UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECT OF NITROGEN, PHOSPHORUS TYPE AND INOCULATION ON GRAIN YIELD OF SOYBEAN IN TWO SOIL SERIES

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FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCE

DEPARTMENT OF AGRONOMY

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BY

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THESIS SUBMITTED TO THE DEPARTMENT OF CROP SCIENCE, FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCES, UNIVERSITY FOR DEVELOPMENT STUDIES, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE

JULY, 2022

DECLARATION

I, ABUKARI FUSEINI declare that this submission is my own work for the award of master's degree in crop science (agronomy), and that to the best of my knowledge, it contains no material previously published by a different person nor material which has been recognized for the award of any other degree of the University, except where due acknowledgment has been made.

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ABSTRACT

An experiment to investigate the effects of nitrogen, phosphorus type and inoculation on grain yield of soybeans in two soil series. Soybean ranks first as an oilseed crop in the world and been a legume, it goes through a biological N-fixation process which is the second most important biological process after photosynthesis. Low soil fertility results in low crop yield which affects the livelihood of farmers and increasing yield of oil seed crops such as soybean has the potential to save Ghana foreign exchange. There are hypothesis that application of phosphate fertilizer blend with rhizobia inoculants will stimulate plant N accumulation to enhanced grain yield of soybean in low N environments. It was conducted at Gbulahigu in the Tolon district of the northern part of Ghana in 2021 farming season. The study was 2 x 9 factorial experiment which were laid down in a randomized complete block design (RCBD) with four replications. The factors include; Soil type at two levels (upland and lowland soils) and Fertilizer amendments at nine levels, which consisted of NK + DAP, NK + PR + Inoculant, NK + DAP + Inoculant, NK + DAP + Inoculant + Foliar (Zn + Fe), NK + DAP + Inoculant + Foliar Zn, NK + (DAP + RP), NK + (DAP + RP) + Inoculant, NK + DAP + Inoculant + Soil Zn and control. Afayak soybean variety was used as planting material. Data was analyzed using ANOVA and separated at 5 % probability level using GENSTAT, 18th edition. Results showed some interaction and soil type were not significant, but was significant ($P<0.05$) for all parameters for fertilizer treatments, NK + DAP + Inoculant + Foliar (Zn + Fe) did better in terms of growth and yield and was therefore recommended for good growth and yield of soybean. Further studies were also recommended, especially the timing and rates of application of these micro nutrients.

DEDICATION

To my parents, Dr. Karim Musah and Munira Alhassan and to Mr. Abubakari Musah, Mr Issahaku Salifu Diploma and Dr. Ahmed Rufai Mahama (my supervisor and mentor).

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Agriculture, which originated as food hunting and gathering, has quietly grown through the decades into a highly industrialized and advanced system that uses massive farm inputs to produce large quantities of food for today's growing global population. For decades, agricultural production expectations have shifted, posing a significant challenge for farmers, agronomists, and all industry players in meeting population demand and producing more food and other industrial raw materials such as fiber and energy generation (Foley *et al*., 2011), which must increase as the world population grows. A considerable increase in agricultural productivity, on the other hand, is expected to be sustainable, economically profitable, and environmentally helpful (Tilman *et al.*, 2002).

Ghana's agricultural sector is the country's economic backbone, accounting for 51% of Ghana's gross domestic product and employing 54% of the country's workforce in 2010. (GSS, 2010). Cereals like rice, maize, millet, and sorghum account for the majority of Ghana's food crops, as do root and tuber crops and legumes such as cowpea, soybeans, and groundnuts. Ghana's total land area is estimated to be 23,853,900 hectares, with agriculture accounting for 13,628,198 hectares (MoFA, 2009a). Permanent farmland accounts for 9.22% agricultural land area, whereas total agricultural land area accounts for 9.22% of total vegetative area. In 2002, 9.22% of the total vegetative land in Ghana were accounted for crop cultivation and other agricultural land use (CIA, 2011). While forest cover accounted for 20.70% area in 2010 (FAO, 2011), the remaining land area is covered by savannah grass woodland, implying that Ghana's whole land area is still underutilized. Peasant farming, on the other hand, accounts for 80% of Ghana's domestic production (MoFA, 2009b). Despite better technology, almost 90% of farm properties are less than 2 hectares in size. There are, however, a few big farms and plantations, mostly for oil palm, cocoa, coconut, and rubber plantations, as well as pineapple, maize, and rice plantations. Postharvest losses of up to 30% (MoFA, 2009b), insufficient storage and processing, improper soil fertility management as a result of improper farming activities, inappropriate marketing strategies and market information and structures, and bushfires have all contributed to poor productivity, with yield of soya around 60% (MoFA, 2009a). Majority of farmers rely significantly on erratic and occasional seasonal rains.

When legumes, such as soybeans, are planted among effective and compatible bradyrhizobia strains, they can supply a percentage of their nitrogen requirements. Seed inoculation is crucial for assuring the occurrence of an efficient bradyrhizobia in the plant roots due to the paucity of some bradyrhizobia strains in soils (Bekere and Hailemariam, 2012). Soil microorganisms that dwell in the root nodules, such as *Bradyrhizobium japonicum* contained in inoculum, and other soil microorganisms that promote plant nutrient absorption, have a large influence on soil nutrient composition (Saharan and Nehra, 2011).

Many researchers and research institutions in Africa and other parts of the world have focused on legume biological nitrogen fixation in the rhizobium-legume relationship, and it offers an environmentally friendly and safe alternative to other farmers and researchers who use synthetic chemical nitrogen fertilizers (Ellafi *et al.*, 2011). In the 1830s, Boussigault explored and discovered the biological N-fixation mechanism, and Hellriegel and Wilfarth corroborated his findings a few years later in 1888 McCosh's (1984). After photosynthesis, biological nitrogen fixation is the second most important biological nitrogen activity (Unkovich *et al*., 2008). Soybeans and other legumes can get up to 80% of their nitrogen requirements through the biological nitrogen fixation process, according to Solomon *et al.* (2012).

Available phosphorus and nitrogen are the most sought components in the symbiotic nitrogen fixation process due to their impact on nodulation and nitrogen fixation (O'Hara *et al.*, 2002). Many experimental studies have shown that phosphorus fertilizers have a role in leguminous plants, such as improved root nodulation, root development, and grain yield of soybean (Tang *et al.*, 2001). Because of the energy-demanding nature of the nitrogen fixation process in legumes (Schulze *et al.*, 2006) and the energy-developing breakdown, biological nitrogen fixation necessitates huge amounts of phosphorus (Plaxton, 2004). The addition of P fertilizers to our crops has resulted in a significant improvement in legume production (Yakubu *et al.,* 2010).

Crop production in Africa is mostly affected by N and P deficiencies, these two (2) elements are mostly insufficient in the soil (Mburu *et al.*, 2011). Legumes production and also their contribution to nitrogen fixation through biological nitrogen fixation method, are impeded mostly by P deficiency (Sinclair and Vadez, 2002). Soil nutrient insufficiency appears to be a key barrier for both governmental and non-governmental organizations striving to alleviate food insecurity and eliminate hunger in Sub-Saharan Africa and around the world (Mburu *et al*., 2011).

Despite the social, environmental, and nutritional benefits of legume cultivation in the guinea savanna agro ecological zone of Ghana, crop yields are reduced by soil infertility caused by a combination of lack of soil organic materials and macro- nutrients like nitrogen and phosphorus (CSIR-RELC, 2005). For optimum crop yields, legumes require extremely important crop nutrition as well as other production conditions. Low crop yield in legume crops can be improved in part by adding P and N to the soil (Daria *et al*., 2012). Reduced soil fertility, on the other hand, results in lower agricultural output, which has an impact on farmers' life (CSIR-RELC, 2005). Furthermore, increasing the yield of oil seed crops, such as soybean, will increase Ghana's foreign exchange by reducing imports of soybean grains ranging from 35,000 to 63,000 metric tonnes required by the domestic market annually processed soy meal worth 37.1 - 66.7 million US dollars (Daria *et al.*, 2012).

1.2 Problem statement

A lot of research has been done recently on the direct supply of rock phosphate (RP) to crops because of its possibility as a replacement for phosphate fertilizers such as single and triple superphosphate, which are substantially more expensive than rock phosphate (Akande *et al*., 2010). Yara Ghana Limited manufactures the well-known "Yara legume" blend of RP fertilizer with plant nutrient formulation; 18% P_2O_5, 13% K_2O, 31% CaO, 4 %S, 2% MgO, and 0.6% Zn for legume cultivation in Ghana (Yakubu *et al.*, 2010). However, scientific research suggests that in a low N environment, this fertilizer combination has a short-term effect on soybean growth and productivity (Akande *et al.,* 2010). Little is known regarding phosphorus (P) effects, availability, absorption and utilization efficiency as well as its cost-effectiveness (Solomon *et al*., 2012). The major goal of this study was to see if combining rhizobia inoculants, diammonium phosphate (DAP), and rock phosphate (RP) fertilizer could increase soybean yields.

1.3 Justification

It is expected that using a rock phosphate fertilizer blend with rhizobia inoculants in low-nitrogen soils will stimulate plant N accumulation, resulting in increased soybean grain output.

1.4 Objectives

i. To establish the contribution of N and P application to Soybean yield

ii. Study the suitability of using DAP and RP

iii. To determine the contribution of inoculation on yield

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Family and Botany

Glycine max (L.) Merrill belongs to the plant family and sub-family Leguminosae and Papilionaceae respectively. This can thrive in a variety of soil types and temperatures. The subgenera Soja and Glycine make up the genus Glycine. *Glycine max* as well as its annual natural relatives, Glycine soja, are native to eastern Asia, which includes China, Japan, Korea, and much of Russia (Chen *et al.*, 2015).

Soybeans grow well in a wide range of climates, including tropical, subtropical, and temperate zones (Oyekanmi *et al.*, 2007). On various times, most plant breeders and researchers have contended that different varieties of the soybean species respond positively to photoperiod and have categorized them as long day, short day, or day-neutral plants (Borget, 1992). Soybean is a short-day plant that is physiologically adapted to temperate temperatures (Singh *et al*., 2007). Some have, on the other hand, adapted to the hot, humid temperature of the tropics. This affects their vegetative development, flower induction, pollen grain production, lengthening, pod filling, and seed maturity features (Norman *et al*., 1995).

Seedlings contain sets of chromosomes (four haploid daughter cells) and are a species with self-fertility with less than 1% out-crossing (IITA, 2009; Shurtleff and Aoyagi, 2007). Temperatures between 20^{o}C and 30^{o}C are good for soybean cultivation, whereas temperatures above 35^{o}C are regarded to be productivity inhibitors. Yearly rainfall in Ghana ranges from 350 to 750mm and is evenly distributed throughout the growing season (Ngeze, 1993). Shorter day lengths cause the soybean plant to bloom because it is a short-day plant. Each soybean variety must achieve a peak day duration before thriving may begin. Depending on the weather, soybeans should be sown in Northern Ghana between early and late June. Soybeans grow in fertile, well-drained loamy soils. Drought is a major limiting factor for soybean germination in Northern Ghana during the early wet season (Luo *et al.*, 2013).

Soybean is a dicotyledonous plant with epigeal emergence. During the germination process, an elongating hypocotyl pushes the cotyledons to the surface. Soybeans germinates well when planted no more than 5cm deep to reduce the energy input required to force the massive cotyledons through the heavy soils.

During emergence, the green cotyledons expand and release stored energy to the young leaves while also absorbing a little amount of sunlight energy (Fehr *et al.*, 1971). The first to appear are the unifoliolate leaves. Both of such solitary leaves occur exactly opposite one another above the cotyledons (Mahama, 2011).

There are two distinct growth stages in the development of a soybean plant. The vegetative phase, which lasts from emergence to flowering, is the first stage. The reproductive stage, which lasts from blossoming to maturation, is the second phase. The development of leaves, flowers, pods, and/or seeds is used to classify plant growth phases (Gary and Dale, 1997).

Flowers appear in purple or white auxiliary racemes on peduncles at nodes. The papilionaceous flower has a corrugated head with five sepals, a corolla with five petals (one banner, two wings, and two keels), one pistil, and nine stamens (one separate posterior stamen). The flower stamens form a ring around the base of the flower stigma and lengthen one day before pollination when the elevated anthers form a ring around the stigma and the plants self-pollinate (Acquaah, 2007).

Despite the large number of blooms on the soybean plant, only around two-thirds to three-quarters of the blossoms develop into pods (Acquaah, 2007). The pods are likewise pubescent, with colours ranging from light yellow to dark brown. They have a straight or slightly curved form, are two to seven (2 – 7) cm long, and are made up of two halves of a single carpel linked by a dorsal and ventral suture.

Soybean pods typically produce one to three seeds (rarely four) (Asafo-Adjei, 2005). The generally oval seed form varies across cultivars and can vary from almost spherical to elongated and flattened. The seeds are colorless and might be straw-yellow, greenish-yellow, brown, or black (Acquaah, 2007). There are bicolored seeds available, such as yellow with a black or brown saddle. The hilum is also available in a variety of hues, including yellow, buff, brown, and black (Acquaah, 2007).

2.2 Origin and Distribution

Soybean is among the world's oldest cultivated crops, despite the fact that its early history has been lost to time. Soybeans were domesticated in the eastern part of northern China about the eleventh century B.C. or before. Soybeans are one of China's top five plant-based diets, along with rice, wheat, barley, and millet (Gibson and Benson, 2005). Chinese soybean production remained concentrated until after the Sino-Japanese War of 1894–1895, when Japan began to import soybean oil cakes for fertilizer and other uses (Hymowitz, 1984; Wilcox, 1987; Shurtleff *et al.,* 2014). Soybeans gained international notice after being transported to Europe in 1908. Soybeans have been known in Europe since 1712, thanks to research conducted by German botanists (Bertheau and Davison, 2011). As early as 1740, some missionaries are reported to have brought soybeans from China, and these soybeans were grown in France when the country was first settled (Gibson and Benson, 2005).

Soybeans gained international notice after being delivered to Europe in 1908. Soybeans have been known in Europe since 1712, thanks to German botanists' studies (Bertheau and Davison, 2011). Some missionaries are thought to have transported soybeans from China as early as 1740, and these soybeans were produced in France when the country was initially planted (Gibson and Benson, 2005).

