Sorghum alone under Conventional Tillage; SI=SDIC=Sorghum/*Desmodium*-incorporated under Conservation Tillage; SN=SDNT=Sorghum/*Desmodium* under No-Tillage & SO=SDOR=Sorghum/*Desmodium* on Old Ridge.
N= Nitrogen Fertilizer (Urea) Where; N1= 30kgN ha^{-1}, N2= 40kgN ha^{-1}, N3= 50kgN ha^{-1}, N4= 60kgN ha^{-1}.
WAP= Weeks after Planting.

4.8.1 Land management, N and P rates interaction effect on Plant height, 14 WAP

At 14WAP, there was a consistent increase in plant height as P rates increase from 6.6kgP ha^{-1} to 13.2kgP ha^{-1} and decreased at 26.4kgP ha^{-1} when 40kgN ha^{-1} was applied along with each P rate in both SC and SDNT. However, in SDOR plant heights decreased with P rates and increased at 26.4kgP ha^{-1} when 40kgN ha^{-1} was applied along with each P rates. On the other hand, the combination of 30kgN ha^{-1} with each of 6.6kgP ha^{-1}, 13.2kgP ha^{-1} and 26.4kgP ha^{-1} resulted in increased plant height with increase in P rates under SDOR and SDNT at 14 WAP.

SDIC resulted in tallest sorghum plant height (312.5 cm) when 60kgN ha^{-1} was applied with P rate of 6.6kgP ha^{-1} (Fig. 4.19). Generally, the interaction was statistically significant ($P<0.001$).

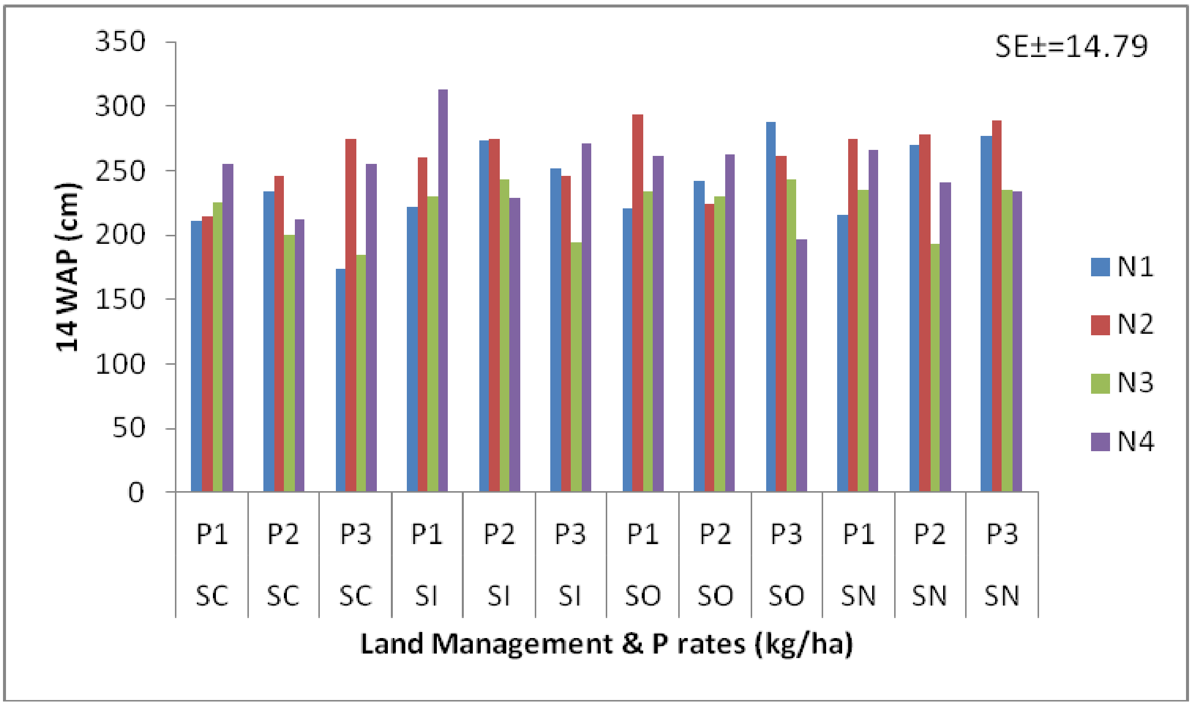


Fig. 4.19 Land management, N and P rates interaction effect on Plant height (cm), 14 WAP

SC= Sorghum alone under Conventional Tillage, SI=SDIC=Sorghum/*Desmodium*-incorporated under Conservation Tillage, SN=SDNT=Sorghum/*Desmodium* under No-Tillage & SO=SDOR=Sorghum/*Desmodium* on Old Ridge.
P= Phosphorus Fertilizer (SSP) Where; P1= 6.6kgPha^{-1}, P2= 13.2kgPha^{-1} & P3= 26.4kgPha^{-1}.
N= Nitrogen Fertilizer (Urea) Where; N1= 30kgNha^{-1}, N2=40kgNha^{-1}, N3=50kgNha^{-1} & N4=60kgNha^{-1}.
WAP= Weeks after Planting.

4.8.2 N and P rates interaction effect on plant height, 14WAP

At 14 WAP, 60kgN ha^{-1} and 6.6kgP ha^{-1} resulted in the tallest sorghum plant height (275 cm), followed by 40kgN ha^{-1} and 26.4kgP ha^{-1} which had (260 cm). 50kgN ha^{-1} and 26.4kgP ha^{-1} resulted in the least sorghum plant (205 cm) height. Therefore, 60kgN ha^{-1} and 6.6kgP ha^{-1} would interact to result in higher sorghum plant height than other N and P rates interaction (Fig 4.20). The interaction was generally significant ($P<0.001$).

