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GROWTH AND YIELD RESPONSE OF SCREENED SOYBEAN (*GLYCINE MAX* (L.) MERRIL) GENOTYPES TO FERTILIZATION AND RHIZOBIA INOCULANTION IN NORTHERN GHANA

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BY

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SEPTEMBER, 2020

DECLERATION

Student

I hereby declare that this is the result of my own work and that no previous submission has been made in this university or elsewhere for a degree. References made therein are duly acknowledged.

ABEL CHARLES ……………………….. ……………………

(Student) Signature Date

Supervisors'

I hereby declare that the preparation and presentation of the thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies.

DR. SHIRLEY LAMPTEY ………..…………… …………………..

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ABSTRACT

Soybean remains an important crop for the sustenance of livelihoods of resource-constrained farmers in northern Ghana. However, yield of the crop has continuously remained low due to poor soil fertility and low productivity. A two-phase experiment was carried out during the 2019 cropping season to evaluate the growth and yield response of screened soybean genotypes to nitrogen, phosphorus and rhizobia inoculation. In the first phase, growth and yield of 100 selected genotypes were studied under optimum phosphorus fertilization using the lattice design. In the second phase, 3 best performing genotypes (N19, N119, N135), selected in phase one together with a known variety (Jenguma) were accessed for growth and yield under phosphorus, nitrogen and inoculants using a 4 (genotype) x 7 (nutrient regime) split plot design. The nutrient regimes were sole triple super phosphate (TSP), sole inoculant, sole booster nitrogen, TSP + booster nitrogen, TSP + inoculant, TSP + booster nitrogen + inoculant and a control (No fertilizer). Each treatment was replicated three times. Data collected were subjected to analysis of variance and means separated at 5% probability using the least significant difference. The results showed that plant height, days to 50% flowering, number of unfilled pods and 100 grain weight were significantly influenced by genotype. Number of nodules, biomass dry weight and pod weight were significantly affected by the nutrient regime. Leaf area, number of leaves per plant, number of primary branches and number of effective nodules were significantly affected by both genotypes and fertilizer regime. Genotypes N135, N119 and Jenguma flowered almost at the same time (from 42 to 43 days after planting) whereas genotype N19 took a longer period to flower. There was a significant ($P = 0.032$) interaction effect between genotype and nutrient regime on grain yield. Jenguma, treated with TSP

+ inoculant recorded the highest yield of 4 t/ha followed by Jenguma variety treated with TSP + inoculant + booster nitrogen (3.9 t/ha) and genotype N135 treated with TSP + nitrogen (3.7 t/ha) while genotype N19 without treatment (control) recorded the least grain yield. The high yield obtained for inclusion of P, N and inoculants exceeded what is documented for northern Ghana (1.5 t/ha). It is recommended to farmers to include P, booster N and inoculants in cultivation of the Jenguma variety. Based on economic cost analyses, farmers stand to achieve higher profit upon application of sole TSP. Sole TSP is therefore recommended to maximize profit.

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DEDICATION

To God almighty and my family especially to my mum Mrs Lucy Uzor for their support and kind gesture during the period of this work

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of study

Soybean (*Glycine max* (L.) Merrill) is an annual leguminous crop which is cultivated in the subtropical, tropical and template regions. It is known that the crop is a fundamental source of high quality and less expensive protein (around 40%) and contains about 20% of very edible and cholesterol-free oil. The protein from soybean has incredible potential as an essential source of dietary protein. Ghana produces around 15,000 tons of soybean grain every year (MoFA and CSIR, 2005). The crop is cultivated mostly in the northern savannah and parts of Ashanti and Brong-Ahafo Regions. Among these Regions, Northern Region happens to be the main grower of soybeans with 70% of national soybean area and around 77% of national soybean production (SRID, 2012). Regardless that soybean is moderately new in Ghana (Akramov and Malek, 2012), the relevant function of soybean in the villages and in, family units particularly in Northern parts of Ghana cannot be over emphasized. A report by MoFA (2006) indicated that there are good varieties of soybean cultivated in Ghana which produces seeds of 3.75 kg/ha and yields of 1.8 to 2.5 t/ha, compared with that of USA which is 4.6 t/ha (Lawson *et al.*, 2008). Soybean can add atmospheric nitrogen through symbiotic association with local rhizobia. Sanginga *et al.* (2003) reported that some soybean varieties biologically fix 44 to 103 kg N /ha every year. There is a joint force by Savannah Agricultural Research Institute (SARI), Ministry of Food and Agriculture (MoFA) and other development partners, for example, US Aid, IITA and others to advance soybean production in view of its capacities to upgrade income and improve dietary status of households (Mbanya, 2011). Soy milk, soy oil, soybean yogurt, and corn-soy mix are different ways by which soybean is utilized in Ghana. Presently, soybean products, such as Tom Darker is notable in most Ghanaian home throughout the nation. Consequently, more than 100 food products with great nutritive values and customer acceptability have been produced from the crop. Soybean feast, which is a by-product of oil extraction, has a high unrefined protein content of 44% to 50% and a fair amino acid composition, complementary to maize meal for feed processing (Ngeze, 1993, MoFA and CSIR, 2005). For this reason, a good level of inclusion (30-40%) is utilized in the preparation of feed for monogastrics. Soybean cake, a by-product from the oil production is utilized as a high-protein animal feed in Ghana. Aside from its nutritive value, soybean oil is utilized in factories for paints, printing inks, flooring, detergents, disinfectants and bug sprays (Ngeze, 1993; Rienke and Joke, 2005). Soybean meal and soybean protein are also utilized for artificial wool (synthetic fibre) synthesis, waterproofing, material, glue firefighting froth, textiles and adhesives. Ugwu and Ugwu (2010) reported on details regarding the advantages of soybean compared to other legumes like cowpea, groundnut and Bambara beans which included better storage quality, less prone to diseases and pests and bigger leaf biomass which better improves soil fertility and increases the fertility of the soil for the next season's crop. Regardless of the various advantages of soybean, in Ghana the yield of the grain per hectare is low in Ghana because of limitations, such as, decreasing soil fertilities, use of low yield varieties, low plant stand, erratic and unpredictable rainfall (Addo-Quaye *et al.*, 1993).

1.2 Problem statement

Inspite of the numerous advantages of this crop, the yield of the grain per hectare is still low in Ghana. MoFA (2011) revealed that farmers' average soybean yields of 1.5

t/ha is well below attainable yields of 2.3 t/ha. A number of research studies have ascribed the low soybean yields in sub-Saharan Africa to poor yielding varieties and, soil infertility due to the limited use of chemicals such as fertilizers. Mbanya (2011) also reported that most farmers in the Northern part of Ghana do not apply improved technologies such as improved varieties, good management practices, fertilizer application poor spacing and row planting. According to Hailu (2011), low yield of soybean is attributed to negligence in improving the crop generally in Africa. Soybean which is high-yielding needs a lot of N and it is estimated that biological nitrogen fixation (BNF) can contribute 60 to 70% of the N needed by the crop (Herridge *et al.*, 2008; Salvagiotti *et al.*, 2008) through nodulation by rhizobium. Although BNF is the main way through which nitrogen input is obtained in agricultural systems, the main potential of the symbiotic system may not be realized because of inefficient strains of rhizobia. Phosphorus unavailability is one of the most significant nutrient that limit crop growth (Fernandez *et al*., 2007). Phosphorus plays an important function in the formation nodules and atmospheric fixation of nitrogen hence during nodulation legumes require more P over a crop which is not nodulating crops. Several reports indicated that symbiotic fixation of N_2 alone may not sufficient for N requirement of soybean during early and late stages of growth especially in very poor soils. The need for small amounts of N fertilizer supplied at the early stage of the crop mostly enhance N_2 fixation and growth in legumes (Sanginga, 2003; Okugun and Sanginga, 2003; Osborne and Riedell, 2006; Tahir *et al.*, 2009). The biological nitrogen fixation (BNF) process is fundamentally constrained by four key variables: capacity of host plant to accumulate nitrogen, viability of rhizobia-host plant beneficial interaction, measure of accessible soil nitrogen and ecological limitations (Van Kessel and Hartley, 2000).

1.3 Justification

Choice of highest yielding varieties in combination with rhizobia inoculant and inorganic fertilizer management regimes are essential for increase in soybean yield. A few variables including declining soil fertility, utilization of poor yielding varieties, inadequate utilization of rhizobium inoculant, poor utilization of mineral fertilizer and absence of or low use of booster nitrogen influence the grain yield of soybean in northern Ghana (Ahiabor *et al,*. 2014). The continuous utilization of low yielding cultivars and varieties by farmers in the Northern part of Ghana has brought about low yields of the crop. High yielding varieties in combination with rhizobia inoculant and fertilization are essential to increase soybean yield. Despite the fact that local soybean varieties freely nodulate with native rhizobia populations, it is not in every instance that they form effective symbiosis with the native rhizobia. The local soybean variety may profit from inoculation by utilizing very high effective rhizobia strains (Pulver *et al.*, 1985). Other experiments have also indicated significant responses of the crop to rhizobia inoculation (Osunde *et al.*, 2003, Ronner *et al.*, 2016). Report made by Bouquet (1998) stated that, selection of genotypes is one of the most relevant ways of enhancing the yield of pods in soybean. Hence the need to exploit available germplasm to find new genotypes that can improve nodulation, reduce shattering score and increase yield. P is required in relatively good amounts by soybeans and other legumes for growth and has been indicated to enhance, biomass, yield, leaf area, nodule mass and nodule number in different leguminous crops (Berg and Lynd, 1985: Pacovsky *et al.*, 1986: Kasturikrishna and Ahlawat, 1999). Treating legumes with inoculant supplies sufficient number of bacteria in the root zone of soybean, so that effective nodulation will occur (Lamptey *et al.*, 2014). Too much use of N fertilizer hinders the fixation of N_2 but low quantities (<30 kgN/ha) of N fertilizer usually promotes early growth of leguminous crops and stimulates the total N_2 fixation. The quantity of this booster N must be known in relation to N available in the soil (Graham, 1992). Soybean with high-yielding quality needs a large quantity of N and it is approximated that BNF can contribute 60 to 70% of the N required by soybean (Herridge *et al.*, 2008; Salvagiotti *et al.,* (2008). Tahir *et al.* (2009) reported that application of rhizobia inoculant and Phosphorus fertilization statistically improved nodule numbers from 73 in un-inoculated control (with no P application) to 125 and 95 in rhizobium inoculation and P application, respectively. Rhizobia inoculants, utilization of booster nitrogen and phosphorus fertilization stimulate nodule formation (Alam *et al*., 2015). For balanced nutrition and optimum yield, integrated soil fertility management (ISFM) is essential. Increased soybean production through the use of improved technologies such as the use of inoculants and fertilizer applications has been recorded in recent works in Ghana. Promiscuous soybean varieties have been introduced to curb pertaining issues and to enable the plant to nodulate freely with the local rhizobia (Okogun and Sanginga, 2003). The nitrogen need of a soybean crop is evaluated at 350 kg N /ha (Abendroth *et al.*, 2006). With sufficient supply of P, soybean can fix up to 450 kg N /ha (Unkovich and Pate, 2000) making it easier for the crop to fulfill its nutritional needs and leave some residual nitrogen for use by the subsequent crop (Salvagiotti *et al.*, 2008). There is a potential to enhance the fertility of the soil and soybean yields per unit area if the farmer uses high yielding variety in addition to adopting appropriate utilization of rhizobium inoculant, booster nitrogen and phosphorus fertilization. Although numerous study have been conducted on one or a combination of two and or three of these yield enhancing factors, data remains relatively unavailable. Lack of knowledge on soybean performance in combination with these factors limits soybean productivity by resource-poor smallholder farmers. The need therefore arises to understudy the combined effect of enhanced genotype, booster nitrogen, phosphorus fertilization and inoculation on productivity of soybean.

1.4 Main Objective

To evaluates soybean genotypes for improved yield under booster nitrogen fertilization, phosphorus application and rhizobium inoculation.

1.5 Specific Objectives

1. To assess the yield potential of soybean genotypes.

2. To determine the effect of phosphorus, inoculant and booster nitrogen on productivity of high yielding soybean varieties in northern Ghana.

3. To determine the most economical technology to be used in soybean production to maximize profit for resource the poor farmer.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and distribution of soybean

Soybean originated from Eastern Asia, basically, Korea Japan and China, it spread from there to America and Europe and different parts of the world in the eighteenth century (Ngeze, 1993). Proof in the history of China demonstrates its existence over 500 years before, being used as nourishment and a component of medications (Norman *et al.*, 1995). Few researchers have reported Eastern Africa and Australia as other potential origins of soybean (Addo-Quaye *et al.*, 1993). It is largely grown on extensive scale in the tropical and temperate zones, which includes Thailand, Indonesia, China, Brazil, Japan and the USA; where it has become a potential agricultural crop and an important export commodity (Evans, 1996). The crop was first brought to Africa in the mid nineteenth century, through Southern Africa (Ngeze, 1993). Shurtleff and Aoyagi (2007) have expressed that; it may have been under cultivation presented at earlier date in East Africa, since that area had since been trading with the Chinese for a very long time. The same report indicates that the crop is been under development in Malawi in 1909 and Tanzania in 1907. The Portuguese missionaries were the first to introduce soybean in Ghana in 1909. This first introduction did not survive due to the temperature difference between the place of origin and the new destination of the crop (Mercer-Quarshie and Nsowah, 1975). However, serious effort to sustain the cultivation of soybean in Ghana started in the mid-1970s. This was a joint breeding effort between Ministry of Food and Agriculture (MoFA) and the International Institute of Tropical Agriculture (IITA) (Tweneboah, 2000).

2.2 Botany of soybean

Soybean (*Glycine max* (L.) Merrill) is a leguminous crop which is found in the family leguminasea Subfamily papilionideae (Shurtleff and Aoyagi, 2007). The genus *Glycine*, directly comprise of two subgenera, *Glycine* which is made up of seven perennial wild species found only in south-eastern Asia; and Soja, consisting of the domesticated and commercial varieties, *Glycine max* and its wild originator, *Glycine soja*. Which are annuals and can do well in the temperate, subtropical and tropical conditions? Soybean contains 40 chromosomes (2n=2x=40) and are fertilized by its species with less than 1% out-intersection (Norman *et al.*, 1995). The genus name *Glycine* was first documented by Linnaeus in his initial release of Genera Plantarum; with the grown Species first showing up in that version, 'Species Plantarum', under the name *Phaseolus max* L.

2.3 Morphological description

Soybean is a yearly, herbaceous erect plant; the height ranges from 30 to 183 cm based on the genotype (Ngeze, 1993). Growth propensity are of two forms for the soybean: Six released and approved varieties cultivated in Ghana indicates two growth; determinate and indeterminate (Ngeze, 1993; CSIR and MoFA, 2005). The determinate types are shorter and produce less leaves, yet produce relatively more pods, while the indeterminate growth are taller, produce more leaves and more pods directly from the stem to shoot. Additionally, the self-pollinated flower are inconspicuous and the flowers are tiny borne in the axils of the leaves and are pink, purple or white (Ngeze, 1993).The pods, leaves and stems are secured with fine dark colored or silver hairs. The trifoliate leaves are having three to four pamphlets for every leaf. The fruits are hairy and they grow in groups of three to five, every one of which is five to eight centimeters in length and generally contains two to four seeds (Rienke and Joke, 2005). Soybean seeds come in different sizes, shape and the seed coatcolor ranges from cream, dark, brown, yellow to mottle. The hull of the developed bean is hard, water safe and shields the cotyledons and hypocotyls from harm (Borget, 1992). Gary and Dale (1997) have reported soybean growth and development in two principal stages: the vegetative phase and the reproductive phase. The vegetative phase begins with the emergency of seedlings, unifoliate leaves unfolds, through to completely create trifoliate leaves, nodules formation on principle stem, nodulation and the development of branches. The reproductive phase starts with flower bud development, through full sprout flowering, pod formation, pod filling to full development.