Soybeans have been farmed for three millennia in Asia and are now being grown all over the world. Today, the top soybean producers in the world are the USA, Brazil, Argentine, China, and India (USDA, 2007). Soybean crops were introduced to Africa in the early nineteenth century and spread rapidly over the continent, commencing in South Africa (Ngeze, 1993). It was introduced early in East Africa since the region had long been exploited by the Chinese, according to Shurtleff and Aoyagi (2007). Soy was produced in Tanzania in 1907 and Malawi in 1909, according to the same source.

Soybeans were first introduced into Ghana in 1909 by Portuguese missionaries. Due to the crop's roots in temperate zones, its early introduction was a failure (Mercer Quarshie and Nsowah, 1975). However, substantial efforts were made in the early 1970s to establish the crop's production in Ghana. This breeding experiment was a partnership between the Ghanaian Ministry of Food and Agriculture (MoFA) and the International Institute of Tropical Agriculture (IITA) (Tweneboah, 2000).

Around 1977, a team from the United States' Illinois International Soybean Program (INTSOY) developed a strategy for soybean growth in Ghana for the Grain and Legume Development Board (GLDB) and the United States Department of Agriculture. The purpose was to help Ghana's government develop a five-year national soybean production, processing, and use strategy. According to GLDB and INTSOY, 1978, Ghana will grow around 4,800 hectares of soybeans by making the country self-sufficient in soybean oil and meal, and more than 50,000 acres of soybeans will be planted every year (Nsowah and Mercer-Quarshie 1982).

Soya production in Ghana and Africa are lower than in other countries and continents (Addai *et al.*, 2001). According to FAO, 1982, Africa produces about 0.05% of the world's soybeans. In 1981, the United States was the world's largest soybean producer, harvesting more than 2,000 kg ha^{-1} on 27 million hectares of land, whereas African countries harvested less than 900 kg ha^{-1} on 300,000 hectares. The crop is grown largely in Ghana's northern, the upper west, eastern, and Volta regions. North Ghana, located in the Guinea steppes and the Sahel agro-ecological zone, is the most prolific of these geographical areas (Lawson *et al.*, 2008).

Temperatures between 20^{o}C to 30^{o}C are considered optimal for soybeans, whereas temperatures above 35^{o}C are thought to impede productivity. The ideal soil temperature for seedling germination and early growth is 25 to 30^{o}C. Soy can grow and produce under 180mm of rain, but yields are projected to reduce by 40% – 60% when compared to ideal circumstances.

2.3 Importance of soybean

Legumes play a very important role in our natural ecosystem, agroforestry, agriculture, and many other industries. In Ghana, both the government and NGOs are working hard to increase the production of pulses because they have the potential to increase the income of smallholder farmers and improve the nutritional status of the farmers as reported by Mbanya (2011). In Ghana, there are numerous agricultural intervention programmes, such as the Government of Ghana's Youth Agriculture Program, the African Green Revolution Alliance (AGRA), the United States Agency for International Development (USAID), IFDC-FERRARI, and others, with the primary goal of improving the production value chain to promote pulse production and utilization (Etwire *et al*., 2013).

Two of Ghana's most popular legumes are *Glycine max* and *Vigna unguiculata*. Soybean is progressively becoming a significant commercial crop in West Africa since it is the most widely planted grain legumes. Soybeans, like all legumes, are predicted to be the most cost-effective source of nutritious protein and other essential elements for the global population (Rao and Reddy 2010). It is both a protein source for humans and a food source for farm animals (Masuda and Goldsmith, 2009). According to ElAgroudy *et al*. (2011), Soybean contains 30% cholesterol-free oil, 40% protein, and numerous essential vitamins for healthy human growth. According to Ugwu and Ugwu (2010), soybeans have several advantages over other legumes such as peanuts and cowpeas, including lower disease and insect vulnerability, improved storage quality, and higher plant biomass. Improving soil fertility is beneficial for future harvests.

Soybean is an excellent source of high-quality vegetable protein and oil, as well as the capacity to fix nitrogen, which is particularly useful in agriculture. Soybean is widely distributed across the universe, grows best in tropical to high temperate zones, and yields the most in the United States, China, Mexico, Indonesia, and Argentina. In 2008, total global soybean production was predicted to reach 231.27 million tons, covering an estimated 96.47 million hectares of land (FAO, 2009). Because of its tremendous nutritional value, it is known as the Miracle Golden Bean. Soybean is high in dietary protein, unsaturated fatty acids, minerals including calcium and phosphorus, and vitamins, all of which can help people meet their nutritional requirements (USDA, 2009).

When compared to other legumes, soybean is a unique crop in Ghana; yet, it has grown in popularity and has the approval of many farmers in northern Ghana (Etwire *et al*., 2013). Soybeans are critical to Ghana's local economy and farmers' livelihoods, particularly in the country's northern and eastern areas (Akramov and Malek, 2012). According to SRID (2012), the northern area accounts for at least 70% of the country's soybean growing fields and 77% of total output.

2.4 Nitrogen Fixation in Soybean

Large-scale grain planting with small amount or without fertilizer input, combined with yearly forest fires, has reduced soil fertility and vegetative cover in the Guinea savanna, including crop leftovers (Braimoh and Vlek, 2006). To achieve the same output target, farmers must either shift to newer and more fertile land or expand the area of arable land (Konlan *et al.*, 2013). These concerns can be reduced by incorporating legumes, such as soybeans, into the agricultural system via intercropping or rotation.

Legumes have been increasingly promoted in the last decade as an alternative method for boosting soil fertility in agricultural areas (Lal, 2009). Other performance-enhancing management factors, such as genotype selection, should be used to enhance the quantity of fixed N_2 molecules (Keyser and Li, 1992). According to Lupuwei *et al*. (2000), N is not usually the most significant limiting factor for soybean production, but inoculation fails when it is lacking. Other variables that restrict soybean production will inevitably limit inoculation and N response (Salvagiotti *et al*., 2008). Nitrogen fixation is defined by Postgate (1998) as the process of turning atmospheric nitrogen (N_2) into ammonia (NH_3). Atmospheric nitrogen (N_2), also known as molecular dinitrogen (N_2), is highly inert, which means it does not readily mix with other molecules to generate new compounds.

Nitrogen atoms are emancipated from their triple bond diatomic form, N≡N, during the immobilization process and can be used in a number of ways. Nitrogen fixation, whether natural or synthetic, is required for all living forms since nitrogen is required for the basic components of biosynthesis in plants, animals, and other life forms (Augusto *et* *al.,* 2013). Nitrogen-fixing bacteria are referred to as symbiotic nitrogen fixers due to their tight relationship with plants (Unkovich and Baldock, 2008). Biological nitrogen fixation is the process of converting inert N_2 into physiologically useful NH_3 (Parsons *et al.,* 1993). Bacteria are the only organisms that mediate this process in nature. Nitrogen-fixing bacteria help other plants when they die and release nitrogen into the environment, or when the bacteria are closely connected to plants (Maier *et al*., 2009). Bacteria dwell in nodules, which are tiny growths on the roots of beans and other plants. Bacteria fix nitrogen in these nodules, and plants absorb the NH_3 generated (Parsons *et al.*, 1993). Legumes fix nitrogen as a result of a symbiotic relationship between bacteria and plants. In contrast, legumes fix 11 to 34 kg N ha^{-1} $year^{-1}$ in natural ecosystems and 100 kg in cropping systems (Lindemann and Glover 2003).

Peanuts, cowpeas, soybeans, and lima beans are a few more grain legumes that fix nitrogen. In addition to being absorbed from the soil, they can supply the majority of your nitrogen demands. These beans have a nitrogen fixation potential of up to 279 kg N ha^{-1} and are normally grown without fertilization (Yusuf *et al*., 2009).

Soybean nodules are spherical and can increase in size to that of pea. They live for a brief time and are routinely replaced during the growing season. Because the plant relies on growing seeds rather than nodules, nodules frequently lose their ability to fix nitrogen during pod filling (Maier *et al*., 2009). Legumes normally have fewer than 100 nodules per plant, but soybeans have hundreds and peanuts might have 1,000 or more nodules on mature plants (Fehr *et al*., 1971). As the nodules grow in size, their color changes to pink or red, suggesting that nitrogen fixation has commenced. Leghumoglobin, which regulates bacterial oxygen availability, is responsible for the pink or red hue (Steenhoudt and Vanderleyden, 2000).

Soybean nodules are spherical and can reach the size of a large pea. They live for a brief time and are routinely replaced during the growing season. Because the plant relies on growing seeds rather than nodules, nodules frequently lose their ability to fix nitrogen during pod filling (Maier *et al*., 2009).

Salvagiotti (2008) reported that soybean plants will effectively use residual soil nitrate and mineralized nitrogen in soil organic matter to obtain 25% to 75% of plant nitrogen, and the rest will come from symbiotic fixation.

2.5 Effect of plant population on nitrogen fixation in soybean

Plant population is a factor in production that affects how much light is intercepted by the plant canopy (Board, 2011). Improvements in soybean nitrogen fixation have been identified as part of a larger effort to raise output (Hunter *et al*., 1982; Scott and Aldrich, 1983; Anon, 1984; Russell *et al*., 1989). According to Oljaka *et al*. (2000), intraspecific competition in soybean plants appears to be more intense than the interspecific competition. The height of plant, pods length, harvest index, and grains yield of soybean increase as crop population density and nitrogen application rate increase, according to Mehmet (2008), whereas the number of branches per plant, pods per plant, number of seed yields per plant, and 100 seed weight per plant drop.

According to Kapustka and Wilson (1990), increased soybean plant density lowered the quantity and dry weight of nodules per plant while retaining a high specific activity of each nodule, resulting in the same nitrogen fixation value for each plant. According to Shamsi and Kobraee (2012), at lower plant densities, each plant's photosynthetic rate increases, resulting in an increase in nodules and nitrogen fixation rates due to a greater supply of carbon to the nodules. In terms of nodule efficiency. Lower plant densities increase each plant's photosynthetic activity, resulting in a bigger supply of carbon to the nodules, improving nodule rate and nitrogen fixation (Lucca, 2014).

2.6 Need for starter N to improve soybean response to inoculation in low fertility soils

According to Masso *et al*. (2016), 95% of soils utilized for soybean agriculture in northern Ghana are nitrogen-deficient. The primary limiting factor for plant growth and development is a lack of nitrogen. Various nutrient supplement procedures should be investigated in low fertility soils to develop suitable management options for enhancing soybean response to inoculation (Woomer *et al*., 2014). Legumes require a considerable quantity of "initial nitrogen" in low-nitrogen soils for the formation of nodules, roots, and shoots prior to the active process of biological nitrogen fixation (BNF). Although the sensitivity of soybean to initiator N was demonstrated to be minimal (Mendes *et al*., 2003), other studies have discovered further positive reactions (Osborne and Riedell, 2006; Sohrabi *et al*., 2012; Janagard and EbadiSegherloo, 2016). It was nevertheless necessary to specify the soil N concentration threshold (percent or g N kg^{-1} of soil) in this study, particularly in low fertility soil, because no initial nitrogen is required above this level.

2.7 Growth requirements of soybean

2.7.1 Soil and moisture requirement

Soil is essential for plant germination, growth, and survival. Soybeans may grow in a variety of soil conditions, but for early germination and growth, they prefer warm, wet, well-drained, fertile soils with enough nutrients and good seed-to-soil contact (Hans *et al.*, 1997; Addo Quaye *et al.*, 1993). This soil, on the other hand, is beneficial to a wide variety of crops. As a result, in terms of profitability, soybeans must compete with other crops (Gibson *et al.*, 2008). Various soils have different effects on plant nutrient utilization. Because sandy soil is less effective at retaining nutrients, it will prevent nutrients from being absorbed by plants. Nutrient availability will be reduced if soil is compacted. Soil compaction reduces the permeability of plant roots (Martono *et al.*, 2007). Compacted soil, in addition to preventing root penetration, obstructs oxygen and water transmission through the soil (Lipiec and Hatano, 2003). Aerating and mixing the top few inches of soil can loosen the soil, increase permeability, and enable more water, air, and nutrients to pass through. It is vital to establish suitable development circumstances for soybean in order for it to fully use its genetic potential. The yield on clay-like soil is good, according to Rienke and Joke (2002). If the seeds germinate, they will grow faster in the clay.

Soybeans may flourish in soils with pH values ranging from 4.5 to 8.5 if they are properly cared for. Soybeans, on the other hand, like soils with a pH range of 5.5 to 6.5.

According to Gary and Dale (1997), applying nitrogen fertilizer will avoid the benefits of rhizobia because rhizobia will not modify nitrogen in the atmosphere when plants easily make use of nitrogen in the soil. However, where soybeans have not been planted recently, seed inoculation with specific Rhizobium strains is essential for successful nitrogen fixation (Darryl *et al.*, 2004). Drought is the greatest limiting factor for soybean germination at the start of the rainy season, however, it is not soil type-specific. Soybeans are susceptible to drought because their roots are shallow and their root structure inhibits water intake during dry periods (Fenta *et al.*, 2014). As a result, soybeans perform poorly in sandy soils and soils with little water storage capacity, such as gravel or shallow soils, owing primarily to drought stress. In the clay, low rainfall diminishes the likelihood of seed germination and plant establishment (Zahoor *et al.*, 2013). The direct impact of drought stress on soybean physiological development is dictated by their water usage efficiency (Earl, 2002). Waterlogging is a problem for soybeans between the emergence and four-leaf stages (Moreta *et al.*, 2014). However, beyond this stage, soybeans outperform other crops in terms of waterlogging resistance. Soybeans may also resist flood irrigation better than other crops (Farquharson *et al.*, 2006). Soil moisture is required for seedling growth, but too much or too little will impede soybean emergence.

2.7.2 Temperature and rainfall

Most legume plants require an ideal temperature range of 17.5^oC to 27.5^oC for development (Ngeze, 1993). In the case of soybean, the lowest temperature generated is 10^oC, while the optimum value is 22^oC and can go up to 40^oC. The seeds germinate successfully at temperatures ranging from 15°C to 40°C, with 30°C being the ideal range (Rienke and Joke, 2002). The ideal temperature for growth, according to Addquaye *et al*. (1993), is between 23 and 25°C. Soybeans require adequate moisture for seed germination and growth. According to Addquaye *et al*. (1993) and Rienke and Joke (2002), it is crucial for the moisture requirements of soybean, from germination and flowering to pod filling. Before seeds can germinate, the soil must be 50 to 85% saturated with water during germination. The number of fluids grows and reaches a high during the feeding stage before declining to reproductive maturity. In Ghana, the ideal climate for soybean growth is an annual precipitation of 700 mm or more distributed throughout the growing season in ecological agriculture and Guinea Savanna agricultural areas (Asafo Adjei *et al.*, 2008).

