INFLUENCE OF COMPACTION AND MOISTURE REGIME ON PERFORMANCE OF RHIZOBIUM-INOCULATED SOYBEAN (*Glycine max* L. Merill) IN AN ALFISOL OF NORTHERN GUINEA SAVANNA OF NIGERIA

BY

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(P13AGSS8021)

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS DEGREE IN SOIL SCIENCE

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

AUGUST, 2018

DECLARATION

I declare that the work in this dissertation entitled "Influence of Compaction and Moisture Regime on Performance of Rhizobium-Inoculated Soybean (*Glycine Max* L. Merill) in an Alfisol of Northern Guinea Savanna of Nigeria" has been carried out by me in the Department of Soil Science, Ahmadu Bello University Zaria. The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this project report was previously presented for another degree or diploma at this or any other Institution.

Maryam Adamu

Name of Student	Signature	Date

CERTIFICATION

The dissertation entitled "**INFLUENCE OF COMPACTION AND MOISTURE REGIME ON PERFORMANCE OF RHIZOBIUM-INOCULATED SOYBEAN (*Glycine max* L. Merill) IN AN ALFISOL OF NORTHERN GUINEA SAVANNA OF NIGERIA**" by Maryam ADAMU meets the regulations governing the award of the degree of Master of Soil Science of the Ahmadu Bello University, Zaria, and is approved for its' contribution to knowledge and literary presentation.

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AKNOWLEDGEMENT

All praises be to Almighty Allah who granted me health and guidance to pursue this program. This work would have not been accomplished without the help of Almighty Allah (SWT).

My sincere appreciation goes to Dr Aisha Abdulkadir, the Chairperson of the supervisory committee, for her professional and motherly advice. The same appreciation also goes to members of the supervisory committee; Professor Ado A. Yusuf (Head of Department Soil Science) and Dr Abdelgadir Abdel Aziz (of IITA) for their valuable contributions to this work.

My appreciation also goes to my lecturers Prof. E.Y. Oyinlola, Prof. S.T. Abu, and Prof. A. C. Odunze, Dr N. Abdu. My gratitude goes to the Department of Soil Science for allowing me to use its facilities during the course of this study. Special appreciation also goes to the university (ABU Zaria) for tuition free study to enhance my capacity being a member of staff.

I am also grateful to my entire lecturers and all staff in the Department of Soil Science including the laboratory technicians that contributed to the completion of this work. My sincere gratitude goes to COMPRO II project for sponsoring this project.

Special appreciation also goes to my parents Hauwa Ishaq and my late father Adamu Abdullahi may Allah have mercy on his soul. I cannot end without thanking my husband Abdulkadir Abdullahi for his support and prayers.My appreciation also goes to my friend Fatima Abubakar for her advice and my course mates who have in one way or the other assisted in this work.

DEDICATION

I dedicate this work to Islam.

ABSTRACT

An experiment was conducted to determine the effect of soil moisture deficit (stress), soil compaction and nitrogen sources on performance of soybean. The trial was conducted in two phases; the first was a screen-house experiment in the Department of Soil Science, Ahmadu Bello University, Zaria while the second was a field trial at the University Research Farm of the Institute for Agricultural Research, Samaru, Zaria. The screen house experimental treatments involved three (3) soil compaction levels [no compaction (C_0), compaction at 1.3 kg F cm^{-2} (C_1) and 1.7 kg F cm^{-2} (C_2)], three (3) sources of nitrogen [Legumefix (commercial rhizobium inoculants), Mineral nitrogen fertilizer (20 KgN/ha, urea) and negative control (no rhizobium and nitrogen)] and four (4) levels of available soil moisture deficit [0%, 25%, 50% and 75%] arranged in a factorial combination using randomized complete block design (RCBD) and replicated three times. The field experiment was laid in RCBD in split-split plot arrangement with four (4) available soil moisture deficit level [ASMD (0, 25%, 50%, and 75%)] as main treatments, two compaction levels [no compaction (C_0) and compaction at 1.5 kgF cm^2 (C_3) (representing conventional and minimum tillage)] as sub-treatments and three nitrogen sources (sub-sub treatment) involving Rhizobium, Mineral nitrogen (20 kg N/ha) and a negative control (without nitrogen). In both experiments, parameters observed were plant height, root length, shoot and root fresh weight, shoot and root dry weight, leaf area, nodule number, nodule fresh and dry weight, bulk density and penetration resistance, nitrogen concentration of the plant. The amount of nitrogen fixed, chlorophyll index, total dry matter, grain yield and hundred seed weight were only observed in the field trial. In the screen-house, soil compaction at C_1 significantly ($P \leq 0.05$) increased root length by 7.77% and decrease by 5.09% at C_3 relative to the control (C_0). The result showed that compaction at C_0 and C_1 were statistically similar in leaf area and both were higher than C_3. There was a decrease in nodule number and nodule fresh weight with an increase in soil compaction level. Plant height, root length, shoot and root fresh weight, shoot and root dry weight, leaf area, nodule number, nodule fresh weight, nodule dry weight were found to decrease with each increase in the soil moisture deficit. Nitrogen sources significantly ($P \leq 0.05$) influence root length, nodule number and nodule fresh weight. Rhizobium gave the highest mean value for both nodule number and nodule fresh weight compared to mineral N. However, in the field trial, soil compaction had significant ($P \leq 0.05$) influence on plant height, root length, root fresh weight, chlorophyll content, soil bulk density (BD) and penetration resistance (PR). There was increase in soil BD with increase in soil compaction level at 0-5 cm, 5-10 cm and 10-15 cm depths except at 15-20 cm where soil BD decreases with increase in soil compaction level. Up to 15.11% increase in PR was observed in the compacted soil over the un-compacted soil. Available soil moisture deficit significantly ($P \leq 0.05$) affected plant height, root length, root fresh weight, shoot dry weight, nodule number, total dry matter, and leaf area. The results also showed no significant influence of N sources on these parameters except total dry matter. Accumulation in soybean mineral nitrogen significantly ($P \leq 0.05$) increased total dry matter by 27.82% over the unfertilized controlled. The amount of nitrogen fixed by the soybean ranged between 77.02 kg/ha to 152.22 kg/ha. It can be concluded that stressing soybean plant to 25% ASMD would result in similar or even higher yield characters than with full irrigation (0% ASMD). In some cases soybean performance was found to be better in moderately compacted soil (compaction value of 1.3 kg F cm^{-2}). The three nitrogen sources only significantly ($P \leq 0.05$) affected total dry matter.

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CHAPTER ONE

1.0 INTRODUCTION

Soybean (*Glycine max* L.) is the most important and most widely grown of the grain legumes worldwide (Giller and Wilson, 1991) of great nutritional value and enormous uses. It is a source of protein in human food, animal feed and industrial products. Proximate composition of soybean is 40% protein, 20-21 % fat (oil), 32-35% carbohydrate, 5% ash (mineral) and 3% fibre (Anonymous, 2011). Soybean is native to East Asia and first introduced to Africa in late 1800s (Shurtleff and Aoyagi, 2007), and to Nigeria in the year 1904 (Ezedimma, 1964). Nigeria is the largest soybean producing country in Sub-Saharan Africa. A total of about 661,000 ha of soybean were harvested in West Africa out of 99,501,101 ha cultivated worldwide. Nigeria accounts for 95% and the remaining 5% in the rest of the West African countries (FAO, 2009).

Soybean is one of the major legume crops cultivated in northern Guinea Savannah (NGS) of Nigeria. Although its production among legumes requires assimilation of large quantity of nitrogen for maximum yield, soils of this region are poor in nutrient status, especially total N (Machido *et al.*, 2011; Laditi *et al.*, 2012). The situation is further worsened by nutrient depletion by crops and other related processes, such as leaching, denitrification, volatilization and removal of crop residues for alternative uses (Yakubu *et al.*, 2010).

Among the means available to supply and improve soil nitrogen status, fertilizer plays an important role. However, the production and use of chemical nitrogen fertilizers is historically influenced by changing; and often interrelated factors such as increasing populations and economic growth, agricultural production, prices, and government policies (FAO, 2011). Their production requires a great consumption of fossil fuels (1-2 % global fossil fuel) and is subjected to constant variations in prices (Vieira *et al*., 2010). The comparison, in terms of economic and ecological costs, between chemical and biological nitrogen fertilizers shows that biological nitrogen fertilizers represents an economic, sustainable and environmental friendly resource to guarantee the nitrogen requirement of an agro-ecosystem. It has been reported that significant portion of soybean N (up to 80%) (Salvagiotti, 2008) is derived from biological nitrogen fixation (BNF) when grown in association with effective and compatible soil bacteria known as *Bradyrhizobium* (Chianu *et al.*, 2009). Although, yields of legumes can be improved by addition of appropriate rhizobium inoculants, this can only be sustained and assured under suitable soil environment. Suitability of the soil environment depends soil management practices. An important soil management practice that influences soil quality is tillage (Mahdi and Hanna, 2004). The traditional tillage practice in this zone involves manual hoe ridging and weeding. These are done with no special attention to conservation measures against soil nutrient depletion (mining), soil erosion and runoff (Kirchhof and Odunze, 2003) and many changes in soil physical qualities.

However, the introduction of agricultural machinery into the country has led to increased level of mechanized farming with the aim to ease and hasten the processes of cultivation. Heavy machines are extensively used in land cultivation, from sowing to harvesting. This result in varying degrees of soil compaction that causes profound changes in soil structure. Soil structure is important and must not be damaged because it determines the ability of soil to hold and conduct water, nutrients, and air necessary for plant root activity. Compaction affects not only the physical, chemical and hydraulic properties of the soil, but also seed germination, root growth, water utilization, nutrient uptake by crop (Sataranayana and Ghildyal, 1970) and activities of soil microorganisms. It had been reported that the use of machineries and fertilizers may not preserve productivity if significant soil deterioration occurs (Lal, 1979).

Therefore, there is the need to develop better soil management practices that prevent or reduce the effect of soil compaction on soils and crops. This mainly involves management measures aimed at controlling traffic on soils during and after cultivation. This may also include adoption of agronomic practices that would improve soil physical condition such as conservation farming approaches based on no-tillage or minimum tillage. No-tillage practice refers to zero tillage (zero disturbances on the soil) with direct application of seeds into the soil that aims at 100% ground cover with no plow or disk used. Even with the best soil physical quality, crop productivity depends to a great extent on availability of soil moisture.

Moisture deficiency is one of the most important environmental factors affecting agricultural productivity around the world and may result in considerable yield reductions if unchecked. The need to produce more food with less water poses vast challenges to reassign existing water supplies, encourage more efficient use and promote natural resource protection (Hussain *et al.*, 2007). One of the water conserving irrigation scheduling techniques is deficit irrigation which provides a means of reducing water consumption while minimizing adverse effects on yield and the environment (Ghinassi and Trucchi, 2001; Kirda, 2002; Panda *et al.*, 2003). The main objective of deficit irrigation is to increase the water use efficiency (WUE) of a crop by eliminating irrigations that have little impact on yield. The resulting yield reduction may be small compared with the benefits gained through diverting the saved water to irrigate other crops for which water would normally be insufficient under traditional irrigation practices. This objective will be achieved through improvements in agronomic practice, cultivation of superior legume varieties, and increased efficiency of the nitrogen-fixing process itself by better management of the symbiotic relationship between the legumes and bacteria.

1.1 Problem Statement:

Food production capacity is faced with an ever-growing number of challenges, including a world population expected to grow to nearly 9 billion by 2050 and a falling ratio of arable land to population (PDESAUNS, 2007). Crop production in the northern Guinea Savanna of Nigerian is increasing in scope and intensity and crops are commonly grown under rainfed conditions. The major crops include maize, sorghum, rice, cowpea, groundnut, cotton, and soybean. However, the soils are increasingly being degraded by poor management practices. The soils consequently do not contain sufficient plant nutrients to support vigorous crop growth and high yield (Kowal 1972; Jones and Wild, 1975). There is need to ensure adequate food production using sustainable technologies. This may include application of chemical nitrogen fertilizers. However, chemical nitrogen fertilization is associated with environmental problems such as watershed contamination by nitrogen leaching, volatilization and de-nitrification and all these can be source of environmental pollution (Herridge *et al.*, 2008). Rhizobium inoculants are widely used in agriculture for production as to improve soil fertility because of their ability to fix atmospheric nitrogen in association with legume crops. The products are environmentally friendly and cheaper source of nitrogen.

Successful inoculation and establishment of effective legume-rhizobium symbiosis can only be achieved in the presence of favourable soil physical conditions such as soil porosity, moderate bulk density, moisture content and soil temperature which are all influenced by soil tillage systems. Effects of these soil physical properties and processes can be expressed as changes of soil microbiological activity, soil respiration and consequently changes in plant growth and development

1.2 Justification:

The production of soybean in Northern Guinea Savanna of Nigeria is mainly under rainfed conditions. However climate uncertainty is growing, resulting in inconsistency of rainfall amount and distribution pattern (Nicou *et al* 1999, Nicholson *et al,* 2000). Hence there is need to plan for solutions to mitigate these effects of dry spell that may occur within the production period. In this regard, supplementary or full irrigation may be required in order to maintain high yield for this important crop. However, it may not be feasible to practice irrigation to meet the full crop water requirement due to limitations and competition for fresh water between various sectors. This will likely continue to increase pressure on all disciplines to use water resources more efficiently. Deficit irrigation, a practice to apply water which exposes crops to certain (predetermined) levels of water stress during either a particular growth or development stage or throughout the irrigation period during the growing season with an insignificant reduction in yield need to be adopted. In addition to deficit irrigation agronomic measures such as reduced (minimum) or no-till practices can reduce irrigation requirements. This is because it has been reported that no-till improve soil water holding capacity (Heidarpour, 2004). Therefore, field under no-till will have greater potential for maintaining adequate soil moisture under deficit irrigation. Moraru and Rusu (2012) reported that soils subjected to no-tillage system are compacted due to reduce or complete elimination of soil perturbation. This results in high penetration resistance that reduces root growth (Cornish and Lymbery (1987); Moraru and Rusu, 2010), consequently affecting water and nutrient uptake by crops. This high resistance to penenetration can adversely affect emergence and seedling growth under no-tillage (Munawar *et al.*, 1990).

Therefore, the effect of tillage on the aforementioned soil physical properties (soil moisture and penetration resistance) that in turn affect plant performances may also significantly affect biological nitrogen fixation due to modification of the rhizobial environment (soil). Hence the study of soil compaction and soil moisture level as influenced by tillage on the performance of rhizobium inoculated soybean.

Thus, this research was based on the following null- hypothesis:

1. Soybean responds equally to application of rhizobium inoculants and mineral nitrogen.
2. Production of soybean is not influenced by soil compaction
3. Production of soybean is not influenced by moisture deficit.

1.3 Objectives:

The general objective of this study is to assess the effect of soil compaction and varying moisture conditions on performance of soybean treated with different nitrogen sources and selected soil physical properties while the specific objectives are:

1. To assess the response of soybean to rhizobium inoculation and mineral nitrogen.
2. To determine the effect of soil compaction on the productivity of soybean.
3. To determine the effect of soil moisture deficit on the productivity of soybean.
4. To determine the effect of soil compaction and soil moisture regime and nitrogen sources on some selected soil physical properties.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Botany of Soybean

Soybeans are species of legume crop related to clover, peas and alfalfa being grown in varied agro-climatic conditions. It is popularly known as miracle crop and also called as ‘Golden bean’. Soybeans are typically planted in the late spring. They flower in summer and can produce up to 80 pods. Each pod contains pea sized beans, which are high in protein and oil. Seeds are round to oval with large embryo virtually no endosperm. The seed coat has 3 layers with no air exchange due to impermeable cuticle (BRUW, 1994).

Soybean emergence is epigeal; cotyledons are carried above ground by elongation of the hypocotyls. Seedling’s cotyledons are opposite on stem. First leaves that emerge are unifoliolates and opposite, and are followed by trifoliolates leaves which are alternate on stem (BRUW, 1994).

At reproductive stage soybean produce perfect and complete flowers that develop from axillary buds of leaf axils. The flowers are said to be perfect in the sense that both stamen and pistil occur in the same flower, and complete because it has all 4 sets of floral organs; sepals (green tissue under petals), petals (purple or white). The stamen contains filament and another 10 stamens 9 in a ring and 1 free pistil (stigma, style, and ovary). Most flowers (1/2 to3/4) are aborted before forming pods. Flowers are highly self pollinating that open fairly early in the day and pollinate shortly after opening and fertilization occurs 12 hrs after pollination (BRUW, 1994).

Pods eventually develop from axillary buds that are located in the leaf axils. Pubescence covers the stems, leaves, and pods of most soybean varieties, but there are some glabrous types (BRUW, 1994).

Growth period ranges usually between 100 and 120 days. If planted in the proper time and location, most varieties would mature within 100 days (BRUW, 1994).

In terms of growth habit, soybean may be determinate or indeterminate. Determinates types usually have little or no increase in height after flowering is initiated. Shorter, stockier plants with fewer stem nodes, thicker stems; branch more extensively, less likely to lodge on highly fertile soils, flower over a shorter period of time. For the indeterminate types, stems do not terminate in a terminal cluster of pods. They have thinner stems that lodge more easily. They have less branching and narrower canopy. Flower over a longer period of time and continue to increase in height after flowering is initiated. Indeterminate varieties usually have more yield stability and drought tolerance because they have a longer flowering period (BRUW, 1994).

2.2 Agronomic Requirements of Soybean

Soybeans are best adapted to warm weather with plenty of sunshine and sufficient amount of rainfall that is well distributed. Mean daily temperature requirement of 57^{o}F (13.89^{o}C) during the summer appears to be optimum. Like corn, soybeans do not grow when temperatures drop below 50^{o}F (10^{o}C), and require unlimited moisture for germination and emergence, often requiring 325-436 mm of irrigation water for evapotranspiration, depending on the location (Ainer *et al.,* 1999). The most important times for soybean plants to have adequate water are during pod development and seed fill (Kranz *et al.,* 1998). As soybean plant ages from R1 (beginning bloom) through R5 (seed enlargement), its ability to compensate under stressful conditions decreases and yield losses could increase (Foroud *et al* 1993). These are the stages when water stress can lead to a significant decrease in yield. Pronounced wet and dry seasons need supplemental irrigation for successful production. Water stress may reduce crop yield to some extent but will remain economically feasible as long as the marginal benefit from reduced cost of water is equal or greater than marginal cost of reduced yield (Tariq *et al.,* 2003).

Preparation of a weed-free seed-bed to allow rapid emergence is most critical. Soybean requires a well prepared land for uniform seed germination, rapid establishment and less weed competition. For uplands, the crop requires that the soil is thoroughly pulverized. For post-rice cultures, zero or minimum tillage can be practiced (BRUW, 1994)..

Sowing rates depend on seed size, germination rate and field loss. It is absolutely essential that a good plant population is achieved for both weed control and maximum yield. Soybean seed are sown by drilling the seeds along shallow furrows spaced 75to 5cm apart or dibbling. It is possible to obtain yield of 1600 kg /ha (Chianu *et al.,* 2008). More than 3 tons of seeds per hectare can obtain in well-watered, fertile soils (BRUW, 1994).

Since it is a legume, soybean obtains nitrogen through its symbiosis with the nitrogen-fixing bacteria in the roots, and to take advantage of this natural system, bacteria in the form of inoculant can be applied to the seed before planting. Soybean prefers a deep (>1 m) well-drained clay or silt loam soils with a pH near neutral (5.5 to 6.5) since this is the best condition for the nitrogen-fixing bacteria found in soybean root nodules. Nitrogen fertilizers are not required because excessive nitrates from fertilizers restrict nitrogen fixation. Micronutrients, may be applied only when necessary. Organic fertilizers may also be applied where possible(BRUW, 1994).

Aphids and bean fly are common pest during the early vegetative growth. The latter being the most destructive. Compared to cowpea, soybean crop can recover from the initial damage provided optimum cultural management are provided for rapid vegetative growth. During the vegetative stage, a number of larvae from lepidopterist insects can defoliate the crop. Stinkbugs are common pest from seed filling up to maturity. Soybean rust is the fungal disease prevalent during the cool, dry season (BRUW, 1994).

Weed control is critical during period of 2-3 weeks after emergence because soybean grows slowly at this period. It requires a thoroughly prepared seed bed. As soon as possible, cultivate the spaces between rows. For zero or minimum tillage a broad-spectrum herbicide is required before planting. In a well-prepared land, pre-emergence herbicide may be applied (BRUW, 1994).

2.3 Economic Importance of Soybean

Soybean is a multipurpose crop naturally rich in protein and oil. It has the highest natural source of dietary fiber making it a very versatile crop in terms of how it is used. It is high in calcium, phosphorus, and fiber, rich in iron, most essential minerals, and vitamins and has low levels of saturated fat. The approximate composition of soybean is 40% protein, 20 % oil, 34% carbohydrate and 5% ash (Anonymous, 2011). It supplies one-fourth of the world's fats and oils, about two-thirds of the world's protein concentrate in animal feeds, and three fourths of the world trade in high-protein meals. Soy foods are cholesterol free with substantial level of essential amino acids. Studies from China and the United States indicate that consuming just one serving of soy each day when young may offer significant protection against breast cancer (Sirtori *et al.,* 2001) and ease the symptoms of menopause (Levis *et al.,* 2011). In countries with rapidly increasing populations, soybean is viewed as a crop that enhances nutritive value of the local diets and lessens shortages of vegetable oil (Hume *et al.*, 1985). The grain of soybean as a legume which is protein-rich serves as an essential part of the diet in many parts of the tropics, particularly where meat is scarce (Giller, 2001). With the diet of many people in the world deficient in protein and calories, soybean seems destined to remain an important commodity. In recent past it has emerged as one of the important commercial crops in many countries.

Evidence indicates that soy foods reduce the risk of several chronic diseases including coronary heart disease, osteoporosis and certain forms of cancer. People who suffer from digestive problems or diabetes also stand to benefit from soybean-based foods (Mahasi *et al.,* 2010). Experts recommend 2 to 3 servings of soy foods daily for everyday wellness.

Soybean is also used for industrial production of paint, varnishes, caulking compounds, linoleum, printing inks, and other products. Development efforts in recent years have resulted in several soy oil-based lubricant and fuel products that replace non-renewable petroleum products.