2.4 Uses of soybean

Soybean contains more protein than any of the other vegetable or legume nourishment sources in Africa indicated by Dugje *et al.* (2009). Its protein constituent is 40%. The seeds additionally contain around 20% oil on a dry matter basis, and this is 85% unsaturated and without cholesterol. Borget (1992) has expressed that, soybean adds to the nutrition of both people and animals. It also, contains both nutritional and medicinal properties and also possesses commercial and industrial qualities. It also possesses agronomic qualities, for example, it is used as a green manure, nitrogen fixation, compost and conserves the soil. It is usually cooked and eaten as a vegetable, soy milk, tofu, soy yogurt, soy oil, soy flour, and tempeh are made from soybean (Rienke and Joke, 2005; MoFA and CSIR, 2005). Rienke and Joke (2005) revealed that soybean contains a ton of top quality protein and is a significant source of carbohydrate, oil, mineral and vitamins. Research has demonstrated that the quantity of proteins in a single kilogram of soybean is proportional to the amount of proteins in three kilograms of meat or 10 liters of milk or 60 eggs and nearly, the cost of getting one kilogram of soybean is substantially cheaper than purchasing a comparative amount of egg or meat (Ngeze, 1993). In some countries, soybean can be a perfect substitute for eggs and meat, in instances where animal protein-rich nutrition, for example, fish, meat, milk and eggs are frequently rare and costly for low income farmers or households to obtain. Oil content of soybean is likewise rich and exceptionally edible, scentless and colorless, which easily will not coalesce. It is among the most widely recognized vegetable cooking oil utilized in food manufacturing in factories, everywhere throughout the world. And it is also highly used in industries, particularly in the making of paint, typewriter ink, detergent, glycerine, enamels and plastic products (Ngeze, 1993; Rienke and Joke, 2005). The cake acquired from soybean after oil extraction is additionally a significant source of protein feed for fish, poultry and pig. The promotion of soybean production has prompted huge production of fish, poultry and pig rearing (Ngeze, 1993; MoFA and CSIR, 2005). In addition, haulms extracted from seed, provides quality feed to domestic animals like goat and sheep (Dugje *et al.*, 2009). Soybean is said to have numerous health advantages. It also manages menopausal symptom well, because of the estrogen content of soy isoflavones. Studies have shown that frequent consumption of soy made item decreases the occurrence of heart diseases, by decreasing overall cholesterol, less density lipoprotein cholesterol, and avoiding plaque accumulation in blood vessels which results in paralysis or failure of the heart (The Mirror, 2008). The great valuable protein, less cholesterol and some nutritional benefits are valuable in the cure of illnesses relating to nutrition in kids (MoFA and CSIR, 2005). Soy milk, soy oil, soybean yogurt, and corn-soy mix are different ways by which soybean is utilized in Ghana. Presently, soybean products, such as Tom

Darker is notable in most Ghanaian home throughout the nation. It is highly nutritious corn-soy mixed product served, particularly to newborns and pregnant women. The awareness and the utilization of soybean in the country for food improved with the advancement and wide appropriation by small, medium-scale and large scale farming of different soybean-making devices which are used in many African countries. Consequently, more than 100 food items with great nutrition values and customer acceptability have been produced from the crop. Some of the by-product of oil such as soybean feast, has a great unrefined protein of 44% to 50% and a fair amino acid constituent, which complements maize meal for processing of feed (Ngeze, 1993 and MoFA and CSIR, 2005). For this reason, a good level of inclusion (30-40%) is utilized in the preparation of feed for monogastrics. Soybean cake, a by-product from the oil production is utilized as a high-protein animal feed in Ghana. Soybean meal and soybean protein are also utilized for artificial wool (synthetic fibre) synthesis, waterproofing, material, glue firefighting froth, textiles and adhesives. Ugwu and Ugwu (2010) reported on details regarding the advantages of soybean over some leguminous crop like some beans, cowpea and groundnut which included better storage quality, less prone to diseases and bigger leaf biomass which better improves the fertility of the soil and makes the soil fertile for the next season crop.

2.5 Soil and Climatic requirement

2.5.1 Temperature and photoperiod

Soybean is a type of leguminous crops which does well in the temperate, tropical and subtropical atmospheres (IITA, 2007). Within the soybean varieties, some genotypes respond diversely to day-length, and grouped them as day neutral, short and long day plants (Borget, 1992). Notwithstanding, many have become used to the hot, sticky, tropical climatic conditions. In the hot climates, the growth span of adapted species is usually 90-110 days, and as long as 140 days for the late growing types (Osafo, 1997). The generally short growth span is fundamentally as a result of affectability to the length of the day. This influences the degree of growth of the vegetative parts, initiation of flower, viable pollen production, flowering during, filling of pods and attributes of maturity (Norman *et al.*, 1995). Some legumes require an ideal temperature ranging from 17.5 ^{o}C and 27.5 ^{o}C for improvement (Ngeze, 1993). The minimum temperature at which soybean grows is 10 ^{o}C, the ideal is 22 ^{o}C and the most extreme around 40 ^{o}C. Soybean seeds will do well from 15 ^{o}C and 40 ^{o}C; however the ideal being around 30 ^{o}C (Rienke and Joke, 2005). Addo-Quaye *et al.* (1993) have proposed that 23-25 ^{o}C is ideal for soybean growth.

2.5.2 Moisture requirement

Soybean requires ideal moisture for seeds to sprout and grow well. The ideal rainfall amount is somewhere in the range of 350 and 750 mm, distributed well during the period of growth cycle (Ngeze, 1993). Rienke and Joke, (2005) and Addo-Quaye *et al.* (1993) have reported two periods as being crucial for soybean moisture necessity; from planting to germination and flowering, and pod filling periods. Furthermore, when germinating, the soil should be between 50% and 85% soaked with water, as the seed assimilates 50% of its weight in water before it can grow. The quantity of water requirements increases, and peaks up at the vegetative stage, and afterward decreases to reproductive maturity. Differences in the amount and appropriation of soil water limits soybean yield. As indicated by Bohnert *et al.* (1995), there are two essential roles of water in plants, as a dissolvable and transport system of plant supplements, and as an electron giver in the photosynthetic response forms. Troedson *et al.* (1985) opined that, soybean is very susceptible to water stress, and ordinarily react to regular watering by considerably increasing vegetative growth and yield. Jones and Jones (1989) described water stress as the absence of the measure of soil water required for plant growth and development, and which in specific cells of the plant may influence different metabolic process. As indicated by Passioura (1997), grain yield is a function of the measure of water lost through plant leaves, the efficiency of water use and harvest index. Also, soybean, as a C_3 plant, is less efficient in water use because of high evapotranspiration and low photosynthetic rates. Pandy *et al.* (1984) found that, extending drought stress logically decreased leaf area index and leaf area duration, shoot dry matter and crop growth rate; thus, limits soybean yield. Drought stress, most especially when the plant is flowering and early pod formation causes most serious decrease in number of pods and seeds at harvest (Sionit and Kramer, 1977). Decease in soil moisture with high plant population may cause yield decline in light of drought stress (Gary and Dale, 1997).

2.5.3 Soil

Soybean is tolerant to a wide scope of soil conditions yet does best on warm, moist, and very much drained fertile loamy soils, that give satisfactory supplements and great contact between the seed and soil for quick germination and growth (Addo-Quaye *et al*., 1993; Hans *et al*., 1997). Ngeze (1993) stated that, soybean does well in prolific sandy soils with pH in the range of 5.5 and 7.0. It can endure acidic soils compared to other leguminous crop yet does not grow well in water logged, basic and saline soils. Keeping up soil pH somewhere in the range of 5.5 and 7.0 enable the accessibility of nutrients such as, nitrogen and phosphorus, microbial breakdown of crop residues and symbiotic nitrogen fixation (Ferguson *et al*., 2006). Rienke and Joke (2005) revealed significant yield in loamy textured soil, and that if the seeds can sprout, they grow well in clayey soils. Soil is an important factor in the germination, growth and survival of plants. Soils affect different nutrient availability to plants differently. Availability of nutrient changes depending on the types of soil. Clay, for example, can hold more phosphorus and can reduce water flow through the soil, making it possible for more nitrogen to be present. The nutrient holding capacity of sandy soil is less effective, and so the soil with appropriate quantity of sand particles will make the nutrient P unavailable for the plant use. The soil which is compacted will have influence on the nutrient present and therefore P. Soil compaction can make the root ability to penetrate difficult for plants (Martonas, 2012). Beside from root permeability, compacted soil can make oxygen and water flow through the soil difficult. Creating soil aeration and mixing the upper soil several inches can loosen the soil, enhancing soil permeability and improving movement of water, air and nutrients through the soil. The pH of soil is the property that shows the relative alkalinity or acidity of the soil (Jensen, 2010). Technically, pH is the antilog or base 10 value of the concentration of hydrogen ions (H^+). The pH of water is almost neutral, that is 10 to the minus 7 concentration of H^+ ions (10-7 [H^+]). This concentration is represented as 7. Any value more than 7 means the H^+ ion concentration is less than at a neutral pH and the solution is a base and there are greater hydroxyl (OH^-) ions available than H^+ ions. Any value less than 7 means the concentration of H^+ ion is more than at neutral pH and that is an acidic solution (Jensen, 2010). Soils become acidic when the pH is less than 5 and much more acidic when the pH is less than 4. Likewise, soils are said to be alkaline above a pH of 7.5 and much more alkaline above a pH of 8. The present of most plant nutrients is mostly affected by soil pH. The normal pH of soil is close to neutral, and soil which is neutral are said to range from a slightly acidic pH of 6.5 to slightly alkaline pH of 7.5. It has been documented that most plant nutrients are ideally present to plants within the pH range of 6.5 to 7.5 in addition to the fact that this range of pH is usually very compatible to plant root growth (Jensen, 2010). Potassium (K), Sulphur (S) and Nitrogen (N) are essential plant nutrients that happen to be less affected directly by soil pH than any other nutrient, but still are to a certain point. Phosphorus (P), however, is also directly affected. At alkaline pH values, the pH is more than 7.5 for example; phosphate ions begin to react quickly with magnesium (Mg) and calcium (Ca) to form less soluble compounds. When the pH is acidic, phosphate ions react with iron (Fe) and aluminium (Al) to again form less soluble compounds. A number of the other nutrients (micronutrients especially) begin to be less available when soil pH is more than 7.5, and are ideally available at a slightly acidic pH, e.g. 6.5 to 6.8. Excluding molybdenum (Mo), which happens to be less available under acidic pH and more available at slightly alkaline pH values (Marschner, 1995).

Cation exchange capacity (CEC) is defined as the sum total of exchangeable cation that a soil can adsorb (Brady, 2002). Cations available on the clay and organic matter particles in soils can be exchanged with other cations; thus, they are replaceable. For example, calcium can be exchanged with other cations such as potassium or hydrogen, and. The total number of cations that can be held in the soil or its total negative charge is the soil's cation exchange capacity. The greater the CEC, the greater the negative charge and the higher the cations that can be available (Marschner, 1995).

2.6 Fertilizer requirement

Soybean plant has a supplement dense, high protein seed, and accordingly, requires high measure of nutrient for its growth (Lamond and Wesley, 2001). It is a legume that can meet its nitrogen needs by symbiotic association with nitrogen fixing microscopic organisms of the species *Bradyrhizobia japonicum* from atmospheric nitrogen (Sarkodie-Addo *et al.*, 2006). Furthermore, for the most part, the plant won't profit by supplemental nitrogen fertilizer application, where there are indigenous population of the proper *Bradyrhizobia* bacterial strains that reason viable nodulation of the roots and nitrogen fixation (Darryl *et al.*, 2004). Malik *et al.* (2006) gave a report that, soybean seed inoculation with Rhizobium in combination with phosphorus application at 90 kg for every hectare, performed better in yield under irrigated conditions. Soybean can deliver maximum seed yield with moderately low availability of phosphorus in the soil. Phosphorus application isn't probably going to increase seed yield at soil phosphate fixations above 12 ppm (Whinny 1 test). Additionally, most soils only from time to time need potassium fertilizer for soybean production, since K levels are commonly high in both surface soil and subsoil. Potassium fertilizer isn't required if soil test demonstrates more than 124 ppm (Ferguson *et al.*, 2006). Linderman and Glover (2003) have expressed that, of the essential elements (N, P and K), N is provided by the beneficial microbes in the root nodules, while the others originate from the soil, and will be taken into the plant as it takes up water.

2.6.1 Phosphorous as a supplement in soybeans

Phosphorus availability in the soil depends extensively on its fixation in the soil solution (Wahba, 2013). Usually the most constraining element for yield and forage production. Phosphorus' fundamental function in a plant is to keep and transport food manufactured by photosynthesis for use in growth and reproductive process (Wahba, 2013). Soybean requires generally a lot of phosphorus than other crop. Phosphorus is taken up by soybean plant all through the growing period. The time of extraordinary demand begins just before the pods start to form and proceeds until around ten days before the seeds are completely formed (Wahba, 2013). Soybean is progressively effective at manufacturing great yield in a soil which phosphorus (P) than any other major agronomic crops. Phosphorus is the most basic nutrients restricting soybean growth and development, and is inadequate in most of soybean - producing areas (Hellal and Abdelhamid, 2012). Fertilization of legume is mostly P-based, since it is exceedingly basic for concentrated fixation of nitrogen. In this manner, P, by method for its function in energy circulation and improving root development, is important for formation of nodules and effective fixation of nitrogen. The response to P fertilization relies upon soil water content of the soil, as soil water stress may decline the accessibility of Phosphorus used, bringing about low production of biomass and decreased P take-up. The requirement for P fertilizer is typically more in a soils which has high acid level than in others because of greater fixation of Phosphorus. All in all, every sources of P are similarly important in soybean, with the exception of rock phosphate. Rock phosphate is a low phosphorus source in neutral to alkaline soils, however a moderate source for acidic soils (Hellal and Abdelhamid, 2012). Phosphorus is a basic major nutrient for crop growth and function. The necessities of host plants for ideal growth and symbiotic dinitrogen fixation processes for P have been evaluated by estimation of nodules development and functioning (Sa and Israel, 1991). The impact of P on advantageous nitrogen fixation in leguminous plants has gotten significant consideration, however its function in the process stays un-understandable. Robson and Hara (1981) announced that P nourishment expanded symbiotic dinitrogen fixation in subterranean clove by facilitating host plant development instead of applying explicit effects for rhizobial development or on nodule formation. The increments of entire plant growth and plant nitrogen fixation in light of expanded soil P supply have been noted in a few leguminous crops not excluding soybeans (Robson and Hara, 1981). The availability of phosphorus, anyway still comprises a major limitation as it is very much identified that low levels of soil P could restrain growth, dinitrogen fixation and yield of leguminous crops, most especially soybeans (Sarawgi and Tripathi, 1998). Along these lines the application of phosphorus is significant for the growth and improvement of soybeans.

2.6.2 Variability of soybean genotypes in Phosphorus up take

Crop response to P nutrient relies upon hereditary and physiological qualities of the plant that help for effective P take-up and use. This will be encouraged by the development of more P-productive crop cultivars which will yield more per unit of phosphorus input (Jakkeral *et al.*, 2009). Genetic variation for P take-up has been reported for agriculturally beneficial crops, however the knowledge on the degree of genetic variation for P take-up and usage efficiency in semi-arid crops is exceptionally deficient (Jakkeral *et al.*, 2009). The yield potential is an essential factor and relies upon plant germplasm features that can be altered by selection and breeding (Furlani *et al.*, 2002). Yield differences in soybean varieties for phosphorus (P), potassium (K) and N-efficiencies were made known by Sarawgi and Tripathi (1998) and Hanumanthappa *et al.* (1999) in field studies.

2.6.3 Phosphorus Uptake, Use and Utilization Efficiency

Besides increased acquisition of soil P, efficient utilization of acquired P is also considered an important adaptation for plant growth on low P soils. Phosphorus utilization efficiency (PUTE) refers to the ability of a plant species/genotype to produce higher dry matter per unit of P absorbed (Blair, 1993; Richardson *et al*., 2011). The mechanism of higher internal PUTE is not clearly known.

It may be related to the ability of a plant in releasing inorganic P from the storage pool (vacuole) to the cytoplasm (cytoplasmic P homeostasis) (Plaxton and Carswell, 1999; Raghothama, 1999) or to selective allocation of P between cytoplasm and vacuole in favour of cytoplasm thereby ensuring sufficient P concentration in metabolically active compartments for normal functioning of plant metabolism (Lauer *et al*., 1989; Raghothama, 1999). Additionally, higher internal P uptake efficiency (PUTE) may also be due to lower metabolic requirement for inorganic P at cellular level under P stress possibly due to the presence of alternative P-independent enzymes metabolic pathways and/or energy sources (Duff *et al.*, 1989; Plaxton and Carswell, 1999). P uptake efficiency (PUPE) measures the ability of the plant to absorb the available P in the soil (Parentoni *et al.*, 2005). It is defined as the ratio between the total P in the plant (grain+straw) per unit of P available in the soil. On the other hand P use efficiency is a multiplicative relationship from uptake efficiency and utilization efficiency. Phosphorus use efficiency (PUE) is also an important P efficiency phenomenon which is actually the product of PUPE for the measurement of the amount of grain produced per unit of available P in the soil (Parentoni *et al*., 2005).

2.6.4 Nitrogen as a supplement in soybean

Soybean nitrogen nutrition, as in different leguminous crops, is guaranteed both by dinitrogen fixation and inorganic nitrogen uptake. These two sources can complement each other or pose negative interference base on the environmental and developmental variables (Werry *et al.*, 1986). In many where soils nitrate status is moderate, the extent of nitrogen which is gotten from symbiotic fixation in soybean is around 50%

(Bergersen *et al.*, 1985), however can reach 75% in sandy loam soils (Matheny and Chase, 1983).The maximum rate of nitrogen fixation happens toward the end of flowering and when filling the pod (Obaton *et al.*, 1987). The nitrogen absorbed between the beginning of pod formation and the beginning of maturity is by all accounts the prevalent sources of nitrogen for seed development (Warembourg *et al.*, 1982).