Rain and temperature, in addition to altering soil conditions, have a significant impact on the distribution and growth of soybean. Seed germination and seedling growth require an average temperature of 12.8°C and when the temperature rises (to roughly 32.2°C), so do the germination and growth rates (Catara *et al*., 2016).

2.7.3 Photoperiod

Because soybean is a short-day plant, it blooms as the days get shorter. Before flowering, each cultivar has a critical day duration that must be satisfied. The best time to produce soybeans in Ghana is from late June to August in the south and mid-June to mid-July in the north, however, the harvest can also be affected by the year's rainfall pattern. When choosing a variety for planting, keep in mind that day length varies with latitude, which impacts the variety's maturity (Olesen *et al*., 2012). According to Boquet and Clawson (2007), soybeans exposed to less than the required period mature quickly. Soybeans will stunt and underperform if this happens before the plant reaches a specific size. The pace of increase and reduction in photoperiod variations, as well as a shortage of sunshine, will cause soybean flowering to be delayed (Cober *et al*., 2001).

2.7.4 Soil and air temperature

Soil and air temperatures between 12.8 - 15^{o}C are required for seed germination and seedling growth; as the temperature rises (up to roughly 32.2^{o}C), the germination and growth rates increase as well (Catara *et al*., 2016). When selecting a variety for planting, keep in mind that day duration changes with latitude, which affects the maturity of the variety (Olesen *et al*., 2012). Soil temperature affects the long-term survival and survival abilities of rhizobia strains in the soil (Mohammadi *et al.*, 2012). In contrast, the rhizobia isolate from West Africa's Sahelian savanna thrives at 37.0^{o}C, and more than 90% of the strains can grow at 40.0^{o}C (Werner and Newton, 2005). Rhizobia have distinct temperature ranges on different legumes and can successfully fix N within these temperature ranges. For example, the set critical temperature of N_2 for common beans is between 25.0 and 30.0^{o}C, whereas the critical temperature for cowpea, soybean, and peanut is between 35.0 and 40.0^{o}C (Long, 2001).

2.8 Growth analysis (LAI, NAR, CGR, RGR)

Plant growth analysis is a method for evaluating plant growth and development forms and functions that is holistic, integrative, and explanatory. It studies the processes within and involving the entire plant using simple data such as weights, volumes, areas, and contents of plant components (Evans, 1996; Hunt, 1982).

Crop growth rate is a periodic characteristic that impacts crop yield in crops such as cereals and legumes. According to Ball *et al*., (2000), a relatively large soybean population ensures early canopy closure, optimization of light interception, crop growth rate (CGR), and other crop biomass increase, leading in higher crop production potential. NAR, RCGR, and LAI govern crop growth rate, with the latter determined by the light-intercepting efficiency and photosynthetic efficiency of the leaf (Kokubun, 1988). Plant population growth shortens the time necessary to attain light interception levels of 95%, which correspond to LAI values (Higley, 1992).

Despite several efforts to improve soybean production, yields remain poor. Several research has been undertaken to better understand the performance of these crops, the primary focus of which has been the contribution of various yield components to yield (Das *et al.,* 1992). Yield components are dependent on numerous physiological qualities, and to understand the physiological basis, the components of growth and their linked variables, which are critical in crop development, must be measured. A better understanding of soybean crop growth and yield variables, as well as the partitioning of assimilates into seed, can aid in the acceleration of soybean crop yield enhancement. Although the very little study has been done in this area in tropical soybean, there is still room for advancement.

2.9 Approaches to enhancing legume growth and yield

2.9.1 Rhizobial inoculation

In Europe, Australia, and the United States, inoculating legumes with rhizobia is a frequent procedure, with numerous successful cases (Martins *et al.,* 2003). This approach, however, is relatively new to farmers in Africa, particularly Ghana. Due to the different types and quality of strains used in these inoculations, several African countries have inconclusive data on the performance of the inoculants. In Nigeria, Sanginga *et al*. (1997) and Okogun and Saninga (2003) showed no significant increase in soybean production following inoculation. According to Mpereki *et al*. (2000), rhizobia injection increased soybean output in Zimbabwe. Thuita *et al*. (2012) exhibited rhizobia inoculant efficacy on Kenyan soybeans. Even though rhizobia inoculation provides an option for increasing legume and grain yields in nitrogen-deficient soils, research in Ghana has attempted to demonstrate the effect of legume inoculation and its economic worth in farmers' fields. Because of its reputation as a promiscuous plant, cowpea has received relatively little attention from rhizobia inoculation. This led to an average yield of 0.6 t ha^{-1}, which was much lower than the expected output of 2.5 t ha^{-1}. Arkoful *et al*. (2015) established the impact of rhizobia inoculation and its economic benefits in farmers' fields in northern Ghana in his study, generating an increase in food production at 67% of the research sites. As a result, it was established that using rhizobia inoculants has significant economic benefits. As a result, the introduction of highly competitive and effective strains that have been demonstrated locally or worldwide may improve grain legume output.

2.9.2 Mineral nitrogen and phosphorus fertilization

Panchali (2011) observed that because to these circumstances, Legume rhizobium symbioses cannot produce sufficient nitrogen during the early phases of development to meet plant needs, needing a minor application of my ore. Grain legume crops must fulfil their nitrogen requirements by nitrogen fixation in the soil or through mineral fertilizer application. The antagonistic relationship between floor nitrate content and the N_2 fixing process is a significant impediment to legume collecting (Streeter *et al*., 1998). Any abiotic stress on the ground, such as moisture, pH, or soil temperature, has no effect on nitrogen fixation (Purcell *et al*., 2014).

In areas where soybean grains are in high demand, the use of nitrogen fertilizers has been proposed as a technique of improving the ground for N legumes (Salvagiotti *et al*., 2008). Soybean has the greatest nitrogen content of any major legume, absorbing more than 100 kg N every good amount of soy seed consumed (Keyser and Li, 1992). Most of the time, the nitrogen number fixed by soybean is inadequate to replace nitrogen exported from the field by grain collection, or it is modest when N from below ground is included in the plant's N estimation (Salvagiotti *et al*., 2008). The majority of nitrogen fixation in soybean occurs between the beginning of podding and the beginning of grain filling phases in crop growth, and any deficits between application N and offer N must be addressed through nitrogen fixation and other sources (Salvagiotti *et al.*, 2008).

Although soybean exhibits robust responses to frequent additions when the N_2 fixation process is inadequate to fulfil the N_2 needs (Thies *et al*., 1995), Barker and Sawyer (2005) discovered an inconsistent soybean response to commercially acceptable levels of fertilizer application. More study is needed to evaluate whether fertilizer use for legumes like soybean can reduce nitrogen limits without compromising cultivation capacity to fix N_2, as well as the profitability of this option (Salvagiotti *et al*., 2008). In general, fertilizer use throughout the late stages of crop growth (from podding to grain fullness) is assumed to enhance performance; nevertheless, performance measurements are not uniform (Gutiérrez-Boem *et al*., 2004). Salvagiotti *et al.* (2008) examined published data to show that the response of soybean performance to fertilizer N application is affected by factors such as environmental performance potential and any constraint (biotic or abiotic) that negatively affects crops and associated mandate.

Phosphorus (P) is an important nutrient for plant development due to its role in the metabolic processes of plant growth and reproduction. According to Vance *et al*., (2000) phosphorus is the second most important element for plant development after nitrogen. Crop production is frequently affected by a shortage of P, which inhibits plant development on many soils across the world.

Because of their smaller root systems and less fibrous roots, legumes have a stronger affinity for P than other crops. P is required for sufficient development and nodulation in the nitrogen-fixing process of legumes (Tang *et al*., 2001). Although there is some debate over the direct involvement of P in nitrogen fixation and nodulation (Miao *et al*., 2007), it has been observed that supplying P promotes nodulation directly and favorably in certain legumes such as red clover (Hellsten and Huss-Danell, 2000).

Physiologically, a lack of P hampered the growth of the leaves and the development of the session, limiting the photosynthetic surface and glucose absorption (Ahloowalia *et al*., 1995). Yakubu *et al*. (2010) found that applying P at a rate of 40 kg ha^{-1} improved N fixation in cowpea, groundnuts, and Bambara groundnuts by 378%, 169%, and 138%, respectively, above controls. Previous research found that spraying P at rates ranging from 20 to 40 kg ha^{-1} improved the performance of soybeans and cowpeas (Kamara *et al*., 2007). Uzoma with her coworkers (2006)

Although P can be present in many soils in its bound form, it is inefficient for plant absorption (Schachtman *et al*., 1998). The scarcity of P limits the cultivation of 40% of the world's arable land (Vance, 2001). Phosphorus is usually applied fast, especially in sandy soils with thick textures and acid soils (Oxisols). Because of its inclination to form insoluble complexes with Al, Fe, Ca, and Mg, phosphorus is inaccessible, and it is also incorporated in organic matter from bacteria.

Phosphorus fertilizer application on soil can be reduced by combining P with organic fertilizers. However, an overabundance of P in sandy soils can lead to Zn shortage; however, the use of animal fertilizer can help offset these difficulties (Zingore *et al*., 2008).

The reaction of leguminous species to P does not follow a regular pattern. The legume P requirements for optimal growth, as well as the extent of the effect exposed from low or high P at the plant level, are determined by a number of factors, including the leguminous acquisition mode (Sanginga *et al*., 1995), the Plant Genetics discovered (Sanginga *et al*., 2000), plant growth conditions (Passarinho *et al*., 2000), and the physiological phase in which the plants are in (Pongsakul and Jensen, 1991).

2.9.3 Diammonium phosphate

Diammonium phosphate (DAP) is the most widely used phosphorus fertilizer on the earth, containing 18% N and 46% P_2O_5. Because of the high protein content of the end product, soybean is a nitrogen-demanding crop. There are limited resources for biological nitrogen fixation (N_2) and mineral soil ground or nitrogen fertilizer. Phosphorus deficiency can impair soybean nodulation, growth, and yield, but phosphorus supplementation can compensate (Carsky, *et al*. 2011, Kumaga and Ofori 2012).

2.10 Effect of phosphorus fertilizer on soybean nodulation

Phosphorus fertilizer use has significantly boosted soybean nodulation. The reaction of soybean nodule dry weight to increased phosphorus treatment is similar to the findings of Bekere and Hailemariam (2012) and Devi *et al*. (2012), who discovered substantial increases in soybean nodule dry weight with rising soil phosphorus levels. The nodulation response to an increase in phosphorus availability may be considered phosphorus's critical function in the legume nodulation process. Phosphorus is an important nutrient for legume development and nitrogen fixation since it has been proven to have a particular role in nodule formation, growth, and function (Ankomah *et al*., 1996). Carsky *et al*. (2001) shown that phosphorus deprivation can reduce legume nodulation, but that phosphorus fertilizer application can compensate. Phosphorus deficiency in soybean, according to Israel (1993), has a more direct influence on nodule function. Furthermore, the nodule's particular activity has higher ATP needs for nitrogen functioning (Ribet and Drevon, 1996). Furthermore, the needs for signal transduction and nodule formation are heavily reliant on P availability, contributing to the high demand for rejected legumes (Al Niemi *et al*., 1997, Tang *et al*., 2001).

2.11 Factors affecting availability of P from rock phosphate

Direct application of rock phosphate (RP) to the ground has sparked a lot of attention in recent years due to its potential usage as a less expensive alternative to soluble phosphate fertilizers (Akande *et al*., 2010). According to Zapata *et al.* (2003), the open and cemented structure of the large-area microcrystal aggregates informs the direct application of the RP to soils.

Another mechanism that improves RP reactivity is an increase in the rate at which carbonate replaces phosphate, magnesium, and sodium within the apatite structure, as well as a reduction in particle size (Ghosa and Chakraborty, 2012). It was also revealed that lowering the pH of the soil boosts RP effectiveness (Chien *et al*., 2010, Procnow *et al*., 2006).

It was discovered that the efficacy of phosphate as a direct modification has been modified to the soil, such as the chemical makeup of the rock deposit, particle size, reactive characteristics of the soil, and, most importantly, the rate at which the isomorphic replacement of Phosphate carbonate within the crystalline frame of the apatite is produced (Mokwunye, 1995). The breakdown of the applied phosphate rock is influenced by specific soil and humidity conditions, as well as the individual responses of the cultivation site (Vanlauwe *et al*., 2000).

2.12 Foliar application of micronutrients

Leaf spray is a revolutionary crop feeding method that delivers liquid micronutrients in sheets (Nasiri *et al*., 2010). The application of microelements to the foliage is superior to the application of microelements to the soil. Because the application rates are lower than the application rates to the soil, the same application may be completed fast and the soil might respond to nutrient delivery more quickly (Zayed *et al*., 2011). Without a doubt, applying microelements in leaf spray will result in the best performance and quality of soybeans as well as their oil (Vahedi, 2011). When the roots are unable to give the needed nutrients, the microelement leaf spray comes in help (Vahedi *et al.*, 2011). Furthermore, soil contamination would be a serious issue as a result of the application of soil micronutrients directly on the soil.

As people were worried about the environment and the plant's leaves, which catch more nutrients than soil application, the leaf spray was invented (Bozorgi *et al*., 2011). Because soil conditions such as high pH, lime, or coarse texture impede crop roots from collecting critical nutrients such as zinc, leaf spray is preferred to soil treatment (Kinaci and Gulmezoglu, 2007). According to Narimani *et al*. (2010) microelement leaf treatment improves macronutrient efficiency.

People were concerned about the ecology and the plant's leaves, which catch more nutrients than soil application (Bozorgi *et al*., 2011). Because soil conditions such as high pH, lime, or coarse texture impede crop roots from collecting critical nutrients such as zinc, leaf spray is preferred to soil treatment (Kinaci and Gulmezoglu, 2007).