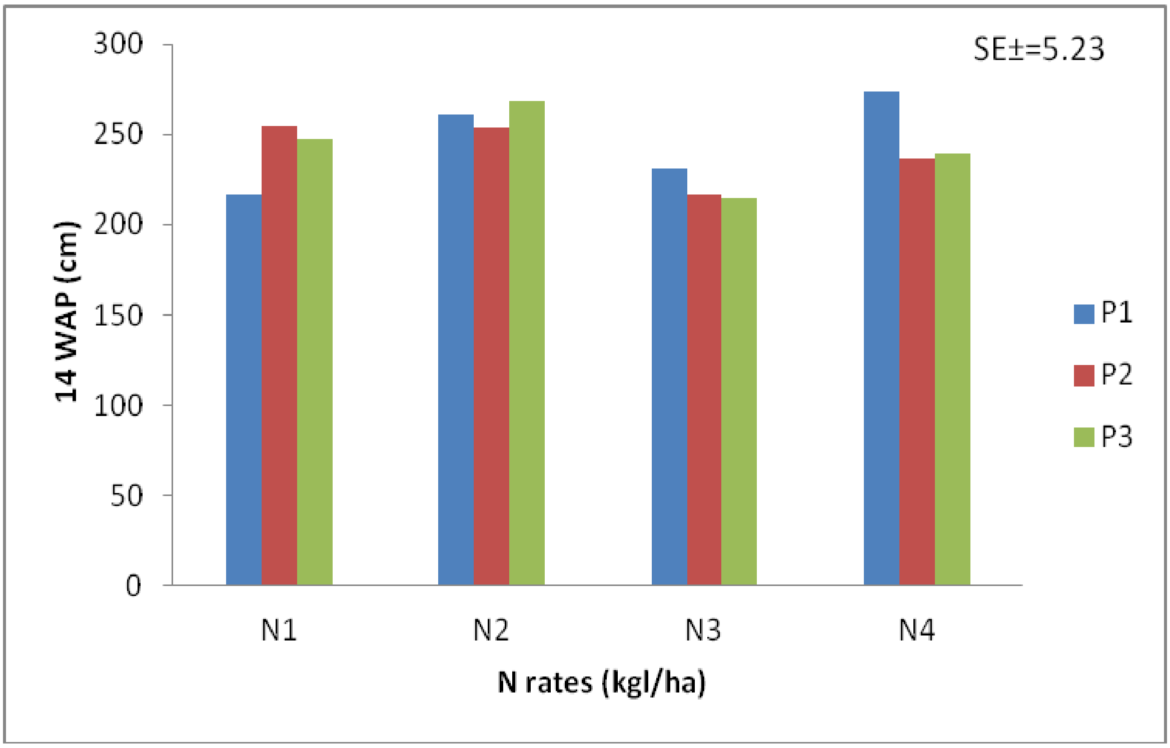


Fig: 4.20 N and P rates interaction effect on Plant height (cm), 14WAP.

N= Nitrogen Fertilizer (Urea) Where; N1=30kgNha^{-1}, N2=40kgNha^{-1}, N3=50kgNha^{-1} & N4=60kgNha^{-1}.
P= Phosphorus Fertilizer (SSP) Where; P1=6.6kgPha^{-1}, P2=13.2kgPha^{-1}, & P3=26.4kgPha^{-1}.
WAP= Weeks after Planting.

4.9 Land management and N rates interaction effect on Plant height at 10 WAP

SDIC had tallest Sorghum plant height (240.5 cm) when 60kgN ha^{-1} was applied, as compared with other land management practices and N rates at 10WAP. 40kgN ha^{-1} produced the second tallest sorghum plant height (208.5 cm) under SDIC but resulted in higher sorghum plant height than other N rates in SDOR, SDNT, and SDOR. The interaction was generally statistically significant ($P<0.001$). However, 50kgN ha^{-1} produced the least sorghum plant height in all land management practices; except in SDNT, where it preceded 40kgN ha^{-1} (Fig. 4.21).

Therefore, it could be inferred that 40kgN ha^{-1} would improve plant height in all land management practices better than other N rates; though 60kgN ha^{-1} produced the highest plant height in SDIC to be better than 40kgN ha^{-1}.

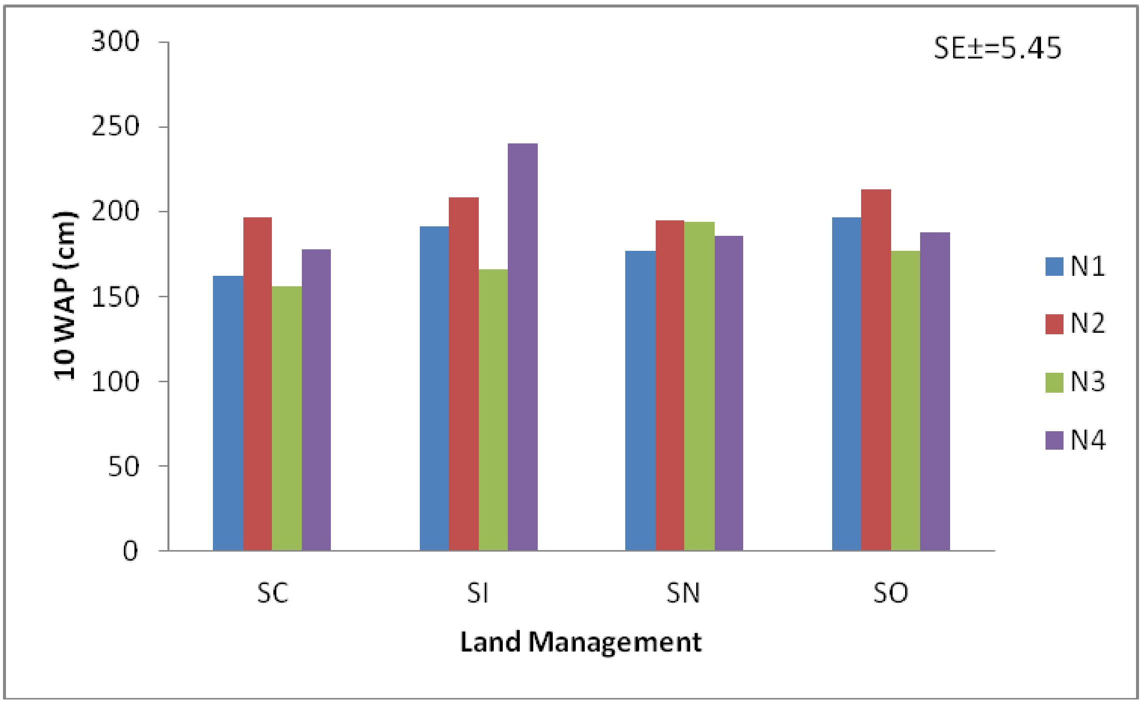


Fig. 4.21 Land Management and N rates interaction effect on Plant height (cm), 10 WAP

SC= Sorghum alone under Conventional Tillage; SI=SDIC=Sorghum/*Desmodium*-incorporated under Conservation Tillage; SN=SDNT=Sorghum/*Desmodium* under No-Tillage & SO=SDOR=Sorghum/*Desmodium* on Ridge.
N= Nitrogen Fertilizer (Urea) Where; N1= 30kgNha^{-1}, N2= 40kgNha$^{-1,}$ N3= 50kgNha^{-1}, N4= 60kgNha^{-1}.
WAP= Weeks after Planting.

4.9.1 Land management, N and P rates interaction effect on Plant height, 10 WAP

At 10WAP, interaction between 40kgN ha^{-1} and 26.4kgP ha^{-1} resulted in highest (237.5 cm) sorghum plant height under SC while 60kgN ha^{-1} and 13.2kgP ha^{-1} resulted in the lowest (110.75 cm) plant height. At SDIC, 60kgNha^{-1} and 6.6kgP ha^{-1} gave the highest (298.5 cm) sorghum plant height followed by 40kgN ha^{-1} and 13.2kgP ha^{-1} while 50kgN ha^{-1} and 26.4kgP ha^{-1} resulted in the least (142.5 cm) sorghum plant height.

Interaction between 60kgN ha^{-1} and 6.6kgP ha^{-1} produced a higher (252.0 cm) sorghum plant height under SDOR, while interaction between 30kgN ha^{-1} and 6.6kgP ha^{-1} resulted in least (117.5 cm). At SDNT, 40kgN ha^{-1} and 6.6kgP ha^{-1} interacted to produce the highest (243.5 cm) sorghum plant height (Fig 4.22). The interaction was generally statistically significant ($P<0.001$).