Soybean like different leguminous crop, is able to fix atmospheric nitrogen when nodulated (Waluyo *et al.*, 2004). Consequently, use of N fertilizer will have little impact on improvement of the yield. In any case, soybean as a C_3 plant has poor N use. Fundamentally, C_4 plants have higher N use efficiency (biomass generation per unit of N in the plant) than do C_3 plants. This distinction probably results from the relatively very little input of N in the photosynthetic carboxylation proteins of C_4 plants than C_3 plant (Wilcox, 1987). Nitrogen fertilizer is supplied in soybean cultivation as a starter N to decrease rivalry with microorganisms in the soil. A starter portion of 10 to 20 kg/ha N is advantageous for good early growth (FAOSTAT, 2011).

Soybean is a leguminous crop and regularly gives itself nitrogen, through a symbiotic association with nitrogen fixing microorganisms of the species, *Bradyrhizobium japonicum* (Sarkodie-Addo *et al.*, 2006; Nastasija *et al.*, 2008). Bacterial present in soybean root nodules will fix nitrogen from the environment, regularly providing most or all nitrogen required by the plant. Soybean grown on well nodulated soils presumably will not require inoculation. In any case, if there is any inquiry concerning the nearness of Rhizobium bacterial, treating seeds with inoculant is suggested (Darryl *et al.*, 2004; Nastasija *et al.*, 2008). The measure of nitrogen that a plant can fix relies upon variety, efficiency of Rhizobium microbes, soil and climatic conditions. Soybean has the ability of fixing between 60 kg and 168 kg of nitrogen for every hectare every year under favorable conditions (Rienke and Joke, 2005). Soybean nitrogen needs are met in a complex way, as it is capable of using both soil nitrogen, as nitrate and nitrogen from the atmosphere, through symbiotic fixation of nitrogen. In the symbiotic association, starches and minerals are provided to the microbes by the plant and the bacterial change nitrogen gas from the air into ammonium and nitrate for use by the plant (Frazen, 1999). The population of plant is one factor that may determine how much nitrogen residue is left in the soil which soybean is adding to a cropping system. The amount of nitrogen fixation of determinate soybean was roughly, expanded from 200 to 280 kg/ha, when plant population was expanded from 48,500 to 194,000 plants /ha individually (Ennin and Clegg, 2001).The process of nitrogen fixation requires the availability of the correct types of the nitrogen fixing bacterial in the soil, and they are frequently pulled in to the roots by chemical signals from the soybean root (Rienke and Joke, 2005). Once in contact with the root hairs, a root compound fixes the bacterial to the root hair cell wall. The bacterial discharge a chemical that causes curling and breaking of the root hair, enabling the microbes to enter inside of the cells, and start to change the plant cell structure to produce nodules. The microorganisms live in compartments of up to 10,000 of every nodule, called bacteroids. The nitrogen fixation is supported by an enzyme nitrogenase, which occurs in an environment without oxygen, through a transfer compound, leghemoglobin. Also, this leads to a pink-red shade of nodules insides, a sign of active fixation of nitrogen (Lindermann and Glover, 2003). Ferguson *et al.* (2006) reported that soybean plant will viably use soil residues nitrate and nitrogen mineralized from soil organic matter, acquiring 25 to 75 percent of plant nitrogen, with the equal amount provided from symbiotic fixation. Legume nodules that are not fixing nitrogen for the most part turn white, dark or green and may really be disposed of by the plant. This might be because of poor Rhizobium strain, poor plant nourishment, pod filling or other plant stresses. Nastasija *et al.* (2008) have stated some of the factors restricting elements to N-fixation: A temperature of 16 ^{o}C to 27 ^{o}C is perfect, while levels above or beneath this adversely affects bacterial operation and reduces the establishment of the N-fixing association. At the point when soil N levels are excessively high, nodule number and operation decline.

2.6.5 N nutrition and plant N up take

The N utilization of crop fluctuates starting with one soybean spices to the next. Among the species, the N quantity differs relying upon the spicy and the environmental components. There is an extensive difference among the plant parts (grains, stems, roots, leaves and so forth.) regarding relative measures of N content. Generally, the majority of the N is put in the harvesting parts than in stover, stems, vines, straw or roots. N up-take can vary depending upon the soil N status, agronomic practices and the atmosphere (Stevenson and Cole, 1999). Mineral from the soil solution is absorbed by plant parts through their roots framework. The soil nutrients up-take by plants turns out to be effective process because of the bigger surface zone of roots and their capacity to obtain ions at low concentration (Taiz and Zeiger, 2006). The soybean plant has protein-rich seeds and needs great amounts of nitrogen to improve yields (Sinclair and DeWitt, 1975). It is reported that there is a good relationship between the accumulated quantity of nitrogen by the crops and the grain yield (Tewari *et al.*, 2004). At the vegetative phase, crops are able to obtain nutrient N quickly resulting to high NO_3-content in the tissue. As the plant gets to the reproductive phase (blossoming), there is a quick decrease in tissue NO_3-content. There is a progressive reduction of tissue NO_3-

content from initiation of flower to early pod filling phase (Thibodeau and Jaworski, 1975). During pod filling phase, producing ovules act as a contending sink for photosynthate bringing about a fast decrease in fixation of nitrogen at mid pod filling phase (Thibodeau and Jaworski, 1975).

2.6.6 Rate and time of N nutrient application on soybean yield

Use of booster nitrogen at early vegetative phase could expand the pod yield and crop biomass by 44% and 16%, respectively. The quantity of the plant N gotten from the fixation of nitrogen is greatest when nitrogen is supplied at the pod filling phase where the plant N requirement is high (Yinbo *et al.*, 1997). Report has it that the utilization of urea $(NH_2)_2$ CO) or ammonium nitrate (NH_2NO_3) as booster nitrogen fertilizer at rates of 8, 16 and 24 kg/ha increased initial plant biomass and plant nitrogen compared with no N application. Additionally, the soybean seed yield improved by 16% at the N rate of 16 kg/ha over no fertilizer application, with no enhancement either in seed protein or oil content (Osborne and Riedell, 2006). Schmitt *et al*. (2001) did a research to determine the impacts of time of application, application technique and the source of nitrogen on soybean development, grain yield, protein and oil content at 12 locations. The experiment indicated that on-season application of nitrogen fertilizer did not have effect on the soybean grain yield or the oil content. Be that as it may, there was a combined impact of every one of the above factor on improving soybean protein content at a rate of 0.4 g/ kg (Schmitt *et al.*, 2001). The soybean grain yield, protein, oil and fiber content did not increase with the fertilizer N rates of 45 and 90 kg/ha (urea/moderate discharging N) application at early reproductive stage (Barker and Sawyer, 2005). The early application (V2/R1) of nitrogen as top dressing at a rate of 25 kg/ha enhances the soybean overall biomass and the nitrogen accumulation during the pod filling phase (R5) which helped the grain yield (Gan *et al.*, 2003). Nitrogen top dressing fertilizer treatment at R1 and R3 growth phases drastically decline the nodulation of soybean, though at V1 phase there was an identifiable impact which increases the nodulation of soybean (Gan *et al.,* 2003). The spreading of nitrogen fertilizer as urea (50 and 100 N kg ha^{-1}) at the pod initiation (R3) and the seed filling phase (R5) promoted the available N at the top 30 cm soil compared with the plots without fertilizer or the control. However, increment in soil NO_3-availability during the seed filling phase had no significant impact on leaf senescence and the seed development (Gutierrez-Boem *et al.,* 2004). According to Lambert *et al.* (2006), the reaction of soybean towards the nitrogen fertilizer was temporally unstable.

2.6.7 N treatment and remobilization on yield

N is an indispensable part of numerous compounds including chlorophyll and enzymes, necessary for plant development process. It is an integral part of amino acids and related proteins. Nitrogen is the most restricting nutrient for production in most farming system, because of the huge quantity of nitrogen taken out with the crops during harvesting process and in light of the fact that it tends to be lost effectively through gaseous loses, runoff, erosion, or leaching (Smaling *et al.,* 1999). Nitrogen necessary for soybean are regularly supplied by the coming together of soil-derived N and nitrogen supplied from the process of symbiotic N fixation through the rhizobia in the nodules of the root. The relative nitrogen supply from these two sources can be transformed widely based on soil nitrogen supply and conditions for nodule development (Varco, 1999; Gan *et al.,* 2003). Field experiment estimating soybean reaction to supplied N has been carried out by many scientists. Fixation of nitrogen only can't meet the N needs to maximize yield of the crop (Oz, 2008). As per Gan *et* *al.* (2003), best planning for additional nitrogen during production is during the initiation of flower phase, which promotes grain yield up to 19 and 21%, when likened with no N application as top-dressing. Nitrogen builds yield by impacting a varieties of agronomic and quality parameters. Seed yield response of soybean to the utilization of N might be on the grounds that N offers a significant fumction in the synthetic of chlorophyll and amino acids (Oz, 2008). Nitrogen impacted seed yield from source-sink connections bringing about greater manufacture of photosynthates and their promotion of translocation to seed bearing parts (Tripathi *et al.,* 1992). Hanway and Weber (1971) indicated that about a half portion of the nitrogen in fully grown soybean grain has been moved from different parts of the crop, the remaining is gotten from soil and nodules. Therefore, soil mineral nitrogen supply might be a basic factor for the crop during the reproductive phase (George and Singleton, 1992). This high nitrogen needed at the maturity phase may be provided by supplying supplemental compost N in the week of initiating flower. To boost yield and the fixation of N_2 by the crop, a good understanding is expected of the associations between inorganic nitrogen application, nitrogen prerequisites and nitrogen up-take during reproductive phase (Gan *et al.*, 2003) Soybean needs a lot of nitrogen for grain formation and thus its yield might be delicate to nitrogen fertilization after flower production (Kinugasa *et al.,* 2011). Be that as it may, the active time of N_2 fixation is restricted during nodules development since nodules senescence happens quickly after flowering and during seed development. N fertilizer supplied at the reproductive phase of soybean (R1 and R5) may enhance the ability and length of the mineral nitrogen to the usage time frame while keeping up N_2 fixation (Barker and Sawyer, 2005). Gan *et al.* (2003) reported that the usage of nitrogen at 50 kg/ha at either V2 or R1 phases, significantly enhanced nitrogen accumulation and yield. Also, Barker and Sawyer (2005) reported that nitrogen use improved nitrogen concentration in the R4 (full pod) stage in soybean crops. High yields of soybean are connected with higher nitrogen (N) remobilization from vegetative tissues to the grain. Research by Shibles and Sundberg (1998) showed that since seed yield and nitrogen status in leaves at the seed-filling stage (SFP) are closely associated, the quantity of nitrogen kept in the vegetative parts during seed-filling phase is clearly relevant for improvement of a good seed yield. Most of the nitrogen in the full grown seed comes from dissemination of N from vegetative plant parts at the time of seed filling with the measure of this addition varying from 30 to 100% (Egli *et al*., 1983). Even though nitrogen fertilization of the crop is not a regular agronomic practice by farmers, there is report that the capacity of soybean to add nitrogen from the atmosphere is not always sufficient for maximum yield (Wesley *et al*., 1998).

2.6.8 Utilization of rhizobium inoculant

Utilization of Rhizobium inoculums in the production of leguminous crops is been widely identified, particularly in regions where native nodulation was observed to be deficient. The advantages by the usage of Rhizobium inoculants demonstrate that a significant amount of money can be saved by peasant farmers by utilizing quality tried inoculants on the field. Additionally, it was reported that leguminous crop enhance the productivity of the soil. Rhizobial inoculation of seed is very much researched on and exploitation of this useful N adding root nodules symbiosis depicts a hallmark of successful supplied agriculture microbiology. Natural nitrogen fixation plays a fundamental function in plant establishment and yield, since no nitrogen fertilizer is supplied and it satisfies the vast majority of plants requirement for nitrogen (Chen *et* *al.*, 2002). In Ghana, phosphorus in soil is commonly very plenteous yet it reacts readily with iron, aluminum and calcium to create insoluble compound. P is however an important element for Rhizobium bacterial to change nitrogen (N_2) in the atmosphere into an ammonium (NH_4) structure usable by plants.

2.7 World production

Soybean production is rapidly spreading in the world today because of uncountable benefits gotten from soybean. Presently, soybean production in the world is 220 million tons of grain every year, and the seven leading producing countries are the USA (32%), Brazil (28%), Argentina (21%), China (7%), India (4%), Paraguay (3%), Canada (1%) and others (4%) (USDA, 2007). With reference to FAO report for 2005, total land space use in the production of soybean in the world was 95.2 million hectares yearly and overall cultivation was 212.6 million tons every year. The leading producers were USA (29 million hectares), Brazil (23 million hectares), and Argentina (14 million hectares) (IITA, 2009).

With regards to production in Sub-Saharan Africa, this same source reported that, soybean was cultivated on an average of 1.16 million hectares with an average cultivation of 1.26 million metric tons of grain in 2005. Leading countries in Africa in terms of the largest area of cultivation were Nigeria (601 000 ha), South Africa (150 000 ha), Uganda (144 000 ha), Malawi (68 000 ha) and Zimbabwe (61 000 ha).

2.8 Soybean in Ghana

Regardless of soybean's significance, the average soybean yield is still not up to its potential. Report by SARI (2000), the mean on-farm soybean yield in northern part of the country is approximated at 1.0 t /ha which is less than its potential yield of 3 t /ha

(Alliance for a Green Revolution in Africa 2016). The low yield has been linked to many factors which include poor soil fertility, the use of varieties with poor yield, high cost and specifically low Phosphorus levels, or insufficient availability of inputs which includes P fertilizer, rhizobium inoculants and certified seeds (ACET 2013). The quantity of nitrogen fixed and/or grain legume yield, will rely on legume genotype (GL), the biophysical environment (E) the efficacy of rhizobium strain(s) nodulating the legume (GR), and agronomic management (M) such as the use of fertilizer. The impact of these factors and their association has been written in literature as (GL ×G R) × E × M (Giller *et al*. 2013). However, research has proven that rhizobium inoculation is able to supply significantly to grain yield of the crop (Ahiabor *et al.*, 2014; Ronner *et al*., 2016) and genotype and phosphorus fertilizers have positive impacts on the yield of soybean (Nwoke *et al.*, 2005), no research at present has tried to study the potential effect that improvement in the above factors may increase soybean yields among small scale farmers. More to the point, impacts of inputs on soybean has been highly variable (Ronner *et al.*, 2016; Thilakarathna and Raizada 2017).

2.9 Production constraints

Average soybean grain yield is still low (<1 t/ha) in Africa (FAO, 2010) basically on the grounds that the improved varieties of soybean have not gotten to numerous soybean producers (IITA, 2009). Many economic, biotic and abiotic variables limits the attainment of optimum soybean yields in Africa. Pod shattering causes yield loss ranging from 57 – 175 kg/ha and 0 – 186 kg/ha in intermediate susceptible and susceptible soybean genotypes respectively (Tukamuhabwa *et al.*, 2002). Inspite of the numerous advantages of the crop, the seed yield per hectare is still below the expected in Ghana. MoFA (2011) revealed farmers' average soybean yields of 1.5 t/ha is well below attainable yields of 2.3 t/ha. A number of research studies have ascribed low soybean yields in sub-Saharan Africa to poor yielding varieties and, soil infertility due to the limited fertilizer application. Mbanya (2011) also reported that most farmers in the Northern part of Ghana do not apply improved technologies which include improved varieties, row planting, fertilizer utilization and appropriate agronomic management practices. According to Hailu (2011), low yield of soybean is attributed to negligence in improving the crop generally in Africa. High-yielding soybean plants needs good amount of N and it is approximated that biological nitrogen fixation can contribute 60 to 70% of the N needed by the plant (Herridge *et al.,* 2008; Salvagiotti *et al.* (2008). Although BNF is the main source of nitrogen input in cropping systems, the maximum potential of the symbiotic system may not be realized because of inefficient strains of rhizobia (Bogino *et al.*, 2011). Phosphorus unavailability is among the major significant nutrient elements that limit plant development (Fernandez *et al.,* 2007). Phosphorus offers an important function in the formation of nodule and atmospheric nitrogen fixation hence, nodulating legumes requires greater P compared to crop which is non-nodulating. In Ghana, the available phosphorus in soil response readily with aluminium, calcium and iron so that insoluble compounds is formed. The reactions lead to low presence of phosphorus and low efficiency of phosphorus fertilizer application by the plants (Jodie and Peter, 2000). P is a necessary nutrient for Rhizobium bacteria to change atmospheric N (N_2) into an ammonium (NH_4) form usable by plants. Insufficient Phosphorus constrains the photosynthetic process, circulation of sugars, root growth and other such functions which directly impact nitrogen fixation by leguminous crops. Several reports indicated that symbiotic N2 fixation alone may not be sufficient for soybean nitrogen needs at the initial and late stages of growth especially in very poor soils. The need for small amounts of N fertilizer supplied at early stage of the crop often enhance growth and N_2 fixation in leguminous crops (Sanginga, 2003; Okugun and Sanginga, 2003; Osborne and Riedell, 2006; Tahir *et al.*, 2009). Biological nitrogen fixation process is fundamentally constrained by four key variables: capacity of host plant to accumulate nitrogen, viability of rhizobia-host plant beneficial interaction, measure of accessible soil nitrogen and ecological limitations (Van Kessel and Hartley, 2000).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site description

The research was carried out at Savannah Agricultural Research Institutes (SARI) at Nyankpala in the Northern Region of Ghana (altitude of 183m located at latitude 9° 25"N and longitude 0°58"W). The soil is sandy loam textured, formed from the Voltaian sandstone known as the Nyankpala series. The site gets a unimodal rainfall of 1000-1200 mm per annum from May, peaks in August and ends in October. Mean minimum temperature is 23.4 °C and maximum is 34.5 °C. A minimum relative humidity of 46% and maximum of 76.8% is recorded for the area (SARI Yearly Report, 2013).