According to Narimani *et al*. (2010), microelement leaf treatment improves macronutrient efficiency.

2.13 Micronutrients in soybean production

Salwa *et al*. (2011) describe microelements as chemicals that are essential for crop growth but in less quantities than macronutrients such as N, P, and K. Cell division, photosynthesis, respiration, and the faster development of vegetative maturity all require them (Zeidan *et al*., 2010). Micronutrients are required for the proper physiology of well-balanced crops. Furthermore, these elements are critical in the flow of CO_2, vitamin A action, and the immune system (Zeidan *et al*., 2010).

2.13.1 Zinc (Zn) and iron (Fe) application in soybean production

Zinc is essential for the production of proteins, ribonucleic acid (RNA), and deoxyribonucleic acid (DNA) (Kobraee *et al*., 2011). Zinc and iron have several functions in agriculture, including as the production, partitioning, and use of photosynthetic assimilates (Sawan *et al*., 2008). The primary role of zinc in crops is uncertain (Nasri *et al*. 2011). While zinc is a crucial component for crop growth, excessive amounts of it may be harmful, according to these experts. The need for zinc leaf stock is directly related to harvests (Aliyu, 2013). According to Gul *et al*. (2011), micronutrients will be profitable when mixed with macronutrients such as nitrogen and potassium. Zinc is essential for the production of chlorophyll and the function of pollen, according to Ghasemian *et al*. (2010).

According to Bozoglu *et al*. (2007), zinc deficiency is a common soil concern in 25 countries. A deficiency of micronutrients, in general, will limit the production of dry matter and its distribution throughout the plant (Sawan *et al*., 2008). Zinc is in low supply in plant cultivation since it cannot be solved in soil, and one of the signs of Zn deficiency is a reduction in growth and cellular development (Ghasemian *et al*., 2010). According to Kobraee *et al*. (2011) and Ghasemian *et al*. (2010), a shortage of iron causes early leaves chlorosis and plant metabolic anomalies, and in the presence of iron stress, Fe absorption improves. Because iron is not soluble in soil, it is applied through the leaves. According to Ai-Qing *et al*. (2011), zinc and iron interact antagonistically in soybean, influencing absorption, partitioning, and utilization. According to these experts, zinc influences iron absorption and translocation, and vice versa. Their study's purpose was to investigate the effects of zinc requirements and leaf iron on the execution of soybean and its components (yield performance, number of pods per plant, number of seeds per pods, and 1000 grain weight).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

From June to October 2021, the experiment was conducted in Gbulahigu, near Nyankpala in the Northern Region's Tolon District. This location was chosen because it serves as a farming hub for the neighboring community, with farmers growing soybeans and other crops. The area is situated in Ghana's inner Guinea Savanna zone at a height of 108 m above sea level (Latitude 09^{o} 36' 12.0" N, Longitude 001^{o} 01' 54.2" W). The climate is warm and semi-arid between May and September, with annual mono-modal rainfall ranging from 800 to 1200 mm (SARI, 2012). After that, there is a 7-month dry season characterized by the North-East Trade Winds (Harmattan), which are dry and dusty with low relative humidity. The average monthly temperature in the area ranges from 26 to 32^{o}C, with the warmest months being March and April (SARI, 2016).

3.2 Source of planting materials and bradyrhizobia inoculants

Savanna Agricultural Research Institute provided soybean seeds and commercial inoculants. Soybean (Afayak variety) was used as a test crop in this study. Afayak is a non-shattering, medium ripening cultivar (105-110 days maturity), with a greater yield of 2.5 t ha^{-1} and a 45-day blooming cycle (Dugje *et al.*, 2009).

3.3 Land preparation

Tractors were used to plough and harrow the two fields. Drilling took place at 0.75 m and 0.05 m intervals between rows. To suppress weed establishment, the land was sprayed with Glyphosate (400 EC, 400 g L^{-1}), a post-emergence weedicide, at a rate of 3 Liters active ingredient ha^{-1}. Weeds were then manually managed at both locations, using a hand hoe as needed.

3.4 Experimental design and treatments used

The trials used a factorial experiment in a randomized complete block design, with four replications at each of the two research locations. Plots were 5 m x 5 m in size, with 0.5 m spacing between plots and 1 m between repetitions.

This was a 2 x 9 factorial experiment in which soil type was a factor and fertilizer treatment been another factor. There were two types of soil to consider: upland soil and lowland soil. The fertilizer application treatments consisted of nine distinct fertilizer mixes as a component (Table 1).

Table 1: Treatment combination list

TREATMENTS	DAP	RP	K (MOP)	$ZnSO_4$ (foliar and soil)	Iron sulphate (foliar)	Inoculant (g)
Control	0	0	0	0		0
NK + DAP	249.1	0.0	125.5	0		0.00
NK + PR + Inoculant	0.0	381.9	125.5	0.0		0.25
NK + DAP + Inoculant	249.1	0.0	125.5			0.25
NK + DAP + Inoculant + Foliar (Zn + Fe)	249.1	0.0	125.5	27.5	62.5	0.25
NK + DAP + Inoculant + Foliar Zn	249.1	0.0	125.5	27.5		0.25
NK + (DAP + RP)	86.0	250.0	125.5	0		0.25
NK + (DAP + RP) + Inoculant	86.0	250.0	125.5	0		0.25
NK + DAP + Inoculant + Soil Zn	86.0	250.0	125.5	27.5		0.25

3.5 Seed inoculation, planting and pest control

The *Bradyrhizobium japonicum* strain was introduced into soybean seeds prior to sowing. At a rate of 5 g kg^{-1} seed, the inoculant was used. The seeds were first sprinkled with water, then the inoculant was applied by continually mixing the seeds and the added inoculant until the seeds were uniformly coated with the inoculant. The seeds were then allowed to air-dry for 15 minutes under a shade. Uninoculated seed plots were sown ahead of infested seed plots to avoid contamination. The seeds were planted two per hill, 5 cm apart within the row and 75 cm apart between rows. Both locations employed the drilling method to apply fertilizer.

3.6 Data collection

The following data were taken for analysis and interpretation.

3.6.1 Plant height

At the 2^{nd}, 4^{th}, 6^{th}, 8^{th}, and 10^{th} weeks after planting, the heights of five (5) tagged plants were measured in each treatment. A straight edge long metallic measuring ruler was used to measure from the base of the plants (above ground) to the tallest growth point.

3.6.2 Days to 50% flowering

This data was taken at a close eye with the crops when it was observed that, about 50% of plants on each treatment had produced flowers. The days were then calculated from the sowing date to the day the data was taken.

3.6.3 Grain yield

This was taken as the crops achieved full maturity and vegetative development ceased, with leaves turning yellow and the remainder of the plants drying up. Due to the crops' sensitivity to breaking when delayed, very thorough monitoring was performed to avoid this loss.

A 1 m × 1m quadrant was thrown on each field, and the area gathered and threshed was used and quantified into the yield per each area. After that, the grains were air-dried and weighed.

3.6.4 Days to 50% maturity

This data was taken at a close eye with the crops when it was observed that, about 50% of plants on each treatment had obtained fully field pods. The days were then calculated from the sowing date to the day the data was taken.

3.6.5 Net assimilation rate

The net assimilation rate was calculated using the formula below (Watson 1952);

$$NAR = \frac{(W2 - W1)(In\ A2 - In\ A1)}{(A2 - A1)(t2 - t1)}$$

Where, W_1 and W_2 were the dry matter weights, A_1 and A_2 were the leaf areas of soybean plants taken at time interval t_1 and t_2, respectively. W_1 was taken at 5^{th} week after planting, while W_2 was taken at 8^{th} week after planting. Samples from each treatment were put in labelled envelopes and oven dried to constant weight at 90^oC for 48 hours, and the mean weight was calculated.

3.6.6 Leaf area index

Leaf area index (LAI) was determined at 2^{nd}, 4^{th}, 6^{th}, 8^{th} and 10^{th} weeks after planting. The leaf areas were estimated, using a meter rule by taking the leaf length and width. The average leaf area was then divided by the row spacing dimensions (inter row by intra row) to get the leaf area index per plant (Cox *et al*., 2011).

3.6.7 Relative growth rate

The relative growth rate (RGR) was calculated using the formula below (Watson 1952);

$$RGR = \frac{(In\, W2 - In\, W1)}{t2 - t1}$$

Where, W_1 and W_2 were the total dry matter weight of soybean plants taken at time interval t_1 and t_2, respectively. W_1 was taken at 5^{th} week after planting, while W_2 was taken at 8^{th} week after planting. Samples from each treatment were put in labelled envelopes and oven dried to constant weight at 90^oC for 48 hours, and the mean weight was calculated.

3.6.8 Number of nodules

At 50% flowering, five (5) soybean plants were randomly uprooted to assess nodulation. The samples were carefully dug out, retrieving detached nodules. The nodules were kept in labelled polythene bags and sent to the laboratory and washed, counted and the fresh weight taken

3.6.9 SPAD chlorophyll reading

The SPAD chlorophyll reading was taken on the sixth week using the SPAD 502 plus chlorophyll meter. This was done at a very early morning before sun sets to avoid closure of stomata. This was done on each of five tagged plants on each treatment and the average was taken for each treatment.

3.6.10 Crop growth rates

Crop growth rate (CGR) was calculated using the formula below (Watson, 1952):

$$CGR = \frac{W2 - W1}{t2 - t1}$$

Where, W_1 and W_2 were the total dry matter weight of soybean plants taken at time interval t_1 and t_2, respectively. W_1 was taken at 5th week after planting, while W_2 was taken at 8th week after planting. Samples from each treatment were put in labelled envelopes and oven dried to constant weight at 90°C for 48 hours, and the mean weight was calculated.

3.6.11 Number of pods per plant

For number of pods, five plants were taken from each plot and all the pods plucked. These were then counted manually and the average pod number was calculated.

3.6.12 Seeds weight (1,000 seeds)

One thousand seeds of soybean grains were picked randomly from individual treatment and the weight was taken.

3.7 Data analysis

Data collected were subjected to analysis of variance (ANOVA) using Genstat Statistical Package software, Teaching and Learning version, 18th edition. Treatment differences were determined using the least significant difference procedure. The significant differences between treatments were separated at a 5% probability level.

CHAPTER FOUR

4.0 RESULTS

This chapter presents the findings of a study that compared the effects of nitrogen, phosphorus type, and inoculation on soybean grain yield in two soil series.

4.1 Effect of fertilizer treatment on plant height of soybean

Plant height were taken on the 2nd, 4th, 6th, 8th and 10th weeks after planting (WAP). The interaction effect had no significant difference on plant height. There was significant differences in the plant heights ($P < .001$) (Figure 1) with respect to the fertilizer treatments.

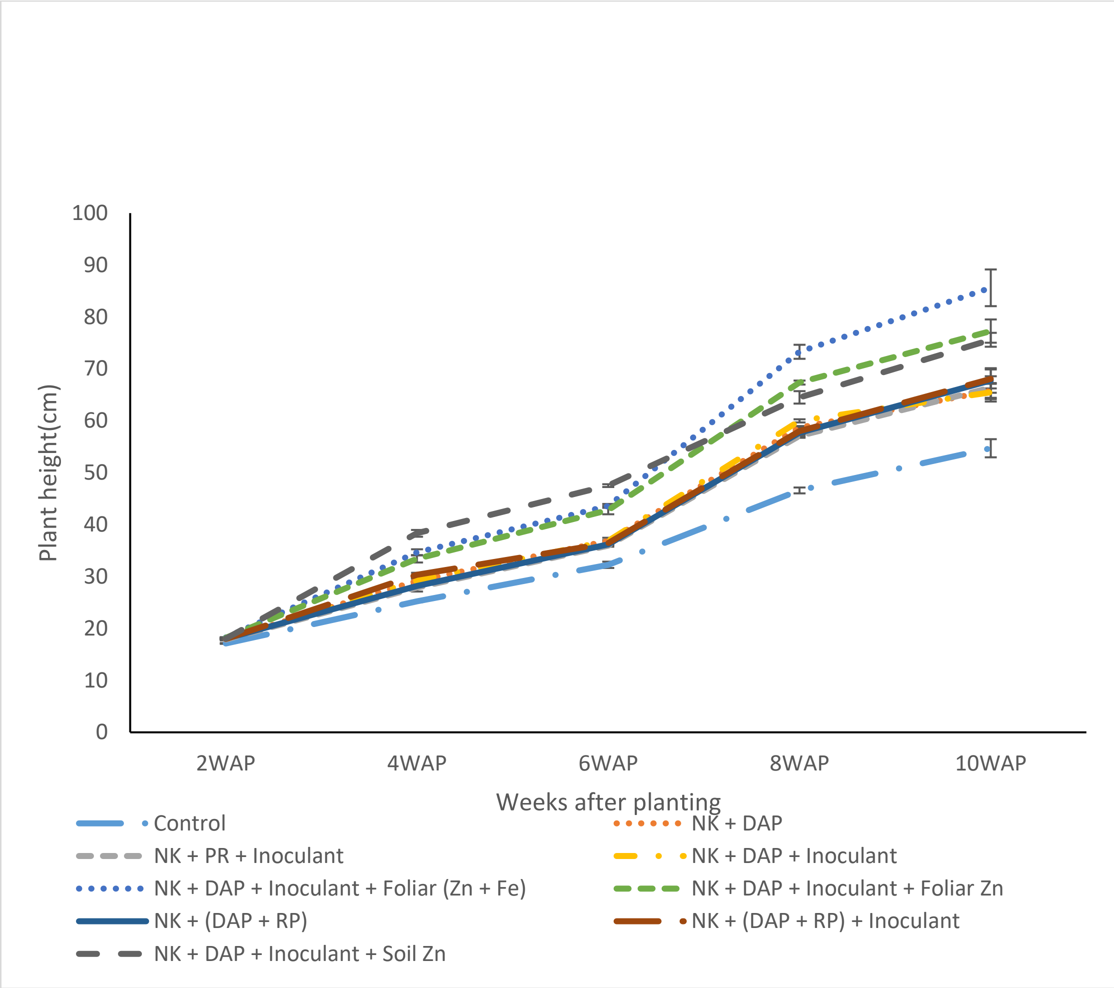

Figure 1: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on plant height of soybean

Fertilizer treatment combination of NK + DAP + Inoculant + Foliar (Zn + Fe) had the highest plant height, whilst the Control treatment lagged in plant height. The soil type also had no significance differences effect.