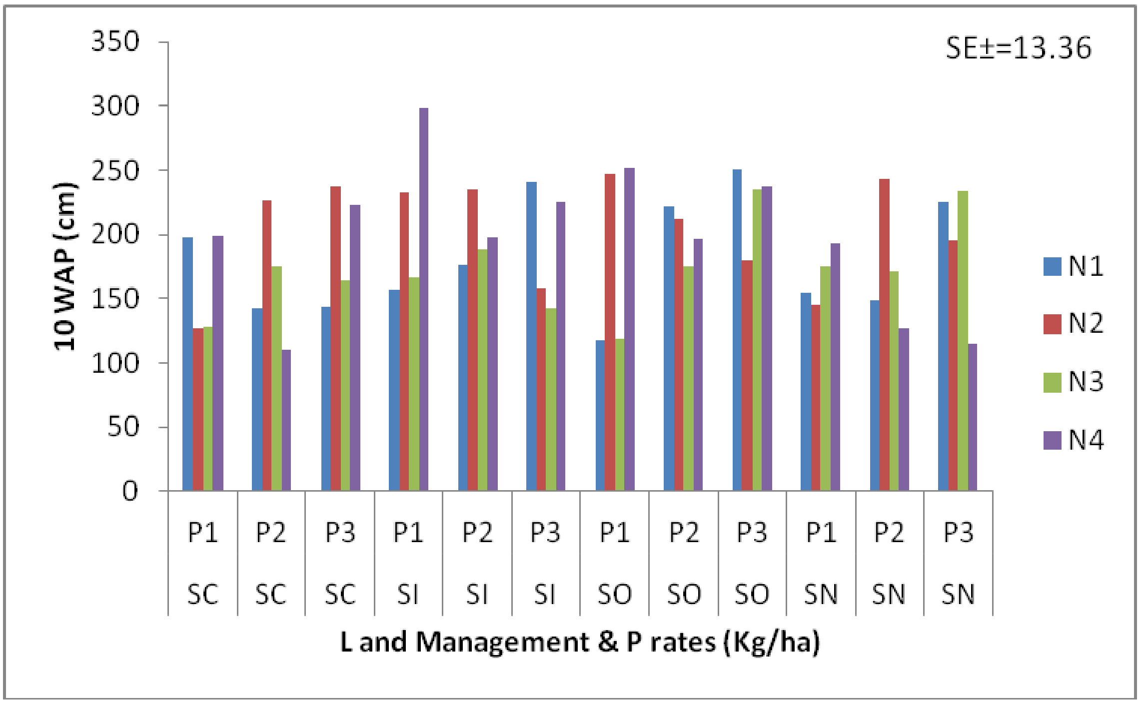


Fig. 4.22 Land management, N and P rates interaction effect on Plant height (cm), 10 WAP

SC= Sorghum alone under Conventional Tillage, SI=SDIC=Sorghum/*Desmodium*-incorporated under Conservation Tillage, SN=SDNT=Sorghum/*Desmodium* under No-Tillage & SO=SDOR=Sorghum/*Desmodium* on Old Ridge.
P= Phosphorus Fertilizer (SSP) Where; P1= 6.6kgP ha^{-1}, P2= 13.2kgP ha^{-1}, P3= 26.4kgP ha^{-1}.
N= Nitrogen Fertilizer (Urea) Where; N1= 30kgN ha^{-1}, N2=40kgN ha^{-1}, N3=50kgN ha^{-1}, N4=60kgN ha^{-1}.
WAP= Weeks after Planting

4.9.2 N and P rates interaction effect on plant height, 10WAP

At 10WAP, 60kgN ha^{-1} and 6.6kgP ha^{-1} resulted in tallest sorghum plant height (235.69 cm), followed by 40kgN ha^{-1} and 13.2kgP ha^{-1} which had (229.25 cm). The 50kgN ha^{-1} and 6.6kgP ha^{-1} interactions resulted in the least sorghum plant height (147.31 cm). The result showed that at 10WAP, plant height increased with increase in N rates at P rate of 13.2kgP ha^{-1}, then decreased from 50kgN ha^{-1}, implying that beyond 40kgN ha^{-1} at 13.2kgP ha^{-1}, plant height will begin to decline. Also, the result showed that at 10WAP, interaction between different N rates of 30kgN ha^{-1}, 40kgN ha^{-1}, 50kgN ha^{-1} with the exception of 60kgN ha^{-1} at 13.2kgP ha^{-1} produced taller sorghum plant heights than when different N rates (30kgN ha^{-1}, 40kgN ha^{-1}, and 50kgN ha^{-1}) interacted with 6.6kgP ha^{-1} (Fig. 4.23). This would suggest that 40kgN ha^{-1} and 13.2kgP ha^{-1} interaction could enhance sorghum plant height performance better than the other N and P rates' interaction. Generally, the interaction was statistically significant ($P<0.001$).