Another advantage of soybean is that it improves soil fertility by fixing atmospheric nitrogen through biological nitrogen fixation (BNF) (Mpepereki *et al.*, 2000; Chianu *et al.*, 2009). This phenomenon thereby helps in promoting the productivity of low nitrogen soils. Benefits of biological nitrogen fixation include not only soil fertility improvement but also savings on mineral fertilizer costs, and cash income from sale of crop surpluses (Mpepereki and Pompi, 2002). The plant assimilates all the nitrogen that it biologically fixes hence, maintaining the balance of global nitrogen cycle keeps nitrogen in a form that will not pollute the environment (Serraj, 2004). It also has the capability for soil fertility improvement in cereal based cropping systems (Carskey *et al.*, 1996; Yusuf *et al.*, 2006). BNF provides a continuous supply of N for plant growth in situ adds organic matter to the soil and is economically viable (Yakubu *et al.*, 2010).

2.4 Biological Nitrogen Fixation of Soybean

The ability of many legumes to form associations with bacteria that fix atmospheric nitrogen (the symbiotic association that improve growth) is a big matter of ecological and economic interest (Zahran, 2009). Biological N_2 fixation represents the valuable and a renewable source of N for agriculture (Peoples *et al.*, 1995; Hayat, 2005). Yield increases of crops planted after harvesting of legumes are often equivalent to those expected from application of 30 to 80 kg of fertilizer-N ha^{-1}(Wani *et al.*,1995).

The symbiosis involving soybean and bradyrhizobia is a well-organized system and goes through many steps, beginning at the root surface and resulting in a N_2-fixing nodule (Vincent, 1980). The host plant provides carbon substrate as a source of energy, and the bacteria reduce atmospheric N to NH_4^+ which is exported to plant tissues for eventual protein synthesis.

Like other nodulating legumes, soybean utilizes two sources of nitrogen for its growth; assimilation of mineral nitrogen in the soil (in the form of NO_3^- and NH_4^+) and atmospheric N_2 fixed in nodules via symbiosis. Although each N input system has independent pathways and control points, soybean plant under almost all field conditions will use both systems, and these systems are inter dependent (Harper, 1987). Soybean has been characterized as rather non-responsive to the application of mineral fertilizer N. Mineral N inhibited soybean nodule formation through localized effects on the root system rather than as a function of whole plant nutrition (Hinson, 1975). Symbiotic N_2 fixation may not meet the soybean N requirement during the early and late phases of growth. Small amount of mineral N during pod fill have increased total N and seed yield of soybean in the field (Thies *et al*., 1991). Field response of soybean to fertilizer N may be related to the same amount of nitrogen in the root zone. When this mount was low, the use of N fertilizer significantly increased soybean seed yield at several soil moisture levels (Al-lthawi *et aI.,* 1980). In the absence of indigenous rhizobia, Thies *et al.* (1991) found that inoculation response was directly proportional to the availability of mineral N in the soil.

If abundantly nodulated, soybean is capable of obtaining substantial amounts of its required N_2 from BNF. The N requirement of soybean is the highest among leguminous crops (Sinclair and Wit de, 1975). Each tonne of soybean seed requires the crop to assimilate approximately 100 kg N. The proportion of N derived from fixation varies substantially from zero to as high as 97%. Most estimates fall between 25% and 75%, Salvagiotti *et al.* (2008) reported up to 80% N fixed, while Sanginga *et al.* (2003) reported that some soybean varieties can biologically fix 44 to 103 kg N ha^{-1} annually when the soil is low in available N and effective strains of bradyrhizobia are supplied in high number. 41 to 50 kg N ha^{-1} was reported to be fixed by Yusuf *et al.* (2006).

Application of biofertilizers has resulted in improved nodulation in plant roots and resulted in supplying higher amount of nitrogen for growth and yield attributes, which in turn helped to realize higher growth parameter and dry matter of soybean. Promiscuous soybeans cultivars have recorded increased nodulation upon inoculation and fertilizer application (Mugendi *et al.,* 2010), However, Muhammad (2010) reported that both inoculated and uninoculated (control) treatments yielded significantly higher number of nodules compared with mineral nitrogen treatment at 60 kg N ha^{-1}. Sanginga *et al.* (1997) observed that inoculation induced on average 25 % of nodules formed by soybeans. However, it has been demonstrated that it is possible to obtain high yield up to 1600 kg $ha\text{-}^{1}$ upon inoculation (Chianu *et al*., 2008). It was reported that the effective symbiosis has resulted in increasing grain yield to an extent of 50% in N deficient soils

(Subbarao, 1977). Muhammad (2010) reported that inoculation and 60 kg N ha^{-1} treatment were not significantly different and were found to significantly ($P \leq 0.05$) increase soybean shoot biomass over those of the uninoculated (control) treatment. He also observed that inoculated, uninoculated and 60 kg mineral N ha-^{1} treatments on soybean were not significantly different in terms of grain yield and grain nitrogen content as well. Only nodule number was depressed significantly by N fertilization among the treatments.

However, it has been suggested that increasing the amounts of N fixed in soybean, and the portion of total plant N derived from fixation, may only be achieved with concomitant yield increases (Herridge and Bergersen, 1988; Singh *et al*., 2003). Experimentally, it is not easy to separate N_2 fixation from yield. This is apparent from studies comparing the two parameters in soybeans of differing maturities; the late maturing cultivars fix more N, and yield more than earlier types due to a longer reproductive phase, when rates of N fixation and seed biomass accumulation are high (George *et al.,* 1988). However, it appears that the portion of total N derived from fixation remains fairly constant for cultivars of different maturity at a given site (George *et al.,* 1988).

Inoculation of soybean with rhizobia in areas with low or ineffective native rhizobia is also reported to increase biological nitrogen fixation (Abaidoo *et al.,* 2007). Inoculated late and medium maturing soybean cultivars exhibit increased nitrogen content and dry matter in seed and vegetative parts (stem and leaves), nitrogen harvest index and seed yield (Sogut, 2006). However the same parameters can be reduced in quantities and quality if the native or indigenous rhizobia are substantial reducing the effective establishment of rhizobial strains in the inoculant (Abaidoo *et al.,* 2007).

2.4.1 Measurement of biological nitrogen fixation

Different techniques have been used to evaluate N_2 fixation by soybean. These methods include the nitrogen balance method, nitrogen difference method, ureides method, 15N isotope technique, acetylene reduction method, hydrogen evolution method and 15N natural abundance method (Unkovich *et al.,* 2008). In the N-difference technique, the difference between total plant nitrogen of an N_2 fixing legume (soybean in this case) and a control crop i.e. non-N_2 fixing (maize) was considered to be nitrogen that has been obtained through biological fixation. A modification to this basic principle is considered to improve accuracy of measurements when the legume and a control are not well matched (Evans and Taylor, 1987).

2.4.2 Factors Affecting Biological Nitrogen Fixation (BNF)

The efficiency of symbiotic BNF is markedly dependent on the mutual compatibility of both partners (legume and rhizobium), and is influenced by a number of environmental factors (Hungria and Bohrer, 2000). The amounts and proportion N fixed varies considerably with the environmental factors such as soil temperature, moisture, and pH which affect the host-plant (macrosymbiont) and the *Rhizobium* (microsymbiont) (Rayar, 2000), root nodule position, quantity and form of fertilizer N and management practices (Hardarson *et al.,* 1989). The amount of N fixed is primarily controlled by four principal factors: the effectiveness of rhizobia-host plant symbiosis, the ability if the host plant to accumulate N, the amount of available soil N and environmental constraints to N_2 fixation. Availability of mineral N decreases or impedes nodulation of legumes (Abaidoo *et al.*, 1990). Catroux *et al,* (2001) reported that the success of commercial inoculants is dependent on the number of viable bacteria available to participate in the infection process at the point of use. Rhizobial population densities tend to be low under dry soil conditions and increase as the moisture stress is relieved (Tate, 1995). High soil temperatures in tropical and subtropical areas are a major problem for biological nitrogen fixation of legume crops. For most rhizobia, the optimum temperature range for growth in culture is 28 to 31 ^{0}C. Havlin *et al.* (2005) reported that excess nitrate in the soil can reduce nitrogenase activity and hence, reduce nitrogen fixation.

Soil environment is influenced by a combination of factors including acidity (leading to toxicities of Al and Fe), salinity, alkalinity (including high concentrations of Ca and boron) soil temperature, moisture, fertility (including nutrient deficiencies), and structure (Hungria and Vargas, 2000). Zahran (1999) reported that the survival of a strain of *Bradyrhizobium* of Cajanus in a sandy loam soil was very poor and it did not persist to the next cropping season when the soil moisture content was low. Successful inoculant strains must be able to rapidly colonize the soil and tolerate environmental stresses, as well as compete with other soil micro-organisms (Slattery *et al.,* 2001). However, the symbiotic relation is governed by many physico-chemical properties of soil like pH, EC, CEC, nitrogen and P levels. Application of mineral N and P has been reported to increase shoot dry matter yield of grain legumes (Jemo *et al*., 2006). Nodulation and nitrogen fixation in legumes occurs effectively if other mineral elements such as Phosphorus (P), Potassium (K) and Sulphur (S), Ca, Mg, and Zn (Hungria and Vargas, 2000) are present in the soil this leads to increased yield components.

Available soil N has a large influence on BNF. George *et al*. (1988) found that soil-N availability at different sites determined the relative contribution of symbiotic N fixation, regardless of crop duration and total N accumulation by different varieties. Therefore, addition of these elements to boost the soil mineral nutrient level especially in low carbon sites is necessary.

Nitrogen fixation requires about 10 kg of carbohydrates/kg of N-fixed, and the equivalent of 25 to 28 molecules of ATP for each molecule of N-fixed. Soybean growth rate is thought to be photosynthetic source-limited rather than sink limited. Host-strain compatibility establishment and functioning of an effective symbiosis is dependent on genetic determinants in both plant and bacteria. The fully compatible symbiosis proceeds from recognition, penetration, and stimulation of host-cell division. 45 genes across eight legume species have been identified as affecting nodulation and N, fixation, including at least eight genes in soybean (Vance *et al.*, 1988). Reports have shown that the number of nodules and their distribution patterns on soy-bean roots are largely dependent on host influence (Carroll *et al.*, 1985). Singleton and Stockinger (1983) demonstrated that the soybean will compensate for ineffective nodulation by producing more mass in those nodules containing effective strains.

2.5 Soil Management Practices for Soybean Production

Different soil management practices have being employed for soybean cultivation. The most important cultural activity carried out for field crop production is tillage. Tillage, according to Davies (1983), is a terminology that is applied to the creation of enabling environment for the germination and growth of crops. Tillage also refers to the mechanical stirring of soil to provide a suitable soil environment for growth of crops. Different tillage practices are being used and they result in modification of soil physical, chemical and biological properties. However the most profound effect of tillage is in relation to soil physical properties. Changes in soil physical properties due to tillage, depend on several factors including intensity of management practices (Elder and Lal, 2008), other soil properties, weather conditions, and type of tillage. Soil physical properties which are altered by tillage are bulk density, water content, penetration resistance, soil temperature and aggregate stability. It is necessary to quantify the modifications of soil properties in order to correctly assess the impact of tillage systems. The most common variables used to assess soil physical strength in tillage studies are bulk density and penetration resistance. These properties (bulk density and penetration resistance) are interrelated. Buader *et al.* (1981) reported that increase in bulk density is correlated with increase in penetration resistance. The two parameters however, express the degree of soil compaction.

2.5.1 Effect of bulk density on soybean performance

Soil bulk density is one of the most frequent soil physical indicators used to evaluate soil compaction. Penetration resistance of a soil gives an indication of the soil's strength and thus resistance to tillage implements or plants roots as they penetrate the soil. Soils with higher proportion of pores to solids have lower bulk densities than those that are compacted and have fewer pores (Brady and Weil, 1999). Soil porosity and organic matter content play a critical role in the biological productivity and hydrology of agricultural soils. Pores are of different size, shape and continuity and these characteristics influence the infiltration, storage and drainage of water, the movement and distribution of gases and the ease of penetration of soil by growing root and influence on crop yield. Usually the relationship between bulk density and crop yield is parabolic with a maximum bulk density that depends on soil texture, crop, and climate (Czyż, 2004). Bulk density from which the soil strength becomes so high that it reduces or prevents root growth is referred to as critical bulk density (Reichert *et al.*, 2009), and its value depends mainly on soil textural class. Reichert *et al (*2003) proposed critical bulk density for some textural classes: 1.30-1.40, 1.40-1.50 and 1.70-1.80 Mg m-^{3} for clayey soils, clay loam soils, and sandy loam soils, respectively. Bowen (1981) suggested a general rule that 1.55 to 1.85 Mg m–^{3} is critical bulk density on clay loam soils. (Smith, 1988) reported values exceeding 1.6 Mg m-^{3}

as critical and also observed a decrease in water infiltration and percolation at value beyond this value.

Michel *et al.* (2015) observed that irrespective of soil textural class and bulk density value imposed, the dry mass of soybean's roots was significantly positively related with the dry mass of shoots. This therefore implies that for a given bulk density the soybean's shoot dry matter increases with increasing root dry matter and vice versa. However, the coefficient of determination (R^2) was low indicating that the variability in the growth of the above ground part of plants (soybean) was possibly influenced by other variables than the root growth variation due the increase in bulk density.

2.5.2 Effect of tillage practice on soil penetration resistance:

Penetration resistance is a measure of the energy that must be exerted by the young seedling to emerge from the soil. It indicates resistance that must be overcome by the young rootlets in their search for nutrients and water in the soil (Olaoye, 2002).

Tillage practice was observed to significantly affected soil penetration resistance over a period of time. Among the tillage treatments, soil penetration resistance was significantly higher under no-tillage as compared with that in the tilled soil treatments (Olaoye, 2002; Aikins and Afuakwa, 2012). Aikins and Afuakwa (2012) reported that in the first year of their experiment the highest soil penetration resistance value of 661 kPa was found in the no-tillage plots and lowest soil penetration resistance value of 117 kPa was recorded in the disc ploughing followed by disc harrowing plots (conventionally tilled plots). In the second year, Aikins and Afuakwa (2012) observed a decrease in soil penetration resistance value for all treatments ranging from 559 kPa under no tillage to 118 kPa under disc ploughing followed by disc harrowing treatment (conventional tillage).

2.5.3 Effect of soil compaction and soil penetration resistance on soybean performance

Soil compaction is defined by Ghildyal and Satyaranayana (1965) as processes of bringing soil particles together to a dense state. It was also defined as the process of compression of unsaturated soil during which the bulk density of soil body increases with a simultaneous reduction in fractional air volume (Koyombo and Lal, 1993).

Numerous studies have shown that crops are affected by soil compaction resulting from land use practices (Reichert *et al.*, 2009; Suzuki *et al.*, 2013). Danmowa (2003) specified that the effect of compaction varied with the soil texture. Smucker and Erickson (1987) informed that plants subjected to soil compaction are more susceptible to water stress. Rahman *et al.* (2005) conducted a greenhouse experiment, with sandy loam andisols soil, to evaluate the cause of different levels of compaction on soybean. He observed significant decreased in root dry weight, root to shoot ratio and shoot dry weight with increased energy levels, due to increased levels of compaction. Root development may be damaged by lack of oxygen in compacted soils. This is because by compacting a soil, air is being forced out of it. Cochran and Brock (1985) reported existing ample evidence supporting the reduction in growth caused by soil compaction. Rosolem *et al.* (2002) reported that some crops may grow better even in compacted soils, depending on the plant characteristics. Danmowa (2003) also observed that soil compaction resulted in dry matter increment but the level of increment depend on soil textural class. The mechanism that compacted soil supported better growth more than uncompacted is not completely understood (Ponder, 2004).Much of the better growth may be likely owing to better soil physical changes that may caused better soil moisture conditions for growth (Hossne, 2015)

Penetrometer values greater than 2 MPa are generally reported to significantly reduced root growth (Atwell, 1993). In a study with sunflower, Sojka *et al.* (1990) showed that penetration resistance of 2 MPa restricted root growth and a resistance of 3 MPa create a total barrier to root elongation of the crop. Penetration resistance of 1.5 MPa was found to be the maximum root pressure for root growth of citrus (Modock *et al.*, 1995). Aikins and Afuakwa (2010) reported that conventionally tilled plots that produced the lowest soil penetration resistance gave the best cowpea performance. On the other hand, the no tillage plots which had the highest penetration resistance values were associated with the poorest cowpea performance.

2.6. Soil Moisture Content

Soil moisture is the source of water for plant use particularly in rain fed agriculture. Soil moisture is highly critical in ensuring good and uniform seed germination and seedling emergence (Arsyid *et al.*, 2009), crop growth and yield. Soil moisture stress is a primary limiting factor in crop production as it affects many physiological and biochemical processes of the plants. The success of crop depends upon the amount of moisture stored and the nature of the soil. Moisture loss from the soil through evaporation (Jalota *et al.,* 2001) and presence of erratic rainfall in the middle of season leads to crop failure.

In most legumes, high grain yield loss is reported to occur when moisture stress occurs at critical growth stages including flowering, podding and pod filling(Ahmed and Suliman, 2010; Al-Kaisi and Broner, 2012). The period at the beginning of the flowering stage is most sensitive to water stress, while maximum yield and yield components were obtained with full irrigation. Maximum yield generally are obtained when irrigation are made to provide adequate water during flowering and fruit formation periods (Blum, 2005).This appears to suggest that in order to increase legume grain yield soil moisture stress has to be alleviated. Some of the methods to improve soil moisture availability or reduce deficit are: cover cropping, tree planting, rain water harvesting, mulching, irrigation and conservation tillage among others.

2.6.1 Effect of soil moisture stress on soybean performance

Plant responses to water stress are very complex and include adaptive changes or deleterious effects (Chaves *et al.*, 2003). The effects of water stress are observed in the form of morphological adaptations, physiological changes and biochemical adaptations. Plant reactions are affected by the amount of soil water directly or indirectly. All physiological processes like photosynthesis, transpiration, cell turgidity, cell and tissue growth in plants are directly affected by water availability (Sarker *et al.*, 2005). Hossne *et al.* (2015) demonstrated that soil moisture was the variable almost influential for plant root development. Ehlers *et al.* (1983) reported that mechanical impediments increased as dry bulk density increased and decreased by amplifying the water content. This indicates that moisture was the parameter that most influenced the root growth. Similar results were reported by Blouin, *et al.* (2004) and Coile (1948). According to Boone *et al.* (1985), soil wetness may affect the rootability of pores smaller than the root diameter. It was observed that in compacted soil, some roots were able to widen pore spaces by deforming the space with root expansion. Such deformation is easier for roots when soil is wet (low soil strength) than when it is dry (high soil strength). This was also observed by Hossne (2004). Therefore, the best areas for soybean roots appear to be soils under conditions of low water stress (Boyer *et al.*, 1980).

2.6.2 Effect of tillage on soil moisture content

Tillage methods have been reported to have significant effect on soil moisture storage. Aikins and Afuakwa (2012) reported that tillage treatments showed significant influence in moisture content from the planting date through the first five weeks after planting, and after harvest.

Ojeniyi and Adekayode (1999) and Olaoye (2002) found higher soil moisture content in no tillage plots compared with that of conventionally tilled plots.

2.6.3 Deficit irrigation

This new concept of irrigation scheduling has different names, such as regulated deficit irrigation, pre-planned deficit evapotranspiration, and deficit irrigation (English, 1990). Stegman *et al.*, (1980) recommended that where water scarcity exists at the regional level, irrigation managers should adopt this approach to sustain regional crop production, and thereby maximize income. Deficit irrigation is a strategy that allows crop to sustain some degree of water deficit in order to reduce costs and potentially increase income. It can lead to increased net income where water costs are high or where water supplies are limited (English and Raja, 1996). Using best irrigation method is not necessarily to give highest production but lead to higher water use efficiency (get higher production per unit water irrigation added) by reducing the irrigations number and have little effect on plant productivity (Kirda, 2002)

Options for administering deficit irrigation include skipping regular irrigation events at selected growth stages (Igbadun *et al.*, 2006; Ayana, 2011) or by applying less water than crop water requirement either at all or some selected growth stages of the crop (Ramalan *et al.*, 2010; Igbadun *et al.*, 2012) or by applying less water than required to restore soil depleted available water to field capacity (Abu and Malgwi, 2011).

Crops or varieties that are most suitable for deficit irrigation are those with a short growing season and tolerant of drought (Stewart and Musick, 1982). Under deficit irrigation practices, agronomic practices may require modification, such as decrease plant population, application of less fertilizer, adopting flexible planting dates, and select shorter-season varieties.

Before implementing a deficit irrigation programme, it is necessary to know crop yield responses to water stress, either during defined growth stages or throughout the whole season (Kirda and Kanber, 1999). High-yielding varieties are more sensitive to water stress than low-yielding varieties; for example, deficit irrigation had a more adverse effect on the yields of new maize varieties than on those of traditional varieties (FAO, 1979). Kang *et al.* (2000) observed that regulated deficit irrigation at certain periods during maize growth saved water while maintaining yield.

Much published research has evaluated the feasibility of deficit irrigation and whether significant savings of irrigation water are possible without significant yield penalties. Works on sugar beet (Winter, 1980), sunflower (Karaata, 1991) and on many other crops has demonstrated the possibility of achieving optimum crop yields under deficit irrigation practices by allowing a certain level of yield loss from a given crop with higher returns gained from the diversion of water for irrigation of other crops.

Results presented by Stegman (1982) showed that the yield of maize, sprinkler irrigated to induce a 30 to 40 percent depletion of available water between irrigations, was not statistically different from the yield obtained with trickle irrigation maintaining near zero water potential in the root zone. The work of Speck *et al.* (1989) had shown that soybean is amenable to limited irrigation. However, water stress during vegetative growth, causing leaf water potential less than a critical midday value of 1.6 MPa, adversely affected the final yield (Grimes and Yamada, 1982). Stegman *et al.* (1990) indicated that although short-term water stress in soybean during early flowering may result in flower and pod drop in the lower canopy, increased pod set in the upper nodes compensates for this where there is a resumption of normal irrigation. Nevertheless, the quality of the yield tends to remain unchanged or even superior to rain fed or full irrigation cultivation (Zhang *et al.*, 2006), but a certain minimum amount of seasonal moisture must be guaranteed. Deficit irrigation requires precise knowledge of crop response to drought stress, as drought tolerance varies considerably by genotype and phenological stage (Geerts and Raes, 2009).Water stress during growth may reduce yield as compared with full irrigation, but the reduction can still be much less than when water stress occurs during flowering period (Tolga, and Lokman, 2003). Appropriate degree of regulated deficit irrigation at the middle vegetative growth period (jointing), late vegetative period (booting), early reproductive period (heading), and late reproductive periods (end of filling or filling and maturity) could result in high grain yield, total biomass, water use efficiency, water supply use efficiency, harvest index, and better yield components in spring wheat in an arid environment (Zhang *et al.*, 2006).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site, Location and Description

The study was conducted at the Institute for Agricultural Research, Ahmadu Bello University (IAR/ABU), Samaru, Zaria. Samaru is located on longitude 07°38' E and latitude 11°11' N of the equator with an altitude of 680m above sea level, in the Northern Guinea Savanna (NGS) zone of Nigeria. The study was conducted in two stages. First was a screen house experiment in the Department of Soil Science, Ahmadu Bello University Zaria located at longitude07°37.967' E and latitude 11°09.973' N while the second was a field trial at the research farm of IAR/ABU located at longitude 07°36.890' E and latitude 11°11.177' N. The study site has a mean annual rainfall of about 1011±161mm and is concentrated between May and October with peak in August (Odunze, 2011). This zone has a pronounced dry season (Jagtap, 1995) that lasts from October to April (Kowal and Knabe, 1972), but adequate rainfall amounts are received in the area during rain-fed cropping periods of May to October (Kowal, 1972; Odunze, 1997). The mean daily air temperature (minimum and maximum) ranges between 15 ^oC and 38 ^oC (Oluwasemire and Alabi, 2004). Most soils of the NGS are mainly Alfisols and the zone is characterized by a growing period of 150 to 270 days (Jagtap, 1995), the soils have low inherent fertility, organic matter, cation exchange capacity (CEC) and are dominated by low activity clays (Jones and Wild, 1975; Odunze, 2003).