4.2 Effect of fertilizer treatment on leaf area index of soybean

Interaction effect had no significant difference. The fertilizer treatments had significant difference effect on the leaf area index ($P < .001$) (Figure 2).

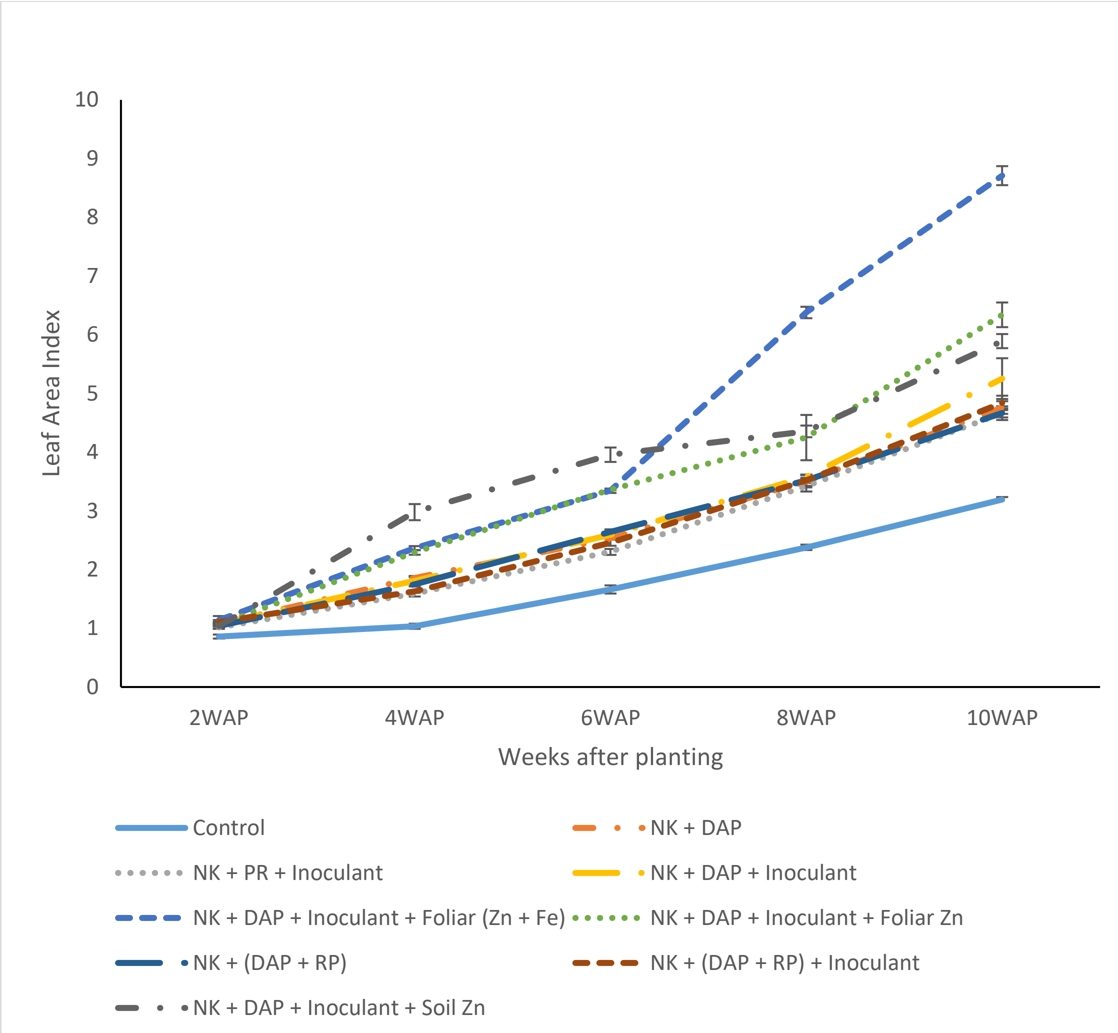

Figure 2: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on Leaf Area Index of soybean

The treatment (NK + DAP + Inoculant + soil Zn) recorded the highest leaf area index at the 6th week and treatment combination of NK + DAP + Inoculant + Foliar (Zn + Fe) recorded the highest leaf area index at the 10th week, whiles the control recorded the least LAI among the treatments.

The soil type for 6th week (P = 0.014) (Figure 2b) showed significance difference, The soil type and interaction effect for 2nd, 4th, 8th and 10th week did not show any significant difference.

4.3 Effect of fertilizer treatment on relative growth rate of soybean

Interaction effect did not show any significant difference. The fertilizer treatments had significant difference effect on relative growth rate (P < .001) (Figure 3).

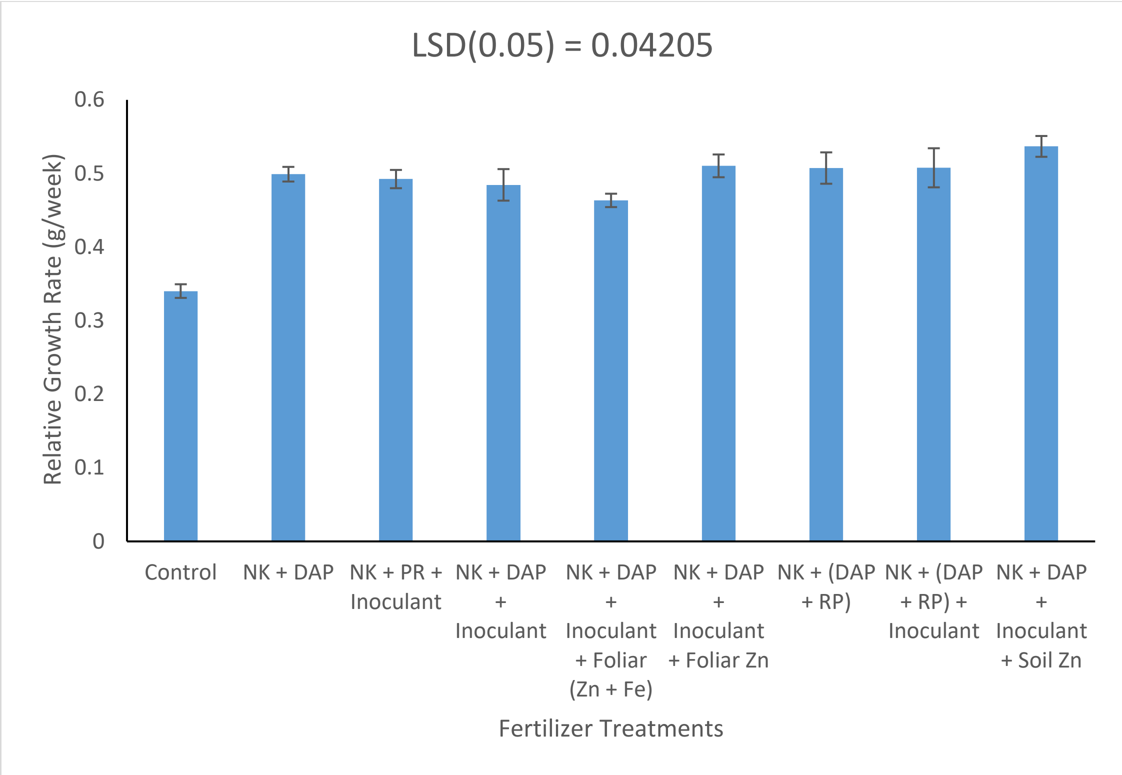

Figure 3: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on relative growth rate of soybean

The treatment (NK + DAP + Inoculant + Soil Zn) fertilizer combination recorded the highest relative growth rate, whiles the control recorded the least among the treatments. The soil type (P = 0.023) (Figure 3) recorded a significant difference. The lowland soil did better than upland soil.

4.4 Effect of fertilizer treatment on crop growth rate of soybean

Results on crop growth rate showed that, interaction effect did not show any significant difference. The fertilizer treatments had significant difference effect on crop growth rate (P < .001) (Figure 4).

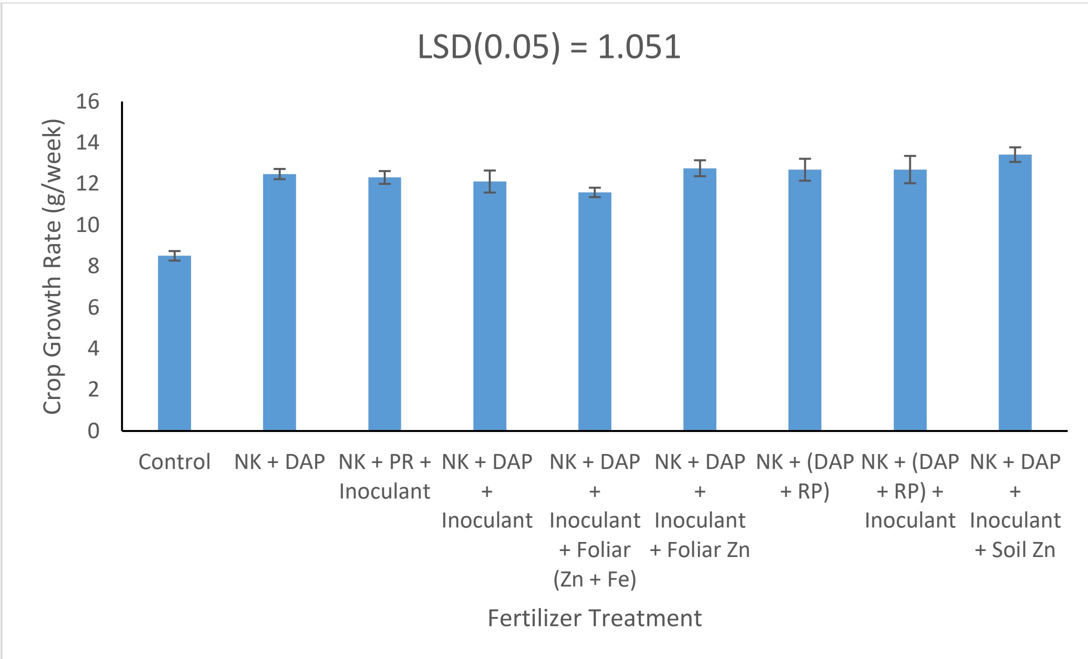

Figure 4: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on crop growth rate of soybean

The treatment (NK + DAP + Inoculant + Soil Zn) fertilizer combination recorded the highest crop growth rate, whilst the control recorded the least among the treatments. The soil type (P = 0.023) (Figure 4) showed significance difference. For the two soil types, the lowland soil did better than the upland soil for crop growth rate.

4.5 Effect of fertilizer treatment on Net Assimilation Rate of soybean

The interaction effect did not show any significant difference on net assimilation rate. However, the fertilizer treatments had significant difference effect on net assimilation rate (P < .001) (Figure 5).

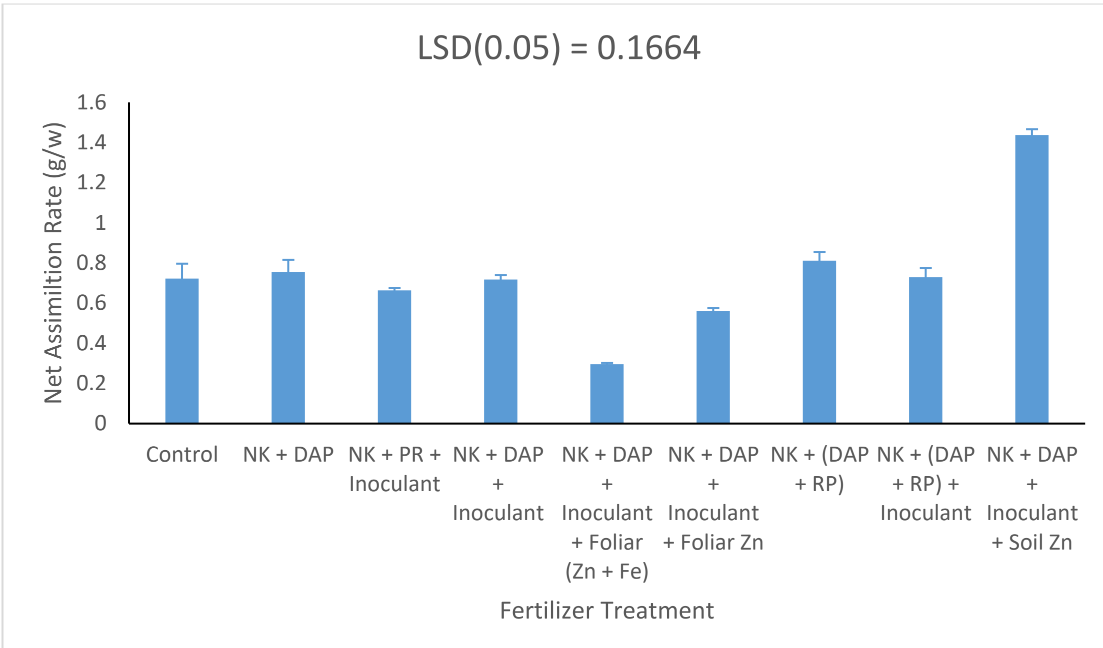

Figure 5: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on Net Assimilation Rate of soybean

The treatment (NK + DAP + Inoculant + Soil Zn) fertilizer combination recorded the highest net assimilation rate, whilst the NK + DAP + Inoculant + foliar (Zn + Fe) recorded the least among the treatments. The soil type did not show any significant differences.

4.6 Effect of fertilizer treatment on SPAD Chlorophyll reading of soybean

Results on SPAD chlorophyll reading showed no significant difference on interaction effect. Fertilizer treatments had significant difference effect on SPAD Chlorophyll reading (P = 0.002) (Figure 6).