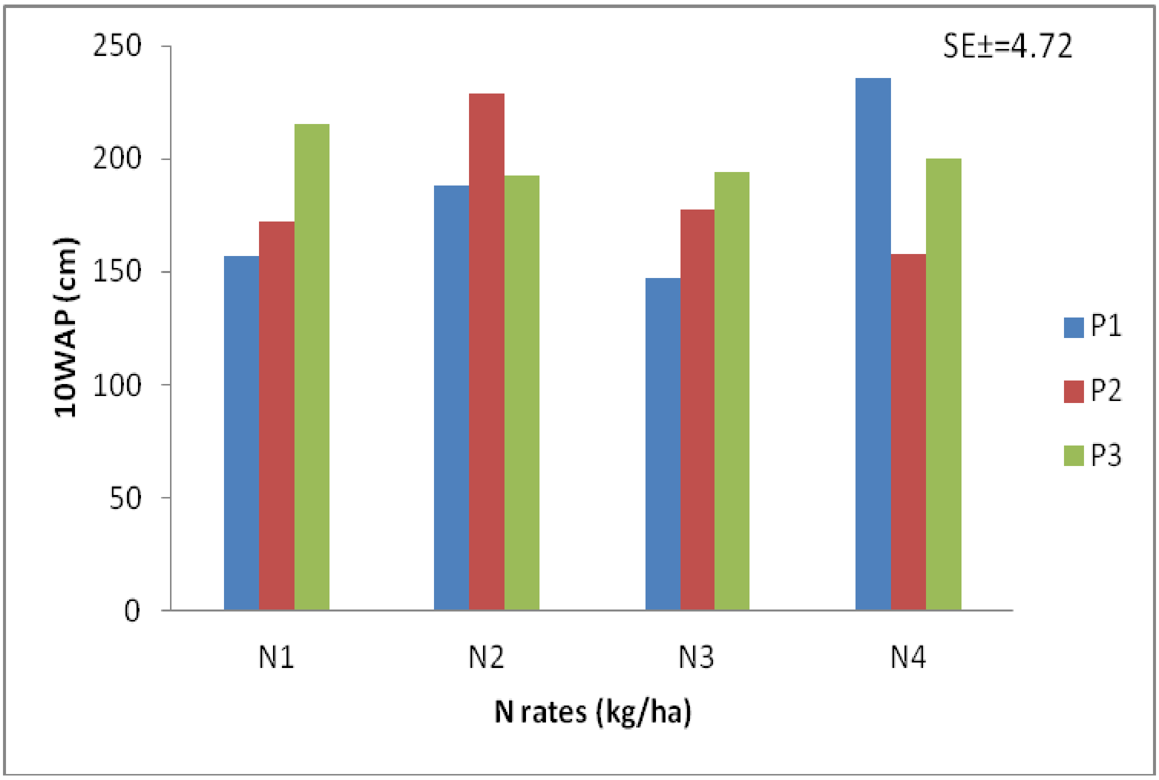


Fig. 4.23 N and P rates interaction effect on plant height (cm), 10WAP

N= Nitrogen Fertilizer (Urea) Where; N1=30kgNha^{-1}, N2=40kgNha^{-1}, N3=50kgNha^{-1}, N4=60kgNha^{-1}. P= Phosphorus Fertilizer (SSP) Where; P1=6.6kgPha^{-1}, P2=13.2kgPha^{-1}, P3=26.4kgPha^{-1}.WAP= Weeks after Planting.

4.9.3 Land management and P rates interaction effect on plant height, 10WAP

At 10WAP, plant height increased with increase in P rates in SDNT and SC while in SDIC, plant height decreased with increased P rates (Fig. 4.24). The interaction was generally statistically significant ($P<0.001$). However, at SDOR, the plant height showed inconsistency with P rates application. At 10WAP, sorghum plant heights was tallest (222.94 cm) in SDNT when 26.4kgP ha^{-1} was applied, followed by SDIC when 6.6kgP ha^{-1} was applied. Thus, under conservation tillage systems with *Desmodium*, 6.6kgP ha^{-1} would be preferred while under No-tillage system with *Desmodium*, 26.4kgP ha^{-1} would improve sorghum plant height performance better.

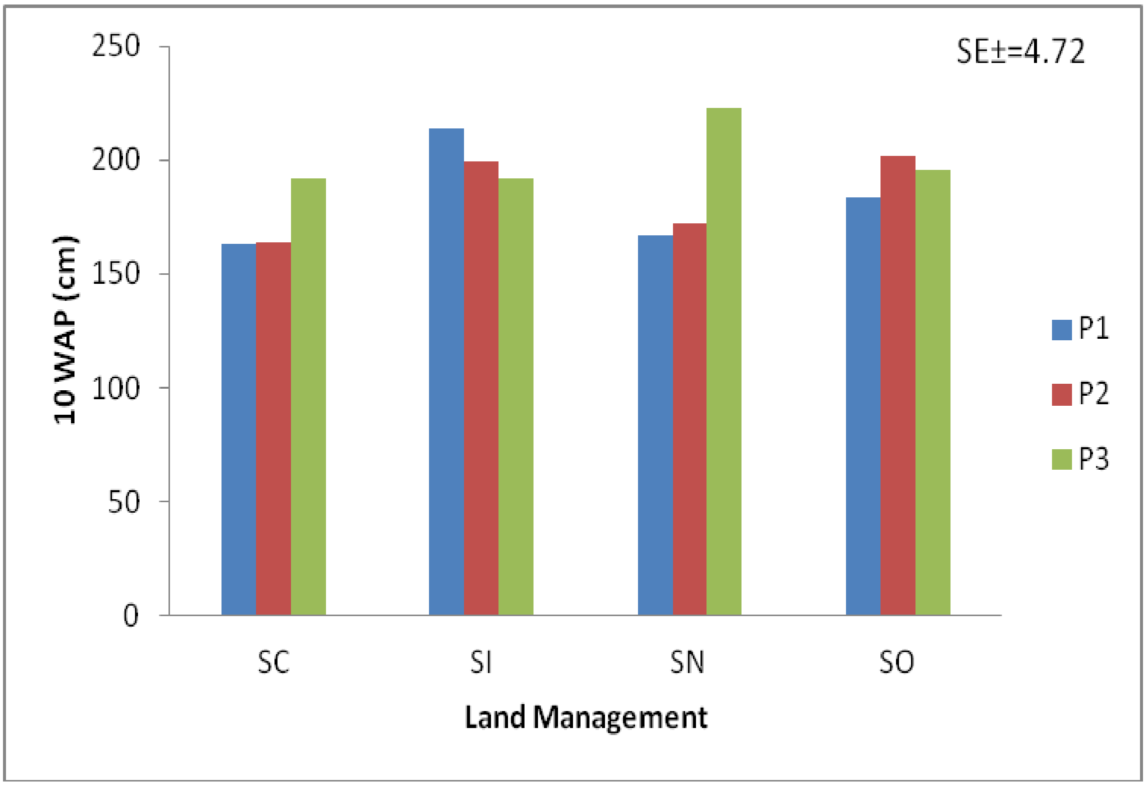


Fig. 4.24 Land management and P rates interaction effect on Plant height (cm), 10WAP

SC= Sorghum alone under Conventional Tillage; SI=SDIC=Sorghum/*Desmodium*-incorporated under Conservation Tillage; SN=SDNT=Sorghum/*Desmodium* under No-Tillage; SO= SDOR=Sorghum/*Desmodium* on Old Ridge.
P= Phosphorus Fertilizer (SSP) Where; P1= 6.6kgP ha^{-1}, P2=13.2kgP ha^{-1}, P3=26.4kgP ha^{-1}.
WAP= Weeks after Planting.

4.10 N and P rates interaction effect on plant height, 6WAP

At 30kgN ha^{-1}, plants decreased with increasing P rates at 6WAP while at 60kgN ha^{-1}, plant height increased with increase in P rates. Sorghum plant height was highest (62.69 cm), at 30kgN ha^{-1} and 6.6kgP ha^{-1}, followed by 50kgN ha^{-1} and 6.6kgP ha^{-1} which resulted in a sorghum plant height of 60.81 cm (Fig 4.25). The interaction was generally statistically significant ($P<0.001$).