3.2 Soil sampling and analysis

Soil was sampled at 0 - 20 cm depth, applying Uchida *et al*. (2000) method and composite sample was prepared and sent to Savannah Agricultural Research Institute (SARI) soil chemical laboratory for chemical and physical analysis. For chemical analysis such as organic carbon, extractable P, total nitrogen, cation exchange capacity (CAC), exchangeable bases (K, Mg and Ca) and pH, samples were air dried and grounded to pass through 2 mm sieve and analyzed (Okelabo *et al*., 1993).

3.2.1 Organic carbon

The organic carbon was estimated by making use of Walkley-Black wet combustion steps (Nelson and Sommers, 1982). 2.0 g of fine air-dried soil sample was weighed and put into a 250 ml Erlenmeyer flask. 10mls of 1.0N Potassium Dichromate solution followed by 20 ml of concentrate H_2SO_4 were added then shaken thoroughly to make sure that the mixed solution was mixed together with every particle of the sample. The flask together with its content was left to become cold for 30 minutes on an asbestos sheet after which 100 ml of deionized Water and 10 ml of orthophosphoric acid were added. 2-3 drops of diphenylamine indicator were then added. 1.0N Ferrous Sulphate solution was used to titrate the mixture and waited for the coloour to change to blue and then to green end-point. The result obtained was noted and corrected for the blank solution.

3.2.2 Organic matter

To estimate the organic matter, 1.724 was multiplied by the percentage of organic carbon (The Van Bemmelen factor) as described by Nelson and Sommers (1996).

3.2.3 Soil PH

10 g of soil which air-dried was weighed and added inside a 50 ml beaker. 25 ml of deionized water added. The mixture was shaken thoroughly for 20 minutes and left to settle for about 30 minutes for the suspension to come together. The pH meter was scaled with standard solutions at pH of 4 and 7 respectively. Electrode of the pH meter was put into the partially settled suspension, the pH value was recorded.

3.2.4 Soil Total Nitrogen

The Macro Kjeldahl method by Bremner and Mulvaney (1982) was used. A 10 g soil sample (< 2mm in size) was digested with a mixture of 100 g potassium sulphate, 10 g copper sulphate and 1 g selenium with 30mls of concentrated sulphuric acid. This was followed by distillation with 10ml boric acid (4%) and 4 drops of indicator and 15 ml of 40% NaOH. It was then titrated with Ammonium sulphate solution. Based on the relation that 14 g of nitrogen is contained in one equivalent weight of NH_3, the percentage of nitrogen in the soil was calculated.

3.2.5 Available Phosphorus

The Bray-1 test method was used for the determination of phosphorus with dilute acid fluoride as the extractant (Jackson, 1958).

3.2.6 Exchangeable Bases (Ca, Mg and K)

The exchangeable base cations were extracted using ammonium acetate at pH of 7.0. Calcium and Magnesium were determined using the EDTA titration method (Moss, 1961) while potassium was determined by the flame photometer.

3.3 Land preparation

Land was ploughed and harrowed just before the season rainfall. Lining and pegging was done according to crop spacing of 60 cm x 10 cm for soybean. Plot size was 4 m by 3.5 m. The spacing between block was 2 m and that within blocks was 1 m.

3.4 Experimental design and treatments

The study was in two stages: Selection of high-yield genotypes from a pool of available germplasm, followed by evaluation of inoculants and mineral fertilization effect on the selected high-yield genotypes.

3.4.1 Selection of high yielding genotypes from germplasm pool

Hundred soybean genotypes, selected from soybean germplasm pool of Savannah Agriculture Research Institute (SARI) were screened in 2019 under irrigation. The experiment was laid out in latice design, sown at 60 cm by 10 cm planting space and plot sizes of 3 m by 4 m were used. Seeds were planted at a rate of four seeds per hill, and two stands were thinned out while two plants per hill were left. Triple super phosphate (TSP) was applied at 60 kg/ha. The feed was weeded by using hoes at 6 and 10 week after panting (WAP). Growth of genotypes was observed and yield recorded at harvest. The best three high-yield genotypes (3% genotypes) were selected and used to assess the impact of inoculants and mineral fertilization on their productivity.

3.4.2 Effects of fertilization and inoculation on high-yield soybean genotypes

The experiment was laid out in a split plot design and replicated three times. The three selected-soybean genotypes and a released variety served as sub- plot factor while mineral fertilizer and inoculant served as main plot factor. Based on result of the genotype-screening experiment, the three soybean genotypes selected and used were

N19, N135, and N119. The Jenguma variety was used as a check in the study. The planting distance was 60 cm by 10 cm. with 2 seeds per stand. The size of each main plot was 4 m by 3 m. The four cultivars (N19, N135, N119 and Jenguma variety) were planted in line on each main plot with 1 m interval.

3.4.3 Treatment details

Fertilization regime was used as the main factor at seven levels (Sole soybean (S), triple superphosphate (TSP), nitrogen (N), inoculant (I), triple superphosphate+ inoculant (T+I), triple superphosphate + nitrogen (TSP+N) and triple superphosphate +inoculant + nitrogen (TSP+I+N) and genotypes as a sub-factor at four levels (N19, N135, N119 and Jenguma). Detailed fertilization combination is presented Table 1. The seed of the soybean genotypes used were gotten from the Savannah Agricultural Research Institute (SARI) germplasm collection of the Council for Scientific and Industrial Research (CSIR) at Nyankpala, Northern Region.

They included:

a.) N19 - A late maturity genotype, of small seed size, fairly spherical and cream seed colour, with average 100 seed dry weight of 13.10 g. It is tolerant to pustule, shattering resistant and promiscuous nodulator with the native rhizobia. Grain yield is 1.5-2 tons per hectare. It matures in about 110-120 days.

b.) N135 – A medium maturity genotype, medium seed size, spherical and cream seed color, with average 100 seed dry weight of 16.0g and matures in 110-115 days. It is resistant to pod shattering, tolerant to pustule and a promiscuous nodulator with the native rhizobia. Grain yield is 1.4-2 tons per hectare.

c.) N119 – A medium maturity dwarf genotype with medium seed size has mean 100 seed dry weight of 13.5g. The seeds are spherical and creamy in color. Pod does not shatter, tolerant to bacterial pustule and is a very promiscuous nodulator with native rhizobia. Grain yield is 1.4-2 tons per hectare. It matures in 110-115 days.

d.) Jenguma – A medium maturity variety with small seed size and mean 100 seed dry weight of 13.5 g. The seeds are fairly spherical and creamy in color. It is also resistant to pod shattering, tolerant to cercospora leaf spots and bacterial pustule is a very promiscuous nodulator with native rhizobia. Grain yield is 2-3 tons per hectare. It matures in 110-115 days, and was also released in 2003 by CSIR-SARI (MoFA and CSIR, 2005).

Table 1: Detailed treatment description of main plot (fertilization regime)

Detailed treatment combination	Treatment code
No fertilization	Control
Triple superphosphate	TSP
Inoculant	I
Nitrogen	N
Triple superphosphate + Nitrogen	TSP + N
Triple superphosphate + Inoculant	TSP + I

Triple superphosphate +Inoculant + Nitrogen	TSP + I + N

3.5 Seed inoculation

Inoculation of seeds was done applying the slurry method described by Woomer, *et al.* (1994). Inoculation was done, using water as adherent. The inoculant was added to the seeds and were placed in a bowl and stirred thoroughly until black film of inoculants covered the seeds completely. Treated seeds were dried for a few minutes after which they were sown. The treatment was done at the rate of 5 g of legume fix inoculant per 1 kg of seed.

3.6 Cultural practices

Below are cultural practices carried out on the farm from planting to harvest.

3.6.1 Thinning

Thinning out was done to ensure 10 cm between plants in a row, After 20 days of sowing, when enough moisture was found in the soil and seedlings well established.

3.6.2 Weeding

Hoe was used to control weeds, on the sixth and tenth week after plant to keep down weeds. Each weeding activity was done within a day for every block.

3.7 Vegetative data collection

Sampling for growth (vegetative) parameters were done at six weeks after planting (6WAP); eight weeks after planting (8WAP) and ten weeks after planting (10WAP). At each sampling period, six plants for each parameter were selected randomly using the simple systematic random sampling technique, as described by Gomez and Gomez (1984). By this technique, 24 plants were counted. And since six plants were to sampled, 24 was divided by six (24/6), resulting into four. A number between one and four was picked to be the starting number. Then, after, every fourth plant was selected until the six plants were sampled. The samples were taken from the second and last but one rows, next to the border rows in each plot. The plants were dug out and taken to the laboratory, where the roots were cut at the ground level and the above ground biomass dry weight was determined after it was oven dried for 24 hours at 82^{o}C. Data measured during the research period were:

3.7.1 Plant height

The height of the plants was determined starting from the base to the highest part of the stem for the six selected crops. This was done with the use of a meter rule at the different sampling time. The mean height of the plants was estimated for every plot and recorded.

3.7.2 Days to 50% flowering

It was recorded as the number of days from the day of sowing to the date when 50% of the plants in a plot produced flower.

3.7.3 Biomass dry weight

The biomass dry weight was taken at 10WAP. Six sampling plants from every plot were placed in envelopes which were labeled and dried in the oven to steady weight at 84^{o}C for 24 hours, and afterward weighed and recorded in g

3.7.4 Number of primary branches

This was taken at 10th week after planting, when all plants had stopped development. The primary branches of six sampled plants from every plot were counted and the average written down.

3.7.5 Leaf area

Leaf area was recorded at 6, 8 and 10 WAP. This was carried out by plucking every opened leave from six tagged plants from each plot. A ruler was used to determine the length and width of each leaf after which the length was multiplied by the width to get the area and divided by the total number of leaves measured to determine the average. The average leaf area was then divided by the row spacing measurements (inter row by intra row) to get the leaf area (Bull, 1968; Wilhelm and Nelson, 2000).

3.7.6 Nodule count and effectiveness

Six sampled plants were taken from every plot 35 days after planting to estimate nodulation. The samples were carefully dug out, to retrieve removed nodules and each nodule was plucked out from the root. The nodules were placed in labeled envelopes and sent to the research centre and washed, counted and the fresh weight taken. After which the nodules were cut opened using a knife and hand lens to determine apparent nodule effectiveness. Nodules which were pink or reddish color were recorded as effective in fixing nitrogen. However, the ones with green, colorless or no color were considered to be ineffective (Gwata *et al*., 2003).

3.7.7 Nodule dry weight

After the root nodules were evaluated for viability. Two plants were uprooted and the nodules were carefully removed and oven dried at constant temperature of 60 ^{o}C for 24 hours. These were weighed and recorded for the average dry weight in g/plant.

3.8 Reproductive (Harvest) data collection

At maturity, when around 85% of become brown in color (Dugje *et al.,* 2009) and more than 75% of leaves shelled, six plants from each plot were harvested, for pod number, number of seeds per pod, 100 seed weight and grain yield per hectare.

3.8.1 Number of pods per plant

For pods number, in every plot six plants were collected and every one of the pod detached. These pods were counted manually and the total number of pods from the six plant were divided by the six plants to determine the average pod number per plant.

3.8.2 Number of unfilled pods per plant

Crops were harvested and the pods were removed from the branches after which each pod was opened with the fingers to determine if filled or not and those which were not filled were counted and divided by the number of plant from which the pods were detached to record the average number of pods which were not filled per plant.

3.8.3 100 Seed weight

The weight of 100 grains was recorded by collecting 100 seeds from the lot per plant and oven drying at 82 ^{0}C for 24 hour. These 100 grains weighed to determine the mean grain weight in gram.

3.8.4 Grain yield (tons per hectare)

Grain yield per hectare was estimated after harvested plants were threshed from the middle one square meter of every plot. Each was placed in named envelopes and dried in the oven to a steady weight at 60 ^{o}C for 48 hours, and after that the weight were recorded. The recorded weights, in grams (g) per square meter were then scaled up to tons per hectare basis to get the mean grain yield in one hectare

3.9 Economic cost analysis

From the various technologies, the economic cost benefit was determined by quantifying the various technologies in terms of monetary values and comparing the cost to determine which has the highest benefit in terms of cost ratio (Das *et al.*, 2010).

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3.10 Data analysis

(ANOVA) model was used to analyze variance of the data obtained by making use GenStat statistical package edition 12. Average were separated using Least Significant difference (LSD) at 5% probability level. Results are presented in graphs and tables.

CHAPTER FOUR

4.0 RESULTS

4.1 Growth and yield response of soybean genotypes under phosphorus fertilization

4.1.1 Soil physio-chemical properties

The physio-chemical analyses of soil indicated that the soil at the research area was sandy-loam in texture and has a neutral pH values of 6.82 at 1:2.5 (H_2O). The organic carbon content and total N of 0.702 and 0.05% respectively were low (Table 2). Availability of phosphorus as measured by Bray-1 was 5 mg/ kg while K was 43 mg/ kg, Mg (0.8 Cmol+/kg) and Ca (1.57 Cmol+/kg).

Table 2: Soil chemical and physical properties

ID. NO.	pH 1:2.5(H_2O)	%O.C	%N	mg/kgP	mg/kgK	Cmol+/kgCa	Cmol+/kgMg
Initial	6.8	0.7	0.05	5	43	1.6	0.8
Final							
Control	5.5	0.5	0.1	4.8	66	1.2	0.8
T+N	5.8	0.5	0.1	8.3	83	2.3	1.6
T+I	5.9	0.4	0.01	9.4	92	3.1	1.04
T+N+I	5.7	0.6	0.06	11.8	86	3.2	1.9
T	5.8	0.5	0.04	8.2	86	2.2	0.8
N	5.7	0.4	0.04	12.9	93	3.04	1.98
I	5.8	0.8	0.08	9.6	73	2.9	0.96
Soil Texture: Sandy-loam							

4.1.2 Plant height response to genotypes

Plant height was statistically (*$P<0.001$*) affected by soybean genotypes. The genotype N221 recorded the tallest plant height (93cm) followed by N19 which did not significantly differ in height with N76 (87cm) (Figure 1). Genotype N154 recorded the least plant height (28 cm) followed by genotype N3 which was not significantly different from the heights of genotypes N205 and N25.

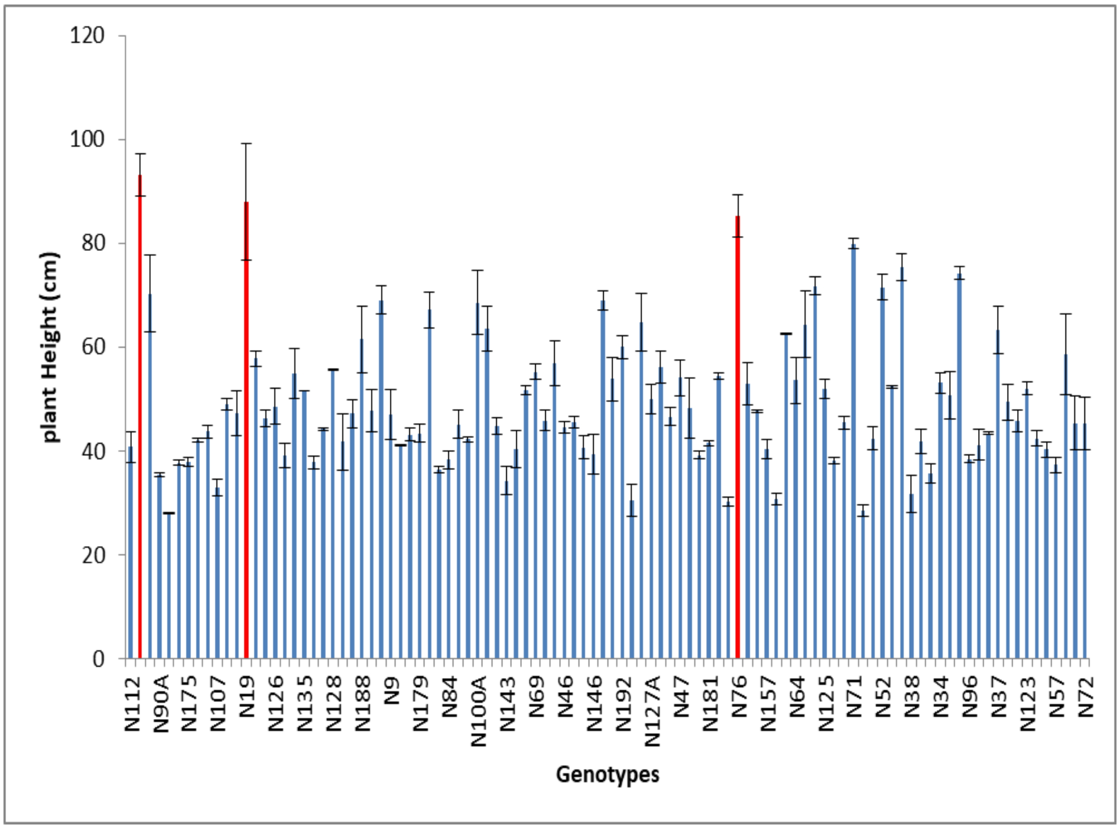

Figure 1: Effect of soybean genotypes on plant height at maturity. Error bars represent standard error of means (SEM)

4.1.3 Days to 50 % flowering response to genotypes

Days to 50% flowering had a significant (*P<0.001*) influenced by genotype with genotype N187 recording the earliest (29 days), followed by the genotypes N38 and N37 which took 30 days and 32 days to flower respectively. There was no significant difference between genotypes N37 and the subsequent ones (Figure 2). The least genotype to flower was SAL-1 which took 56 days to flower after planting.