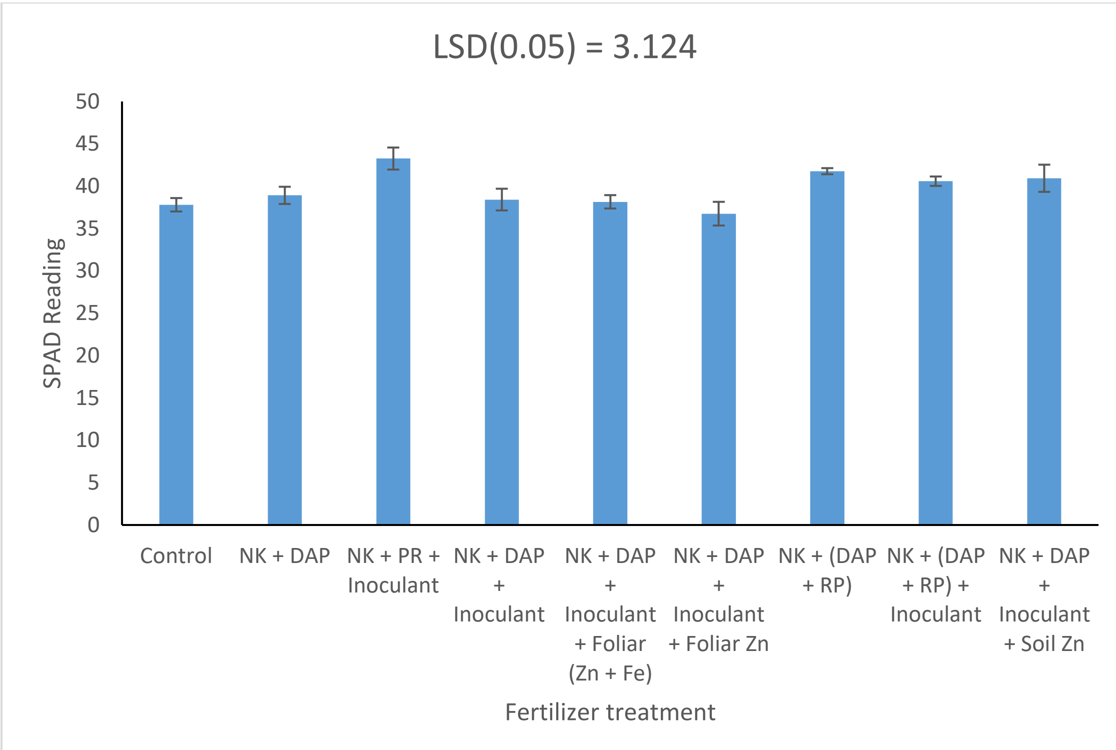

Figure 6: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on SPAD Chlorophyll reading of soybean

The treatment (NK + PR + Inoculant) fertilizer combination recorded the highest, whilst the control recorded the least among the treatments. The soil type did not show any significant effect.

4.7 Effect of fertilizer treatment on number of pods soybean

The number of pods results showed that, interaction effect did not show any significant difference. However, fertilizer treatments had significant difference effect on the number of pods (P < .001) (Figure 5).

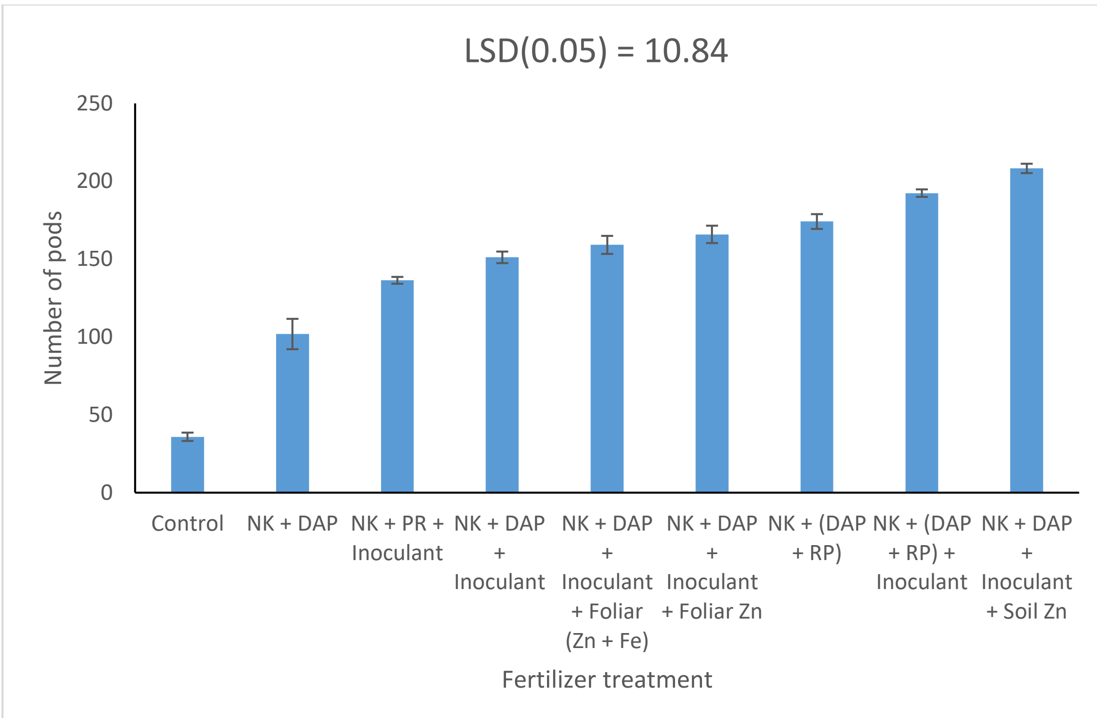

Figure 7: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on Number of pods of soybean

The treatment (NK + DAP + Inoculant + Soil Zn) fertilizer combination recorded the highest number of pods, whiles the control recorded the least among the treatments. The soil type had no significant difference.

4.8 Effect of fertilizer treatment on grain yield of soybean

The interaction had no significant difference. The fertilizer treatments had significant difference effect on the grain yield (P < .001) (Figure 8).

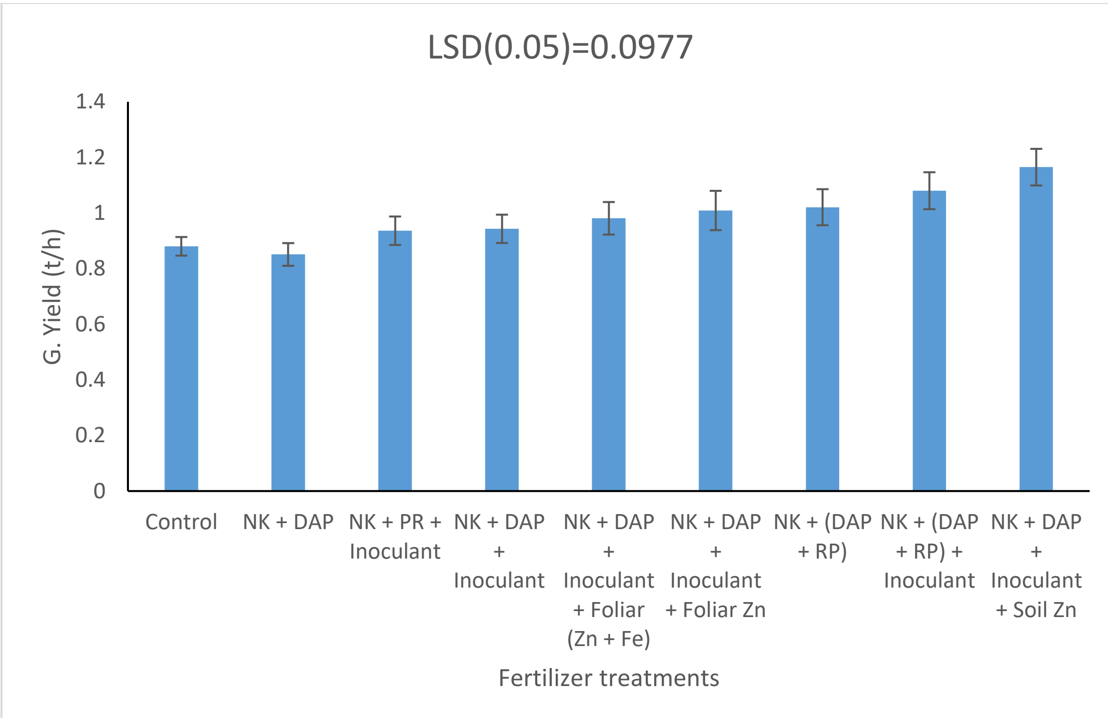

Figure 8: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on Grain yield of soybean

The treatment (NK + DAP + Inoculant + Soil Zn) fertilizer combination recorded the highest grain yield, whiles the control recorded the least among the treatments. The soil type did not show any significance difference.

4.9 Effect of fertilizer treatment on 1,000 seed weight of soybean

Results from the 1,000 seed weight showed that, the interaction effect did not show any significant difference. The fertilizer treatments had significant difference effect 1,000 seed weight (P = 0.002) (Figure 9).

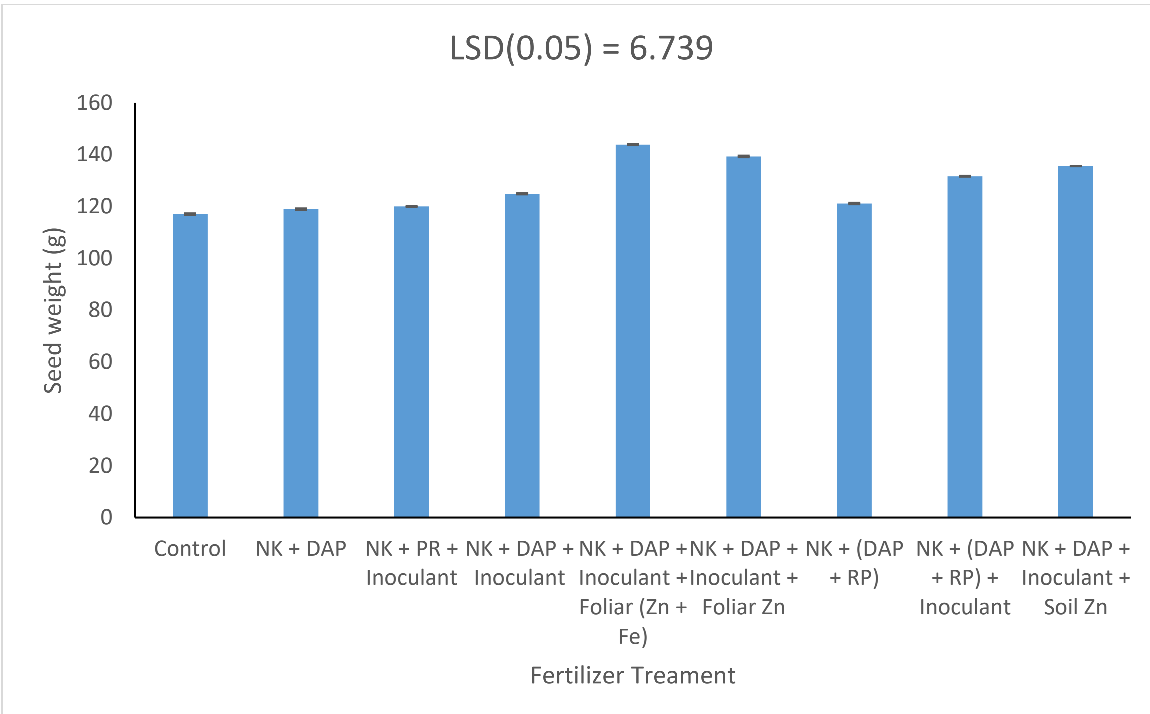

Figure 9: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on Seed weight of soybean

The treatment (NK + DAP + Inoculant + Foliar (Zn + Fe)) fertilizer combination recorded the highest, whiles the control recorded the least among the treatments. The soil type (P = 0.019) (figure 9) also showed significance difference with upland soil which did better than the lowland soil.

4.10 Effect of fertilizer treatment on number of nodules of soybean

The interaction did not show any significant difference. However, fertilizer treatments had significant difference effect on the number of nodules (P < .001) (Figure 10).

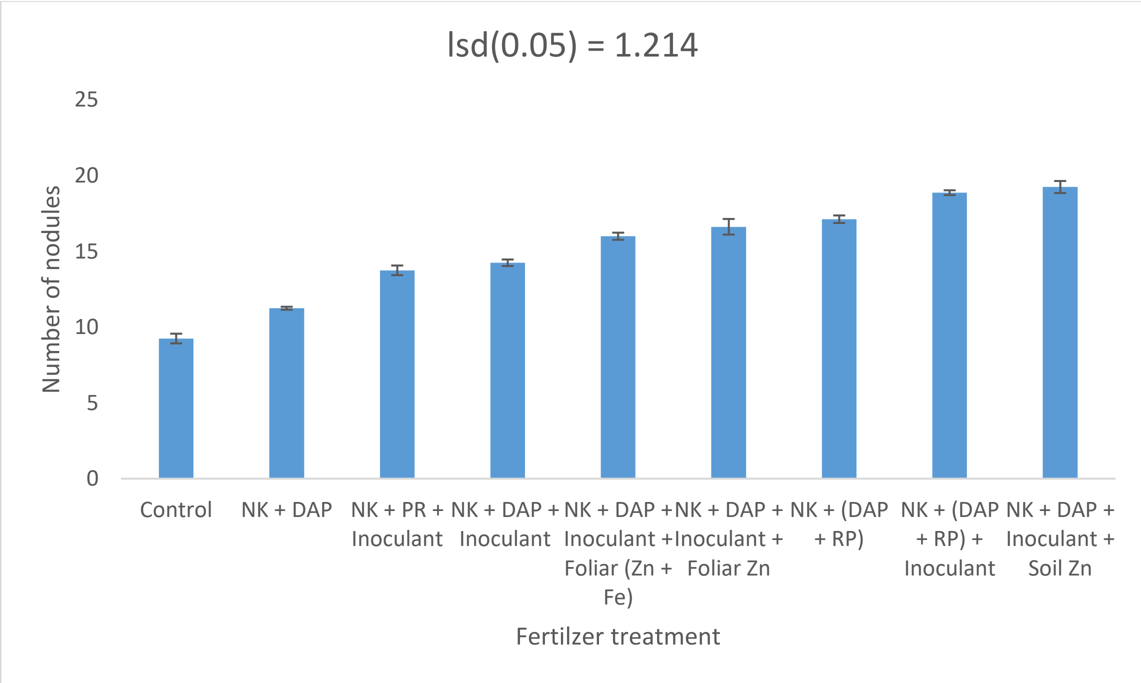

Figure 10: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on Nodule number of soybean

The treatment (NK + DAP + Inoculant + Soil Zn) fertilizer combination recorded the highest nodule number, whiles the control recorded the least among the treatments. The soil type did not also show any significant difference.