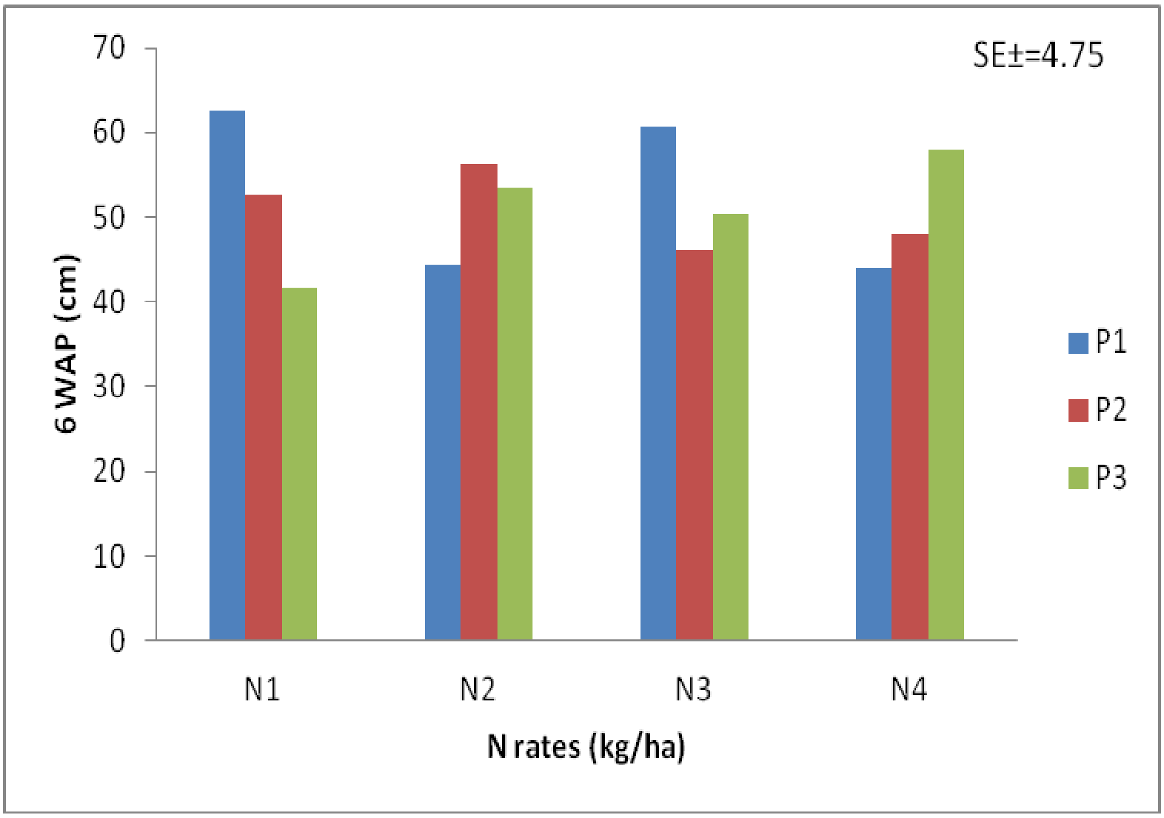


Fig. 4.25 N and P rates interaction effect on plant height (cm), 6WAP

N= Nitrogen Fertilizer (Urea) Where; N1=30kgN ha^{-1}, N2=40kgN ha^{-1}, N3=50kgN ha^{-1}, N4=60kgN ha^{-1}.
P= Phosphorus Fertilizer (SSP) Where; P1=6.6kgP ha^{-1}, P2=13.2kgP ha^{-1}, P3=26.4kgP ha^{-1}.
WAP= Weeks after Planting.

4.11 Land management, N and P rates interaction effect on 1000 grains yield (g)

Interaction between 40kgN ha^{-1} and 26.4kgP ha^{-1} resulted significantly in the highest (37.57 g) 1000 sorghum grains' weight under SC while interaction between 40kNha^{-1} and 6.6kgP ha^{-1} resulted in the least (29.45 g). 50kgN ha^{-1} and 13.2kgP ha^{-1} interacted better ($P<0.05$) under SDIC, resulting in significantly the highest (37.39 g) production of 1000 sorghum grains' weight while 30kgN ha^{-1} and 6.6kgP ha^{-1} gave the least (32.34 g) 1000 sorghum grains' weight. At SDOR, 40kgN ha^{-1} and 26.4kgPha^{-1} resulted significantly in the highest (34.66 g) sorghum grain weight while 50kgN ha^{-1} and 26.4kgP ha^{-1} significantly gave the least (31.23 g) 1000 sorghum grains' weight. At SDNT, interaction between 60kgNha^{-1} and 26.4kgP ha^{-1} produced significantly the highest (35.57 g) 1000 sorghum grains weight than other fertilizer rates interaction, while interaction between 60kgN ha^{-1} and 6.6kgP ha^{-1} significantly resulted in the least (31.32 g) 1000 sorghum grains weight (Fig 4.26). Therefore, 50kgN ha^{-1} and 30kgN ha^{-1} combinations under SDIC resulted in better grain fill (37.39 g) than the other fertilizer rates and land use management practices, and is suggested for adoption by farmers. Generally, the interaction is statistically significant ($P<0.05$).

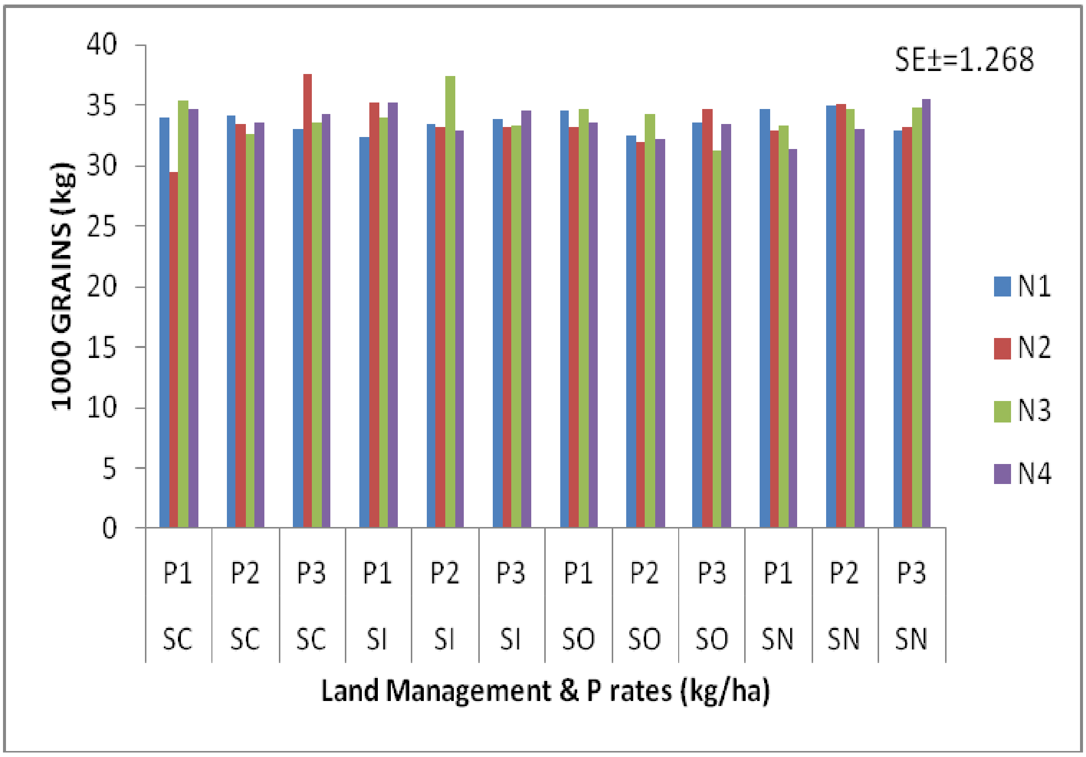


Fig. 4.26 Land management, N and P rates interaction effect on yield, 1000 grains (g)

SC= Sorghum alone under Conventional Tillage, SI=SDIC=Sorghum/*Desmodium*-incorporated under Conservation Tillage, SN=SDNT=Sorghum/*Desmodium* under No-Tillage; SO=SDOR=Sorghum/*Desmodium* on Old ridge.P= Phosphorus Fertilizer (SSP) Where; P1= 6.6kgP ha^{-1}, P2= 13.2kgP ha^{-1}, P3= 26.4kgP ha^{-1}.
N= Nitrogen Fertilizer (Urea) Where; N1= 30kgN ha^{-1}, N2=40kgN ha^{-1}, N3=50kgN ha^{-1}, N4=60kgN ha^{-1}.