3.2 Soil Sampling and Analysis

Before planting, representative soil samples were collected at a depth of 0 - 15cm and 15 - 30cm depth from 20 points along four transects across the experimental field and bulked to provide a composite sample. The soil sample was used for the determination of chemical and physical properties.

3.2.1 Chemical properties

The sampled soil was air dried, crushed and passed through a 2 mm and 0.5mm mesh sieve for determination of the following soil chemical properties using standard laboratory procedures as described below.

3.2.1.1 Soil pH

Soil pH was determined both in water and $CaCl_2$ solutions in the ratio 1:2.5 soil solution using a Pye unicam model 290MK pH meter as described Rhoades (1982).

3.2.1.2 Exchangeable bases

Exchangeable bases (Ca, Mg, K, and Na) were extracted using 1N NH_4OAc solution buffered at neutral pH as described by Anderson and Ingram (1993).

3.2.1.3 Exchangeable acidity

Exchangeable acidity was determined using the method described by Peach (1965).

3.2.1.4 Cation exchange capacity

Cation exchange capacity was determined as described by Anderson and Ingram (1993).

3.2.1.5 Effective cation exchange capacity (CEC)

Effective CEC was estimated by the summation methods of all exchangeable bases and exchangeable acidity.

3.2.1.6 Organic carbon

Organic carbon was determined by wet oxidation methods of Walkley-Black as described by Juo (1979).

3.2.1.7 Available phosphorus

Available phosphorus was determined by Bray No-1 Method (Olsen and Sommer, 1982).

3.2.1.3 Total nitrogen

Total nitrogen was determined by the Macro-Kjeldahl technique (Bremner and Mulvaney, 1982).

3.2.2 Physical properties

3.2.2.1 Particle size distribution

Particle size distribution was determined by hydrometer method as described by Gee and Bauder (1986).

3.2.2.2 Bulk density

Bulk density was determined as described by Blake and Hartge (1986).

3.2.2.3 Water contents at field capacity (FC) and permanent wilting point (PWP)

Moisture contents at FC and PWP were determined using the pressure plate extraction method. Undisturbed soil samples were collected using a 5 cm in diameter core ring of 5cm height at the experimental site to 20 cm depth from each treatment for the determination of water content at FC and PWP and bulk density.

3.3. Screen house Experiment

The experiment involved three (3) soil compaction levels [zero compaction (C_0), compaction at 1.3 kg F cm^{-2} (C_1) and 1.7 kg F cm^{-2} (C_2)], four levels of available soil water deficit (0%, 25%, 50% and 75%) , three (3) sources of nitrogen [Rhizobium (Legumefix), Mineral nitrogen fertilizer (urea) at 20 kg N ha^{-1}, and negative control (no rhizobium and nitrogen)], arranged in a factorial combination using randomized complete block design (RCBD) and replicated three times. The compaction treatment was a simulation of field condition, for a harrowed and ridged field the compaction value was found to be zero while untilled field had average compaction value of 1.5 kg F cm^{-2} with a standard deviation of 0.2 kg F cm^{-2}. In this regard zero compaction was taken to represent a tilled field while 1.3 kg F cm^{-2} (C_1) and 1.7 kg F cm^{-2} (C_2) represent untilled field by subtracting and adding 0.2 kg F cm^{-2} to the average value. The water deficit treatment was imposed after the plants had fully germinated, two weeks after emergence just before branching stage. The water deficiency was imposed through maintaining the soil moisture content below field capacity at the deficit levels indicated above. These gave a total of 36 (3 x 3 x 4) treatment combinations (soil columns) replicated three times. The different factors and treatment levels were as described below:

FACTOR A	**FACTOR B**	**FACTOR C**
Compaction (kg Fcm^{-2})	**N sources**	**Moisture deficit levels**
No compaction (C_0)	Control	0 %
Compaction at 1.3 (C_1)	Rhizobium	25%
Compaction at 1.7 (C_2)	Mineral nitrogen	50
		75%

3.3.1 Soil compaction

The soil collected from the experimental field were packed into a total of 108 sets of soil columns (14.5 cm in diameter and 45cm long), 36 soil columns were compacted by hammering the soil with a flat wood at pressure of 1.3 kg F cm^{-2} (0.128 MPa), another 36 soil columns at 1.7 kg F cm^{-2} (0.167 MPa). The compaction pressure was measured using a pocket penetrometer, (Eijkelkamp equipment) while the remaining 36 columns were left un-compacted and their penetration resistance was measured to be zero.

3.3.2 Measurement of irrigation water applied

Available soil water holding capacity (AWC) was calculated as the difference in moisture content between water held at field capacity (FC) and permanent wilting point (PWP): The matric potentials corresponding to FC (-0.33 bar = 33 kPa) and PWP (-15 bars = 1500kPa) were applied using pressure plate apparatus. The equilibrium water contents at FC and PWP were then determined gravimetrically. The gravimetric water content was converted into volumetric water contents using bulk density value, determined by core method. The depth of AWC was calculated using the following relationship:

AWC (cm) = AWC (g/g) x Ap x Z………………………………………equation (i)

Where:

Ap, apparent specific gravity = ℓ_b/ℓ_w (dimensionless)

ℓ_b = dry bulk density of the soil (g/cm^3) and ℓ_w = density of water assumed to be 1 g/cm^3.

Z = thickness or depth of the root zone (cm), in this case, the depth of the soil columns = 45 cm,

The volume of water applied per irrigation for the control (no deficit) was calculated by multiplying determined values from equation (i) (cm) by circular surface area of the column

(cm^2). Similarly, the depth of water per irrigation for the 25%, 50% and 75% deficit levels were calculated as follows:

d_x= AWC(cm)[1-(x/100)]…………………………………………………..equation (ii)

Where:

d = depth of irrigation water applied (cm) and x is the available soil moisture deficit levels (25%, 50% and 75%). The calculated irrigation depth was converted into volume of water by multiplying it by the circular surface area of the column.

The amount of water depleted through evapo-transpiration was determined daily before irrigating the columns using soil moisture meter (PMS 714). The moisture meter recorded the amount of water (in gravimetric basis) left in the columns. The water in each column was always restored to the initial moisture level in the soil. The columns were filled up with soil to the top leaving only 5cm to the surface. Each column was irrigated with equal amount (100% available soil moisture) for all the treatments up to 2 weeks after emergence, where the water deficit treatment commenced. After establishment, the water contents in the soil were maintained at the indicated deficit levels throughout the crop growth cycle.

3.3.3. Seed inoculation and mineral nitrogen application

The soybean seeds were inoculated with commercial Rhizobium inoculants (Legumefix). This was done prior to planting; inoculants were added to the seeds at the rate of 10 g pure strain of carrier-based inoculants per kg of soybean seeds, using 16% Arabic gum solution as adhesive agent. The seeds were mixed thoroughly with the inoculants in a bowl and allowed to air dry for 30 to 40 minutes under shade before sowing. The mineral nitrogen treatment was applied basally to the soil at the rate of 20 kg N per hectare at one week after sowing.

3.3.4. Seed sowing

Four seeds were sown in each soil column at a depth of about 2 cm. The variety of soybean used was TGx 1904-6F. The seedlings were thinned to two per column, two weeks after emergence (Plate 1).

3.3.5 Cultural practices

Phosphorus and potassium fertilizers were applied to the soil at sowing by placement on the side of the seeds at a distance of 5 cm to a depth of 2 cm. The rates of application were 40 kg P_2O_5/ha as single super phosphate (18% P_2O_5) and 20 kg K_2O/ha as muriate of potash (60% K_2O). Insect pests were controlled by application of cypermethrin and dimethoate at the rate of 1.5 L/ha. Weeds were hand pulled throughout the growing period.

3.3.6 Observation and data collection

The above ground morphological growth parameters taken at 8 weeks after sowing (WAS) include plant height, shoot fresh and dry weight and leaf area while the underground crop parameters studied were number of nodules, nodule fresh and dry weight, and root length, root fresh and dry weight and nitrogen concentration in the plant tissue.

Plate I. A section of soil columns with soybean plants at 6 WAS in the screen house study

3.3.7 Estimation of growth and yield characters

Plant height was measured starting from basal node to top of the main shoot at 8 weeks after sowing. It was taken from one randomly selected plant from each soil column. Leaf area was determined from one basal leaf of the same plant by tracing an individual leaf on a square paper with a dimension of 1 cm^2 and counting the number of squares fully covered by the leaf and multiplying them by the dimension of a square. In this case peripheral squares with an area greater or equal to 0.75 cm^2 were considered as full squares. Shoot dry weight was determined as the weight of the above ground parts of plant excluding the roots (g $plant^{-1}$) dried at 70°C to a constant weight while shoot fresh weight was determine by weighing fresh shoot before drying. Number of nodules per plant was determined by counting. Nodule fresh weight, nodule dry weight, root fresh weight and root dry weight were determined using the same procedure for weight of fresh and dry shoot. Nitrogen concentration was measured as percentage of the amount of nitrogen in the plant tissue using Kjeldahl method (Bremner and Mulvaney, 1982).

3.4. Field Experiment

The experiment was laid out in a randomized complete block design (RCBD) in a split-split plot arrangement with four (4) available soil moisture deficit level (0, 25%, 50%, and 75%) as main treatments, and the two compaction levels; 0 kg F cm^2 and 1.5 kg F cm^2 (representing conventional and zero tillage) as sub-treatments and three nitrogen treatments (sub-sub treatment) involving a commercial rhizobium inoculants; Legumefix, Mineral nitrogen (20 kg N/ha) and a control (no nitrogen, and inoculant). These gave 4 main plots, 8 subplots and 24 sub-subplots, replicated 3 times. The total number of experimental plots was 72.

3.4.1. Soil sampling and analysis

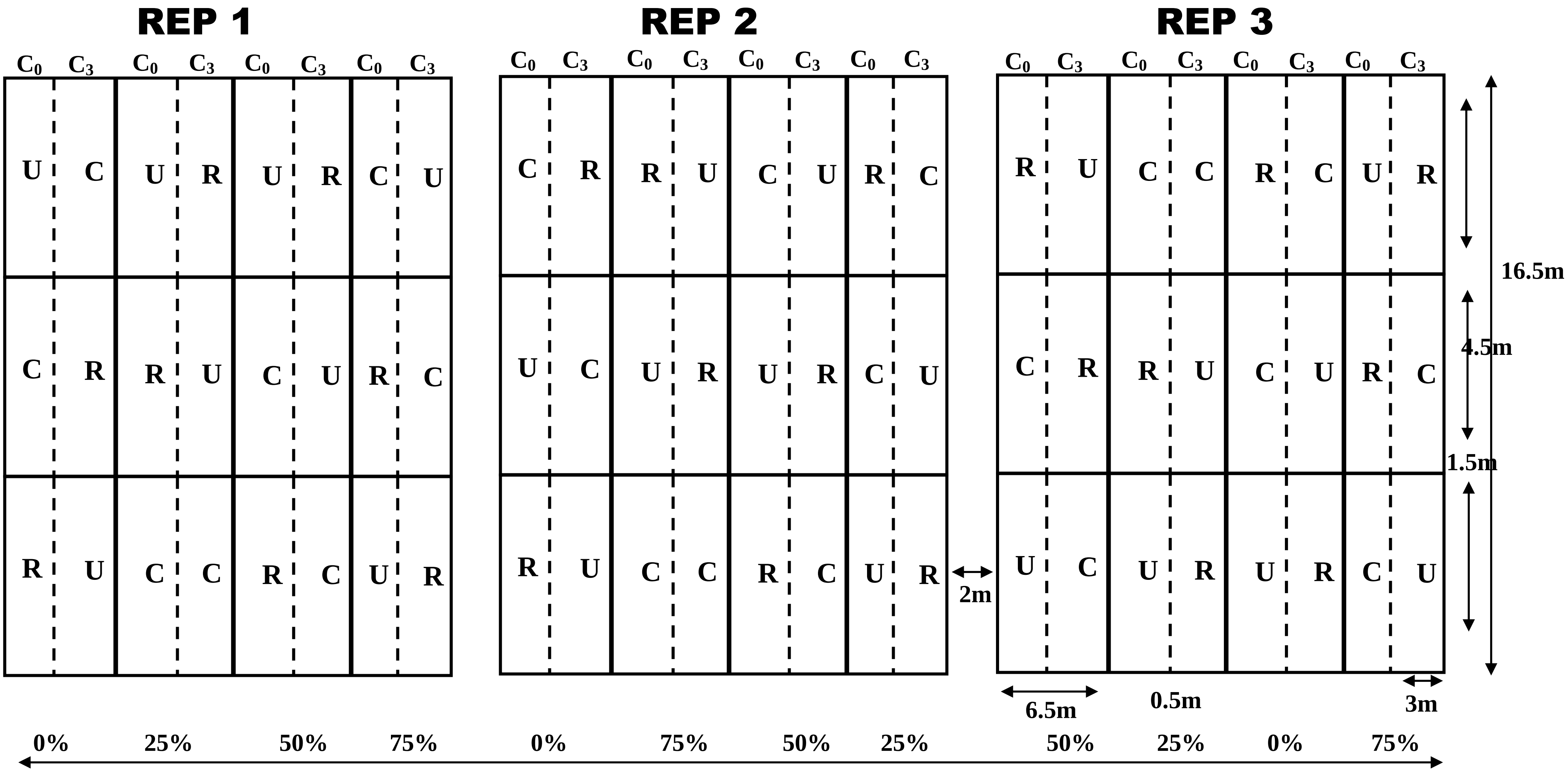
The soil sample was collected and analyzed in the same way as earlier done for the screen house experiment beforethe commencement of the experiment.

3.4.2. Field layout, Land preparation and sowing

The experimental field was divided into 3 blocks separated by 2 m and each comprising of two main plots in a split-split plot design. Each sub-sub plot was 4.5m x 3 m separated by 1.5m, subplot was 16.5 m x 3 m separated by 0.5 m and main plot size was 16.5 m x 6.5 m and the two main plots was separated from the other by 1m. Each replicate was 29 m × 16.5 m with a distance of 2 m between replicates. The total field size was 91 m x 16.5 m. Each block was divided into four main plots with each receiving a different moisture level. Two sub-plots were made from each main plot receiving the different tillage. One of the two sub-plots in each block was harrowed at 30 cm depth and ridged at 75 cm inter- row spacing. Another three plots were created from each sub-plot in which three sources of the nitrogen were randomly applied. Seeds were sown in the month of February, 2016 at the beginning of dry season. For the second sub-plot where the minimum tillage treatment (compaction) was imposed, plant spacing and randomization of all treatments were the same except that the soil was not disturbed (no ploughing, harrowing and ridging). A hoe was used to open a small slot just enough to accommodate the seeds. Seeds were sown by drilling at 5 cm intra-row spacing to a depth of 2 cm. The variety of soybean used was TGX 1904-6F. A control non-N fixing plant (maize) was also planted for determination of amount of N fixed. All treatments were randomized as shown in Figure 3.1.

3.4.3 Seed inoculation and mineral nitrogen application

The soybean seeds were inoculated prior to sowing at the rate of 10 g inoculants per kg of soybean seed, using 16% Arabic gum solution as adhesive agent. The seeds were mixed thoroughly with the inoculants in a bowl and allowed to air dry for 30 to 40 minutes under shade before sowing. The mineral nitrogen fertilizer was applied basally to the soil to plots that are to receive 20 kg N per hectare.



C_3 = No till (compaction at 1.5kgfcm^{-2}), C_0 = conventional tillage (no compaction), C = control, R – Rhizobia, U = Urea (Mineral nitrogen), 0%, 25%, 50% and 75% = Available soil moisture deficit

Figure 3.1: Field Layout

3.4.4 Irrigation water application

Surface irrigation method was used in conveying irrigation water into each subplot. 5 cm diameter polyvinylchloride (PVC) pipes of 40 cm length were used to let water from field ditches into each main plot. These pipes were installed to give a free orifice flow. Stage gauges were placed at the water inlet of each basin to measure the depth of water flowing through the pipes. Thus, discharge through the pipe into the basins was computed and depth of water applied was monitored using a stopwatch. A PVC cork was placed at the entrance such that when the cork was removed, water flows into the basins, and when the desired depth of water was obtained, it was used to stop flow into the basin. Soil moisture status was determined one day before and two days after each irrigation using soil moisture meter (PMS 714) at 0-20 cm depth for determination of water deficit. Using the orifice flow equation and the depth of flow obtained from stage gauge, the flow rate into the basin was determined with equation (iii) and related to time of application to give each plot the desired depth of water applied with equation (iv)

$$Q = A\sqrt{2gh} \quad \text{equation (iii)}$$

Where Q is discharge (m^3/sec), A is area of orifice (m^2) and h is height of water above orifice (m), g is acceleration due to gravity.

$$t = \frac{Ad}{Qn} \quad \text{equation (iv)}$$

where A is area of basin in m^2, n is application Efficiency 75%, d is depth of water applied to each basin with respect to the amount of moisture that has been depleted, t is time (sec).

3.4.5 Agronomic practices

Pests were controlled by pesticides application. Weeds were controlled through the application of pre-emergence herbicides (glyphosate) at 2 weeks before planting. After seedlings emergence, weeds were hand pulled on the compacted plots (no-till plot) throughout the growing period. Fertilizer was basally applied at the rate of 20 kg K_2O/ha as MOP and 40 kg P_2O_5/ha as single super phosphate (SSP) in all plots.

3.4.6. Observation and data collection

The growth parameters taken were plant height (using a meter rule), shoot fresh and dry weight, and leaf area (using graph sheet), nitrogen concentration and chlorophyll index (using chlorophyll meter (KONICA MINOLTA)) at 8 WAS. Below ground parameters studied were number of nodules, nodule fresh and dry weight. The amount of nitrogen fixed was estimated using N-difference method. The N-difference technique was calculated as follows:

Q = N yield (legume) – N yield (control)

Where:

Q (kg ha^{-1}) = Quantity of the biologically fixed nitrogen

N yield (legume) (kg ha^{-1}) = Nitrogen yield of a legume (soybean)

N yield [control] (kg ha^{-1}) = Nitrogen yield of a non-fixing plant (maize)

The amount of nitrogen was determined per plant and converted to amount per hectare based on total shoot dry matter yield each crop produced per hectare.

Root fresh and dry weights were also determined at 8 WAS, total dry matter, grain yield and 100 seeds weight were taken at harvest.

The plants were harvested at full maturity from the two middle rows, dried and the total dry matter was taken. The plant were then threshed and winnowed for grain yield determination.

3.4.7. Measurement of bulk density and penetration resistance

To quantify the influence of tillage (soil compaction) on soil structure, bulk density and penetration resistance were measured at 8 WAS. The bulk density of each plot was determined using 5 cm in diameter core ring of 5 cm length at 0 – 20 cm at 5 cm interval. Three core samples (3 x 4 depths) were collected from each sub-sub plot. Penetration resistance was also measured using pocket penetrometer (Eijkelkamp equipment).

3.5. Data Analysis

Data collected were subjected to analysis of variance using SAS statistical package (SAS institute, 1999) and treatment means with significant difference were compared using Duncan's Multiple Range Test (DMRT) at 5% level of probability. Simple correlation analysis was used to determine the relationship between various measured parameters.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1. Screen House Study

4.1.1 Physical and chemical properties of the soil used for the screen house study

Table 4.1 shows the chemical and physical characteristics of soil used for the screen house experiment. Textural class of the soil was Sandy Loam and it has a moderate bulk density of 1.24 Mgm^{-3}, while moisture content at field capacity was 0.19 g/g and at permanent wilting point, 0.08 g/g. Chemical characteristics revealed the soil to be slightly acidic in reaction (pH in H_2O is 5.43 while pH in $CaCl_2$ is 4.93) therefore, optimum for release of plant nutrient (Sharu *et al*. 2013). The soil has low organic carbon (6.4 g/kg), low total nitrogen (0.1 g/kg), low available P (6.86 mg/kg), exchangeable bases (3.24 $cmol_{(+)}kg^{-1}$) and effective cation exchange capacity (3.57 $cmol_{(+)}kg^{-1}$). The soils was reported to have low inherent fertility, organic matter and cation exchange capacity (CEC) as reported by several scientist / researchers that work in the institute as initially reported by Jones and Wild (1975).

4.1.2 Effect of soil compaction, moisture deficit and N sources on plant height and root length of soybean

Table 4.2 shows the effect of soil compaction, moisture deficit and N sources on plant height and root length of soybean. The results indicated decrease in plant height with increased soil compaction level. However, the differences observed in plant height among the compaction levels were not statistically significant ($P \leq 0.05$). Cochran and Brock (1985) reported ample

Table 4.1: Physical and chemical properties of soil used for screen house experiment at 0-30cm

Property	Test value
Particle size distribution (g/kg)	
Sand	581
Silt	320
Clay	99
Textural class	Sandy loam
Bulk density (Mgm^{-3})	1.24
H_2O content at FC	0.19
H_2O content at PWP	0.08
pH (H_2O)	5.43
pH ($CaCl_2$)	4.93
Organic C (g/ kg)	6.40
Total N(g/kg)	0.10
Total P (g/kg)	0.32
Available P (mg/kg)	6.86
Exchangeable bases ($cmol_{(+)}kg^{-1}$)	
Ca	2.10
Mg	0.41
K	0.50
Na	0.23
Exchangeable acidity($cmol_{(+)}kg^{-1}$) Fe +Al	0.33
ECEC ($cmol_{(+)}kg^{-1}$)	3.57

C= Carbon, N=Nitrogen, P= Phosphorus, Ca=Calcium, Mg= Magnesium, K=Potassium, Na=Sodium, Fe= Iron, AL= Aluminium, ECEC= Effective Cation Exchange Capacity, FC=Field Capacity, PWP=Permanent wilting, Organic.