4.11 Effects of fertilizer treatment on days of maturity of soybean

No significant difference was shown for interaction, but there was significant difference for fertilizer treatments on the number of days to maturity (P < .001) (Figure 11).

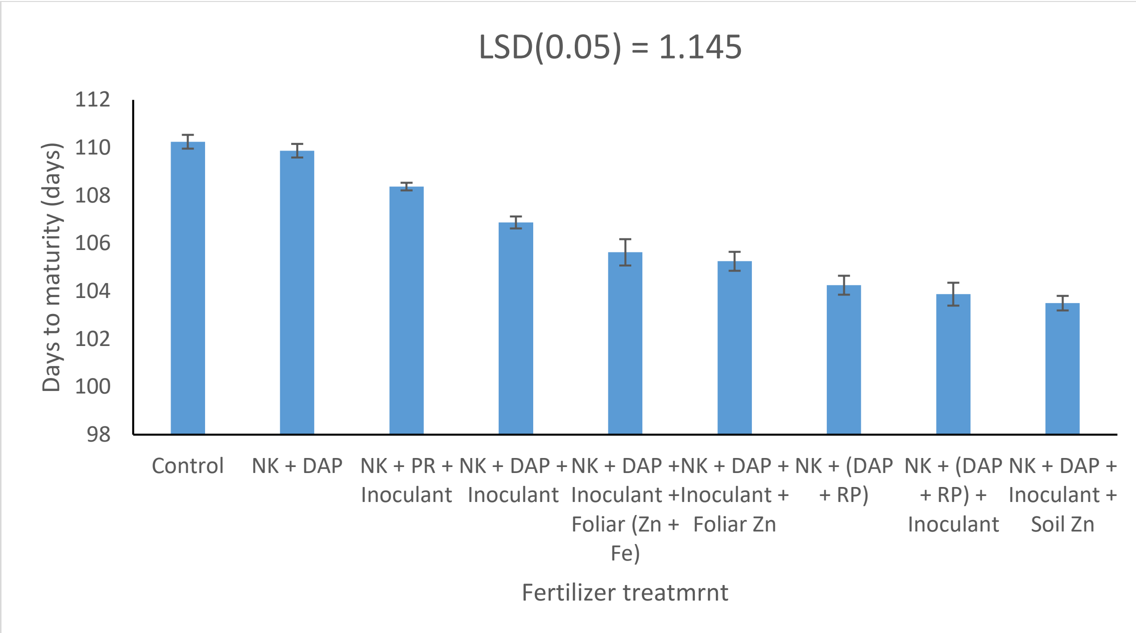

Figure 11: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on Number of days to maturity of soybean

The control treatment recorded the highest number of days, whiles the treatment (NK + DAP + Inoculant + Soil Zn) recorded the least among the treatments. The soil type (P < .001) (Figure 11) had significance difference effects with lowland soil recording least number of days, whilst upland soil recording the highest number of days.

4.12 Effects of fertilizer treatment on days to 50% maturity of soybean

The interaction effect did not show any significant difference. The fertilizer treatments had significant difference effect on the number of days to 50% maturity (P < .001) (Figure 12).

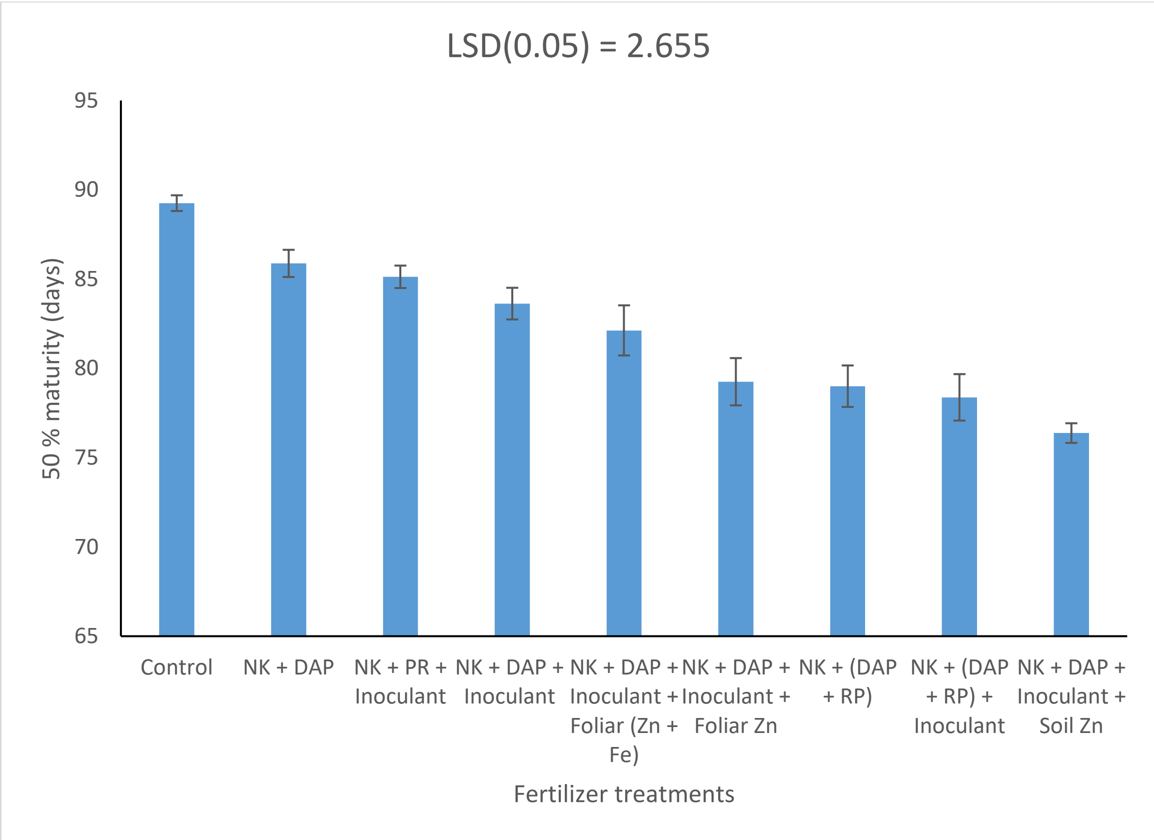

Figure 12: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on Number of days to 50% maturity of soybean

The control treatment recorded the highest number of days, whiles the treatment (NK + DAP + Inoculant + Soil Zn) recorded the least among the treatments. The soil type (P < .001) (Figure 12) showed significance difference, the lowland soil recorded the least number of days whilst the upland soil recorded the highest number of days.

4.13 Effects of fertilizer treatment on days to 50% flowering of soybean

The interaction and soil type did not show any significant difference. The fertilizer treatments had significant difference (P<.001) on the number of days to 50% flowering (Figure 13).

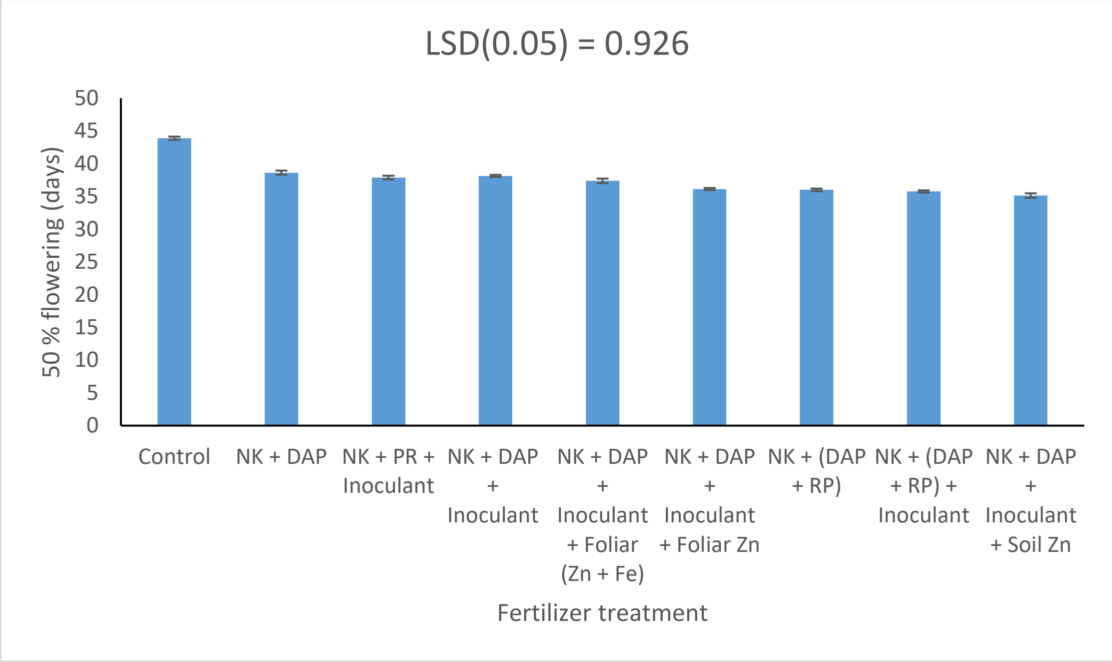

Figure 13: Effects of Inoculation, P, Foliar (Zn, Fe) and Soil Zn on Number of days to 50% flowering of soybean

The control treatment recorded the highest number of days, whiles the treatment (NK + DAP + Inoculant + Soil Zn) recorded the least among the treatments.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Plant height

In terms the height of plant, the fertilizer treatment combination of NK + DAP + Inoculant + Foliar (Zn + Fe) appeared as the highest. The inoculum was the source of rhizobia microorganisms that makes nitrogen available to plants and also make soil conditions favorable for microbial activities to produce more nutrients. DAP was also a source of nitrogen and phosphorus and as such more nitrogen was available to the plants. DAP phosphorus is a key nutrient for nodule development as well as N_2 fixation. The application of phosphorus elements has a direct influence on activities such as nodule formation, nodule activity, and the N_2 fixation process (Nkaa *et al*., 2014). This is also consistent with Kandil's (2013) findings, which demonstrated that raising nitrogen levels had a substantial influence on the height of the majority of plants. According to Ai-Qing *et al*. (2011), zinc modulates iron absorption and translocation and vice versa. Zn was essential for the production of proteins, RNA, and DNA (Kobraee *et al*., 2011). Zinc and iron play distinct functions in the crop, such as photosynthesis assimilation production, partitioning, and use (Sawan *et al*., 2008).

5.2 Leaf area index

The treatment combination of NK + DAP + Inoculant + Foliar (Zn + Fe) supplying the highest N and P rate did better than the other treatments in terms of LAI. A higher nitrogen rate promotes LAI during vegetative development and aids in the maintenance of functional Leaf Area during the growth stage (Cox *et al*., 2011). Higher N was delivered by the inoculum via the activities of rhizobia bacteria, and an increase in soil microbe activity also reduced N loss, making more N available to plants. It is possible that nitrogen loss by leaching or volatilization was lower in the foliar source of nitrogen fertilizer treatment. Moreta *et al*. (2014) reported that 70 % of nitrogen is lost during nitrification and denitrification processes through nitrate leaching and nitrous oxide (N_2O) emission into the environment most especially under humid conditions.

5.3 Crop growth rate

The findings of the experiment revealed that the treatments affect crop growth rate and absolute growth rate. NK + DAP + Inoculant + Soil Zn outperformed the other treatments in terms of crop growth rate. The crop growth rate is the most essential element in soybean growth analysis, according to Pedersen and Lauer (2004), since it displays the amount of canopy assimilation and affects dry matter and balances by modifying the leaf area index (LAI) and net assimilation rate (NAR). Cumudini *et al*. (2011) revealed a substantial and positive association between crop growth rate and seed number in maize, as well as between dry matter production and seed number in soybean, during the early reproductive stage. According to Ruhul *et al*. (2009), crop growth rates were highest up to 60 days after sowing and subsequently fell till 90 days after sowing. Oya *et al*. (2004) observed that crop growth rate during the reproductive development stage was substantially connected to soybean seed output. According to these experts, soybean has a separate phase in which reproductive and vegetative development phases coexist.

5.4 Relative growth rate

The relative growth rate at a given moment in time is the rate of increase in dry matter with a certain amount of assimilatory material (Rajput *et al*., 2017). The treatment combination of NK + DAP + Inoculant + Soil Zn resulted in the highest soybean relative growth rate, which is consistent with the findings of Ruhul *et al*., (2009), who discovered that adequate N and Zn supply to soybeans increases plant biomass, which affects the plant's relative growth rate.

Escalante and Rodriguez (2008), on the other hand, demonstrated a link between soybean plant seed yield and biomass, leaf area, relative growth rate, and specific leaf area. They contend that providing macronutrients at an early stage and supplementing micronutrients such as Zn improve plant biomass and production.

5.5 Net assimilation rate

NAR is influenced by multiple complicated and practically unidentifiable factors, and as a result, the findings of various NAR investigations differ from one another (Heidarian *et al.,* 2011). The results of the experiment show that there are treatment effects on the net assimilation rate of soybean. The highest crop growth rate was achieved by the treatment combination of NK + DAP + Inoculant + Soil Zn, which agrees with other research findings that crop growth rate is the most important factor in soybean growth analysis because it shows the amount of canopy assimilate and influences the amount of dry matter and balances by changing the leaf area index (LAI) and net assimilation rate (NAR) (Pedersen and Lauer, 2004).

The magnitude and leaf area duration (LAD) of a crop, as well as the net assimilation rate (NAR), are the key determinants of dry matter (biomass) output (Escalante and Kohashi, 1993).

5.6 SPAD Chlorophyll reading

The soybean plant has a very low to average susceptibility to zinc deficiency and is far less sensitive than most cereals such as maize, wheat, and sorghum (Spiller *et al.,* 1982). Carbohydrate, protein, and chlorophyll production is drastically reduced in zinc-deficient plants such as soybean. Zinc is predominantly absorbed as a divalent cation (Zn^{2+}), which is found in soil solution and soil exchange sites (Girma *et al.,* 2006). When soil Zn is marginal, phosphorus-induced Zn shortage can arise. However, in soils rich in Zn, excessive P treatment did not result in Zn deficiency (Gul *et al.,* 2011). Fe is one of several compounds in plants that are required for the oxidation-reduction reaction in respiration and the chlorophyll required for photosynthesis, according to Vahedi (2011). Iron is stationary within the plant, and iron minerals become less soluble as soil pH increases.