4.12 Effect of Treatments on Yield and Growth parameters of Sorghum

Data in Table 4.4 shows that Sorghum/*Desmodium*-incorporated (SDIC) under conservation tillage produced the highest sorghum stover yield (5.09t ha^{-1}) which was significantly ($P<0.05$) greater than yields from sorghum/*Desmodium* under No-tillage, SDNT (4.34t ha^{-1}) and Sorghum/*Desmodium* on Old ridge, SDOR (4.01t ha^{-1}) respectively. Sole sorghum under conventional tillage (SC) produced the lowest stover yield (3.74t ha^{-1}) which was significantly ($P<0.001$) lower than other treatments. This result suggests that Sorghum/*Desmodium*-incorporated with conservation tillage (SDIC) significantly ($P<0.05$) improved sorghum dry matter better than the other treatments, (Jekaiye 2012 ; Odunze *et al.,* 2012). This could result from enhanced organic carbon/organic matter sequestration by *Desmodium uncinatum* following 2 years *in situ* planting (Odunze *et al.*, 2012). Application of 50kgN ha^{-1} resulted in significantly ($P<0.05$) higher stover yield (4.83tha^{-1}) of sorghum followed by 40kgN ha^{-1} while 30kgN ha^{-1} significantly resulted in the least (3.54t ha^{-1}) stover yield. On the other hand, application of 26.4kgP ha^{-1} significantly ($P<0.05$) enhanced stover yield (4.50t ha^{-1}) better than other P- fertilizer rates.

Grain yield of sorghum obtained from all the land management practices were significantly ($P<0.05$) different. However, Sorghum/*Desmodium*-incoporated (SDIC) resulted in significantly ($P<0.05$) higher (1.48t ha^{-1}) sorghum grain yield compared to other treatments; particularly sole sorghum under conventional tillage (SC), which had the least sorghum grain yield (1.17t ha^{-1}) and was significantly ($P<0.05$) lower than other treatments. These results agree with Odunze *et al.* (2013) which showed that forage legume incorporated under conservation tillage enhanced maize grain yield.

P rates of 6.6kgP ha^{-1} and 26.4kgP ha^{-1} produced the highest grain yield (1.30t ha^{-1} each) though they were not significantly different; hence, application of 6.6kgP ha^{-1} could be a preferred option because of yields obtained from plots that received different N rates also did not significantly differ from each other. However, the plot that received 50kgN ha^{-1} produced the highest sorghum grain yield (1.35t ha^{-1}). Therefore, it can be inferred that a combination of SDIC, 50kgN ha^{-1} and 26.4kgP ha^{-1} would support higher sorghum grain and stover production on a sustainable basis (Bundy *et al.*,2011; Odunze *et al.*,2013), better than the other treatments in the Alfisols Nigerian Guinea Savanna based on this study.

The result for 1000grains' (Table 4.4) weight shows that there was no significant difference between the land managements. However, treatment with Sorghum/*Desmodium*-incorporated under conservation tillage (SDIC) gave the highest 1000grains weight (34.02g ha^{-1}) followed by Sorghum/*Desmodium* under No tillage SDNT and the least were from sole Sorghum under conventional tillage SC (33.3g ha^{-1}). Application of 50kgN ha^{-1} and 26.4kgP ha^{-1} also had the highest 1000grains weight, suggesting better sorghum grains' filling under SDIC + 50kgN ha^{-1} and 26.4kgP ha^{-1}.

Table 4.4 reveals that, Sorghum/*Desmodium* incorporated under conservation tillage (SDIC), Sorghum/*Desmodium* under no-tillage (SDNT) and Sorghum/*Desmodium* on Old ridge (SDOR) significantly ($P<0.05$) enhanced sorghum height at 10 and 14 WAPs better than Sorghum alone under conventional (SC) tillage. However, at 10WAPs SDIC was more superior in terms of plant height followed by SDOR and SDNT; except at 14WAP, where SDNT produced the highest plant height (250.79 cm) followed by SDIC which gave a plant height of 249.98 cm. This suggests that treatment with *Desmodium uncinatum* (conservation tillage) would better improve Sorghum plant height than where there are no *Desmodium uncinatum* (SC). This result agrees with findings of Odunze *et al.* (2013) and Jekaiye (2012).

At 14WAPs, Sorghum/*Desmodium* under no-tillage, Sorghum/*Desmodium*-incorporated under conservation tillage (SDIC) and Sorghum/*Desmodium* on old ridge (SDOR) significantly ($P<0.05$) enhanced sorghum height better than sole Sorghum under conventional tillage (SC).

Application of 40kgN ha^{-1} and 26.4kgP ha^{-1} affected plant height at both 10 and 14 WAP significantly than other N and P rates. This suggests that 40kgN ha^{-1} and 26.4kgP ha^{-1} would interact better with SDIC, SDNT and SDOR in promoting the sorghum plant height as compared with sorghum alone under conventional tillage (SC).

Table 4.4 Effect of Treatments (Land Management, N and P rates) on Yield and Growth parameters of Sorghum

TREATMENTS	Sorghum grain yield (t ha^{-1})	1000 grains (g)	Sorghum stover yield (t ha^{-1})	6WAP (cm)	10WAP (cm)	14WAP (cm)
Land Management (LGMT)						
SC	1.17d	33.30a	3.74d	60.08a	173.04c	224.13b
SDIC	1.48a	34.02a	5.09a	56.38ab	201.63a	249.98a
SDOR	1.20c	33.79a	4.01c	40.77c	193.44b	246.60a
SDNT	1.32b	33.85a	4.34b	48.85b	187.52b	250.79a
SE±	0.08	0.366	0.245	2.744	2.727	3.019
Phosphorus (P) rates(Kg/ha)						
6.6	1.30a	33.62a	4.26b	52.98a	181.92b	245.89a
13.2	1.28a	33.69a	4.11c	50.75a	184.25b	240.27a
26.4	1.30a	33.90a	4.50a	50.83a	200.55a	242.47a
SE±	0.07	0.32	0.212	2.376	2.361	2.614
Nitrogen (N) rates(Kg/ha)						
30	1.30a	33.66a	3.54d	52.35a	181.48b	239.85c
40	1.20a	33.55a	4.50b	51.40a	203.23a	260.88a
50	1.35a	34.08b	4.83a	52.38a	173.04c	220.81d
60	1.32a	33.67a	4.31b	49.96a	197.88a	249.96b
SE±	0.08	0.366	0.245	2.744	2.727	3.019
Interaction effect						
P×Lmgt	NS	NS	NS	**	***	***
N×Lmgt	NS	NS	NS	NS	***	NS
P×N	NS	NS	NS	NS	***	***
P×N×Lmgt	NS	*	NS	NS	***	***