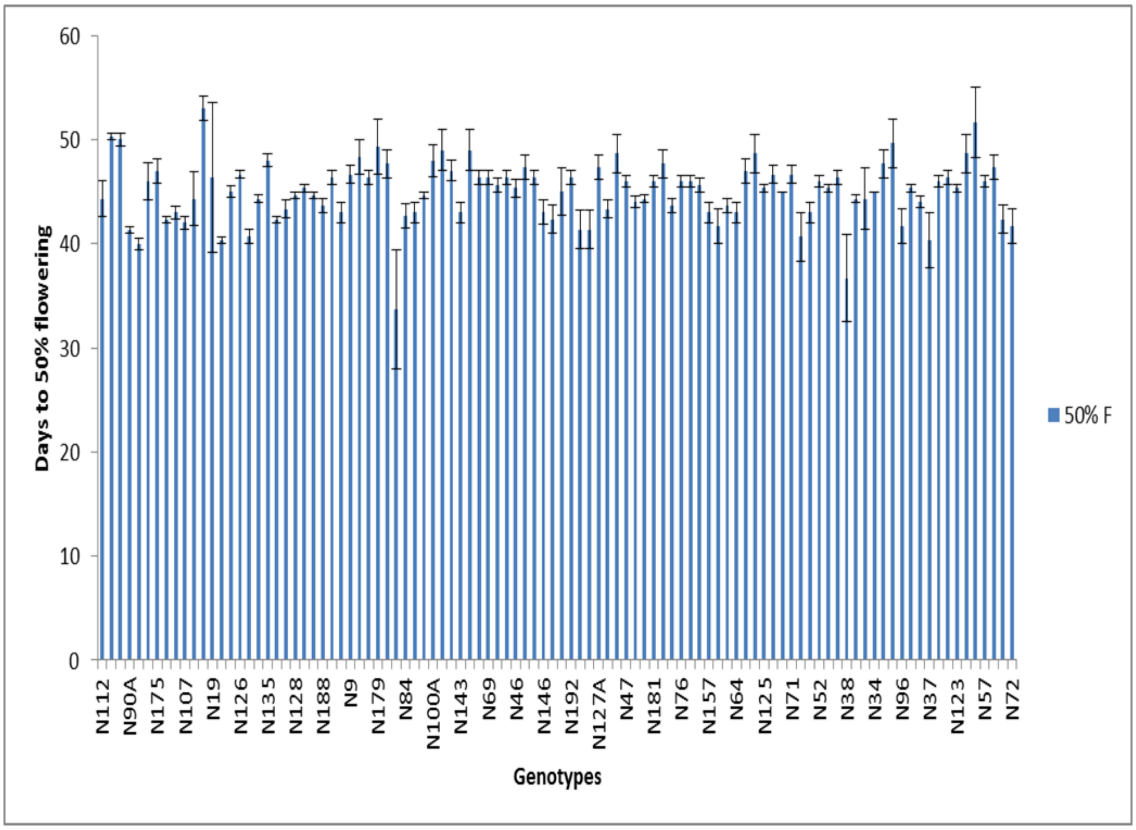

Figure 2: Effect of soybean genotypes on days to 50% flowering. Error bars represent standard error of means (SEM).

4.1.4 Leaf area index response to genotypes

There were significant (*P<0.001*) differences among the genotypes for leaf area index. Genotype N207A had the greatest leaf area index (0.5) which was not significantly different from genotype N19 which recorded (0.5) (Figure 3) and N176 recorded the lowest (0.07) though not statistically different from N201 (0.08).

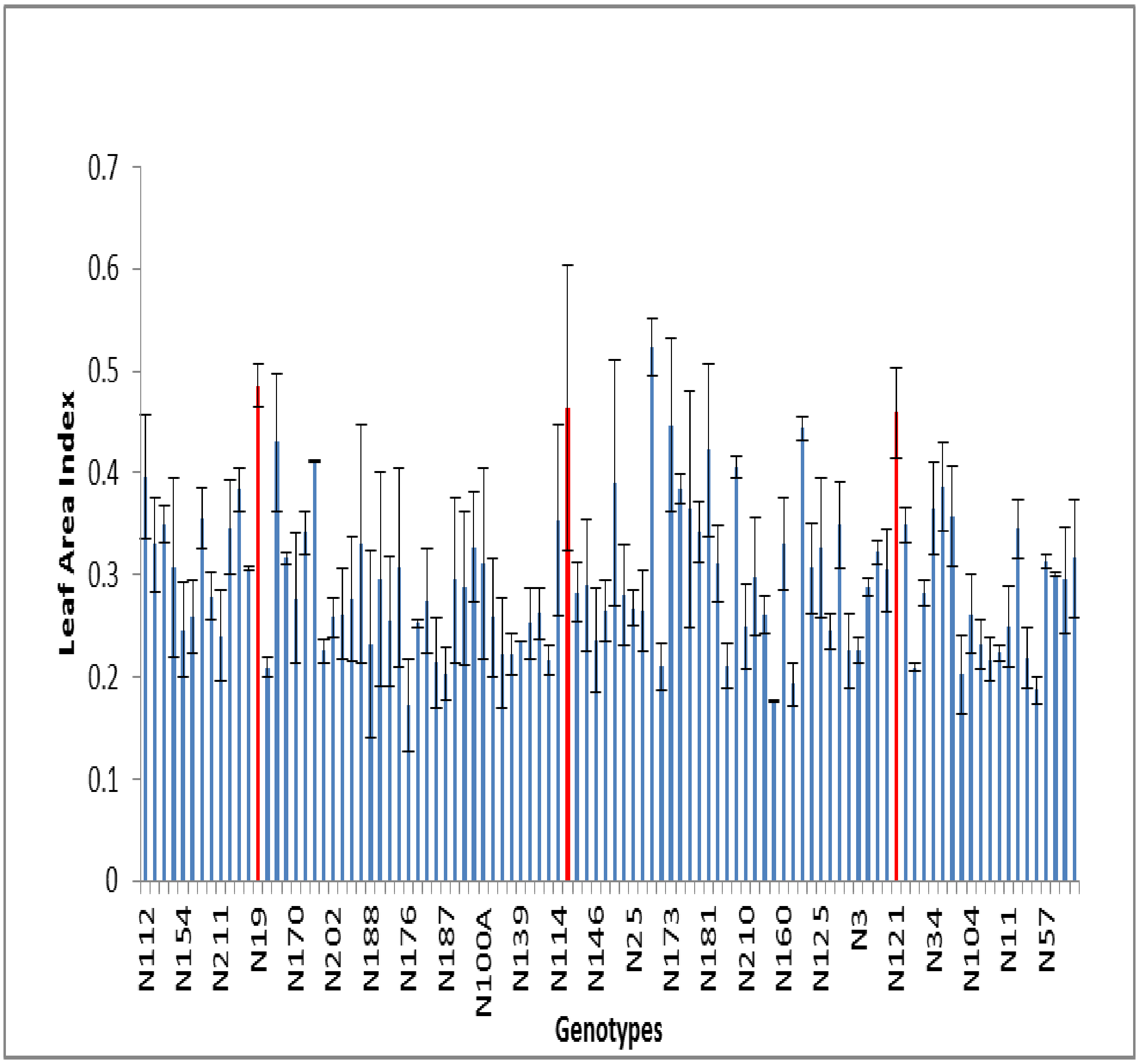

Figure 3: Effect of soybean genotypes on leaf area index at maturity. Error bars represent standard error of means (SEM).

4.1.5 Number of pods response to genotypes

There were significant (*P<0.001*) differences among genotypes for number of pods per plant. GenotypesN19, N102 and N105 recorded statistically similar (98, 82 and 89, respectively) number of pods per plant (Figure 4). The minimum pods number (16) per plant was produced by genotype N110 which was statistically similar to genotype N143 of (22).

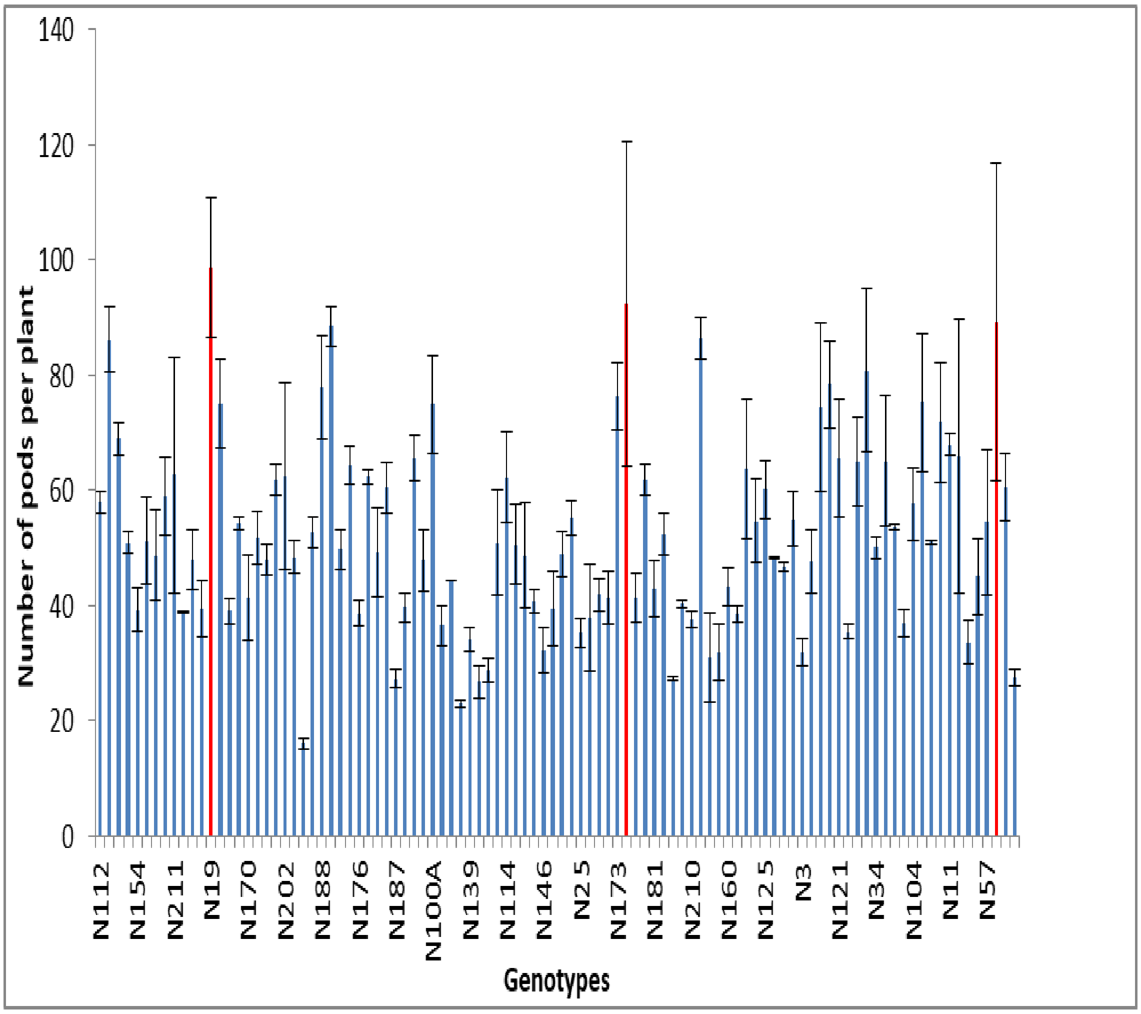

Figure 4: Effect of soybean genotypes on number of pods per plant. Error bars represent standard error of means (SEM).

4.1.6 100 grain weight response to genotypes

There were significant (*P<0.001*) differences among genotypes for hundred grain weights. Genotype N147 recorded the greatest hundred grain weight (23.85 g) followed byN48 (20.15 g) which was statistically similar to N170 (19.70 g) (Figure 5) and genotype N70 (19.45 g). Genotype N79 recorded the least hundred grain weight (57 g) (Figure 5).

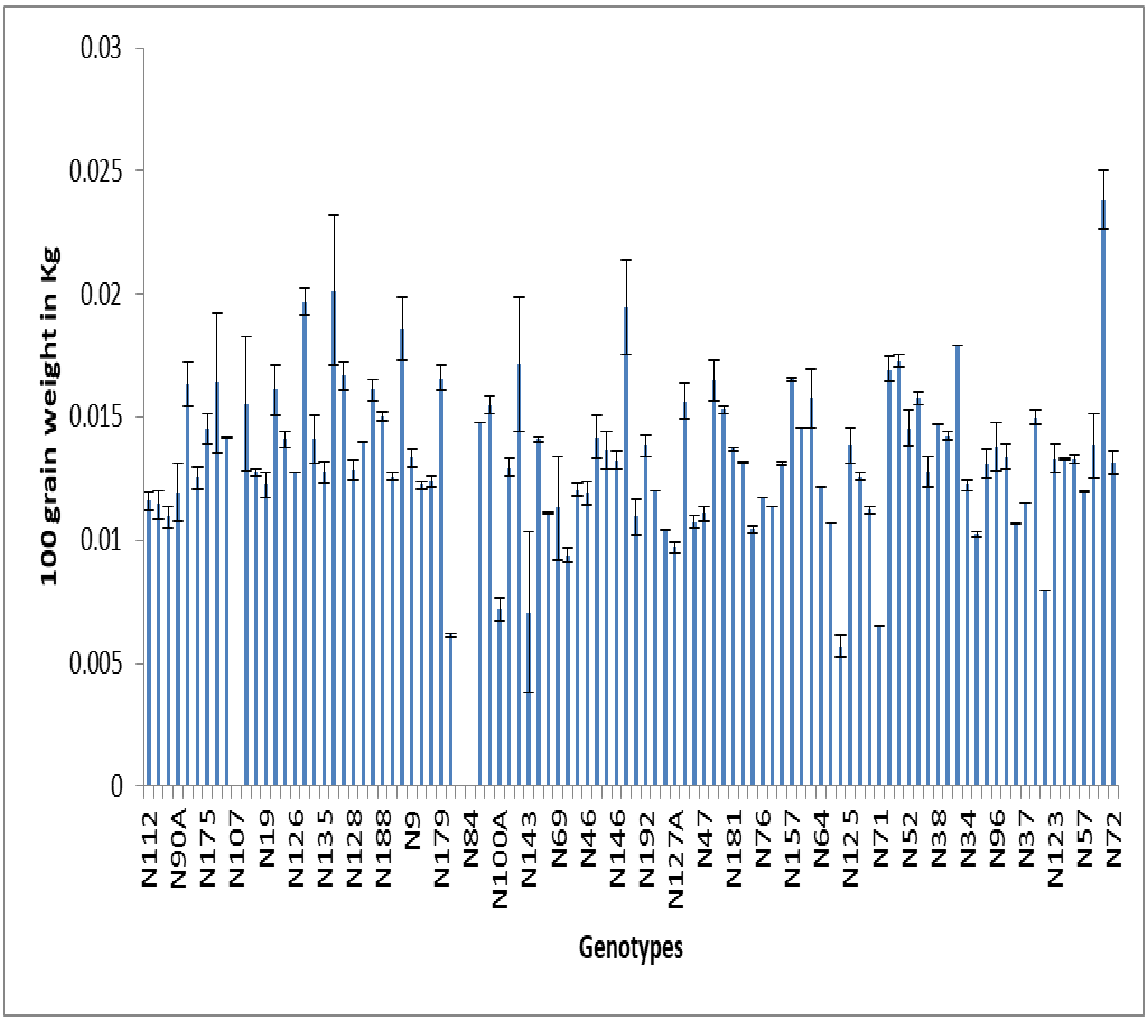

Figure 5: Effect of soybean genotypes on 100 grain yield weight. Error bars represent standard error of means (SEM).