The SPAD Chlorophyll meter readings rose with increasing nitrogen content, and the combined treatment impact of N, Zn, and Fe in the study is similar with Villeneuve *et al*. (2002) in broccoli and Westerveld *et al*. (2003) in cabbage. They discovered that SPAD chlorophyll meter values in leaves were connected to tissue total nitrogen concentrations as well as micronutrient concentrations such as Zn and Fe.

5.7 Number of pods

The findings were congruent with those of Bozorgi *et al*. (2011) in faba bean, Kobraee *et al*. (2011) in soybean, and SeifiNadergholi *et al*. (2011) in common bean, who discovered that zinc spraying increased the number of pods per plant. Elballa *et al*. (2004) observed that supplementing with microelements increased the amount of pods produced per plant. According to Zeidan *et al*., 2006 foliar spraying micronutrients increased the number of pods per plant, 1000 seed weight, and seed yield significantly. According to Kakiuchi and Kobata (2006), one of the most important elements influencing soybean seed output is the quantity of pods per plant. According to these researchers, the rate of pod set in soybean rose with increasing source vigor, whereas bloom thinning and defoliation affected the ratio. Furthermore, the dry matter enhancement ratio in soybean seeds to shoot is an important element determining the pace of soybean podding. Foliar spraying during the flowering and podding stages resulted in the most pods per plant, according to SeifiNadergholi *et al*. (2011), and the increase in pods per plant due to foliar application could be attributed to the significant effect of microelements on reproductive organs such as stamens and pollens. Because soybean is a self-pollinated crop, stamen activity increases the number of blooms that can fertilize efficiently, resulting in a larger number of pods per plant. Katulanda (2011) revealed that nitrogen injection during the vegetative or blooming phases may enhance pod and crop biomass by 44 and 16 %, respectively.

5.8 Grain yield

Because soybean is a self-pollinated crop, stamen activity increases the number of blooms that may fertilise effectively, resulting in a larger number of pods per plant. Katulanda (2011) revealed that nitrogen infusion during the vegetative or blooming phases can enhance pod and crop biomass by 44 and 16 %, respectively. According to Okereke *et al*. (2000), for soybean grown in moist soils of the West African region, the response of soybean crops to inoculation on *Gleyic lixisol* was attributed to bradyrhizobia strains in the inoculants, which were more competitive than the indigenous soybean plant rhizobia, which had a population of 5.71 to 101 g^{-1} of soil. According to Thies *et al*. (1991), the amount of indigenous rhizobia present impacts the response to rhizobial inoculation and an imported strain's capacity to compete with and overcome the indigenous rhizobia.

Foliar $ZnSO_4$ treatment during flowering and seed set significantly increased soybean yield components, according to SeifiNadergholi *et al* (2011). Berglund (2002) claims that foliar Zn treatment increased soybean seed output, notably during the vegetative development stage. According to Bozoglu *et al*. (2007), foliar micronutrient treatment might be used to increase yield and quality. The scientists observed that a lack of particular micronutrients reduced chickpea output. Foliar zinc spraying improved soybean output by altering seed weight and quantity of seeds per plant (Kobraee *et al*., 2011). Foliar micronutrient treatment boosts yield components in lentils, according to Zeidan *et al*. (2006). By increasing enzymatic activity, microelements improved photosynthesis and assimilate transport to the seed. According to Zayed *et al*., 2011, zinc + iron therapy was superior to Zn and Fe treatment in rice due to the synergistic impact. According to Arif *et al*. (2006), foliar spraying can increase yield by ensuring crop dry matter production. According to Kobraee *et al*. (2011), combining zinc and iron can result in greater dry matter and seed output than combining the two independently. According to Kakiuchi and Kobata (2008), seed production in soybeans is lower than in other legumes, and one gram of seed requires two gram of photosynthetic assimilates to produce. Shiraiwa *et al*. (2004) state that pod quantity and seed number are two major factors influencing soybean seed yield. Variations in seed yield in soybean genotypes are mostly attributable to differences in dry matter production during the seed filling stage. Seed number augmentation increased seed output in soybean as a result of adjusting the source-sink ratio during the blooming stage (Cumudini *et al*., 2011). Many authors have also discovered significant gains in legume production as a result of the use of phosphorus fertilizer (Yakubu *et al*., 2010).

5.9 Seed weight

Arif *et al*. (2006) found that foliar spraying in wheat crops increased 1000 seed weight significantly. Zinc foliar spraying raised 100 seed weight significantly in both *P. vulgaris* and soybean, according to Nasri *et al.* (2011) and Ghasemian *et al.* (2010). When photosynthesis is shifted from vegetative organs to other areas, seed weight will grow dramatically, according to Kakiuchi and Kobata (2008). Microelements were found to alter the leaf of the common bean, resulting in the production of more assimilate. They travel to the seeds since they are a primary source of assimilation, and as a result, larger seeds are formed (SeifiNadergholi *et al.*, 2011).

5.10 Number of nodules

Nodule development, particular nodule activity, and the N_2 fixation process are all affected by direct P feeding (Nkaa *et al.*, 2014). Soybean rhizobial inoculation considerably enhances soybean nodule number and dry weight, and soybean response to rhizobial inoculation coincides with other researchers who observed increases in soybean nodule formation after inoculating soybean seeds (Aliyu *et al*., 2013). Kumaga and Ofori (2012) observed an increase in nodule development following bradyrhizobia inoculation of soybean seeds, which they attributed to the bradyrhizobia inoculant's highly competitive ability. Okereke *et al*. (2000) reported similar results for soybean cultivated in the humid savanna of the West African sub region.

On both soil types at Gbulahigu, the indigenous rhizobia population developed nodules on soybean plants in the control treatment, proving the promiscuous character of the Afayak soybean variety employed in this study. According to research, soybean cultivars have lower nodule formation selectivity, and local Brady rhizobium strain populations can successfully create nodules (Abaidoo *et al.*, 2007). The considerable increase in soybean nodule dry weight after rhizobial inoculation on both soils implies that the soybean variety reacted well to seed inoculation, which might be due to the low indigenous soybean rhizobia population at the two research locations (Abaidoo *et al.*, 2007).

5.11 Days to 50 % flowering, 50 % maturity and whole maturity

The results of the experiment demonstrated that the treatments affect flowering time and maturity. This supports the findings of the Agriculture Research Wing (ARW), which discovered that applying nitrogen at a higher rate can hasten early flowering and maturity. On average, it took 40 days for half of the plants to flower, 80 days for half of the plants to mature, and 110 days for the plants to achieve full maturity.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Based on the analyses and interpretation of data on the variables used in evaluating the yield of soybean and as influenced by rhizobial inoculation and application of some fertilizer blend such as rock phosphate fertilizer, DAP, NK, soil and foliar applied zinc and iron, the following conclusions were made;

i. NK + DAP + Inoculum + Soil applied Zn recorded highest with control recording the lowest for grain yield, number of pods, number of nodules.

ii. However, seed weight was different as NK + DAP + Inoculum + Foliar (Zn + Fe) recorded higher seed weight.

iii. In all, the DAP did better than RP in growth and yield.

iv. It should however be emphasized that, foliar fertilizer application was delayed due to drought at the due time of application and subsequently, most of them got burnt due to higher concentration rates of these applied fertilizers and these could be the reason for which NK + DAP + Inoculum + Soil Zn recorded highest in terms of yield, NK + DAP + Inoculum + Foliar (Zn + Fe) recorded highest in terms of seed weight.

Generally, considering the one-time application of both macro and the micro nutrients, blend with inoculum at the early stage of the crop growth led to vigorous growth and higher yield of the soybean crops.

6.2 Recommendations

Results from this study have demonstrated the potentials of the different phosphorus fertilizers and nitrogen application in improving nodulation, biomass and grain yields of soybean. The study was, however, limited in the estimation of the effect of these treatments on the amount of nitrogen fixed by soybean and the residual effects of rock phosphate and diammonium phosphate fertilizer application. It is therefore recommended that:

i. P in a form of DAP and RP, Zn and Fe are important elements in soybean growth and development and their importance should not be overlooked.

ii. However, DAP is recommended as it did better than the RP in terms of growth and yield.

iii. Inoculum as a source of rhizobial microorganisms should be encouraged in soybean cultivation.

iv. Further studies on foliar application of these micronutrients such us Zn and Fe should be conducted and timing and rates of applications should be considered.

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APPENDICES

Appendix A: Plant Height at two weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	1.9668	1.9668	11.79	0.001
Fert_Treat	8	7.2425	0.9053	5.43	<.001
Soil_type.Fert_Treat	8	0.3569	0.0446	0.27	0.974
Residual	51	8.5076	0.1668		
Total	71	18.9788			
%CV		2.3			

Appendix B: Plant Height at four weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	0.133	0.133	0.04	0.846
Fert_Treat	8	1041.259	130.157	37.24	<.001
Soil_type.Fert_Treat	8	6.503	0.813	0.23	0.983
Residual	51	178.262	3.495		
Total	71	1233.653			
%CV		6.1			

Appendix C: Plant Height at six weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	0.517	0.517	0.30	0.588
Fert_Treat	8	1485.133	185.642	106.87	<.001
Soil_type.Fert_Treat	8	10.917	1.365	0.79	0.617
Residual	51	88.588	1.737		
Total	71	1587.759			
%CV		3.4			

Appendix D: Plant Height at eight weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	0.109	0.109	0.02	0.889
Fert_Treat	8	3591.452	448.932	80.97	<.001
Soil_type.Fert_Treat	8	41.324	5.165	0.93	0.499
Residual	51	282.754	5.544		
Total	71	3940.780			
%CV			3.9		

Appendix E: Plant Height at ten weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	0.307	0.307	0.06	0.805
Fert_Treat	8	5682.597	710.325	142.59	<.001
Soil_type.Fert_Treat	8	12.792	1.599	0.32	0.954
Residual	51	254.059	4.982		
Total	71	6074.649			
%CV			3.1		

Appendix F: Leaf Area Index at two weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	0.06079	0.06079	3.99	0.051
Fert_Treat	8	0.40151	0.05019	3.30	0.004
Soil_type.Fert_Treat	8	0.02941	0.00368	0.24	0.981
Residual	51	0.77674	0.01523		
Total	71	1.31174			
%CV			11.8		

Appendix G: Leaf Area Index at six weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	0.28053	0.28053	6.51	0.014
Fert_Treat	8	29.85937	3.73242	86.65	<.001
Soil_type.Fert_Treat	8	0.25921	0.03240	0.75	0.646
Residual	51	2.19688	0.04308		
Total	71	32.70651			
%CV		7.5			

Appendix H: Leaf Area Index at ten weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	0.5403	0.5403	2.83	0.099
Fert_Treat	8	150.1003	18.7625	98.32	<.001
Soil_type.Fert_Treat	8	0.1623	0.0203	0.11	0.999
Residual	51	9.7324	0.1908		
Total	71	165.4954			
%CV		8.1			

Appendix I: Crop growth rate

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	0.009661	0.009661	5.50	0.023
Fert_Treat	8	0.207828	0.025979	14.80	<.001
Soil_type.Fert_Treat	8	0.003031	0.000379	0.22	0.987
Residual	51	0.089517	0.001755		
Total	71	0.374422			
%CV		8.7			

Appendix J: Absolute growth rate

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	6.038	6.038	5.50	0.023
Fert_Treat	8	129.893	16.237	14.80	<.001
Soil_type.Fert_Treat	8	1.894	0.237	0.22	0.987
Residual	51	55.948	1.097		
Total	71	234.014			
%CV		8.7			

Appendix K: Number of nodules

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	5.014	5.014	3.43	0.070
Fert_Treat	8	722.194	90.274	61.72	<.001
Soil_type.Fert_Treat	8	6.361	0.795	0.54	0.818
Residual	51	74.597	1.463		
Total	71	815.319			
%CV			8.0		

Appendix L: Number of pods

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	32.0	32.0	0.27	0.603
Fert_Treat	8	172511.9	21564.0	184.95	<.001
Soil_type.Fert_Treat	8	25.5	3.2	0.03	1.000
Residual	51	5946.2	116.6		
Total	71	184828.4			
%CV		7.3			

Appendix M: Grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	0.026527	0.026527	2.80	0.101
Fert_Treat	8	0.610967	0.076371	8.06	<.001
Soil_type.Fert_Treat	8	0.015122	0.001890	0.20	0.990
Residual	51	0.483496	0.009480		
Total	71	2.257799			
%CV		9.9			

Appendix N: 1000 seed weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	263.35	263.35	5.84	0.019
Fert_Treat	8	1351.73	168.97	3.75	0.002
Soil_type.Fert_Treat	8	35.98	4.50	0.10	0.999
Residual	51	2298.81	45.07		
Total	71	4985.16			
%CV			5.0		

Appendix O: Number of days to full maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	141.681	141.681	108.86	<.001
Fert_Treat	8	418.778	52.347	40.22	<.001
Soil_type.Fert_Treat	8	12.444	1.556	1.20	0.321
Residual	51	66.375	1.301		
Total	71	649.653			
%CV			1.1		

Appendix P: Number of days to 50% maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	480.500	480.500	68.71	<.001
Fert_Treat	8	1129.861	141.233	20.19	<.001
Soil_type.Fert_Treat	8	39.750	4.969	0.71	0.681
Residual	51	356.667	6.993		
Total	71	2259.111			
%CV			3.2		

Appendix Q: Number of days to 50% flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_type	1	1.1250	1.1250	1.32	0.256
Fert_Treat	8	440.6944	55.0868	64.69	<.001
Soil_type.Fert_Treat	8	7.2500	0.9063	1.06	0.403
Residual	51	43.4306	0.8516		
Total	71	504.3194			
%CV		2.5			

Appendix R: SPAD chlorophyll meter reading

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fert_Treat	8	289.071	36.134	3.73	0.002
Soil_type	1	34.694	34.694	3.58	0.064
Fert_Treat.Soil_type	8	2.616	0.327	0.03	1.000
Residual	51	493.891	9.684		
Total	71	906.947			
%CV	7.9				