NS= Not Significant, ***= significant at (P<0.001), **= significant at (P<0.001), *= significant at (P<0.05)

4.13 Changes in Chemical Properties of the Experimental Soil; 2011-2012

The data obtained between 2011 and 2012 (Table 4.5) show that each of the land management practices (SDNT, SDIC, SDOR and SC) at harvest in 2012 lowered the soil pH an indication of increasing acidity. However, pH (6.0) of the surface soil after one year *Desmodium* fallow i.e. CT+D (conventional tillage plus *Desmodium uncinatum* live-mulch) increased by 1.67% compared initial pH (5.9) Table 4.2. At 2012, results of the land management practices show that SDOR caused 4.69% acidity increase, SDIC caused 4.88% increase, and SDNT caused 6.23% increase while SC caused the highest acidity increase of 7.81%.Though, the different land management practices (SDOR, SDIC, SDNT and SC) caused increase in acidity but there were no significant ($P<0.05$) differences between land management, suggesting that one year cropping period was not sufficient for the land management practices to cause significant decrease in acidity level of the soil. However, higher percentage pH increase in SC could be attributed to absence of *Desmodium uncinatum* in that plot after 2 years of continuous tillage of the soil compared SDIC which had *Desmodium uncinatum* live- mulch incorporated and relayed; though the plot was also subjected to 2 years continuous cultivation.

The mean value of organic carbon content of the soil prior to planting at 2011 was low (2.4g kg^{-1}, Table 4.1). At the end of June, 2012, that is, after one year *Desmodium* fallow, organic carbon content increased by 22.58%. At the end of Dec, 2012, there was drastic increase in the values of organic carbon for all the land management (SDIC, SDOR and SDNT) practices; except for SC, which did not show any statistical difference from the values obtained prior to planting in 2011 and at the end of June, 2012 (that is after one year *Desmodium* fallow). SDNT resulted in (65.22%) increase in organic carbon compared with SDIC (58.62%), SDOR (51.02%) while SC had (33.33%) organic carbon. The higher organic carbon content in SDNT could be due to no-tillage effect and impact of *Desmodium* *uncinatum* in the soil plus the *Desmodium uncinatum* live mulch permanent cover, while the lower or slow changes that occurred in SC could be attributed to 2 years continuous cultivation or tilling of the soil and non-incorporation of *Desmodium* or absence of *Desmodium uncinatum* in the soil (Odunze, 2006; Sanchez, 1976; Lal, 1984 and Wild, 1975). This suggests that SDNT would sequester more organic carbon to the soil better than other treatments.

Following one year *Desmodium* fallow CT+D (conventional tillage plus *Desmodium uncinatum* live mulch) available phosphorus increased by 2.35% at surface soil (0-5cm depth) compared to initial surface soil value (8.3mg kg^{-1}) (Table 4.1and 4.2). This increase at the surface after one year could be due to the effect of *Desmodium uncinatum* biomass to improve the top soil layer and also because legumes use more phosphorus for protein synthesis (Marschner, 1998; Odunze *et al.,* 2013) which are returned to the soil following decomposition. However, available phosphorus decreased generally by 1.65% after one year *Desmodium* fallow (Table 4.5). At harvest in 2012, SDNT gave more available phosphorus (10.19mg kg^{-1}) showing an increase of 21.20% compared with SDIC (15.30%), SDOR (1.35%) and SC (2.19%). This result does not agree with the findings of Odunze *et al.* (2013) which revealed decreases in available phosphorus in all treatments after 2 year cropping season. However, the increase in available phosphorus under this experiment could be attributed to the impact of nodules at the root of *Desmodium uncinatum*, biomass decomposition as well as reduced tillage disturbance of the soil under SDNT, SDIC and SDOR.

Total nitrogen content of the Experimental field increased by 50% after one *Desmodium* fallow under CT+D (conventional tillage plus *Desmodium uncinatum* live mulch). At 2012, all the land management practices increased significantly the N contents; SDIC showing 70.59% increase, SDOR (68.75%), SC (66.67%) and SDNT (61.54%) increase. It can then be inferred that conservation tillage with *Desmodium uncinatum* incorporated and relayed would better enhance total nitrogen increase in soils better than other treatments.

Table 4.5 Changes in Chemical Properties of the Experimental Soil; 2011-2012

Parameter	**Initials Aug, 2011**	**CT+D June, 2012**	**% change from Initials**	**SDNT Dec, 2012**	**% change from Initials**	**SDIC Dec, 2012**	**% change from Initials**	**SDOR Dec, 2012**	**% change from Initials**	**SC Dec, 2012**	**% change from Initials**
Soil pH(H_20)	5.8	5.8	0.0	5.46	-6.23	5.53	-4.88	5.54	-4.69	5.38	-7.81
Organic.M	4.1	5.3	22.64	11.7	64.96	9.9	50.59	8.3	50.60	6.1	32.79
Organic. C	2.4	3.1	22.58	6.9	65.22	5.8	58.62	4.9	51.02	3.6	33.33
Avail. P	8.03	7.9	-1.65	10.19	21.20	9.48	15.30	8.14	1.35	8.21	2.19
Total .N	0.5	1.0	50	1.3	61.54	1.7	70.59	1.6	68.75	1.5	66.67

CT+D=Conventional Tillage plus *Desmodium uncinatum* live-mulch (after one year *Desmodium* fallow)
SDNT=Sorghum/*Desmodium* live-mulch under No-Tillage
SDIC= Sorghum/*Desmodium* incorporated under conservation Tillage;
SDOR=Sorghum/*Desmodium* under Old Ridge.

4.14 Soil quality Assessment

Soil quality was assessed using a score scale of 1 to 5 where 1 is rated best and 5 rated worst. Thus, treatment (Land management) with the lowest total score is rated best (SQ1) while that with highest total score is rated worst (SQ4).

Table 4.6 shows that Sorghum/*Desmodium* under conservation tillage (SDIC) scored best for sorghum grain yield (1.48t ha^{-1}), and enhanced soil quality conditions (optimum soil pH, available phosphorus, soil carbon and total nitrogen). Hence, SDIC was rated SQ1 in quality. Optimal conditions in terms (pH, available phosphorus and organic carbon) also prevailed under SDNT, resulting in second sorghum grain yield of 1.32t ha^{-1}. However, this relatively low yield compared with SDIC could have resulted from the lower total nitrogen (61.54%) contents of the soil, against 70.59% obtained under SDIC and other land management's (Table 4.5). Soils under SDNT were rated SQ2 in quality. Soils under SDOR resulted in lower (third) sorghum grain yield (1.20t ha^{-1}) than SDIC and SDNT; perhaps, because of optimal pH, total nitrogen, moderate organic carbon, and lower available phosphorus (Table 4.6). Hence, soils under SDOR were rated SQ3. Conventional tillage without *Desmodium uncinatum* SC resulted in the least sorghum grain yield (1.17t ha^{-1}), had higher acid conditions, lowest organic carbon, moderate available phosphorus and total nitrogen to become SQ4 in quality rating between the different land management practices studied.