4.1.7 Grain yield response to genotypes

There were significant (*P<0.001*) among genotypes for grain yield. The yield of grains ranged from 33.7 kg/ha to 1238 kg/ha (Figure 6 and 7). Genotype N119 recoded the greatest grain yield of 1238 kg/ha which did not statistically differ from N19 (1223.8 kg/ha) which was significantly different from N135 (1056.9 kg/ha). Genotype N210 recorded the least grain yield of 33.7 kg/ha which was statistically different from the grain yield of other genotypes.

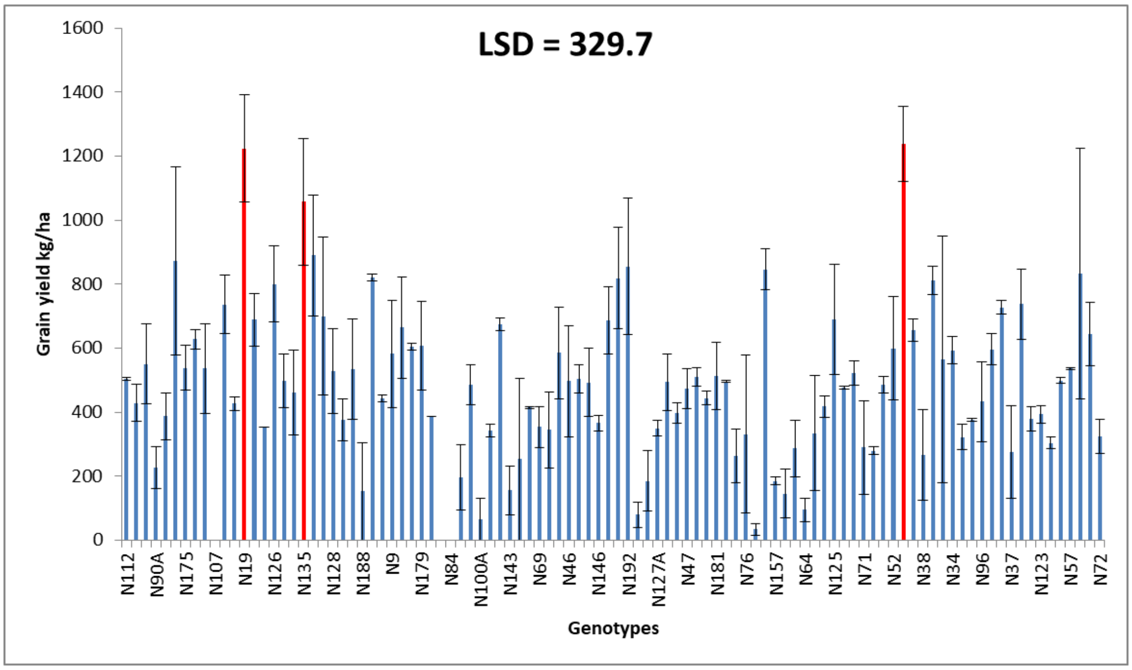

Figure 6: Effect of soybean genotypes on grain yield. Error bars represent standard error of means (SEM).

4.2 Fertilization and genotype effect on growth and yield

4.2.1 Plant height

There were no significant (*P>0.05*) interaction of genotype and fertilizer on plant height in all the weeks. However, N19 treated with Tsp + booster nitrogen had the highest plant height which was not statistically different from N19 treated with Tsp + nitrogen + inoculant. The N119 treated with sole inoculant had the least plant height (35 cm) at 10WAP. Genotype had a significant (*P < 0.001*) impact on plant height from 6 to 10 WAP. Genotype N135 produced the highest plant height of 32 cm at 6WAP followed by genotype N19 which was not statistically different from Jenguma. N119 had the lowest plant height of 28 cm (Figure 8). On the 8 and 10WAP, N19 produced the tallest plant height (47 cm and 61cm respectively) and N119 had the shortest plant height (37 cm and 36 cm respectively). There was no significant difference between

N135 and the Jenguma variety on the 8 and 10 WAP. In contrast to genotype, fertilizer treatments had no significant (*P > 0.05*) influence on plant height in all the weeks but TSP + nitrogen + inoculant generally produced the highest plant height of 48 cm while sole nitrogen application had the lowest plant height of 40.cm at 10WAP.

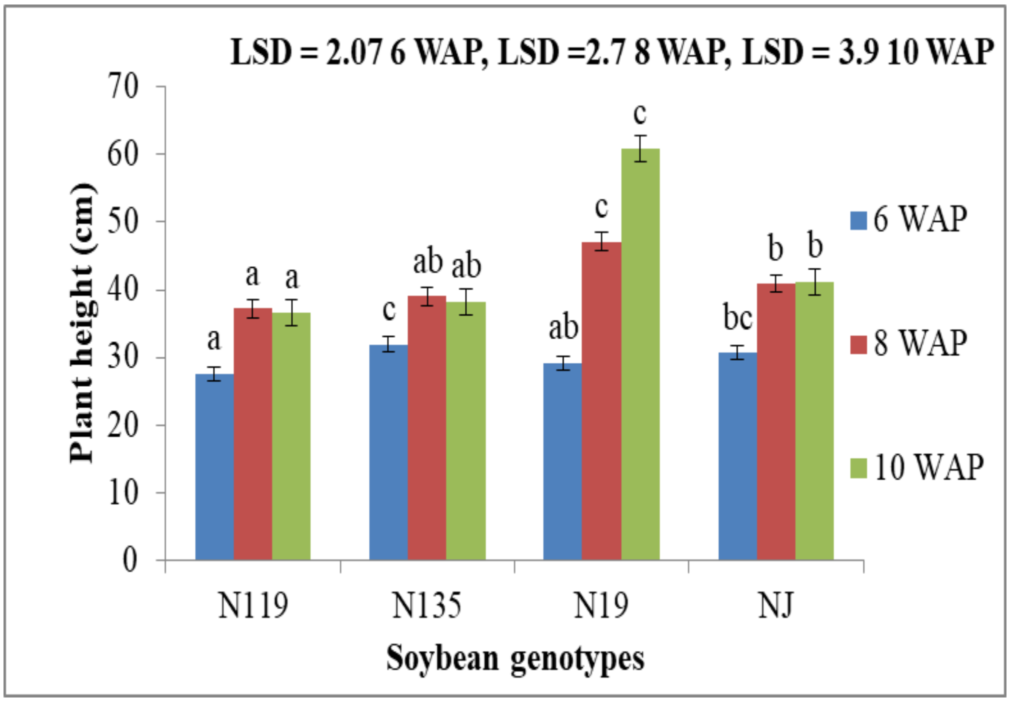

Figure7: Effect of high-yield soybean genotypes on plant height. Error bars represent standard error of means (SEM). NJ = Jenguma variety.

4.2.2 Days to 50 % flowering

There was no interaction (*P=0.456*) effect between genotype and fertilizer regime. Fertilizer regime had no significant (*P=0.347*) influence on days to 50% flowering. Genotype significantly (*P<0.001*) influenced days to 50% flowering with N119, NJ and N135 flowering almost the same time (42, 41 and 43 respectively) while N19 took longer time (56 days) to flower (Figure 9).

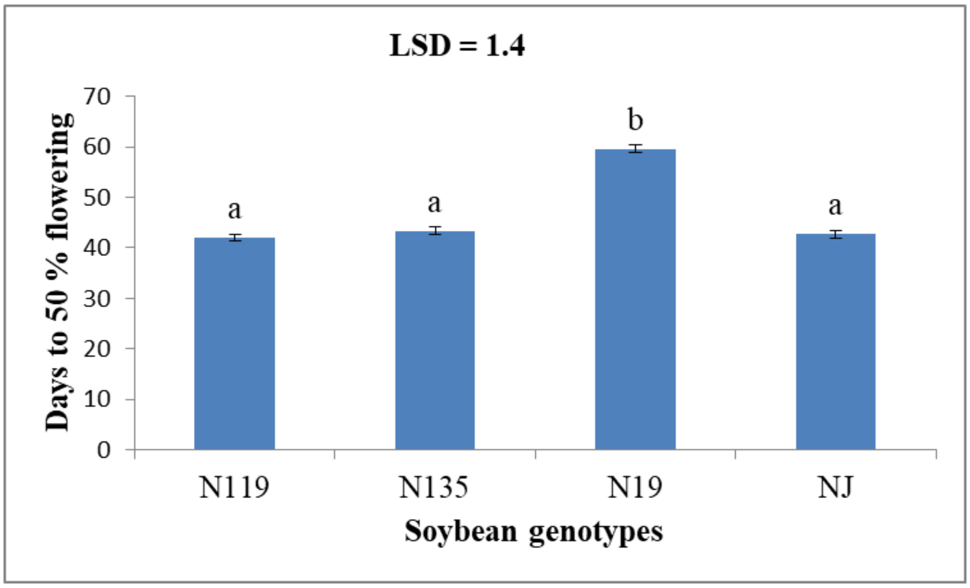

Figure 8: Effect of high-yield soybean genotypes on days to 50% flowering in the Guinea savanna of northern Ghana. Error bars represent standard error of means (SEM). NJ = Jenguma variety.

4.2.3 Leaf area

There were no interaction (*P>0.05*) effects between genotype and fertilizer on leaf area in all the weeks. However, N19 treated with Tsp + inoculant produced the greatest leaf area (104 cm^2) which was statistically similar to N19 treated with Tsp +nitrogen + inoculant (102cm^2). Genotype N119 treated with sole nitrogen recorded the least leaf area (49 cm^2) at 8 WAP. N19 treated with Tsp + nitrogen + inoculants recorded the largest (111cm^2) leaf area followed by N19 combined with Tsp + inoculant (109 cm^2) while genotype N19 treated with sole inoculant recorded the least (45 cm^2). On the 10th week, N19 treated with Tsp + inoculant + nitrogen recorded the highest leaf area (110 cm^2) followed by sole Tsp combined with genotype N19 (96.4 cm^2) whereas N119 without treatment (control) had the least leaf area (39.7 cm^2). The result showed that genotype significantly (*P<0.001*) impacted leaf area (LA) at 6WAP, 8WAP and 10WAP (Figure 10). The highest (87 cm^2) leaf area was recorded on 10 WAP by N19.

Genotype N119 recorded the least (56 cm^2) leaf area. Fertilizer had no significant (*P>0.05*) effects on LA in all the weeks but Tsp+ nitrogen + inoculant generally had the highest leaf area of (96cm^2) which did not differ from sole Tsp while sole Inoculant had the least leaf area (57 cm^2) (Figure 11).

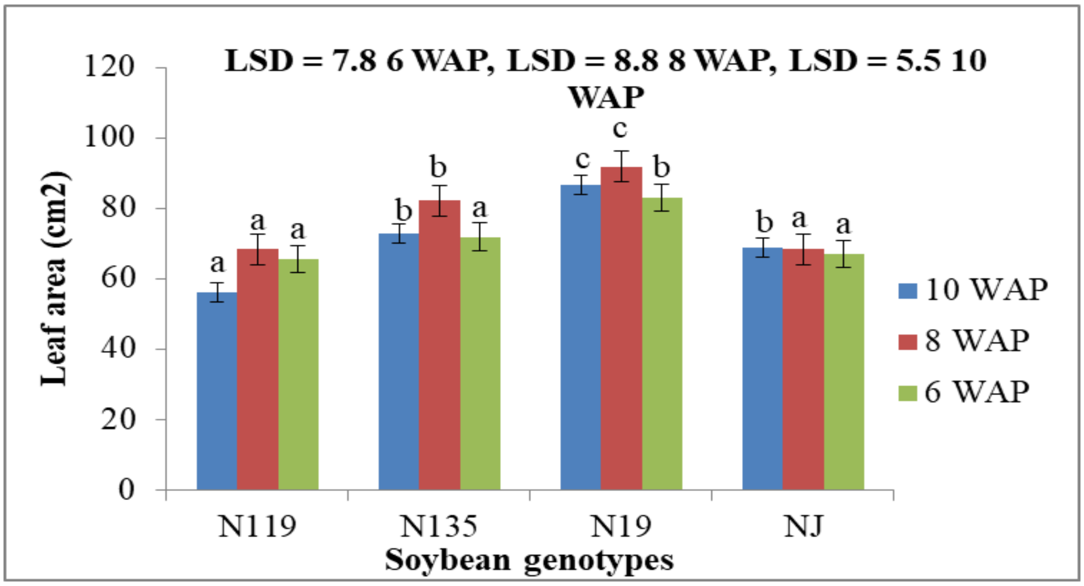

Figure 9: Effect of high-yield soybean genotypes on leaf area. Error bars represent standard error of means (SEM). NJ = Jenguma variety.

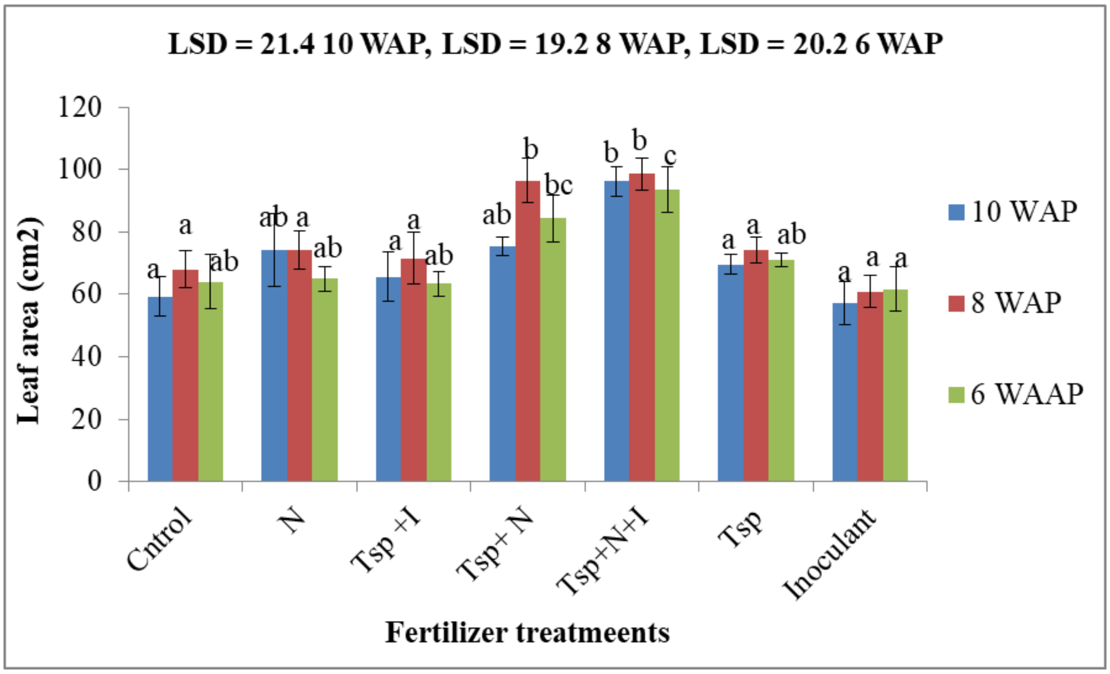

Figure 10: Effect of fertilizer regime on leaf area. Error bars represent standard error of means (SEM).

4.2.4 Number of nodules per plant

There were no significant interaction (*P=0.182*) between fertilization regime and soybean genotype. However, fertilization and inoculant had a significant (*P=0.003*) impact on number of nodules in which Tsp + inoculants produced the highest number of nodules per plant (108) which is not significantly different from sole inoculants (96) followed by the control (No fertilizer) and sole Tsp while sole nitrogen and Tsp + N recorded statistically similar number of nodules (37 and 40 respectively) (Figure 12). Though genotype had no significant (*P=0.226*) impact on number of nodules per plant, N119 recorded the higher number of nodules (87.0) compared to Jenguma (83.0) which is significantly similar to N135 (74) while genotype N19 recorded the least number of nodules (63) per plant.

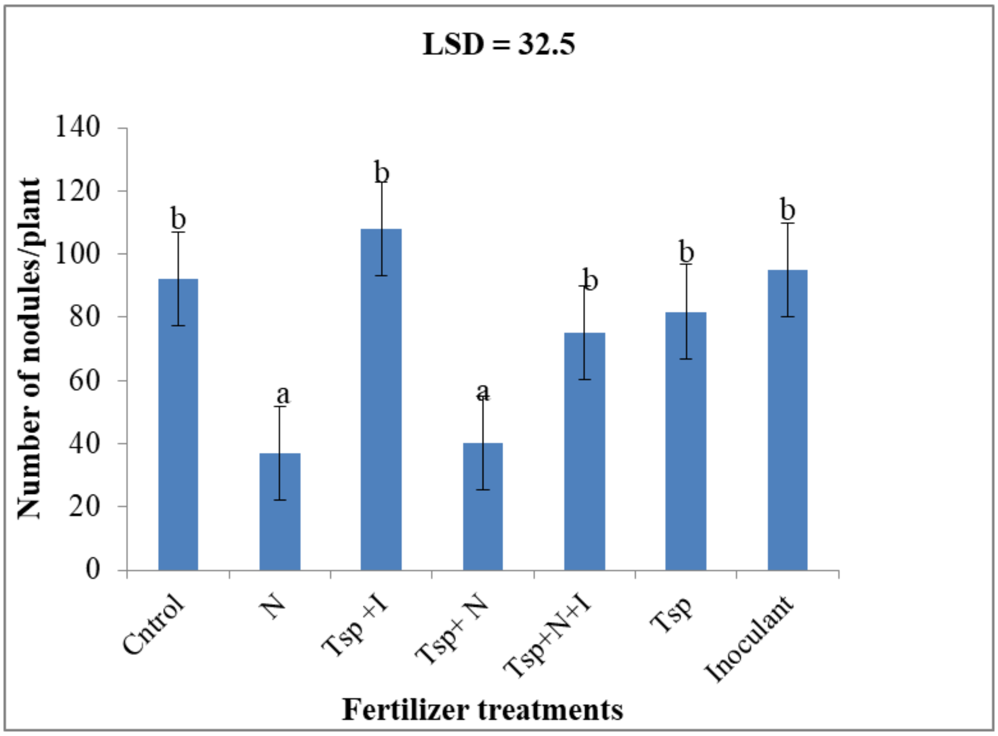

Figure 11: Effect of fertilizer regime on number of nodules per plant. Error bars represent standard error of means (SEM).