Table 4.2:.Effect of soil compaction, soil moisture deficit and nitrogen source on plant height and root length of soybean in screen house experiment at 8 WAS.

Treatment	Plant Height (cm)	Root Length (cm)
Compaction (C)		
C_0	63.44	62.26b
C_1	61.20	67.10a
C_2	57.64	59.09b
SE ±	2.187	1.692
ASMD (%)		
0	71.72a	68.44a
25	68.41a	67.46a
50	53.64b	58.58b
75	49.28b	56.80b
SE ±	2.525	1.954
Nitrogen Source (N)		
Control	62.16	59.60b
Rhizobia	60.05	62.03b
Mineral Nitrogen	60.08	66.82a
SE ±	2.187	1.692
Interaction		
C x MD	ns	ns
C x N	ns	ns
MD x N	*	ns
C x MD x N	ns	ns

Means with the same letters within a treatment column are not significantly different, ns= not significant, *= significant at $P \leq 0.05$ probability, WAS= weeks after sowing, C_0= No compaction, C_1=Compaction at 1.3kgFcm^{-2}, C_2= Compaction at 1.7 kgFcm^{-2}, ASMD = Available soil moisture deficit.

evidence supporting the reduction in growth of soybean caused by soil compaction. The result showed significant ($P \leq 0.05$) differences in plant height with respect to soil moisture stress. In terms plant height 0% and 25% available soil moisture deficit (ASMD) were found to be statistically the same ($P \leq 0.05$) and produced the tallest plants. 50% and 75% ASMD which were also statistically the same and produced the shortest plants. Differences in growth could be due to hormonal imbalance under moisture stress (Pandey *et al.,* 2000).This is because water deficit results in oxidization, increases enzyme activity and decreases auxin concentration therefore reduced plant height (Pandey *et al.,* 2000). Since 25% ASMD produced similar plant height with soybean that received 100% ASM, it could be deduced that stressing the plant up to 25% would not cause significant reduction in plant height. The effect of nitrogen sources on plant height of soybean at 8WAS showed no significant ($P \leq 0.05$) difference among the three (3) nitrogen sources with respect to plant height. This is in conformity with the findings of Abdul-latif (2013) who observed that inoculation with rhizobia (Legume-fix) did not significantly ($P \leq 0.05$) affect plant height of soybean. However, this contradicts the findings of Mohammad *et al*. (2013) who reported that rhizobia (Legume-fix) significantly increased plant height. According to Ravikumar (2012) inoculated plants possessed greater height over their respective control. The reason for the observed contradicting report could be due to difference in strains of rhizobia inoculants at different concentration as reported by Abdul-latif (2013) and Ravikumar (2012). Significant interaction was observed between available soil moisture deficit and nitrogen sources.

Figure 4.1 shows the combined effect of soil moisture deficit and nitrogen source on soybean plant height. It indicated that irrespective of the nitrogen source, plant height decreases with increase in available soil moisture deficit (ASMD). Under 0% ASMD, soybean treated with urea

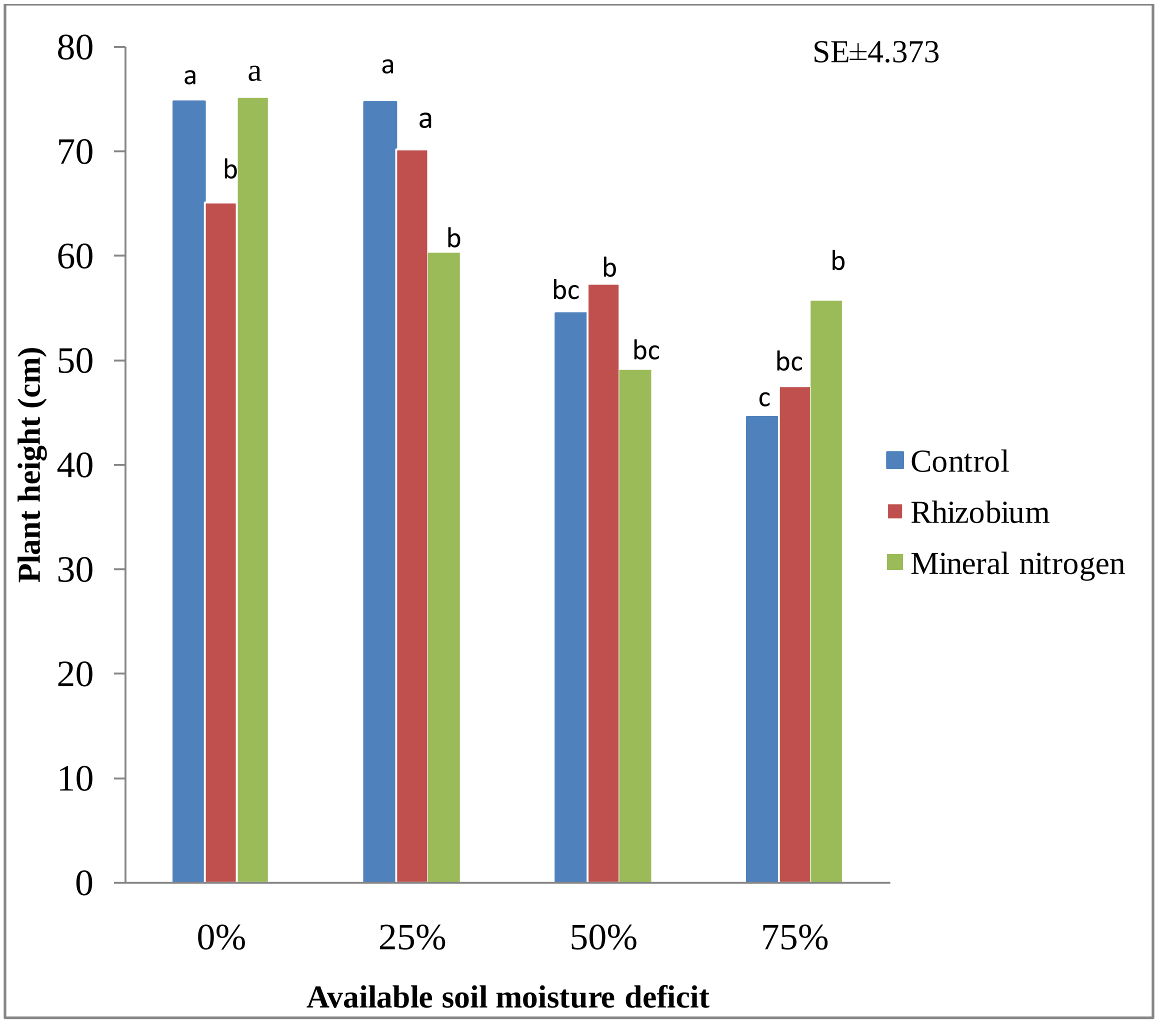


Figure 4.1: Interactions between nitrogen sources and available soil moisture deficit on plant height of soybean in screen house experiment at 8WAS

Bars with the same letter across treatments are not significantly different at P≤0.05; WAS= weeks after sowing.

or no nitrogen fertilizer yielded the taller plants than where no nitrogen or rhizobia inoculants was applied under 25% ASMD. This implies that it is possible to stress soybean plants up to 25% ASMD without application of nitrogen from any source and obtain the tallest plant. Hence production of tallest soybean plant does not require application of nitrogen and up to 25% soil moisture could be saved. However, irrespective of the ASMD level rhizobia inoculated soybean produced plant of similar height except at 25%. Any of the N sources evaluated would not improve plant height once moisture stress is beyond 25%. Also for the rhizobia being an aerobic microbe; availability of oxygen or air with increase in ASMD will enable the plant to continue to fix N and grow. This is because rhizobial population densities tend to be low under dry soil conditions and increase as the moisture stress is relieved Tate, (1995). Also application of mineral nitrogen decreases plant height with increase in soil moisture stress except at 75% ASMD. The possible reason could be because the effects of water stress were mostly reduced to greater extent at high nitrogen level. Nitrogen applied at higher rates had effectively balanced the adverse effects of water stress.

Effects of soil compaction, available soil moisture deficit and N sources on root length of soybean are presented in Table 4.2. Significant difference ($P \leq 0.05$) was observed among the three (3) compaction levels in terms of root length. Soil compaction at 1.3 kg F cm^{-2} (C_1) averagely produced longer roots while the shortest roots were obtained at a soil compaction value of 1.7kgF cm^{-2} (C_2). The reason for the observed result could be due to the soil textural class (Sandy loam) that had better pore size distribution at 1.3 kg F cm^{-2} (C_1) with moderate compaction. This therefore, resulted in longer roots due to low resistant to penetration. While at C_2 the soil became highly compacted and reduction in root length in the highly compacted soil could be due to increased resistance to root penetration. In response, root spread out horizontally and exhibited stunted growth due to limited access to soil moisture and nutrient. Veen *et al* (1992) conducted a pot experiment with maize at restricted nitrogen supply and five levels of soil compaction and the percentage root-soil contact was measured. At the highest soil porosity tested, shoot growth was slightly slower than that at intermediate soil porosity. In the more compacted soil, shoot growth was clearly shown to lag behind. In the most compacted soil, roots were mainly restricted to the upper zones of the pot and total root length was smaller than in less compacted soil.There were significant ($P \leq 0.05$) differences in root length with respect to soil moisture deficit. 0% and 25% available soil moisture deficit (ASMD) were found to be statistically ($P \leq 0.05$) the same in terms of root length and produced the longer roots. Available Soil Moisture Deficit of 50% and 75% were also statistically the same and averagely produced the shortest roots. The decrease in growth could be due to hormonal imbalance under moisture stress (Pandey *et al.,* 2000). Roots lengths from the three nitrogen sources differed significantly ($P \leq 0.05$). At 8WAS average longer roots length (66.82cm) were obtained where mineral nitrogen (urea) was applied. However, rhizobia inoculated and the un-inoculated (control) soybean produced statistically similar roots length. This implies that inoculation with rhizobia did not increase root length of soybean at 8WAS. And this could be due to the presence of indigenous competitive strains in the soil (Abdul-latif, 2013) or the N fixed was not enough to significantly increase root length as urea did. Whereas the significant increase in plant root under the application of urea could be due to the critical role nitrogen plays in photosynthesis by which plants manufacture their own food from sunlight. Furthermore, nitrogen is essential in plants' manufacturing of proteins and in virtually every other aspect of plant physiology. Therefore, the readily availability of nitrogen to plant from urea resulted in longer roots.

4.1.3 Effects of soil compaction, moisture deficit and N sources on shoot fresh and dry weight of soybean

Table 4.3 shows the effect of soil compaction, moisture deficit and N sources on shoot fresh and dry weight. The result showed that compaction significantly ($P \leq 0.05$) affected shoot fresh weight. There was no significant difference in shoot fresh weight between 1.3 kg F cm^{-2} and the un-compacted soil. However, a significant reduction ($P \leq 0.05$) was observed in shoot fresh weights when compaction levels increased to 1.7 kg F cm^{-2}. The lack of significant difference in shoot fresh weights of the un-compacted soil and the slightly compacted soil is because soil porosity of un-compacted soil was high, hence shoot growth were slightly slower than that at moderate soil porosity (1.3 kg F cm^{-2}). While in the more compacted soil, shoot growth was stunted. This result is not in line with the findings of Veen *et al.* (1992). They reported that shoot fresh weight per unit root length decreased with increasing soil porosity. Effect of soil moisture deficit on shoot fresh weight revealed significant decrease ($P \leq 0.05$) in shoot fresh weight with increase in soil moisture deficit (stress). The reduction in shoot fresh weight under moisture stress could be due to hormonal imbalance (Pandey *et al.,* 2000).

The result of shoot fresh weight as affected by nitrogen sources showed no significant ($P \leq 0.05$) difference in shoot fresh weight among all the three nitrogen sources used. Nevertheless, mineral nitrogen was found to produce the highest shoot fresh weight (34.92 g $plant^{-1}$) than the other sources. This was followed by rhizobia that produced 33.85 g $plant^{-1}$ shoot fresh weight. The least shoot fresh weight was produced under the control treatment. This agrees with the findings of Lamptey *et al.* (2014), who reported that plant inoculated with legumefix recorded higher fresh weight compared to the un-inoculated control.

Table 4.3: Effect of soil compaction, soil moisture deficit and nitrogen source on shoot fresh and dry weight of soybean in screen house experiment.

Treatment	**Shoot Fresh Weight (g plant^{-1})**	**Shoot Dry Weight (g plant^{-1})**
Compaction (C)		
C_0	35.27a	11.18a
C_1	36.88a	10.98a
C_2	29.27b	8.98b
SE±	0.867	0.356
ASMD (%)		
0	52.39a	14.98a
25	43.11b	13.16b
50	24.30c	7.94c
75	15.43d	5.44d
SE±	1.002	0.411
Nitrogen Source (N)		
Control	32.64	10.65
Rhizobia	33.85	10.53
Mineral Nitrogen	34.92	9.96
SE±	0.867	0.356
Interaction		
C x MD	ns	ns
C x N	ns	**
MD x N	ns	ns
C x MD x N	ns	ns

Means with the same letter within a treatment column are not significantly different, ns= not significant, **= highly significant at P≤ 0.01 probability, WAS= weeks after sowing, C_0= No compaction, C_1=Compaction at 1.3kgFcm^{-2}, C_2= Compaction at 1.7 kgFcm^{-2}, ASMD =Available soil moisture deficit.

Table 4.3 presents the effect of soil compaction, moisture deficit and N sources on shoot dry weight. The result indicated that soil compaction influenced shoot dry matter. It was observed that un-compacted soil (C_0) yielded the highest shoot dry matter weight (11.18 g plant^{-1}). At 1.3 kg F cm^{-2} (C_1), decrease in shoot dry matter weight (10.98 g plant^{-1}) was observed which was not significantly different from the un-compacted soil. However, significant ($P \leq 0.05$) reduction in shoot dry matter (8.98 g plant^{-1}) was recorded at soil compaction value of 1.7 kg F cm^{2} (C_2). This result is in conformity with the findings of Rahman *et al*. (2005). In their screen house experiment, they also observed significant reduction in shoot dry matter with increase in energy level and suggested that the decrease could be due to the increase in soil compaction as a result the higher energy they imposed while compacting the soil. Significant reduction ($P \leq 0.05$) was observed in shoot dry matter with increase in available soil moisture deficit (ASMD).The significant reduction in shoot dry matter of soybean could be due to reduction in growth as a result of interference of moisture stress in the processes of energy production such as photosynthesis and respiration (Sarker *et al.*, 2005). The result showed no significant difference between all the 3 nitrogen sources on shoot dry matter weight. This is in line with the findings of Abdul-latif (2013) who reported that there was no significant differences between the inoculated and the un-inoculated control treatment in terms of shoot dry matter. Similarly, Bekere *et al.* (2012) found no significant difference for shoot dry matter with seed inoculation. The lack of significant increase in shoot dry matter could be due to significant response of nodulation to inoculation and effective indigenous rhizobium population which were comparable to mineral N. This is because nodulation and nitrogen fixation required higher amount of plant dry matter hence, higher nodulation was produced at the expense of dry matter production. There was significant interactions between soil compaction and nitrogen sources on shoot dry weight of soybean.

Figure 4.3 shows the interaction between soil compaction and nitrogen source on shoot dry weight. Application of either rhizobia to plots compacted at 1.3 kg F cm^{-2} and un-compacted control plot (without nitrogen) significantly ($P \leq 0.05$) produced the highest shoot dry matter per plant. Much of the increment in shoot dry matter with rhizobia at soil compaction value of 1.3 kg F cm^{-2} could be due to the soil being moderately compacted, thus resulting in better growth owing to better physical changes. At soil compaction level, C_0 and C_1 mineral nitrogen produced statistically similar shoot dry matter. The least mean for shoot dry matter was produced when mineral nitrogen was applied at soil compaction level of $C_{2.}$ This indicates that crops planted on highly compacted soils will experience yield reduction when mineral nitrogen is applied. This is because compaction may prevent nitrate from reaching the plant root such that N is lost through denitrification. Moreover, where no nitrogen was applied, both plots compacted at 1.3 kg F cm^{-2} and 1.7 kg F cm^{-2} yielded significantly ($P \leq 0.05$) the same shoot dry matter which was statistically similar to the dry matter yields obtained when rhizobia was applied on both plots compacted to 1.3 kg F cm^{-2} and un-compacted plots.

4.1.4 Effects of soil compaction, moisture deficit and N sources on root fresh and dry weight of soybean

Effects of soil compaction, moisture deficit and N sources on root fresh and dry weight are presented in table 4.4. Compaction significantly ($P \leq 0.05$) affected root fresh weight. There was no significant difference in root fresh weight between 1.3 kg F cm^{-2} and the un-compacted soil. However, a significant reduction ($P \leq 0.05$) was observed in root fresh weights when compaction

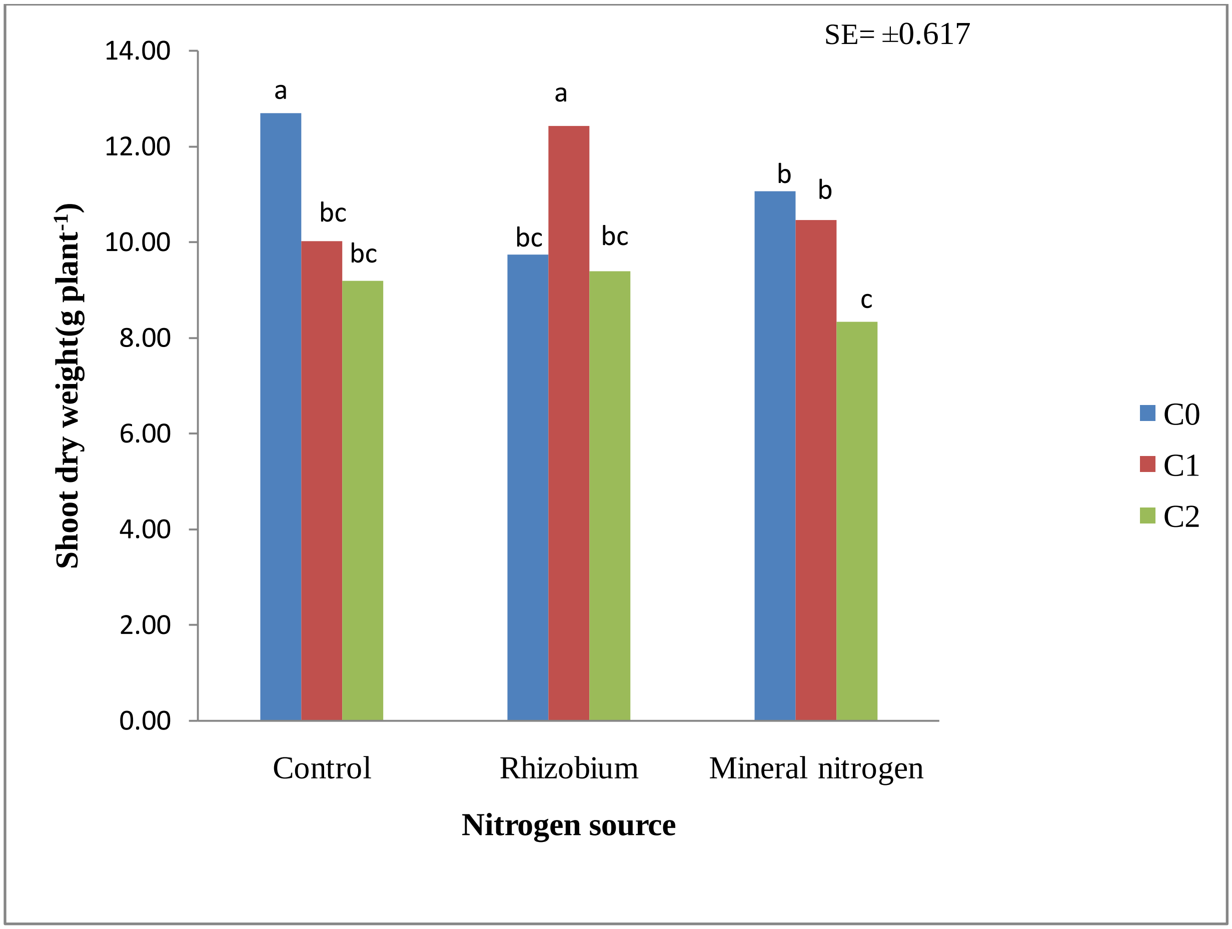


Figure 4.2: Interactions between soil compaction level and nitrogen source on shoot dry matter of soybean in screen house experiment at 8WAS.

Bars with the same letters across treatments are not significantly different at P<0.05; WAS= weeks after sowing; C_0= No compaction, C_1=Compaction at 1.3kgFcm^{-2}, C_2= Compaction at 1.7 kgFcm^{-2}.

Table 4.4: Effects of soil compaction, soil moisture deficit and nitrogen source on root fresh and dry matter of soybean in screen house experiment at 8WAS.

Treatment	**Root Fresh Weight (g/plant)**	**Root Dry Weight (g/plant)**
Compaction (C)		
C_0	11.42a	2.43a
C_1	12.04a	2.40a
C_2	9.70b	1.93b
SE±	0.493	0.103
ASMD (%)		
0	16.51a	3.06a
25	13.51b	2.82b
50	8.81c	1.77c
75	5.38d	1.35d
SE±	0.57	0.119
Nitrogen Source (N)		
Control	10.48	2.18
Rhizobia	11.17	2.36
Mineral Nitrogen	11.51	2.22
SE±	0.493	0.103
Interaction		
C x MD	**	ns
C x N	ns	ns
MD x N	ns	ns
C x MD x N	ns	ns

Means with the same letters within each treatment column are not significantly different, ns= not significant, **= highly significant at P≤ 0.01probability, WAS=weeks after sowing, C_0= No compaction, C_1=Compaction at 1.3kgFcm^{-2}, C_2= Compaction at 1.7 kgFcm^{-2}, ASMD =Available soil moisture deficit.

level increased to 1.7 kg F cm^{-2}. Moreover, the increase in root fresh weights for the un-compacted soil, is because soil porosity was high, hence root growth were slightly slower than that at intermediate soil porosity (1.3 kg F cm^{-2}). While in the more compacted soil, root growth was stunted. This disagrees with the findings of Veen *et al.* (1992) who reported that fresh weight decreased with increasing soil porosity. Root fresh weight significantly ($P \leq 0.05$) decrease with increase in soil moisture deficit (Table 4.3). This is in line with the result of Vinicius *et al* (2014) who reported that root fresh weight are influenced by water availability with means for plants kept at 100% FC higher than those for plants being kept at 50%.