Table 4.6 Soil quality Assessment according to Parr *et al.*, 1992

INDICATORS	SDIC	SDNT	SDOR	SC
pH	2	3	1	5
O.C	2	1	3	5
A.VP	2	1	5	3
TN	1	5	2	3
S/YIELD	1	2	3	5
TOTAL SCORE	**8**	**12**	**14**	**21**
Rank	**1**	**2**	**3**	**4**

Source; (Parr *et al*., 1992)
1= Best while, 5= worst.
SDIC= Sorghum/*Desmodium* incoportaed, **SDNT=** Sorghum/Desmodium under no till, **SDOR=** Sorghum/*Desmodium* on old ridge, **SC=** Sole Sorghum under Conventional tillage, **O.C**= Organic Carbon, **A.VP**= Available Phosphorus, **TN**= Total Nitrogen, **S/YIELD=** Sorghum Yield.

CHAPTER FIVE

SUMMARY AND CONCLUSION

5.1 Summary

The need to develop soil fertility enhancement techniques for sustainable crop production in the Guinea Savanna zone of Nigeria is well known because the soils are currently of low fertility status. This study was therefore conducted by intercropping sorghum with a forage legume (*Desmodium uncinatum*) under different tillage systems for soil quality improvement and enhanced sorghum production. The study was carried out in 2011 and 2012. The trials were laid out using a split plot randomized complete block design. The site used was characterised before the fields were cultivated. The test crop was sorghum (samsorg 14).

The results obtained showed that before planting in 2011, bulk density (Bd) and Soil Moisture Content (SMC) of the field was 1.56Mg m^{-3} and 18.5g g^{-1} respectively and increased with depth. Available phosphorus, organic carbon, CEC and total nitrogen values were 8.03mg kg^{-1}, 2.4g kg^{-1}, 5.03cmol kg^{-1} and 0.5g kg^{-1} respectively. These parameters, except available phosphorus and total nitrogen increased with depth. Result also showed that pH of soils before planting in 2011 was slightly acidic; while textural class of experimental soil is silt loam.

By August 2011, the field was planted to *Desmodium uncinatum* and was left to fallow for a period of one year. Soil samples were analyzed and the following results were obtained in June 2012.

- There was no significant change in pH status of the soil.
- Available phosphorus increased at the surface soil (2.35%). However, there was a general decrease in available phosphorus from 8.03mg kg^{-1} to 7.9mg kg^{-1}.

- Organic carbon increased by 22.58% while the CEC was still low (<10cmol kg^{-1}), but increased drastically at the surface soil by 31.34%. Total nitrogen on the other hand, increased by 50% from 0.5g kg^{-1} to 1.0g kg^{-1}.

By December, 2012 (At Harvest), analyzes of soil samples taken from different land managements (SC), (SDIC), (SDOR), and (SDNT) revealed that;

The pH of soils decreased in all land management practices compared to the initial pH status pH (5.8) in June 2012 with SC having the lowest pH (H_20) value (5.38) when compared to other land management practices. This reduction in pH status in SC could be from effect of conventional tillage and absence of *Desmodium uncinatum* for a period of 2-year cropping season.

Sole sorghum under conventional tillage (SC) contributed the least organic carbon (33.33%) compared with the other land management practices. However, SDNT sequestered significantly ($P<0.05$) highest organic carbon content (65.22%) followed SDIC (58.62%) and SDOR (51.02%). The highest available phosphorus was also contributed by SDNT (21.20%) and least in SC (2.19%).

Significantly higher total nitrogen was obtained from SDIC (70.59%) followed by SDOR (68.75%), SC (66.67%) and least in SDNT (61.54%). This implies conservation tillage with *Desmodium uncinatum* live-mulch and incorporated (SDIC) significantly improved total nitrogen compared to other tillage practices.

Sorghum stover at harvest showed that sorghum/*Desmodium* live mulch and incorporated under SDIC treatment resulted in significant ($P<0.05$) production of highest sorghum stover (5.09t ha^{-1}) followed by SDNT (4.34t ha^{-1}) and in SC (3.74t ha^{-1}) which was significantly lower than other treatments.

SDIC treatment also resulted in significantly ($P<0.05$) highest production (1.48t ha^{-1}) of sorghum grain yield followed by SDNT (1.32t ha^{-1}) compared with SC which had significantly least (1.17t ha^{-1}). This result shows that SDIC and SDNT would enhance production of sorghum grains and stover better than SC which had no *Desmodium uncinatum,* though subjected to the same levels of fertilizer treatments.

Height of sorghum plants at 6WAP under SC, SDNT and SDIC were not significantly different, though sorghum plants at 6WAP were higher (60.08 cm) in SC than other treatments. At 10WAP, SDIC resulted in significantly higher sorghum plants than other land management practices. At 14WAP, SDNT, SDIC and SDOR resulted in significantly higher sorghum plant height compared with SC, which was only higher in the first 6WAP and later resulted in the lowest sorghum plant at both 10 and 14 WAP. This reveals that Zero tillage with *Desmodium uncinatum* (SDNT) and Conservation tillage with *Desmodium uncinatum* Live-mulch and incorporated (SDIC) enhanced Sorghum plant height better than conventional tillage without *Desmodium uncinatum* (SC). Zero tillage (SDNT) and conservation tillage (SDIC) practices combination with *Desmodium uncinatum* management practices adopted in this study could be advanced for sustainable sorghum grain and stover yields as well as soil quality maintenance in the Nigerian Savanna Alfisols.

5.2 Conclusion

It was drawn from the study that a combination of 50kgN ha^{-1} and 13.2kgP ha^{-1} interacted better than other N and P interaction in enhancing soil quality and yield of sorghum.

Sole Sorghum under conventional tillage (SC) sequestered the least organic carbon, available phosphorus, and total nitrogen, despite being subjected to the same levels of fertilizer (N and P) rates compared to other land management practices. Both Sorghum/*Desmodium*-incorporated under conservation tillage (SDIC) and Sorghum/*Desmodium* under No- tillage (SDNT) were more effective at replenishing more organic carbon, available phosphorus and total nitrogen into the soil. Sole Sorghum under conventional tillage (SC) significantly resulted in the least (1.17t ha^{-1}) production of Sorghum grains compared with (SDIC) Sorghum/*Desmodium*-incorporated and relayed (1.48t ha^{-1}) and (SDNT) Sorghum/*Desmodium* under No-tillage (1.32t ha^{-1}). 50kgN ha^{-1} interacted with 26.4kgP ha^{-1} to result in highest production of Sorghum grains and Stover yield. Therefore, it can be concluded from the results obtained in this study that the land management that resulted in the best soil quality is SDIC; hence rated (SQ1) followed by SDNT (SQ2), SDOR (SQ3) and SC (SQ4) in rating.

6.0 Recommendation

From the study, the use of conservation tillage with incorporation of *in situ* grown *Desmodium uncinatum*(SDIC) and Zero-till with *Desmodium uncinatum* cover (SDNT) land management practices in combination with 50kgN ha^{-1} plus 13.2kgP ha^{-1} were recommended as they best improved soil quality and yield of sorghum in the Nigeria Guinea Savanna Alfisol.

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