4.2.5 Effective nodules percentage

There were no significant interaction (*P=0.141*) between fertilizer regime and soybean genotype on effective nodule percentage. However, genotype significantly (*P<0.001*) impacted on effective nodules percentage; Jenguma recorded the highest (70%) which is statistically similar to N119 (65%). Genotype N19 recorded significantly least (49%) effective nodules compared to Jenguma (Figure 13). Fertilization had a significant (*P = 0.045*) impact on effective nodules percentage (Figure 14). Triple superphosphate + inoculant (Tsp +I) recorded the greatest effective nodule percentage (81.2%) which is not significantly different from TSP (72.5%) followed by I (68.5%) while N recorded the least percentage of effective nodules (31.5%).

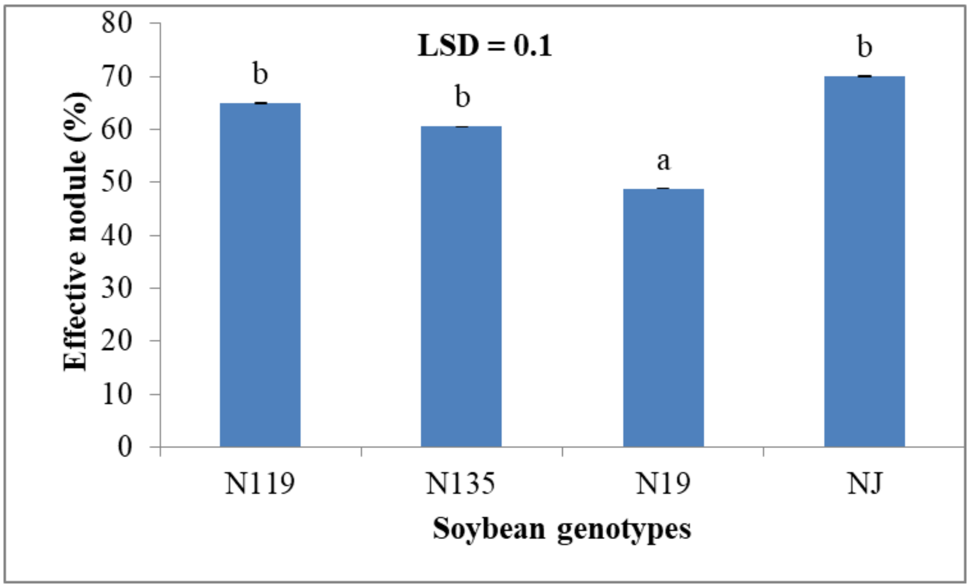

Figure 12: Effect of high-yield soybean genotype on effective nodule percentage. Error bars represent standard error of means (SEM). NJ = Jenguma variety.

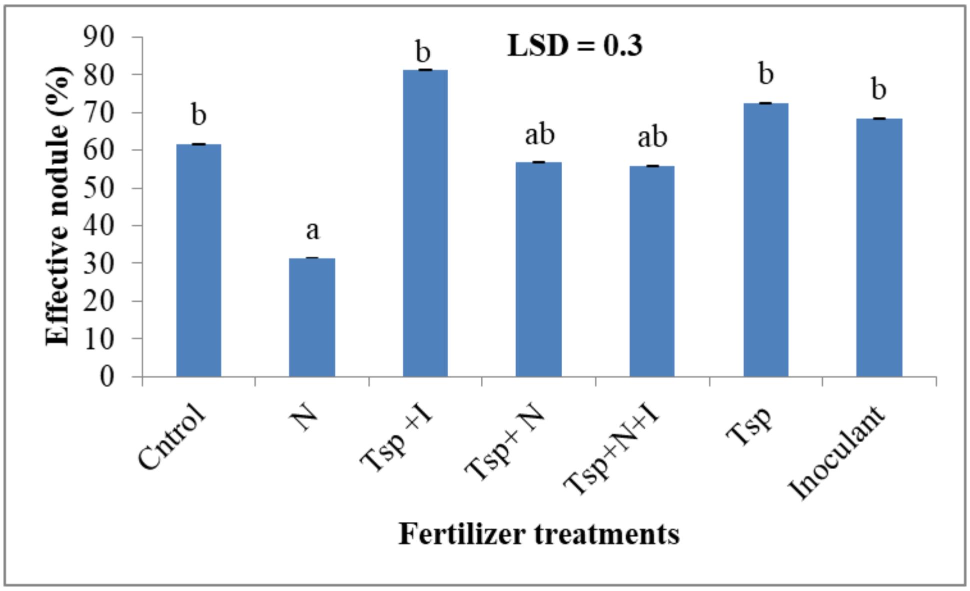

Figure 13: Effect of fertilizer regime on effective nodules percentage of soybean. Error bars represent standard error of means (SEM).

4.2.6 Number of leaves per plant

There were no significant interaction (*P>0.05*) between fertilizer regime and genotype in all the weeks. Number of leaves per plant was significantly (*P<0.001*) influenced by soybean genotypes at 6 and 8 WAP. The highest number of leaves (48) per plant was produced by Jenguma at 6WAP which did not significantly differ from N119 while genotype N19 had the least (28) number of leaves per plant on both 6WAP and 8WAP (Figure 15). Fertilizer had significant (*P=0.003*) impact on the number of leaves at 8WAP (Figure 16). Tsp + inoculant + nitrogen produced the highest number of leaves (95) per plant which is significantly similar to Tsp + N while sole inoculant recorded the least number of leaves per plant (49).

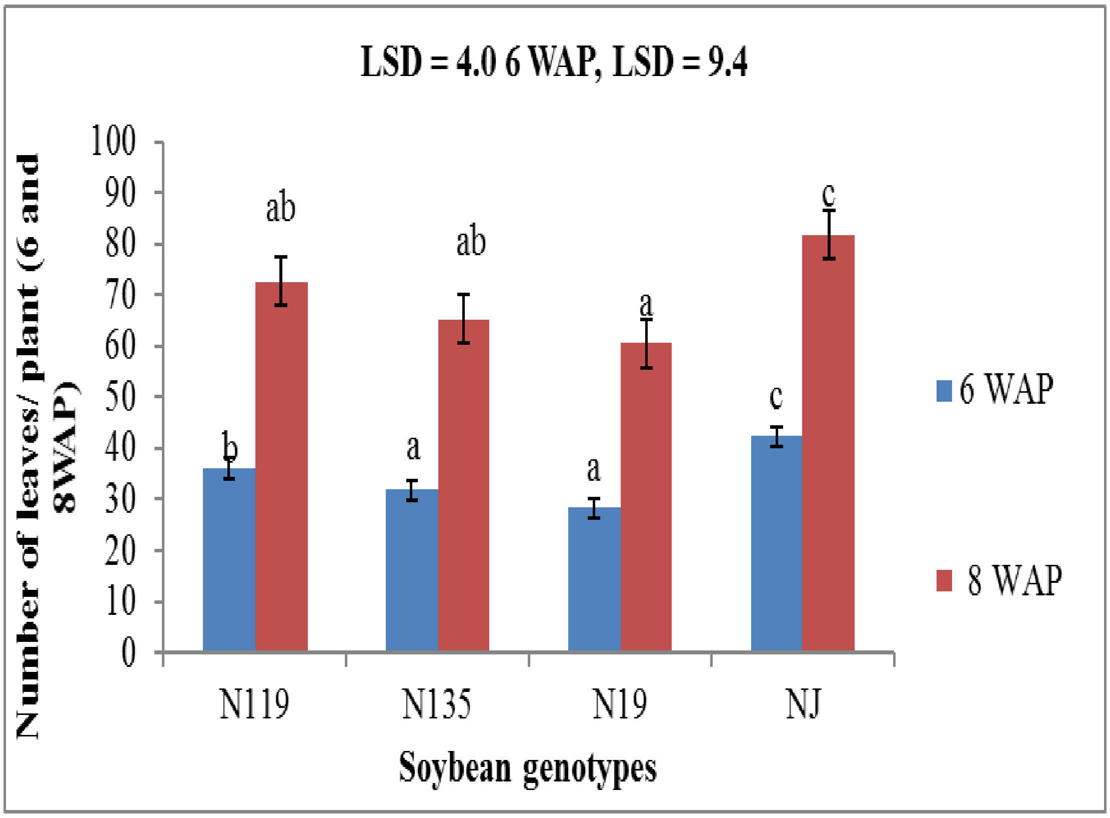

Figure 14: Effect of high-yield soybean genotypes on number of leaves per pant in the Guinea savanna of northern Ghana. Error bars represent standard error of means (SEM). NJ = Jenguma variety.

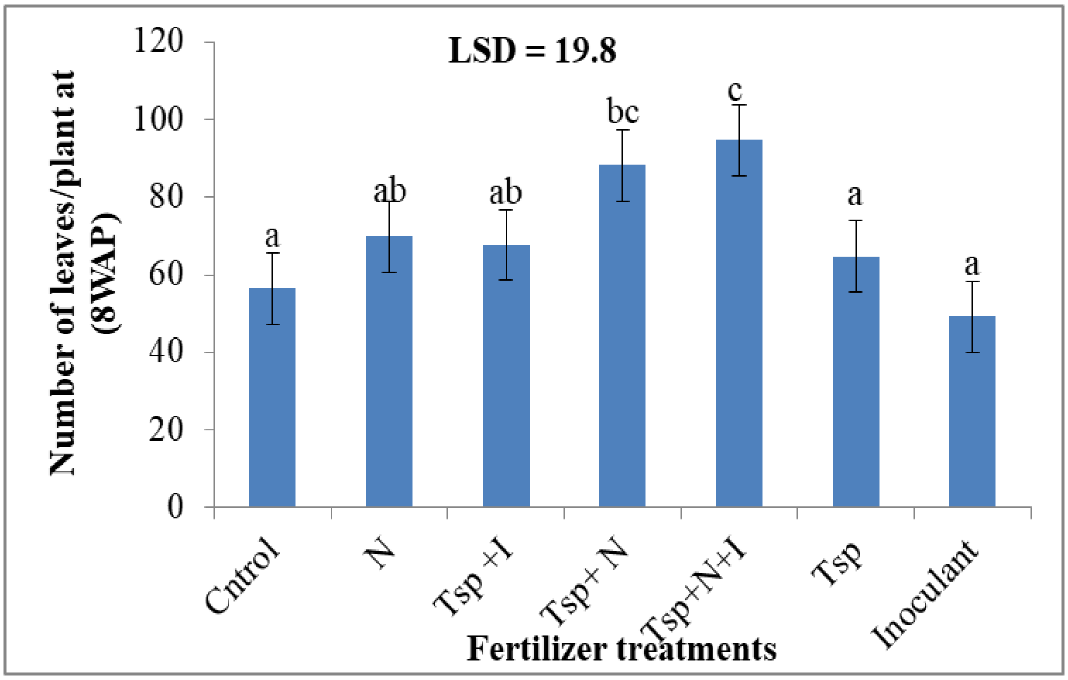

Figure 15: Effect of fertilizer regime and inoculant on number of leaves per plant at 8 weeks after planting. Error bars represent standard error of means (SEM).

4.2.7 Number of primary branches per plant

There were no significant interaction (*P=0.899*) effect between fertilizer regime and soybean genotype on number of primary branches per plant. Genotype had a significant (*P<0.001*) influence on the number of primary branches (Figure 17). Genotype N19 produced the highest number of primary branches (5) which is statistically similar to Jenguma. Genotype N135 recorded least number of primary branches (4) compared to N19. Fertilizer treatment had significant (*P=0.011*) effect on primary branches (Figure 18), Tsp + nitrogen + inoculants recorded the greatest number of primary branches (5) per plant followed by Tsp + inoculant and control recorded the least (4) number of primary branches per plant.

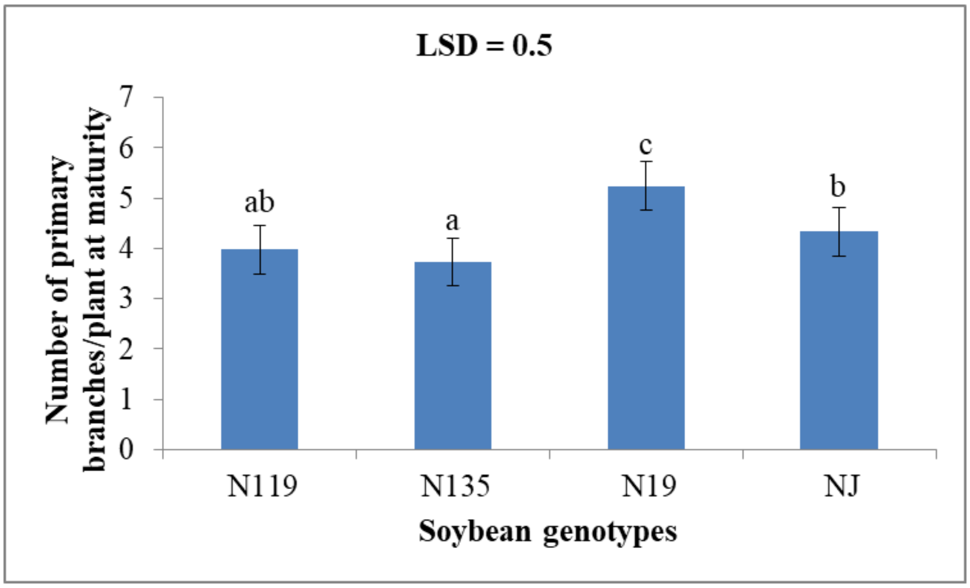

Figure 16: Effect of high-yield soybean genotypes on number of primary branches. Error bars represent standard error of means (SEM). NJ = Jenguma variety.

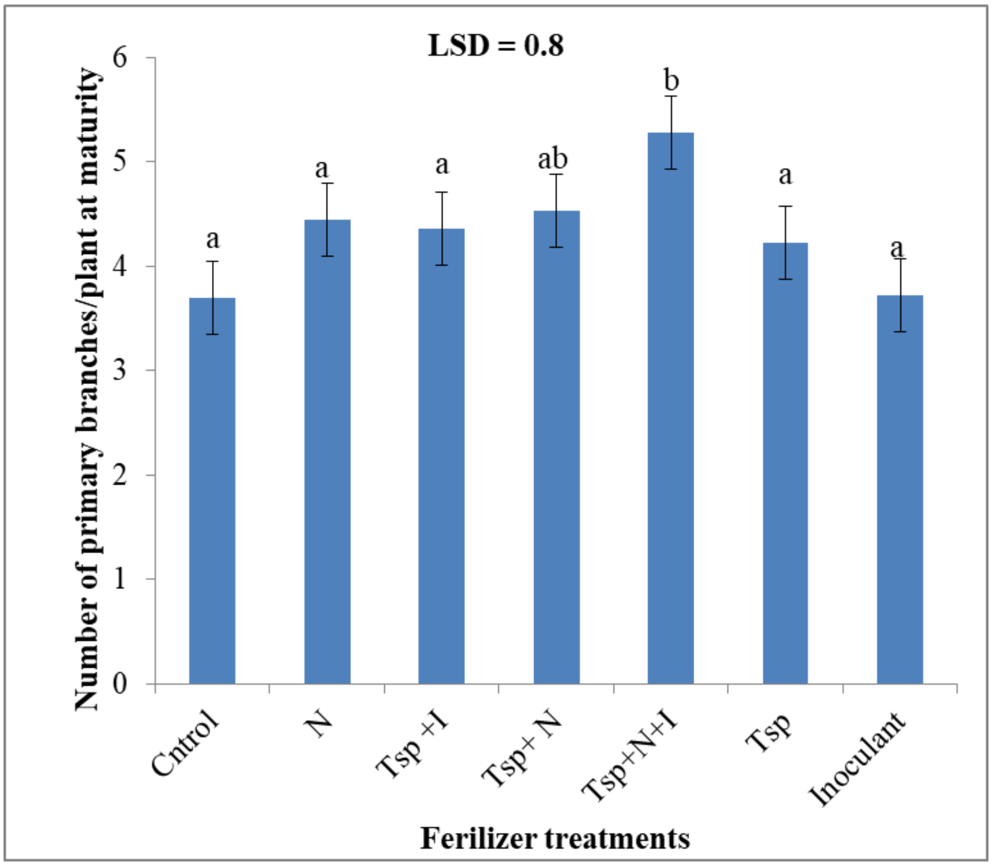

Figure 7: Effect of fertilizer regime on number of primary branches per plants. Error bars represent standard error of means (SEM).