The result of root fresh weights as affected by nitrogen sources showed no significant difference ($P \leq 0.05$) in root fresh weight among all the three nitrogen sources used. Nevertheless, mineral nitrogen was found to produce the highest root fresh weights (11.51 g plant^{-1}) than the other sources. This was followed by rhizobia inoculated soybean which produced 11.17 g plant^{-1} root fresh weight. The least root fresh weight was produced under the control treatment. This is in comformity with the findings of Ravikumar (2012). He observed that, inoculated plants possessed greater fresh weight over their respective un-inoculated control. Significant interaction was observed between soil compaction and soil moisture deficit on root fresh weight.

The interactions between soil compaction and moisture deficit on soybean root fresh weight are presented on Figure 4.2. Root fresh weight decreased with increase in ASMD irrespective of the compaction level. However, with respect to the soil moisture deficit treatment, un-compacted soil (C_0) produced root with the highest fresh weight, followed by C_1 and the lowest root fresh weight was obtained where C_2 was imposed. This trend was not observed where 0% ASMD was imposed, as the un-compacted soil produced plant with the lowest mean value for root fresh

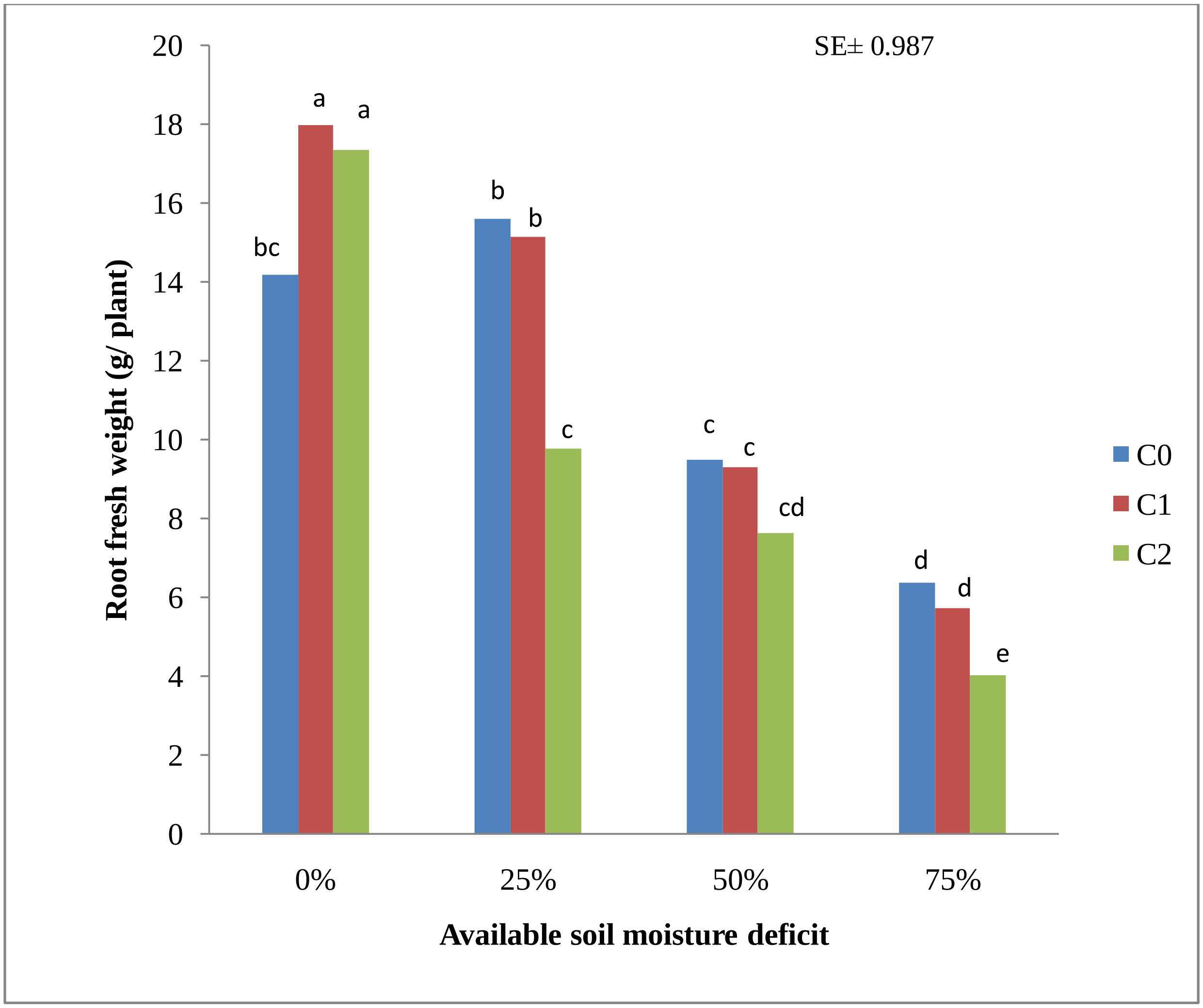


Figure 4.3: Interactions between soil compaction levels and available soil moisture deficit on root fresh weight of soybean in screen house experiment at 8WAS.

Bars with the same letters across treatments are not significantly different at $P<0.05$; WAS= weeks after sowing; C_0= No compaction, C_1=Compaction at 1.3kgFcm^{-2}, C_2= Compaction at 1.7 kgFcm^{-2}

weight. This could be because water and nutrients uptake were highest at the intermediate pore volume (C_1) and slightly lower at the highest soil porosity (C_0). This is supported by Veen *et al* (1992) that water absorption and nutrients uptake decreased per unit root length from compacted to loose soil due to decreasing root-soil contact in the less compacted soil. At 0% deficit, the un-compaction soil, drained more water than was retained for roots compared to compacted soils which are expected to have higher soil moisture.

There was significant ($P \leq 0.05$) decrease in root dry matter with increase in soil compaction. It was observed that un-compacted soil and that compacted at 1.3 kg F cm^{-2} (C_1)yielded the highest root dry matter weight (2.43 g $plant^{-1}$ and 2.40 g $plant^{-1}$ respectively). Although at 1.3 kg F cm^{-2} (C_1), decrease in root dry matter weight (2.40 g $plant^{-1}$) was observed which was not significantly ($P \leq 0.05$) different from the un-compacted soil. However, significant reduction in root dry matter (1.93g $plant^{-1}$) was recorded at soil compaction value of 1.7 kg F cm^{-2} (C_2). The result disagrees with the findings of Danmowa (2003) who reported increase in root dry matter with increase in soil compaction. In terms of soil moisture, significant ($P \leq 0.05$) reduction was observed in root dry matter with increase in soil moisture stress. Hossne *et al.* (2015) demonstrated that soil moisture was the variable almost influential for plant root development. The result also showed no significant ($P \leq 0.05$) difference between all the 3 nitrogen sources on root dry matter weight.

4.1.5 Effects of soil compaction, moisture deficit and N sources on leaf area of soybean

The results of the effects of compaction, moisture deficit and N sources on leaf area are presented in Table 4.5. The result showed significant ($P \leq 0.05$) difference in the leaf area among the three compaction levels. The un-compacted soil (C_0) and soil compacted at 1.3 kg F cm^{-2} (C_1) produced leaves of similar area (55.17cm^2 and 58.89cm^2 respectively) and were significantly

Table 4.5: Effect of soil compaction, soil moisture content and nitrogen source on leaf area of soybean in screen house experiment.

Treatment	**Leaf Area (cm^2)**
Compaction (C)	
C_0	55.17a
C_1	58.89a
C_2	45.53b
SE±	1.652
ASMD (%)	
0	69.48a
25	62.81b
50	43.48c
75	37.00d
SE±	1.908
Nitrogen Source (N)	
Control	54.53
Rhizobia	51.50
Mineral Nitrogen	53.56
SE±	1.652
Interaction	
C x MD	ns
C x N	ns
MD x N	ns
C x MD x N	ns

Means with the same letters within each treatment column are not significantly different, ns= not significant, WAS=weeks after sowing, C_0= No compaction, C_1=Compaction at 1.3kgFcm^{-2}, C_2= Compaction at 1.7 kgFcm^{-2}, ASMD =Available soil moisture deficit.

higher than the compaction level of 1.7 kg F cm^{-2} which produced leaves of averagely least size ($45.53cm^2$). This contradicts the findings of Danmowa (2003) who studied the effect of soil compaction and soil moisture stress on some yield parameters of cowpea. He reported that increase in soil compaction resulted in an increase in leaf area. He further explained that, whether the increase is significant or not depends on the soil texture. Observed increase in leaf area at C_1 over C_0 is due to the soil textural class used for this experiment which was sandy loam. This soil type had higher proportion of macro-pores that hold less amount of available water when it was not compacted. At C_1 the soil became moderately compacted with increased water holding capacity. Hence the more water was available to the crop and the better the crop growth and Thus, the greater the leaf area. Increasing soil compaction to 1.7 kg F cm^{-2} (C_2) would reduce the micro-pores to ultra micro-pores which hold water that may not be available to plants; therefore plants produced smaller leaves due to reduction in plant growth.

There was significant ($P \leq 0.05$) decrease in leaf area with increase in available soil moisture deficit. On average, leaves with the largest area were produced where no moisture stress was imposed and the smallest leaves were produced when the plant were stressed to 75% ASMD. The increase in leaf area with decreasing moisture stress is due to the increase in cell volume in the presence of higher soil moisture absorbed by the plant that increase growth of leaves from increased photosynthetic rate ((Sarker *et al.,* 2005). All the three nitrogen sources (rhizobia, mineral nitrogen and control) produced leaves of averagely similar area**.** This contradicts the findings of Malik *et al.* (2006) who reported that inoculants promote growth factors thereby produced larger leaves. The insignificant increase in leaf area observed could be attributed to lack of significant influence of inoculation on shoot growth.

4.1.6 Effects of soil compaction, moisture deficit and N sources on nodule number, nodule fresh and dry weight of soybean

Table 4.6 shows the effect of soil compaction, moisture deficit and N sources on nodule number, fresh and dry weight. The result showed significant ($P \leq 0.05$) decrease in nodule number with increase in soil compaction level. The largest nodule number was obtained from un-compacted soil while at compaction level of 1.7 kg F cm-^{2} (C_2) the lowest value for nodule number was obtained. This is in conformity with the findings of Buttery *et al* (1998) who reported that increased bulk density reduced the numbers of nodules. The result revealed a significant inverse relationship between soil moisture stress and nodule number. This is in line with the report of Buttery *et al* (1998) that low moisture reduced nodule numbers and weights in both soybean and common bean. On average, up to 86.46 nodules per plant were obtained when the soil was at 100% (0% ASMD) available soil moisture and only about 11.89 nodules per plant were produced when the soil moisture deficit increased to 75%. The result revealed significant variation ($P \leq 0.05$) among the three nitrogen sources used with respect to nodule number. It was observed that rhizobia gave the highest nodule number per plant (54.14). While mineral nitrogen yielded significantly ($P \leq 0.05$) the same nodule number with the control. This is in agreement with the result of Hinson (1975) who reported that mineral N inhibited soybean nodule formation through localized effects on the root system rather than as a function of whole plant nutrition. However, this result is not in line with the result reported by Abdul-latif (2013) that inoculation with legumefix had no significant effect on nodule number. There was significant interaction between soil compaction and soil moisture deficit on number of nodules.

Table 4.6: Effect of soil compaction, soil moisture deficit and nitrogen source on nodule number, nodule fresh and dry weight of soybean in screen house experiment at 8 WAS.

Treatment	**Nodule Number (per plant)**	**Nodule Fresh Weight(g plant^{-1})**	**Nodule Dry Weight(g plant^{-1})**
Compaction (C)			
C_0	51.64a	2.49a	0.87
C_1	44.49b	2.28a	0.61
C_2	34.61c	1.98b	0.62
SE±	2.471	0.089	0.159
ASMD (%)			
0	86.46a	4.06a	1.54a
25	51.63b	2.90b	0.73b
50	24.33c	1.65c	0.41c
75	11.89d	0.39d	0.11c
SE±	2.853	0.104	0.184
Nitrogen Source (N)			
Control	38.79b	2.21b	0.80
Rhizobia	56.14a	2.60a	0.67
Mineral Nitrogen	35.81b	1.92c	0.62
SE±	2.471	0.090	0.159
Interaction			
C x MD	**	**	ns
C x N	ns	ns	ns
MD x N	ns	ns	ns
C x MD x N	ns	ns	ns

Means with the same letter within each treatments column are not significantly different, ns= not significant, ** = highly significant at $P \leq 0.01$probability, WAS=weeks after sowing, C_0= No compaction, C_1=Compaction at 1.3kgFcm^{-2}, C_2= Compaction at 1.7 kgFcm^{-2} , ASMD =Available soil moisture deficit.

Figure 4.4 represents the interaction between soil compaction and soil moisture deficit on nodule number. Significantly ($P \leq 0.05$) highest nodule number per plant was produced where 0% ASMD was applied in the un-compacted soil columns. Application of 0% ASMD significantly decreased nodule number per plant where the soil was compacted. Decrease in nodule number was also evident where 25% ASMD was imposed. Within the 25% ASMD, 1.3 kg F cm^{-2} produced the highest ($P \leq 0.05$) mean value for nodule number while lowest mean value of nodule number was obtained at 1.7 kg F cm^{-2}. At 50% ASMD, fewer nodule numbers were obtained; it was statistically similar with number of nodules obtained when no compaction and 1.3 kg F cm^{-2} was imposed on soils with 75% ASMD and the least number of nodules were observed in soil compacted at 1.7 kg F cm^{-2} with 75% ASMD This implies that abundant supply of water alleviate the adverse effect of compaction on nodulation.

Table 4.6 shows the effect of soil compaction, moisture deficit and N sources on nodule fresh. Significant difference ($P \leq 0.05$) was observed among the three compaction levels imposed with respect to nodule fresh weight. The soil compacted at 1.3 kg F cm^{-2} (C_1) and the un-compacted soil gave statistically similar nodule fresh weight per plant while compaction at 1.7 kg F cm^{-2} (C_2) was found to produce significantly ($P \leq 0.05$) lower nodule fresh weight. The reduction in nodulation with increase in soil compaction levels could be attributed to the changes in root mass caused by reduction of pore spaces that increase resistance to root penetration in the soil profile. The result revealed a significant inverse relationship between soil moisture stress and nodule fresh weight for all the soil moisture deficit level imposed. For the nodule fresh weight, up to 4.06 g plant^{-1} at 0% ASMD and only 0.39 g plant^{-1} at 75% ASMD were obtained.

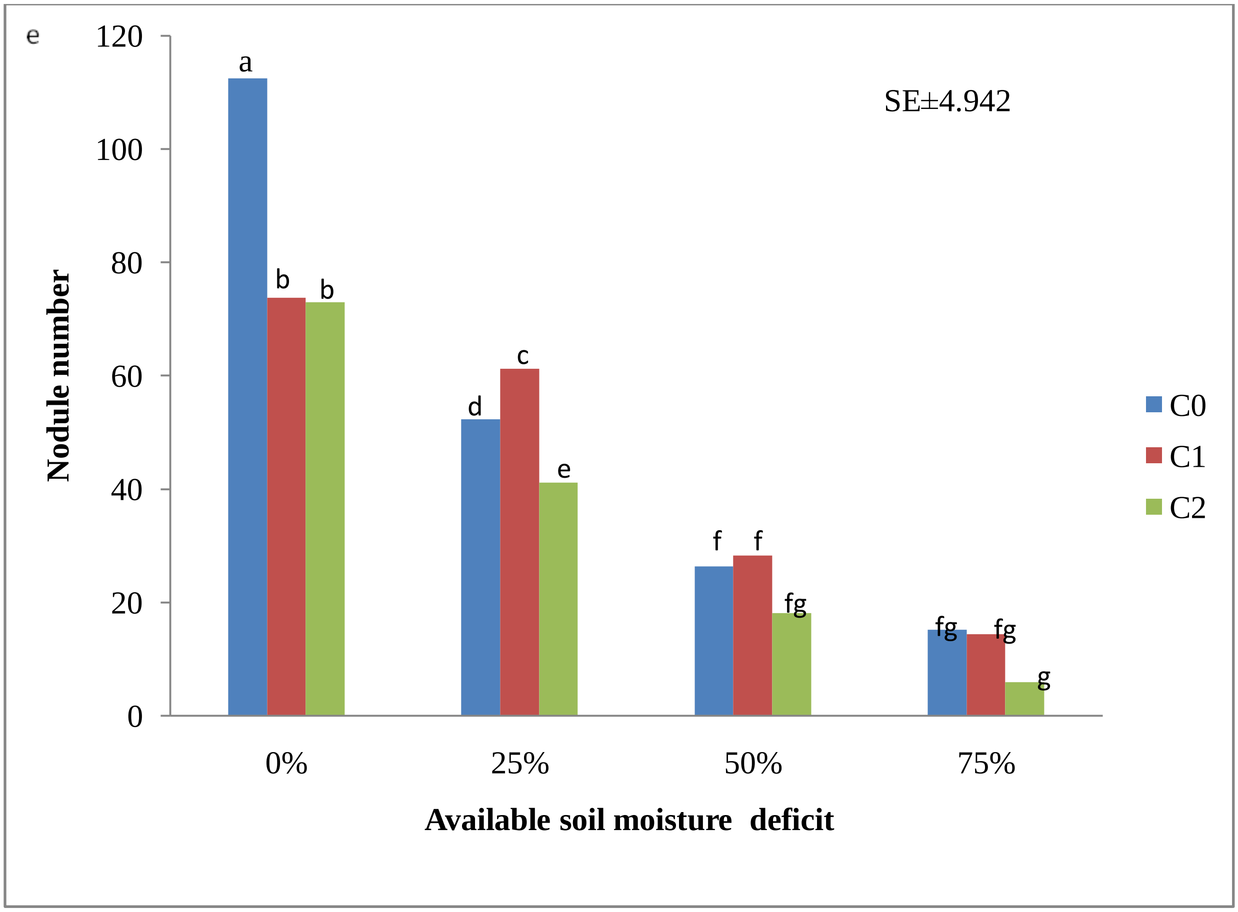


Figure 4.4: Interactions between soil compaction level and available soil moisture deficit on nodule number of soybean in screen house experiment at 8WAS.

Bars with the same letters across treatments are not significantly P≤0.05 different, WAS= weeks after sowing; C_0= No compaction, C_1=Compaction at 1.3kgFcm^{-2}, C_2= Compaction at 1.7 kgFcm^{-2}.

The result revealed significant variation ($P \leq 0.05$) among the three nitrogen sources used with respect to nodule fresh weight. Significantly, heaviest nodule fresh weight per plant (2.60 g plant^{-1}) were produced where rhizobia was applied. This was followed by the control (2.21 g plant^{-1}), and the least nodule fresh weight was obtained where mineral nitrogen was applied. The best result in terms of rhizobia with respect to fresh weight could be attributed to rhizobia supply of nitrogen and growth hormones, hence, in the process, stimulating growth of secondary root resulting in greater absorption of water and nutrient (Glick, 2012). Similarly Hinson (1975) reported that mineral N inhibited soybean nodule formation. Significant interaction was observed between soil moisture deficit and soil compaction on nodule fresh weight of soybean

Figure 4.5 shows the combined effect of soil moisture deficit and soil compaction on nodule fresh weight of soybean 8WAS**.** It was observed that irrespective of the compaction levels, nodule fresh weight decreased with increase in available soil moisture deficit level. Within 0% ASMD, un-compacted column and column compacted to 1.7 kg F cm^{-2} gave statistically the same ($P \leq 0.05$) mean for nodule fresh weight and were significantly higher than compaction at 1.3 kg F cm^{-2}. Conversely, for 25%, 50% and 75% ASMD treatments, the same trend was observed, where un-compacted soil and soil compacted to 1.3 kg F cm^{-2} were significantly the same but both were higher than 1.7 kg F cm^{-2} for nodule fresh weight. This is in line with the report of Buttery *et al* (1998) who observed in their pot experiment with soybean and common bean that the effect of reduced water supply was more severe in the highly compacted pots, and more severe in the clay loam than in the sandy loam.

Table 4.6 shows the effect of soil compaction, moisture deficit and N sources on nodule dry weight. Soil compaction did not significantly influence nodule dry weight. This supported the

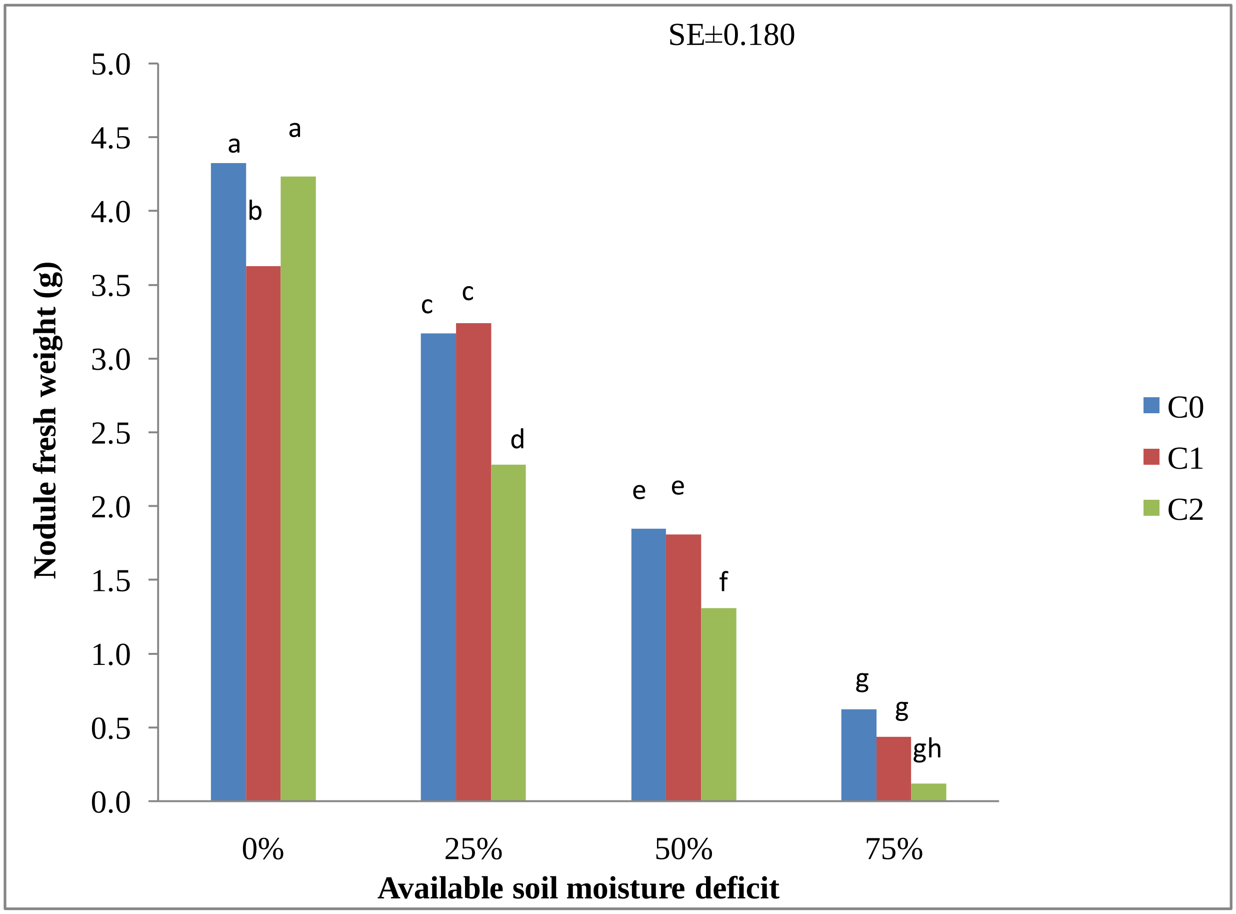


Figure 4.5: Interactions between soil compaction levels and available soil moisture deficit on nodule fresh weight of soybean in screen house experiment at 8WAS in 2015.

Bars with the same letters across treatments are not significantly P≤0.05 different, WAS= weeks after sowing; C_0= No compaction, C_1=Compaction at 1.3kgFcm^{-2}, C_2= Compaction at 1.7 kgFcm^{-2}.

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findings of Buttery *et al*. (1998) that increased bulk density did not reduce nodule dry weight. Significant (P≤0.05) difference in nodule dry weight was also observed among the different ASMD imposed. At 0% the highest nodule dry weight was obtained; followed by 25% ASMD and the least nodule dry weight were obtained at 50% and 75% ASMD which were statistically at par. Ahmed and Quilt (1980) reported that moisture stress had little or no effect on the nodulation or nitrogenase activity of the plants. According to Ndimbo *et al* (2015) moisture stress significantly affected nodulation, nitrogen fixation, and finally grain yields. However, there was no significant difference among the different nitrogen sources with regards to nodule dry weight.

4.1.7 Effects of soil compaction, moisture deficit and N sources on nitrogen concentration

Table 4.7 shows the effect soil compaction; moisture deficit and N sources on nitrogen concentration of soybean at 8WAS.The result shows that soil compaction had no significant (P≤0.05) effect on nitrogen concentration of the plant. Although the difference was not significant, it was observed that nitrogen concentration of the soybean plant decrease with increase in soil compaction. This could be due to the limited amount of nutrients absorbed by the plant in compacted soil. Soil moisture stress did not significantly (P≤0.05) affect nitrogen concentration of soybean plants at 8WAS. This is not in line with the findings of Mohammad *et al.* (2013) who showed that moisture stress had negative effects on the quantitative and qualitative yield (such as N concentration) of soybean. Kalima (2013) reported that the severity of effects of water stress depend on many factors, such as stage of development of the plant, duration and degree of stress. Moisture stress levels no matter the degree of its severity has the capacity to affect/reduce nodulation, nitrogen fixation, root and shoot biomass and finally yield at different growing stages (Ndimbo, 2015). The result showed that all the three nitrogen sources

Table 4.7 Effect of soil compaction, soil moisture deficit and nitrogen sources on nitrogen concentration in soybean plant in screen house experiment.

Treatment	**N concentration (%)**
Compaction (C)	
C_0	1.75
C_1	1.69
C_2	1.63
SE ±	0.074
ASMD (%)	
0	1.76
25	1.74
50	1.42
75	1.83
SE±	0.085
Nitrogen Source (N)	
Control	1.65
Rhizobia	1.70
Mineral Nitrogen	1.70
SE±	0.074
Interaction	
C x MD	ns
C x N	ns
MD x N	ns
C x MD x N	ns

Means with the same letter s within each treatments are not significantly different, ns= not significant, WAS=weeks after sowing, C_0= No compaction, C_1=Compaction at 1.3kgFcm^{-2}, C_2= Compaction at 1.7 kgFcm^{-2}, ASMD = Available soil moisture deficit.

did not significantly affect nitrogen concentration of soybean. However, both rhizobia and urea gave exactly the same value and were higher than the control with respect to nitrogen concentration. The fact that inoculation resulted in higher N% concentration, implies a positive effect of nodulation on plant N concentration and nitrogen fixation. Biological nitrogen fixation is one of the most important sources of nitrogen in the production of soybean crops (Mohammadi *et al*., 2012). A symbiotic relationship between rhizobia and soybean plants can provide large quantities of N to the plant.

4.1.8 Effect of soil compaction, moisture deficit and N sources on soil penetration resistance

Effects of soil compaction, moisture deficit and N sources on soil penetration resistance at 8WAS are presented in Table 4.8. There was significant ($P \leq 0.05$) increase in soil penetration resistance with increase in soil compaction soil. At 1.7 kg F cm^{-2} the highest mean for soil penetration resistance was recorded. While both un-compacted soil and compactions at 1.3 kg F cm^{-2} gave the lowest mean for soil penetration resistance and were statistically at par. The reason for the observed high penetration resistance is due to compaction which leads to compression of soil aggregate thus, resulting in greater mass per unit volume of soil. The results showed that soil moisture deficit did not significantly ($P \leq 0.05$) influence soil penetration resistance. However, there was an increase in soil penetration resistance over the initial value imposed during the time of sowing. Although the difference among the nitrogen sources was not significant ($P \leq 0.05$) with respect to soil penetration resistance, the highest mean value for soil penetration resistance was obtained where urea was applied followed by the control and the lowest mean value was obtained where rhizobia was applied. The plausible explanation could be that the soil physical condition (such as better aeration) had been improved by the bacteria introduced due to increased

Table 4.8: Effect of soil compaction, soil moisture deficit and nitrogen sources on penetration resistance of soybean soil in screen house experiment at 8WAS.

Treatment	**Penetration resistance (kgFcm^{-2})**
Compaction (C)	
C_0	2.88b
C_1	2.96b
C_2	3.63a
SE±	0.180
ASMD (%)	
0	2.87
25	3.24
50	3.07
75	3.44
SE±	0.208
Nitrogen Source (N)	
Control	3.13
Rhizobia	3.12
Mineral Nitrogen	3.22
SE±	0.180
Interaction	
C x MD	ns
C x N	ns
MD x N	ns
C x MD x N	ns

Means with the same letter are not significantly different, ns= not significant, WAS=weeks after sowing, C_0= No compaction, C_1=Compaction at 1.3kgFcm^{-2}, C_2= Compaction at 1.7 kgFcm^{-2}, ASMD = Available soil moisture deficit.

root growth which make the soil aggregates more stable thereby resulting in a lower mean value for soil penetration resistance.

4.2 Field Study

4.2.1 Physical and Chemical Properties of soils of the Study Area.

Table 4.9 shows the physical and chemical characteristics of soil of the study area. The soil for the field experiment also had similar characteristics with that used for the screen house study. Physical characteristics revealed that the soil textural class was Sandy Loam and has a moderate bulk density of 1.24 Mgm^{-3}. Soil moisture at field capacity and Permanent wilting points are 0.20g/g and 0.08g/g respectively. While the chemical characteristics of the soil revealed that the soil is slightly acidic in reaction (pH in H_2O is 6.08 while in $CaCl_2$ is 5.54) implying that the soil pH is optimum within the range for release of plant nutrient (Sharu *et al.*, 2013). The soil has low total organic carbon (0.57g/kg), low total nitrogen (0.09 g/kg), low available phosphorus (5.78 mg/kg), low in exchangeable bases and effective cation exchange capacity (4.05 $cmol_{(+)}$/kg).

4.2.2 Effect of soil moisture deficit, soil compaction and N sources on plant height and root length of soybean

Effects of soil moisture deficit**,** soil compaction and N sources on plant height and root length are presented in Table 4.10. The result showed significant difference ($P \leq 0.05$) among the soil moisture deficit treatment with respect to plant height. On average, tallest plants were produced where the available soil moisture deficit (ASMD) was only 25% and the shortest plants were obtained when the ASMD increased to 75%. However, plots with 0% and 50% ASMD produced statistically similar plants of intermediate height between the tallest and the shortest plants. This result did not follow a similar trend with that of the screen house. A deviation was observed at 0% ASMD whereby plant height was shorter than that obtained at 25% ASMD. The reason could be due to water logging that was observed at 0% ASMD and which may have impeded root respiration, and consequently, retarded plant growth.

Table 4.9: Physical and chemical properties of soil of the experimental field

Property	Test value
Particle size distribution (g/kg)	
Sand	621
Silt	300
Clay	79
Textural class	Sandy loam
Bulk density (Mgm^{-3})	1.24
H_2O content at FC	0.2
H_2O content at PWP	0.08
pH (H_2O)	6.08
pH ($CaCl_2$)	5.54
Organic C (g/ kg)	0.57
Total N(g/kg)	0.09
Total P (g/kg)	0.46
Available P (mg/kg)	5.78
Exchangeable bases ($cmol_{(+)}kg^{-1}$)	
Ca	2.3
Mg	0.44
K	0.59
Na	0.39
Exchangeable acidity ($cmol_{(+)}kg^{-1}$) Fe +Al	0.33
ECEC ($cmol_{(+)}kg^{-1}$)	4.05

C= Carbon, N=Nitrogen, P= Phosphorus, Ca=Calcium, Mg= Magnesium, K=Potassium, Na=Sodium, Fe= Iron, AL= Aluminium, ECEC= Effective Cation Exchange Capacity, FC=Field Capacity, PWP=Permanent wilting.

Table 4.10: Effect of soil moisture deficit, soil compaction and nitrogen sources on plant height and root length of soybean at IAR Irrigation farm Samaru Zaria.

Treatment	**Plant Height (cm)**	**Root Length (cm)**
ASMD (%)		
0	28.06ab	21.95a
25	31.19a	21.02ab
50	27.94ab	20.21ab
75	25.38b	17.93b
SE ±	1.261	1.141
Compaction (C)		
C_0	30.23a	21.43a
C_3	26.06b	19.12b
SE ±	0.892	0.807
Nitrogen Source (N)		
Control	27.17	19.18
Rhizobia	27.75	20.29
Mineral Nitrogen	29.51	21.36
SE±	1.092	0.988
Interaction		
MD x C	ns	ns
MD x N	ns	ns
C x N	ns	ns
MD x C x N	ns	ns

Means with the same letters within a treatment are not significantly different, ns= not significant, WAS=weeks after sowing, C_0= No compaction, C_3=Compaction at 1.5kgFcm^{-2}. ASMD = Available soil moisture deficit.

This finding contradicted work by Amos *et al.* (2009) who reported that plant height increased as soil water content increased. Soil compaction significantly ($P \leq 0.05$) influences plant height of soybean. Plant were significantly ($P \leq 0.05$) taller (30.23cm) where no compaction was imposed and shorter (21.43cm) on the compacted plots. The reason for decrease in plant height may be due to damage to root development by lack of oxygen in the compacted soil. This is because by compacting a soil, air is being forced out of it, hence decreasing it concentration in the soil. This consequently reduced growth. There was no significant effect of the three nitrogen sources in plant height of soybean. The average plant height values are higher for the urea treated plots followed by rhizobia and the lowest values were obtained from the control (un-inoculated) plots. This is in line with the findings of Abdul-latif (2013) who reported that inoculation with Legume fix had no significant influence on plant height.

Effects of soil moisture deficit, soil compaction and N sources on root length are presented in Table 4.10. The result showed significant difference ($P \leq 0.05$) among the soil moisture deficit treatment with respect to root length. Long roots were produced where no moisture stress was imposed which statistically differ from the other moisture deficit treatments. As with plant height, 75% ASMD also produced the shortest roots, where as 25% and 50% ASMD produced root of intermediate length and which were statistically ($P \leq 0.05$) at par. This result did not follow a similar trend with that of the screen house. Soil compaction significantly ($P \leq 0.05$) influenced root length of soybean. Roots were significantly ($P \leq 0.05$) shorter (19.12) in the compacted plots and longer (21.43cm) in the plots without compaction. This result is in conformity with that obtained from the screen house experiment with respect to the root length. The increase in root length with decrease in compaction levels may be due to lower penetration resistance in the un-compacted soil that favored water and nutrient absorption and thus producing longer roots. According to Veen *et al.* (1992) total root length was smaller in compacted than in less compacted soil. They further demonstrated that in the most compacted soil, roots were mainly restricted to the upper zones of the soil studied.There was no significant effect of the three nitrogen sources in root length of soybean. The average root length values are higher for the urea treated plots followed by rhizobia and the lowest values were obtained from the control (un-inoculated) plots.

4.2.3 Effect of soil moisture deficit, soil compaction and N sources on shoot fresh and dry weight of soybean

Soil moisture did not significantly ($p<0.05$) influenced shoot fresh weight (Table 4.11). Although there was no significant variation among the four (4) ASMD levels with respect to shoot fresh weight, up to 83.28% increase in shoot fresh weight was observed with 0% ASMD over 75% ASMD. The possible reason for the insignificant difference in shoot fresh weight observed with respect to the four (4) ASMD levels could be due to the plants not being able to store excess water within their tissue. This is not in conformity with the screen-house result where soil moisture significantly affected shoot fresh weight. Table 4.11 presents the effects of soil compaction on shoot fresh weight. Although, more than 100 % increment in shoot fresh weight was obtained from the compacted plots with respect to the un-compacted soil, no significant statistical difference ($P\leq0.05$) was revealed among the compaction treatments. The mechanism that compacted soil supported better growth more than un-compacted soil is not clearly understood as reported by Ponder (2004). The three nitrogen sources did not differ significantly ($P\leq0.05$) with regards to shoot fresh weight. This is similar to the result of the screen-house experiment. However, it contradicts the findings of Ravikumar (2012) who showed that inoculated plants possessed greater fresh weight over their respective un-inoculated control.

Table 4.11: Effect of soil moisture deficit, soil compaction and nitrogen source on shoot fresh and dry weight of soybean at IAR Irrigation farm Samaru, Zaria.

Treatment	**Shoot Fresh Weight (g plant^{-1})**	**Shoot Dry Weight (g plant^{-1})**
ASMD (%)		
0	94.2a	13.64a
25	27.48a	15.86ab
50	20.04a	14ab
75	15.75a	10.44b
SE ±	34.457	1.480
Compaction (C)		
C_0	26.22a	16.79a
C_3	52.51aa	10.17b
SE ±	24.365	1.046
Nitrogen Source (N)		
Control	71.89	12.50
Rhizobia	22.74	13.35
Mineral Nitrogen	23.47	14.61
SE±	29.841	1.281
Interaction		
MD x C	ns	ns
MD x N	ns	ns
C x N	ns	ns
MD x C x N	ns	ns

Means with the same letters within a treatment column are not significantly different, ns= not significant, WAS= weeks after sowing, C_0= No compaction, C_3=Compaction at 1.5kgFcm^{-2}, ASMD =Available soil moisture deficit.

Shoot dry matter significantly varied ($P \leq 0.05$) among the four ASMD treatments imposed (Table 4.11). 25% ASMD produced the highest shoot dry matter per plant. At 75% ASMD the lightest shoot dry weight per plant was obtained. No deficit and 50% ASMD produced statistically similar shoot dry weight ($P \leq 0.05$) of intermediate value. However, the result did not follow a similar trend with that of the screen-house experiment where significant ($P \leq 0.05$) reductions were observed in shoot dry matter with increase in soil moisture stress. The reason could be due to water logging that was observed at 0% ASMD and which may have impeded root respiration, and consequently, retarded plant growth. Significant decrease ($P \leq 0.05$) in shoot dry weights was observed in compacted soils (1.5 kg F cm-^{2}). Up to 39.43% decrease in shoot dry matter was observed in compacted soil compared to the un-compacted control. Contradictory findings were reported by Danmowa (2003) who found 26-34% increase in shoot dry matter in the compacted soil over the un-compacted control treatment. The reason for conflicting results could be due to the different compaction levels imposed in the two experiments. Soil compaction in this experiment was higher and affected shoot dry weights negatively. There was no significant difference among the three nitrogen sources used in terms of shoot dry matter. This corresponds to results of the screen house experiment and work by Abdul-latif (2013). Mineral nitrogen gave the highest mean value for shoot dry matter (14.61 g/plant), followed by rhizobia (13.35 g/plant) and least mean value was obtained from the control un-inoculated plots (12.50 g/plant). Muhammad (2010) reported that inoculation and 60 kg N ha^{-1} treatment were not significantly different and were found to significantly ($P \leq 0.05$) increase soybean shoot biomass over those of the uninoculated (control) treatment.

4.2.4 Effect of soil moisture deficit, soil compaction and N sources on root fresh and dry weight of soybean

Soil moisture deficit significantly ($P \leq 0.05$) influenced root fresh weight (Table 4.12). 0% ASMD gave the highest mean value for root fresh weight and 75% ASMD gave the least. 25% and 50% ASMD produced roots of intermediate fresh weight value and were statistically ($P \leq 0.05$) similar. This finding does not correspond to the result obtained in the screen-house experiment where a linear inverse relationship between soil moisture stress and root fresh weights of soybean was observed. However, this finding is in conformity with the result of Vinicius *et al.* (2014) who reported that root fresh weight were influenced by water availability. Moreover, compaction did not show significant ($P \leq 0.05$) influence on root fresh weight. The three nitrogen sources did not differ root fresh weight significantly ($P \leq 0.05$). This is similar to the result of the screen-house experiment.

No significant ($P \leq 0.05$) difference existed among all ASMD levels with respect to root dry matter (Table 4.12). 25% deficit gave the highest mean value and 75% gave the least value for root dry matter. While 0% and 50% gave exactly the same value for root dry weight. This disagrees with the result of Ndimbo (2015) who reported that moisture stress reduced root biomass. Significant ($P \leq 0.05$) decrease in root dry weights was observed in compacted soils. This agrees with the findings of Buttery *et al* (1998) who reported that root growth of soybean was restricted by compacted conditions. Up to 32.49% decrease in root dry matter was observed in compacted soil compared to the un-compacted control. There was no significant difference among the three nitrogen sources used in terms of root dry matter. This corresponds with results of the screen house experiment. Significant difference was observed between moisture deficit and nitrogen sources on root dry weight.

Table 4.12: Effect of soil moisture deficit, soil compaction and nitrogen sources on root fresh and dry weight of soybean at IAR Irrigation Station Samaru, Zaria.

Treatment	**Root Fresh weight (g plant^{-1})**	**Root Dry Weight (g plant^{-1})**
ASMD (%)		
0	2.89a	2.07a
25	3.32ab	2.18a
50	2.43ab	2.07a
75	2.00b	1.62a
SE±	0.305	0.208
Compaction (C)		
C_0	3.11a	2.37a
C_3	2.21b	1.60b
SE±	2.216	0.147
Nitrogen Source (N)		
Control	2.21	1.78
Rhizobia	2.90	2.08
Mineral Nitrogen	2.88	2.09
SE±	0.264	0.181
Interaction		
MD x C	ns	ns
MD x N	ns	**
C x N	ns	ns
MD x C x N	ns	ns

Means with the same letters within a treatment column are not significantly different, ns= not significant, ** = highly significant at P≤ 0.01probability, WAS= weeks after sowing. , C_0= No compaction, C_3=Compaction at 1.5kgFcm^{-2}, ASMD =Available soil moisture deficit.

Figure 4.6 shows the interaction between soil moisture deficit and nitrogen source combinations on root dry weight. From the Figure, it was observed that application of 0% ASMD without nitrogen (no nitrogen) or 25%ASMD with mineral nitrogen (urea) significantly ($P \leq 0.05$) produced the heaviest root dry matter per plant. Up to 75% ASMD produced significantly ($P \leq 0.05$) lower root dry mass in soils of the control plots. However, irrespective of the moisture stress (ASMD) rhizobia inoculated plants produced statistically the same root dry matter per plant. This contradicts the findings of Tate (1995) that rhizobial population densities tend to be low under dry soil conditions and increase as the moisture stress is relieved. The mean value of root dry matter obtained for the rhizobia inoculated plant is statistically similar to that when urea was applied and with application of 0% ASMD, 50% ASMD, and 50% ASMD when no nitrogen was applied. The least mean values for root dry matter were obtained at 25%ASMD without nitrogen and at 75%ASMD with urea application. This agrees with the result of Amos *et al.* (2009) who reported that maize response to applied nitrogen was influenced by availability of water in soil.

4.2.5 Effect of soil moisture deficit, soil compaction and N sources on leaf area of soybean

Effects of soil moisture deficit on leaf area of soybean are presented in Table 4.13. The results showed that ASMD levels significantly ($P \leq 0.05$) influenced leaf area. The mean value for the leaf area was highest when the plants were not subjected to any moisture stress (0% ASMD). A decrease in the leaf area value was obtained when 25% ASMD was applied. The least value was obtained when the plants were stressed up to 75% of the ASMD. While intermediate mean values that are significantly ($P \leq 0.05$) different were obtained at 25% and 50% ASMD which are 53.67cm^2 and 44.94 cm^2 respectively. Ashraf and Oleary (1996) also reported that reduction in growth is the first plant response to drought stress. These results also corroborated with what was

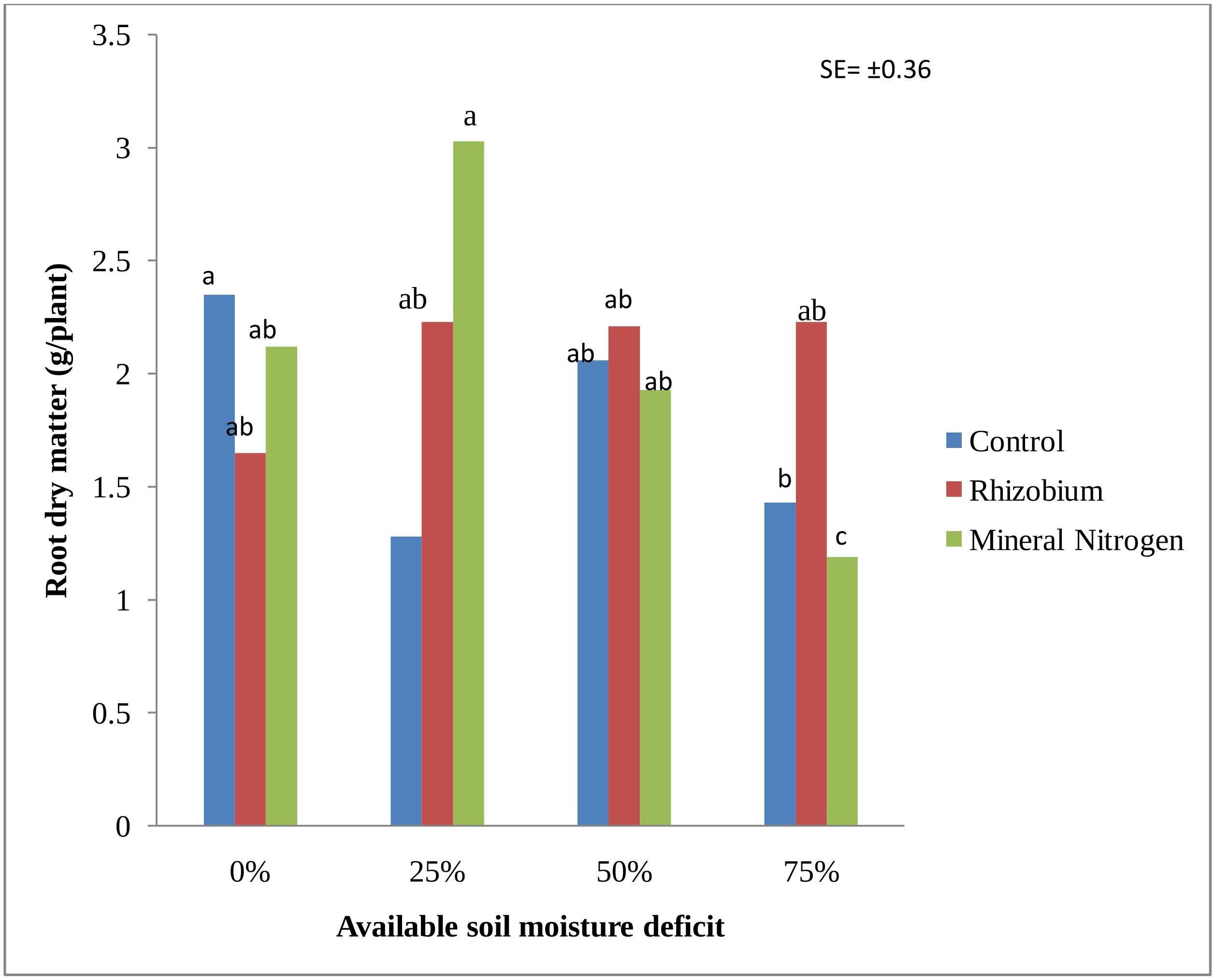

Figure 4. 6: Interactions between soil compaction levels and available soil moisture deficit in root dry matter weight of soybean in field experiment at 8WAS.

Bars with the same letter across treatments are not significantly different, WAS= weeks after sowing

Table 4.13 Effect of soil moisture deficit, soil compaction and nitrogen source on leaf area of soybean at 8WAS in IAR Irrigation farm Samaru Zaria at 8WAS.

Treatment	**Leaf Area cm^2**
ASMD (%)	
0	63.38a
25	53.67ab
50	44.94bc
75	40.11c
SE±	4.178
Compaction (C)	
C_0	50.22
C_3	50.83
SE±	2.954
Nitrogen Source (N)	
Control	50.50
Rhizobia	50.21
Mineral Nitrogen	50.88
SE±	3.618
Interaction	
MD x C	ns
MD x N	ns
C x N	ns
MD x C x N	ns

Means with the same letters within a treatment column are not significantly different, ns= not significant, WAS = weeks after sowing, C_0= No compaction, C_3=Compaction at 1.5kgFcm^{-2}, ASMD =Available soil moisture deficit.

found in the screen-house experiment. The result shows that compaction did not have significantly ($P \leq 0.05$) influence on leaf area of soybean at 8 WAS. This corresponds to the findings of Agber (2002). Soybean depends on the green surface area for the vast majority of photosynthetic output that is deposited in the seeds and other plant parts. Thus, the potential photosynthetic capacity of the plant as indicated by green leaf surface area did not differ with respect to the two compaction levels. The result showed that the three nitrogen sources did not have significant ($P \leq 0.05$) influence on leaf area of soybean. This implies that inoculation had no significant effect on leaf of soybean. This is similar to what was observed in the screen-house. The reason for the observed result could be due to the fact that inoculation does not significantly promote plant growth with regards to the other traits (such as plant height and dry matter) observed.

4.2.6 Effect of soil moisture deficit, soil compaction and N sources on nitrogen concentration

The results of the effects of soil moisture deficit on nitrogen concentration are presented in Table 4.14. No significant ($P \leq 0.05$) difference was observed in ASMD levels with respect to nitrogen concentration of the plant at 8 WAS. This supported the screen-house results but contradict the findings of Kalima (2013) and Ndimbo (2015). They reported that moisture stress levels reduced nodulation, nitrogen fixation, root and shoot biomass and finally yield at different growing stages. Moreover, Mohammad *et al.* (2013) also reported a contradicting result that qualitative yield of soybean including oil and protein were significantly ($P \leq 0.05$) higher with full irrigation.

Nitrogen concentration of the soybean plant was not significantly ($P \leq 0.05$) affected by soil compaction. Despite the insignificant ($P \leq 0.05$) effect of soil compaction on nitrogen concentration, nitrogen concentration of soybean increased in compacted soil by 11. 19%

Table 4.14: Effect of soil moisture deficit, soil compaction, and nitrogen sources on nitrogen concentration of soybean at IAR Irrigation farm Samaru, Zaria.

Treatment	**Nitrogen Concentration (%)**
ASMD (%)	
0%	2.76
25%	2.93
50%	2.94
75%	2.68
SE±	0.17
Compaction (C)	
C_0	2.68
C_3	2.98
SE±	0.120
Nitrogen Source (N)	
Control	2.59
Rhizobia	3.05
Mineral Nitrogen	2.84
SE±	0.147
Interaction	
MD x C	ns
MD x N	ns
C x N	ns
MD x C x N	ns

ns= not significant, WAS = weeks after sowing, C_0= No compaction, C_3=Compaction at 1.5 kgF cm^{-2}, ASMD = Available soil moisture deficit compared to the un-compacted treatment. This result did not support the findings of the screen-house experiment. In the screen house, it was observed that nitrogen concentration of the soybean plant decrease with increase in soil compaction although the difference was not significant. Positive effect of soil compaction on cowpea plant growth has been reported by Danmowa (2003). The result shows that different nitrogen sources did not significantly ($P \leq 0.05$) affect nitrogen concentration in soybean plant at 8WAS. These agree with the findings of Mengel *et al* (1987) who found soybeans to be less responsive to application of nitrogen fertilizer than the use of symbiotically fixed nitrogen source. However, rhizobia produced soybean plants with the highest nitrogen content which is followed by urea (mineral nitrogen) and are 17.76% and 9.65% greater than the control un-inoculated plants. This supported the findings of Muhammad (2010) who reported that inoculation and mineral N fertilization (60kg/ha) resulted in increased grain and haulm N contents.

4.2.7 Effect of soil moisture deficit, soil compaction and N sources on number of nodules, nodule fresh and dry weight and amount of N fixed by soybean

Nodule number was significantly ($P \leq 0.05$) affected by soil moisture stress imposed (Table 4.15). This may be due to greater root proliferation with little or no moisture stress thus increasing nodulation. Nodule number at 0% and 25% ASMD was found to be statistically the same and gave the largest mean value than the other treatments (50 and 75% ASMD) which were statistically similar with the lowest means. This result is in line with the screen-house findings. In the screen house experiment, it was found that moisture stress also significantly reduced nodule number. Gaurav *et al.* (2014) showed a similar report supporting the screen-house findings. They found that moisture stress resulted in decreased nodulation and nitrogen fixation.

Table 4.15: Effect of soil moisture deficit, soil compaction and nitrogen source on nodule number, nodule fresh and dry weight and amount of nitrogen fixed of soybean at 8WAS in IAR Irrigation farm Samaru, Zaria.

Treatment	**Nodule Number**	**Nodule Fresh Weight(g/plant)**	**Nodule Dry Weight (g/plant)**	**Amount of Nitrogen Fixed (kg/ha)**
ASMD (%)				
0	24.11a	2.25	0.22	152.22
25	23.67a	1.96	0.19	166.36
50	10.56b	1.06	0.12	77.02
75	6.89b	6.49	0.13	104.93
SE±	3.026	2.883	0.052	44.373
Compaction(C)				
C_0	18.06	1.62	0.13	111.27
C_3	14.56	4.27	0.20	138.99
SE±	2.140	2.039	0.037	31.377
Nitrogen Source (N)				
Control	17.50	5.76	0.16	85.40
Rhizobia	17.75	1.59	0.17	102.24
Mineral Nitrogen	13.67	1.47	0.17	187.75
SE±	2.621	2.497	0.045	38.428
Interaction				
MD x C	ns	ns	ns	ns
MD x N	ns	ns	ns	ns
C x N	ns	ns	ns	ns
MD x C x N	ns	ns	ns	ns

Means with the same letter within a treatment column are not significantly different, ns= not significant, WAS= Weeks after sowing, C_0= No compaction, C_3=Compaction at 1.5kgFcm^{-2}, ASMD = Available soil moisture deficit.

The results showed that soil compaction did not significantly ($P \leq 0.05$) affect nodule number. Although no significant ($P \leq 0.05$) difference was observed among the compaction levels, mean value for nodule number was highest in un-compacted soil than compacted soil. Anna and Jerzy (2011) reported corresponding results that nodulation and nitrogenase activity decreased with increasing soil compaction level. Anna and Jerzy (2011) further explained that the influence of soil compaction on nodulation and nitrogen fixation depend on other factors including mulching. They found that at every compaction level, the nitrogenase activity was higher in mulched when compared to the un-mulched soil. Therefore they concluded that the effect of compaction can be mitigated through mulching. Different nitrogen sources did not have significant influence on nodule number. However, the result of this experiment corresponds to the report of Abdul-latif (2013) but contrary to what was observed in the screen-house experiment. Despite the lack of significant ($P \leq 0.05$) difference among the three nitrogen sources, rhizobia gave the highest nodule number which is 1.43 % greater than the control un-inoculated plot and 23.31 % more than the urea treated plots with respect to the control. This confirms the findings of Muhammad (2010) who reported that nodule number was suppressed by mineral N fertilization among the treatments.

Effects of soil moisture deficit, soil compaction and N sources on nodule fresh weight are presented in Table 4.15. It was observed that soil moisture deficit did not significantly ($P \leq 0.05$) affect nodule fresh weight. This contradicts the findings of Kalima (2013) who found that moisture stress reduce nodulation. However, the possible reason for the lack of significant ($P \leq 0.05$) effect of moisture stress on nodule fresh weight could be due to the development of resistance to water stress by the plants during its growing period. The results showed that soil compaction did not significantly ($P \leq 0.05$) affect nodule fresh weight. Different nitrogen sources did not have significant ($P \leq 0.05$) influence on nodule fresh weight. However, the result of this experiment corresponds to the report of Abdul-latif (2013) but contrary to what was observed in the screen-house experiment.

Effects of soil moisture deficit, soil compaction and N sources on nodule dry weight are presented in Table 4.15. It was observed that soil moisture deficit did not significantly ($P \leq 0.05$) affect nodule dry weight. This result is not in line with the screen-house findings. In the screen house experiment, it was found that moisture stress significantly reduced nodule dry weight. This may be due to residual soil moisture around the root zone that played a role which was not the case in the screen house where moisture was drained away from the root zone in the soil columns. Although no significant ($P \leq 0.05$) difference was observed among the compaction levels, mean values for nodule dry weight was highest in compacted soil than un-compacted soil. Different nitrogen sources did not have significant ($P \leq 0.05$) influence on nodule dry weight. Result of this experiment corresponds to the report of Abdul-latif (2013) but contrary to what was observed in the screen-house experiment. Regarding the nodule dry weight, the control un-inoculated plots gave the lowest mean while the legumefix and the urea treated plot recorded exactly the same value and were 6.25% greater than the control.

Soil moisture deficit did not significantly ($P \leq 0.05$) affect the amount of nitrogen fixed (Table 4.15). Gaurav *et al.* (2014) and Ndimbo (2015) showed a contradicting report. They found that moisture stress resulted in increased nitrogen fixation. The results showed that soil compaction did not significantly ($P \leq 0.05$) affect amount of N fixed. Although no significant ($P \leq 0.05$) difference was observed among the compaction levels, mean value for amount of nitrogen fixed was highest in compacted soil than un-compacted soil. Different nitrogen sources did not have significant ($P \leq 0.05$) influence on nodule number, nodule dry weight as well as amount of nitrogen fixed. Result of this experiment corresponds to the report of Abdul-latif (2013), who reported that inoculation with legumefix did not significantly increase the amount of nitrogen fixed. The fact that inoculation of soybean did not influence the amount of N fixed, therefore inoculation with legumefix is not a significant agency for the manipulation of rhizobium for improving soil fertility and crop production.

4.2.8 Effect of soil moisture deficit, soil compaction and N sources on chlorophyll index of soybean

Table 4.16 shows the effect of soil moisture deficit on chlorophyll index of soybean. The results showed that soil moisture deficit did not significantly ($P \leq 0.05$) affect chlorophyll index of soybean. This implies that irrespective of the soil moisture stress the chlorophyll index of soybean remain essencially the same. These could be attributed to soil moisture not having significant effect on nitrogen concentration and nitrogen fixation. Chlorophyll content of soybean was significantly ($P \leq 0.05$) affected by soil compaction. There was significant ($P \leq 0.05$) decrease of about 7.34% in chlorophyll index of soybean on the compacted soil compared to the un-compacted control plots. This result conforms to that of Nubia *et al.* (2016). They found significant increase in Falker chlorophyll index of cowpea at 52 days after sowing in un-compacted soil. They reported that it is possible to obtain a reduction of 8.35% in Falker chlorophyll index when plants are grown in compacted soil. The application of nitrogen from different sources had no significant effect on soybean chlorophyll index. Nevertheless the control un-inoculated plants recorded the highest mean for soybean chlorophyll content which was 1.10% and 0.04% greater than the rhizobia and the urea treated plots respectively. The possible reason for the insignificant effect of inoculation on chlorophyll index of this crop could

Table 4.16: Effect of soil moisture deficit, soil compaction and nitrogen source on chlorophyll index of soybean in IAR Irrigation farm Samaru, Zaria at 8 WAS.

Treatment	**Chlorophyll Index**
ASMD (%)	
0	41.38
25	40.84
50	40.35
75	41.26
SE±	0.798
Compaction (C)	
C_0	42.41a
C_3	39.51b
SE±	0.564
Nitrogen Source (N)	
Control	41.03
Rhizobia	40.85
Mineral Nitrogen	40.99
SE±	0.691
Interaction	
MD x C	ns
MD x N	ns
C x N	ns
MD x C x N	ns

Means with the same letter(s) within a treatment column are not significantly different, WAS=weeks after sowing, ns= not significant, C_0= No compaction, C_3=Compaction at 1.5kgFcm^{-2}.

be because the three nitrogen sources did not significantly affect nodulation, nitrogen concentration and nitrogen fixation.

4.2.9 Effect of soil moisture deficit, soil compaction and N sources on total dry matter grain yield and 100-seed weight of soybean

Water stress is the most important factor that affects plant metabolic activities and significantly reduced yield. Moisture deficit could be a useful factor by reducing the rate of moisture loss through evapo-transpiration. However, in this experiment total dry matter was significantly ($P \leq 0.05$) affected by ASMD (Table 4.17). Total dry matter of soybean significantly ($P \leq 0.05$) decreased with increase in available soil moisture stress. This finding is in agreement with the previous report revealing that the water stress substantially alters plant metabolism, decreasing plant growth and photosynthesis (Tezara *et al.*, 1999). Moreover, a decrease of 35.52% in soybean total dry matter was obtained when the crop was stressed to 75% of the available soil moisture. Soil compaction resulted in decreasing total dry matter. However, the reduction was not significant. This is in line with the findings of Murshidul and Tohru (2015). They reported that soil compaction reduced total dry matter of rice. Total dry matter was significantly ($P \leq 0.05$) affected by the different nitrogen sources. Mineral nitrogen gave the highest mean value for total dry matter yield while rhizobia and the control un-inoculated plot gave the lower total dry matter yields which were statistically the same. It was reported that increase in dry matter yield over control depend on the strain of rhizobia used (Patra *et al*., 2012).

Grain yield was not significantly ($P \leq 0.05$) affected by soil moisture stress (Table 4.17).

Table 4.17: Effect of soil moisture deficit, soil compaction and nitrogen sources total dry matter, grain yield and 100-seed weight of soybean at IAR Irrigation farm Samaru, Zaria at 8WAS.

Treatment	**Total Dry Matter (ton/ha)**	**Grain yield Weight (ton/ha)**	**100-Seed Weight (g)**
ASMD(%)			
0	14.36a	2.48	16.70
25	12.86ab	2.39	16.61
50	10.18bc	1.98	15.92
75	9.26c	1.85	16.49
SE±	1.134	2.656	0.442
Compaction(C)			
C_0	12.07	2.25	16.75
C_3	11.26	2.10	16.12
SE±	0.802	0.187	0.313
Nitrogen Source (N)			
Control	10.71b	1.89	16.58
Rhizobia	10.60b	2.14	16.07
Mineral Nitrogen	13.69a	2.49	16.65
SE±	0.983	0.239	0.383
Interaction			
MD x C	ns	ns	ns
MD x N	ns	ns	ns
C x N	ns	ns	ns
MD x C x N	ns	ns	ns

Means with the same letter within a treatment column are not significantly different, ns= not significant, WAS = Weeks after sowing, C_0= No compaction, C_3=Compaction at 1.5kgFcm^{-2}, ASMD = Available soil moisture deficit.

According to Gaurav (2014), growth of plants decreases with the increase in moisture stress. Soil compaction resulted in decreasing grain yield. However, the decrease was not significant ($P \leq 0.05$). This is in conformity with the findings of Murshidul and Tohru (2015). They reported that soil compaction reduced grain yield of rice by decreasing the number of fertile spikelet. There was no significant ($P \leq 0.05$) difference between the three nitrogen sources in term of soybean grain yield. This corresponds to the findings of Zahra and Zahra (2012) in their experiment with chick-pea. They reported that single application of bio-fertilizer and mineral nitrogen did not significantly increase pod weight (which is an indicator of the weight of grains they contained) as compared to the control.

One hundred (100) seed weight was not significantly ($P \leq 0.05$) affected by soil moisture stress (Table 4.17). Soil compaction resulted in decreasing 100-seed weight. However, the decrease were not significant ($P \leq 0.05$).The three nitrogen sources did not significantly ($P \leq 0.05$) influenced 100 seed weight of soybean. This corresponds to the findings of Zahra and Zahra (2012) in their experiment with chick-pea. They reported that there was no significant ($P \leq 0.05$) difference between bio-fertilizer and mineral nitrogen in terms of 100-seed weight.

4.2.10 Effect of soil moisture deficit, soil compaction and N sources on soil bulk density and penetration resistance

Soil moisture stress did not significantly ($P \leq 0.05$) affect soil bulk density and penetration resistance at 8WAS at all the depth measured (Table 4.18). Although, there was an increase in both soil bulk density over the initial bulk densities at the time of sowing. These values did not

Table 4.18: Effect of soil moisture deficit, soil compaction and nitrogen source on soil bulk density and penetration resistance (PR) in soybean field at IAR Irrigation farm Samaru Zaria, at 8WAS.

	Bulk density(Mgm3)				
Treatment	**(0-5cm)**	**(5-10cm)**	**(10-15cm)**	**(15-20cm)**	**PR(kgFcm^{-2})**
ASMD (%)					
0	1.91	1.93	2.58	2.20	3.07
25	1.93	1.87	2.10	2.20	3.06
50	2.05	1.93	2.31	2.25	3.73
75	1.93	1.99	2.22	2.26	3.51
SE±	0.086	0.088	0.190	0.061	0.250
Compaction(C)					
C_0	1.92	1.83b	2.46	2.33a	3.11b
C_3	1.99	2.02a	2.14	2.14b	3.58a
SE±	0.061	0.063	0.014	0.043	0.173
Nitrogen Source (N)					
Control	1.91	1.94	2.49	2.15	3.47
Rhizobia	1.97	1.97	2.18	2.25	3.30
Mineral Nitrogen	1.88	1.88	2.24	2.30	3.26
SE±	0.074	0.077	0.167	0.053	0.213
Interaction					
MD x C	ns	ns	ns	ns	ns
MD x N	ns	ns	ns	*	ns
C x N	ns	*	ns	*	ns
MD x C x N	ns	ns	ns	*	ns

Means with the same letters within a treatment are not significantly different, PR= penetration resistance, WAS = weeks after sowing, ns= not significant, * = significant at $P \leq 0.05$ probability, C_0= No compaction, C_3=Compaction at 1.5kgFcm^{-2}, ASMD = Available soil moisture deficit vary significantly ($P \leq 0.05$) among the various soil moisture deficits imposed after 8 week of the plant growth. Soil compaction on the other hand significantly affected soil bulk density at 5-10cm and 15-20cm. Soil bulk density was found to be significantly ($P \leq 0.05$) higher on the compacted (no till) plots at 5-10cm depth. Kooistra and Tovey (1994) reported that soil bulk density increase with increase in soil compaction. Nevertheless, at 15-20cm depth soil bulk density was found to be significantly ($P \leq 0.05$) higher on the un-compacted plots. This indicated that the effect of compaction had not reached this depth of 15-20cm. The results showed that nitrogen sources had no significant ($P \leq 0.05$) influence on soil bulk densities at 8WAS. This disagrees with the findings of Waseem *et al.* (2013) who reported significant ($P \leq 0.05$) effect of nitrogen sources on soil bulk density. They found that bulk density was highest in the control plot where no nitrogen was applied. Significant interaction was observed between soil compaction and nitrogen sources on bulk density at 5 to 10cm depth.

Figure 4.7 shows the combined effect of soil compaction and nitrogen source on soil bulk density at 5 to 10 cm. It was observed that mineral nitrogen gave the highest mean for soil bulk density when the soil was compacted (C_3). This account for the decrease in shoot dry matter obtained earlier where the soil was compacted and mineral nitrogen was applied. This is because a combination of high compaction and mineral nitrogen increase soil bulk density. Mineral nitrogen also gave the least mean value for soil bulk density when the soil was not compacted (C_0). However, irrespective of the soil compaction level, the un-inoculated control plot gave statistically similar soil bulk density value with rhizobia treated plot.

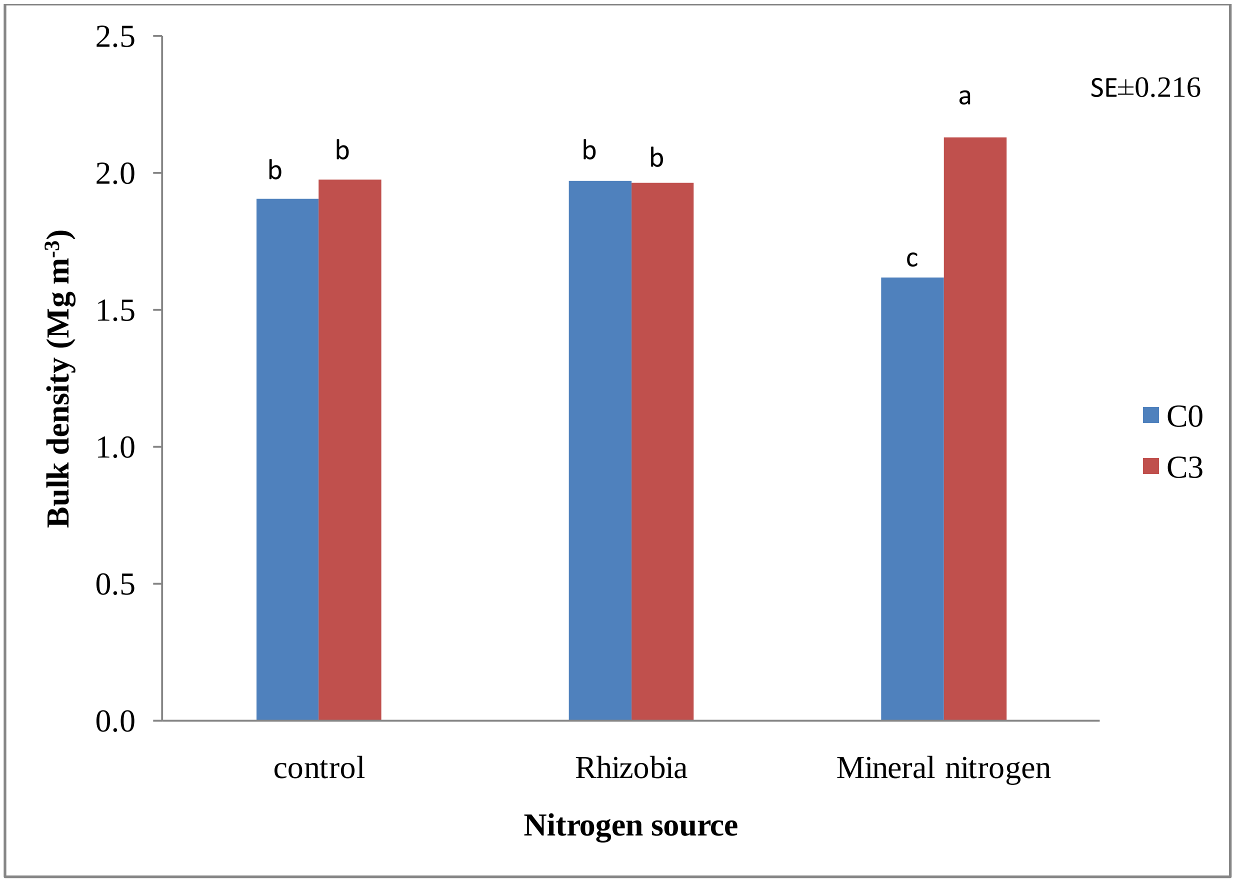

Figure 4.7: Interactions between soil compaction levels and nitrogen source on soil bulk density at 5 to 10 cm in soybean field at 8WAS.

Bars with the same letter across treatments are not significantly different at $P<0.05$; WAS= weeks after sowing C_0= No compaction; C_3=Compaction at 1.5kgFcm^{-2}.

Significant interaction was also observed at 15 to 20 cm soil depth between moisture deficit, soil compaction and nitrogen source.

Figure 4.8 shows the interactions of soil moisture deficit, soil compaction levels and nitrogen sources on soil bulk density at 15 to 20 cm in soybean field at 8WAS. It was observed that irrespective of the ASMD, the combination of mineral nitrogen under the un-compacted soil yielded the highest soil bulk density. While the lowest mean value for bulk density was obtained where the soil was compacted and no nitrogen was applied. Application of rhizobia or no nitrogen in the un-compacted plots yielded the same soil bulk density with plots that received either rhizobia or mineral nitrogen in the compacted soil.

Soil moisture stress did not significantly ($P \leq 0.05$) affect soil penetration resistance at 8WAS (Table 4.18). Although, there was an increase in both soil penetration resistance over the initial values imposed at the time of sowing. These values did not vary significantly ($P \leq 0.05$) among the various soil moisture deficits imposed after 8 weeks of plant growth. It was observed that soil compaction significantly ($P \leq 0.05$) influenced soil penetration resistance. This is in agreement with the screen-house findings. This also supported the findings of Kooistra and Tovey (1994). They observed that soil compaction increases bulk density and decreases pore volume. As the pore volume decrease plant roots encounter greater resistance to penetration. This is also inconformity with the findings of Aikins and Afuakwa (2010). Aikins and Afuakwa (2010) reported that conventionally tilled plots produced the lowest soil penetration resistance. The results showed that nitrogen sources had no significant ($P \leq 0.05$) influence on penetration resistance at 8WAS.

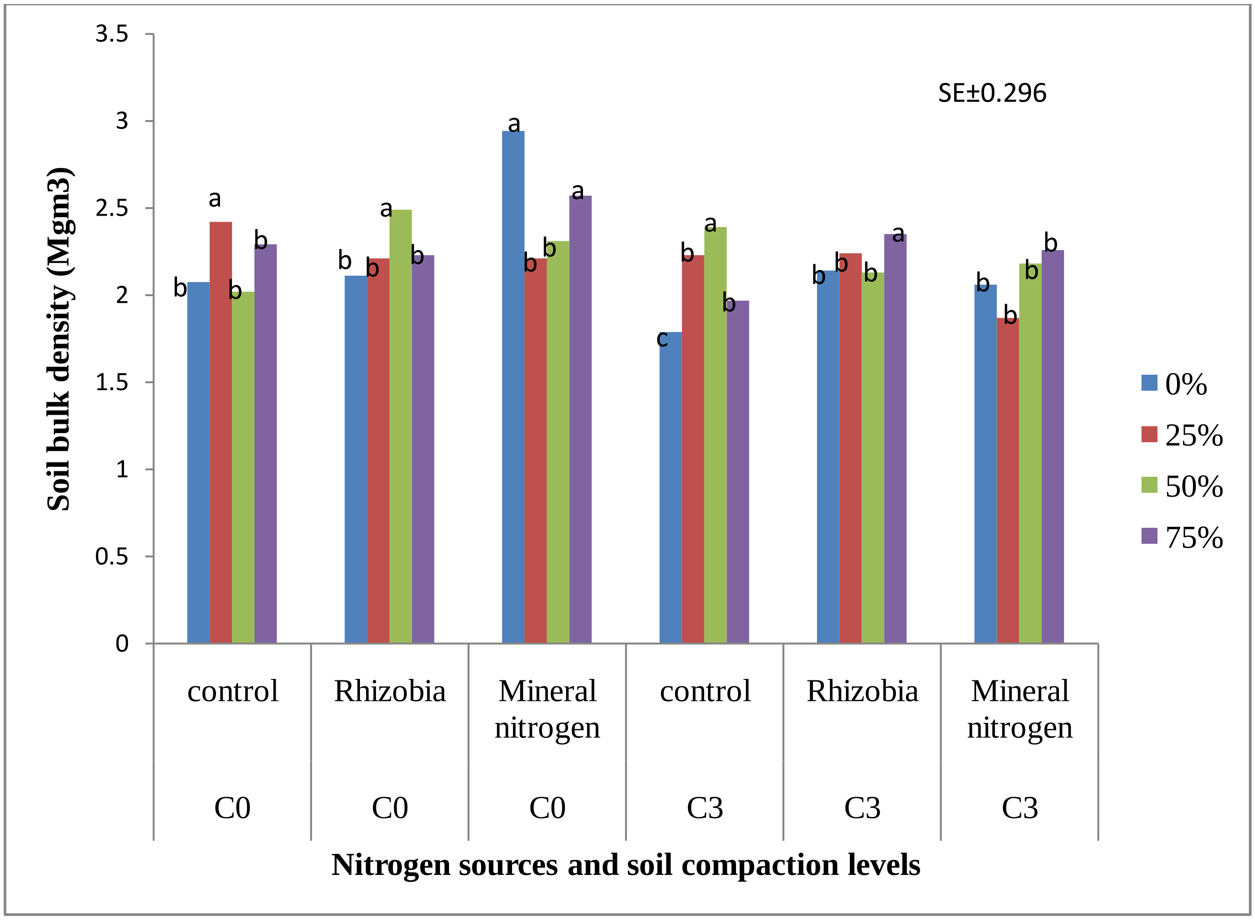

Figure 4.8: Interactions between soil moisture deficit, soil compaction levels and nitrogen source on soil bulk density at 15 to 20 cm in soybean field at 8WAS.

Bars with the same letter across treatments are not significantly different; WAS= weeks after sowing C_0= No compaction; C_3=Compaction at 1.5kgFcm^{-2}.

4.2.11 Association between all measured parameters.

Table 4.19 shows the association between all the measured parameters. It was observed that plant height had positive and significant correlation with root length, root fresh weight, shoot dry weight, root dry weight, nodule number and 100-seed weight. Root length was also positively and significantly correlated with root fresh weight, shoot dry weight, root dry weight and total dry matter. There was also positive and significant correlation between shoot fresh weight with root dry weight and 100-seed weight. Shoot dry weight, root dry weight, nodule number, total dry matter and grain yield per hectare were significantly and positively correlated with root fresh weight. Root dry weight, nodule number, nodule fresh weight, chlorophyll content, 100-seed weight and soil bulk density at 15 to 20cm had positive and significant correlation with shoot dry weight. Irrespective of soil textural class and bulk density value imposed, Michel *et al.* (2015) observed that the dry mass of soybean's roots was significantly positively related with the dry mass of shoots. This therefore implies that for a given bulk density the soybean's shoot dry matter increases with increasing root dry matter and vice versa. However, the coefficient of determination (R^2) was low indicating that the variability in the growth of the above ground part of plants (soybean) was possibly influenced by other variables than the root growth variation due to the increase in bulk density. Nodule number and grain yield per hectare also had positive and significant correlation with root fresh weight. Correlation analysis also showed positive and significant relationship between nodule fresh weight, nodule dry weight and soil bulk density at 15-20cm of soil depth with nodule number. Nodule fresh weight had positive and significant correlation with nodule dry weight, leaf area and total dry matter. Chlorophyll content ha positive and significant relationship with soil bulk density at 10 to 15 cm of soil depth. Grain

Table 4.19: correlation coefficient of measured parameters in the field experiment

Parameter	PH	RL	SFW	RFW	SDW	RDW	NDN	NFW	NDW	CC	NC	N_2FX	LA	TDM	GY	100-SW	BD (0-5cm)	BD (5-10cm)	BD (10-15cm)	BD (15-20cm)	PR
PH	1																				
RL	0.25*	1																			
SFW	-0.03	0.01	1																		
RFW	0.58***	0.55***	-0.04	1																	
SDW	0.74***	0.50***	-0.02	0.86***	1																
RDW	0.53***	0.51***	0.39**	0.83***	0.82***	1															
NDN	0.37*	0.05	0.02	0.42*	0.50***	0.37*	1														
NFW	0.13	0.13	0.07	0.22	0.23*	0.22	0.31*	1													
NDW	0.17	-0.02	-0.02	0.02	0.05	-0.02	0.39*	0.48***	1												
CC	0.22	0.09	0.02	0.09	0.24*	0.18	0.11	-0.07	0.11	1											
NC	0.13	0.03	-0.01	0.16	0.15	0.11	0.10	0.00	0.09	0.04	1										
N_2FX	0.1	0.04	-0.01	0.10	0.03	0.06	0.04	0.10	0.09	-0.03	0.23	1									
LA	-0.19	-0.01	-0.10	0.05	0.00	0.04	-0.04	0.26*	0.10	0.07	-0.11	0.06	1								
TDM	0.19	0.27*	-0.02	0.27*	0.08	0.14	0.11	0.28*	0.14	-0.01	0.14	0.45	0.23	1							
GY	0.21	0.09	0.02	0.35*	0.12	0.24*	0.07	0.16	0.08	-0.09	0.11**	0.38	0.12***	0.70	1						
100-SW	0.37**	0.02	0.23*	0.14	0.28*	0.22	0.11	0.18	0.09	0.00	0.00	-0.06	-0.06	0.04	0.04	1					
BD	-0.11	-0.08	-0.11	-0.09	-0.05	-0.08	-0.01	0.04	-0.03	-0.10	-0.01	-0.12	0.22	-0.15	-0.07	-0.14	1				
BD	-0.23	-0.13	-0.04	-0.19	-0.19	-0.16	-0.06	0.11	0.10	-0.16	-0.10	0.00	-0.04	-0.06	-0.03	-0.02	0.07	1			
BD3	0.22	0.02	-0.05	0.16	0.28*	0.08	0.03	0.06	0.03	0.23*	0.06	-0.04	0.03	-0.02	-0.11	0.24	-0.04	0.01	1		
BD4	0.09	0.01	-0.19	0.24	0.196	0.13	0.25*	-0.22	-0.05	0.13	-0.21	-0.10	-0.08	0.03	0.09	0.07	-0.06	-0.21	0.02	1	
PR	-0.09	-0.19	0.13	-0.09	-0.03	0.01	0.035	0.06	0.22	-0.13	0.07	0.02	-0.10	-0.18	-0.17	0.17	0.03	0.07	-0.24	-0.07	1

WAS= weeks after sowing *= significant at $P \leq 0.05$, **= significant at $P \leq 0.01$,***= significant at $P<0.001$, PH= plant height, RL= root length, SFW=shoot fresh weight ,RFW=root fresh weight, SDW=shoot dry weight, RDW=root dry weight, NDN= nodule number, NFW=nodule fresh weight, NDW=nodule dry weight, CC=chlorophyll content, NC=nitrogen concentration, N_2 FX=nitrogen fixed, LA= leaf area, TDM=total dry matter, GY=grain yield, 100- SW=seed weight, BD= bulk density, BD_{1234}=bulk density at 0-5cm, 5-10cm, 10-15cm and15-20cm respectively, PR= penetration Resistance.

yield have significant and positive relationship with nitrogen concentration in the plant and leaf area. However, the remaining parameters were not significantly correlated with each other.

The positive and significant correlation between these parameters implies that, an increase in one of these variables leads to corresponding increase in the other related variable. However, it was noted that amount of nitrogen fixed and the nitrogen concentration in the plants were not correlated with any parameter measured. This implies that a change in those parameters would not be accompanied with a corresponding change in amount of nitrogen fixed and nitrogen concentration of the plant. This contradicts the findings of Abdul-latif (2013) who reported that nitrogen concentration of soybean and amount of nitrogen derived from atmosphere were significantly correlated with each other and with grain yield.

CHAPTER FIVE

5.0 SUMMARY AND CONCLUSION

5.1 Summary

The experiments were conducted during the 2015 and 2016 dry seasons. The first experiment was a screen-house trial in the Department of Soil Science Ahmadu Bello University Zaria. The second experiment was a field trial at the Institute for Agricultural Research (IAR) irrigation research farm. The experiments were conducted to evaluate the effect of soil compaction, soil moisture deficit, rhizobium inoculation and mineral nitrogen on soybean production and selected soil physical properties in northern Guinea savannah of Nigeria. The yield and yield parameters observed were plant height, root length, shoot and root fresh weights, shoot and root dry weight, leaf area, nodule number, nodule fresh and dry weight, amount of nitrogen fixed, nitrogen concentration of the plant, chlorophyll index, total dry matter, grain yield and hundred seed weight. Soil properties observed were Bulk density and penetration resistance.

In the screen-house study, there was significant ($P \leq 0.05$) reduction in yield parameters with increase in soil compaction. However at 1.3 kg F cm^{-2} compaction level there was significant ($P \leq 0.05$) increase in root length and shoot fresh weight over the un-compacted treatment. There was no significant ($P \leq 0.05$) difference in plant height and nodule dry weight with respect to soil compaction. However, soil compaction significantly ($P \leq 0.05$) increased soil penetration resistance. Available soil moisture deficit (ASMD) significantly ($P \leq 0.05$) decrease shoot and root fresh and dry weight, nodule number and nodule fresh and dry weights. However, 0% and 25% ASMD produced plants of statistically similar height and root length. There was no significant (P≤0.05) difference among the nitrogen sources in all the parameters studied except in root length where mineral nitrogen (urea) gave the highest mean with up to 10% increase in root lenght over the un-inoculated control treatment. Rhizobia inoculation gave significantly highest mean for nodule number and nodule fresh weights where 44% and 17.65% increase were recorded over their respective control.

In the field study the result showed significant difference (P≤0.05) among the soil moisture deficit treatment with respect to both plant height and root length. On average, tallest plants were produced where the available soil moisture deficit (ASMD) was only 25%. Longer roots were produced where no moisture stress was imposed which statistically differed from the other moisture deficit treatments. Although there was no significant variation among the four (4) ASMD levels with respect to shoot fresh weight, up to 83.28% increase in shoot fresh weight was recorded with 0% ASMD over 75% ASMD. 0% ASMD gave the highest mean value for root fresh weight and leaf area while 75%ASMD gave the least values. 25% ASMD produced the heaviest shoot dry matter per plant. No statistical difference was observed in ASMD levels with respect to nitrogen concentration of the plant at 8 WAS. Soil moisture deficit did not significantly (P≤0.05) affect nodule fresh and dry weight, amount of nitrogen fixed and chlorophyll index. Nodule number at 0% and 25% ASMD were found to be statistically the same and gave the highest mean value than the other treatments (50 and 75% ASMD). Total dry matter of soybean significantly decreased with increase in available soil moisture stress. Grain yield and 100-seed weight were not affect by moisture stress. Soil moisture stress did not significantly affect soil penetration resistance and bulk density at 8WAS at all the depth studied.

The effect of soil compaction followed the same trend as with both plant height and root length. The plants were significantly (P≤0.05) taller (30.23cm) where no compaction was imposed and shorter (21.43cm) on the compacted plots. Similarly, the roots were significantly ($P \leq 0.05$) shorter (19.12cm) in the compacted plots and longer (21.43cm) in the plots without compaction. More than 100 % increment in shoot fresh weight was obtained from the compacted plots with respect to the un-compacted soil, no statistical difference was revealed among the compaction treatments. Up to 39.43% and 32.49% decrease in shoot and root dry matter respectively were observed in compacted soil compared to the un-compacted control. Compaction did not have significant ($P \leq 0.05$) influence on leaf area and nitrogen concentration of the soybean plant. Despite the insignificant effect of soil compaction on nitrogen concentration, soybean N content increased in compacted soil by 11. 19% compared to the un-compacted treatment. Although no significant ($P \leq 0.05$) difference was observed among nodule number, nodule fresh and dry weight and amount of nitrogen fixed, mean values for nodule fresh and dry weight and amount of nitrogen fixed were highest in compacted soil than un-compacted soil except for nodule number. There was significant ($P \leq 0.05$) decrease of about 7.34% in chlorophyll index of soybean on the compacted soil compared to the un-compacted control plots. Soil compaction resulted in insignificant decrease in total dry matter, grain yield and 100-seed weight. Soil compaction significantly ($P \leq 0.05$) increased penetration resistance and affected soil bulk density at 5-10 and 15-20cm depth.

The three nitrogen sources did not significantly affect plant height and root length, shoot and root fresh and dry weights, leaf area, grain yield and 100-seed weight, nitrogen concentration of the plant, chlorophyll index, nodule number, nodule fresh and dry weight as well as amount of nitrogen fixed. Despite the insignificant differences among the three nitrogen sources, rhizobia gave the highest nodule number which was 1.43 % greater than the control un-inoculated treatment and 23.31 % more than the urea treatments with respect to the control. In terms of nodule fresh weight, the control gave the highest mean which is 72.40% and 74.48% greater than what was obtained in the rhizobia and urea treated plots respectively. Regarding the nodule dry weight, the control un-inoculated plots gave the lowest mean while the rhizobia and the urea treated plot recorded exactly the same value and were 6.25% greater than the control. Mineral nitrogen gave the highest mean value for total dry matter yield while rhizobia and the un-inoculated control gave the lowest total dry matter yield and both were statistically the same. The results showed that nitrogen sources had no significant ($P \leq 0.05$) influence on soil bulk densities and penetration resistance at 8WAS

5.2 Conclusions

It can be concluded that water use for soybean production can economically and sustainably reduced up to 25%ASMD.

Soil compaction significantly ($P \leq 0.05$) increase penetration resistance by 15.11% over the un-compacted soil at 1.5kg F cm^{-2}. Moreover, the effects of compaction on soil bulk density depend on soil depth and could be positive or negative.

The three nitrogen sources did not significantly ($P \leq 0.05$) affect most of the yield and yield characters as well as the soil physical properties. However rhizobia treatment increased nodule number by 44.72% and nodule fresh weight by 17.65% over the control un-inoculated treatment in the screen-house study. This was not obtained in the field trial result.

5.2 Recommendations

Decreasing ASMD to 25% is recommended for soybean production under minimum tillage because it gave statistically similar or even higher yield parameters in some cases than with full irrigation (0% ASMD).

It is recommended to produce soybean under minimum tillage where soil compaction is moderate (not greater than 1.3kg F cm^{-2}) for better yield. This will reduce cost of production.

The results indicated that the different nitrogen sources did not significantly influence most of the parameters measured. It is therefore recommended that other experiment should be conducted using different inoculants and different varieties of soybean.

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