4.2.8 Biomass dry weight

There were no interaction (*P>0.05*) effect between fertilizer regime and Soybean genotypes on biomass dry weight at 6, 8 and 10WAP. Fertilizer regime significantly (*P<0.001*) influenced biomass dry weight at 10WAP (Figure 19). Tsp + nitrogen + inoculant recorded the highest biomass dry weight (18 g/plant) which is significantly similar to Tsp + inoculant (15 g/plant) followed by Tsp, with sole N recording the least biomass dry weight (8 g/plant). Soybean genotype had no significant (*P=0.827*) influence on biomass dry weight at 10WAP but N119 recorded the greatest biomass dry weight (13 g/plant) followed by N135 and Jenguma recording the least biomass dry weight (12 g/plant).

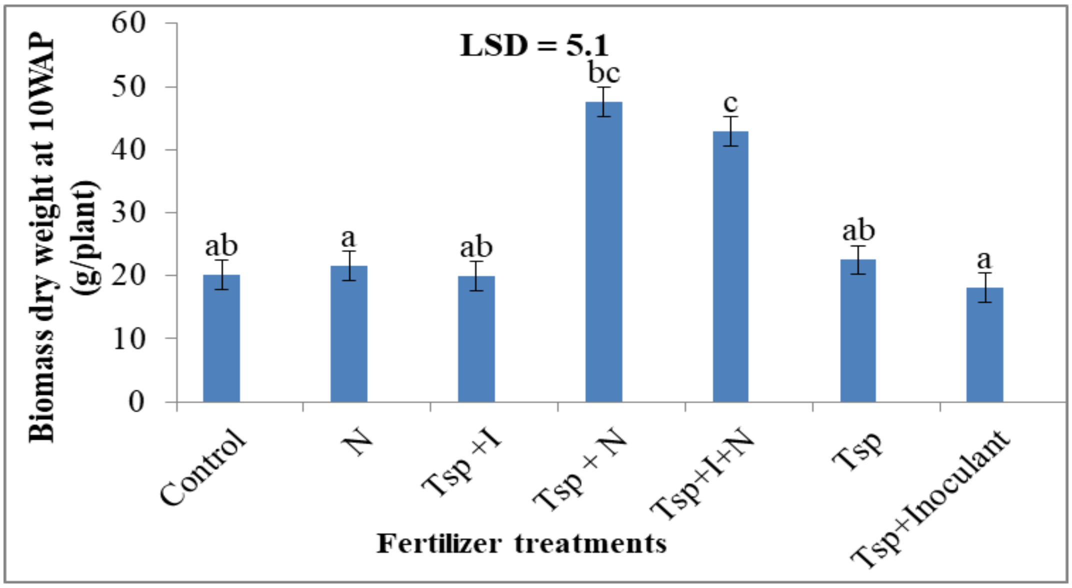

Figure 18: Effect of fertilizer regime on biomass dry weight at 10 weeks after planting. Error bars represent standard error of means.

4.2.9 Pod weight per plant

There were no interaction (*P=0.517*) effect between fertilizer regime and genotype on weight of pods. Pod weight was not significantly (*P=0.0683*) affected by soybean genotypes. However, Jenguma recorded the highest pod weight (36.2 g) followed by N135 (35.1 g) and N119 and N19 recorded same pod weight (32.8 g) (Figure 20). Fertilization had significant (*P=0.042*) influence on pod weight with Tsp + inoculant recording the greatest pod weight (43.2 g) which is significantly similar to Tsp (42.9 g) and Tsp + nitrogen + inoculant (40.7 g) whereas the control recorded the least (23.7 g).

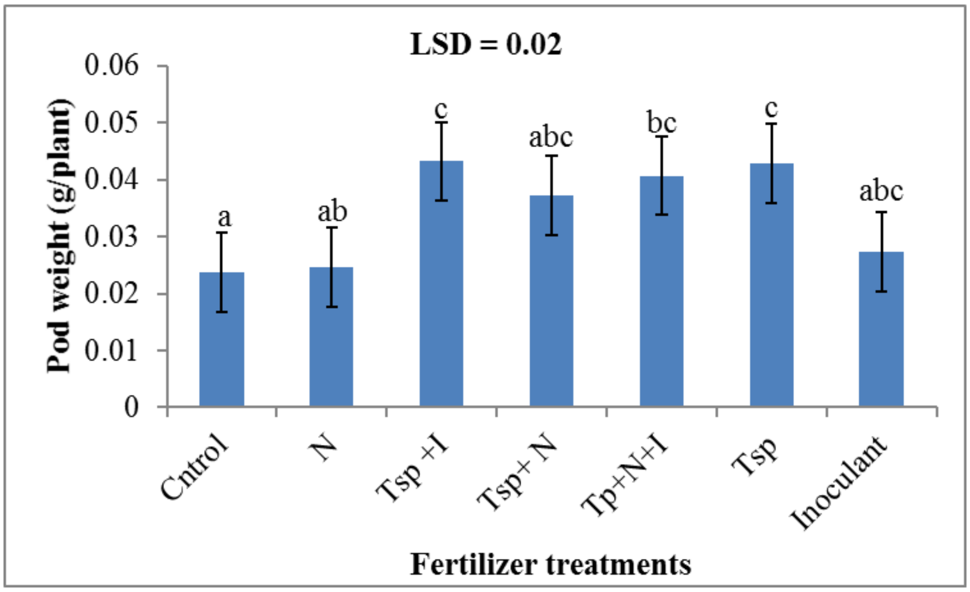

Figure 19: Effect of fertilizer regime on pod weight per plant in g. Error bars represent standard error of means (SEM).

4.2.10 100 Grain weight

There were no interaction (*P=0.920*) effect between fertilization and genotype on hundred grain weight (Figure 22). Hundred grain weight was significantly ($P < 0.001$) impacted by soybean genotype. Genoype N135 recorded the highest hundred grain weight (13.9 g) which did not statistically differ from Jenguma (13.7 g) and N119 while genotype N19 had the least hundred grain weight (8.8g). There was no significant difference (*P=0.405*) among the fertilizer treatments. However, Tsp + inoculant obtained the greatest (13.9g) followed by Tsp and the control had the least hundred grain weight (11.0g).

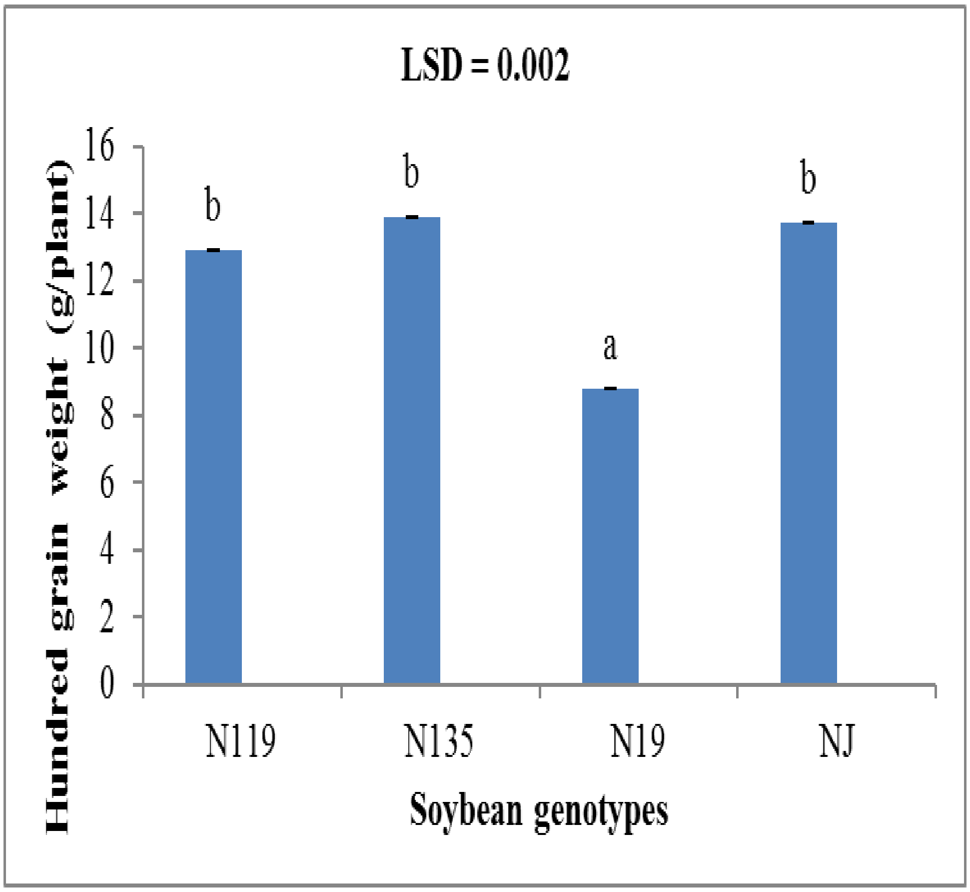

Figure 20: Effect of high-yield soybean genotypes on 100 grain weight. Error bars represent standard error of means (SEM). NJ = Jenguma variety.

4.2.11 Grain yield

There were significant interaction (*P=0.039*) effect between genotype and fertilization regime on grain yield (Table 3). Jenguma treated with Tsp + inoculant recorded the highest grain yield (4.06 t/ha) which was significantly similar to Jenguma treated with

Tsp + nitrogen + inoculant (3.86 t/ha) followed by genotype N135 treated with Tsp + nitrogen (3.74 t/ha). The least grain yield (0.01 t/ha) was recorded by genotype N19 without treatment (control).

Table 3: High-yield soybean genotype and fertilization regime effect on grain yield (t/ha). NJ = Jenguma variety.

Fertilizer Regime	N119	N135	N19	NJ
	←	Genotypes		→
Control	1.428	2.325	0.010	1.685
Nitrogen	1.174	1.905	0.325	1.549
Tsp + I	2.127	3.295	0.678	4.062
Tsp + N	1.756	3.743	1.089	1.956
Tsp + I + N	3.251	3.301	0.261	3.862
Tsp	2.657	2.781	0.690	3.435
Inoculant	1.959	1.930	0.941	2.300
LSD (5%)		**1.66**		
CV (%)		**36**		

4.3 Economic cost analysis

Based on the results on comparative analyses of the economic productivity of soybean production, soybean treated with sole Tsp gave the highest benefit cost ratio, followed by the soybean with Tsp + nitrogen +inoculant. Treatment with Tsp + nitrogen and Tsp + inoculant recorded the same benefit cost ratio followed by soybean treated with sole inoculant (Table 4). The control treatment (sole soybean) gave a higher benefit: cost than Soybean with sole nitrogen which gave the least benefit cost ratio.

Table 4: Benefit and cost analysis for production of high yield soybean genotypes as influenced by fertilization

Technology	Production cost (GH¢)	Gross return (GH¢)	Benefit (GH¢)	Benefit/cost ratio
Control	1245	407 3.5	2828.5	2.3
Tsp + soybean	1695	6072.2	4325.2	2.5
Inoculant + soybean	1470	4072.5	2602.5	1.7
Nitrogen + soybean	1445	3364.2	1919.2	1.3
Tsp + I + N + soybean	1870	6728.4	4858.4	2.5
Tsp + I + soybean	1795	7082.6	5287.6	2.9
Tsp + N + soybean	1770	6551.4	4781.4	2.7

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Soil chemical property

It was realized from the initial soil analysis that the soils were highly deficient in percentage of total N and organic carbon, which are key to crop growth and yield. Phosphorus was also found to be insufficient thus prompting the application of 60 kg P/ha at planting. Donald (2016) stated that soybean grows well in a soil with more than 25 ppm available P, 0.1% N, 25 meq/100g CEC and 1.5% OM. The final soil test (after harvest) showed that the soils decreased in pH level that could be attributed to fertilization effects. It was established that organic carbon increased over the initial organic carbon level which could be due to enhanced organic matter build up through fertilization. This agrees with the work of Obalum *et al*. (2011) who reported that soybean enhances organic carbon relative to sorghum when cultivated in South-eastern Nigeria since sorghum does not add large biomass to the soil. However, it contradicts the findings of Conti *et al.* (2014) in their work in Argentina that revealed a significant decrease in total organic carbon level in cropped soybean plots as compared with grassland plots as a result of low amount of soybean stubble.

There was also a total reduction in percentage total N except for the plots treated with sole N which increased total N by 2.3%. The reduced N might be attributed to high N mined by the crop. The findings contradict the work of Adeleke and Haruna (2012) in the Northern Guinea Savanna agroecological zone in Nigeria, where four legumes (soybean, cowpea, lablab and groundnuts) were reported to have increased total N after harvest. However, the finding of this study agrees with Heichel (1987) who reported increase in soil N after soybean harvest. The use of phosphorus and rhizobium inoculant improves soil P availability except for the control which recorded a reduction in soil P. This is an indication that soil amendments with P fertilizers increases phosphorus availability in the soil.

5.2 Plant height

Frequent or continuous measurement of plant height throughout the crop growing season is necessary *Takala et al*. (2014) because plant height is linked to yield potential. The insignificant differences in plant height among fertilizer treatments may be as a result of the competition among the native rhizobia present in the soils which overcame the inoculated rhizobium isolate, though the indigenous rhizobia population in this study site was not evaluated. The result of this research contradicts that of Mehmet (2008) who indicated that the application of inorganic nutrients to soybean plots had significant influence on the height of plant. Plant height in the current study increased progressively during the growing season for all the genotypes (Figure 8). This supports findings from Amani (2007) and Caliskan *et al.* (2007). The significantly higher plant height by N221 and N135 at the phase one and phase two of this experiment respectively might have been as a result of genotypic difference enabling N122 and N135 at 6WAP to effectively utilize available environmental resources like light, water and nutrients, because of its genetic make-up. This is in line with El Naim and Jaberereldar (2010) who reported non similarities in the height of plants among genotypes. In a similar study, Talaka *et al.* (2013) also showed significant difference among five different soybean varieties cultivated under non-irrigated environment. Ahmed *et al*. (2010) and Ponnuswamy *et al.* (2001), also reported varietal differences in plant height had it to genotypic difference among varieties. Differences in plant height and WAP is in agreement with Lambon (2016) who reported some crops are normally small at the early stage and are not able to use all the growth resources at the initial stages of growth. General rise in plant height from 6^{th} to 10^{th} WAP which correlates with the report of Amani (2007) and Caliskan *et al*. (2007) who observed that height plants increases with the use of inoculants together with mineral fertilizer.

5.3 Days to 50% flowering

The relatively shorter days to 50% flowering in N119, N135, and Jenguma are linked to genotypic difference in growth characteristics. Verma *et al*. (2009) reported to have observed differences growth patterns among groundnut genotypes which they attributed to varying genetic make-up. It could have also be because of the effective utilization of available environmental conditions like light, water and nutrients by some genotypes than others at the first phase (screening stage) of the experiment.

5.4 Leaf area index and leaf area

Leaves are one of the main plant organs responsible for the productivity of a plant (Koester *et al.*, 2014). The differences in Leaf area index (LAI) and leave area (LA) exhibited by the genotypes at the various growth periods might have been due to genotypic characteristics. This is a vital condition at the reproductive stage for improved soybean yield. The greatest leaf area recorded by N19 in all the sampling periods followed by Jenguma variety whereas genotype N119 recorded the least has been attributed to genetic make-up (Ponnuswamy *et al.*, 2001; Ahmed *et al.*, 2010). The findings of this experiment contradict the observation by Malone *et al*. (2002) that late maturing soybean genotypes recorded minimum LA at reproductive stage of growth because N19 is a late maturing genotype but recorded the greatest leaf area. The greatest LA by Tsp + inoculant + nitrogen throughout the sampling periods (From 6 to 10WAP) followed by Tsp + nitrogen could be due to the presence of N. The observed findings are not different from the observation of Siam *et al.* (2012) in Egypt who opined that the addition of nitrogen increases the vegetative parts of soybean.

5.5 Number and effective nodules

Improved nodule count leads to increase N fixed into the soil; this improves soil fertility and increase crop development and growth (Bogino *et al.*, 2011). The greatest nodule number recorded by Tsp + inoculants might be that phosphorus played an important function in the formation of nodule and atmospheric nitrogen fixation. Research by Tagoe *et al*. (2008) and Waluyo *et al.* (2004) showed that the available of P helps to initiate the formation of nodules as well as growth, development and functioning of nodules formed, this might explain why all the treatment combinations with Tsp produced higher number of nodules and percentage of effective nodule than the other treatments. The result of this study agrees with Kumaga and Ofori (2004) who indicated that the nodule number and dry weight appeared to have reached their maximum when P fertilizer was applied at 30 kg P_2O_5/ha in a promiscuous soybean variety as compared to where sole inoculant was applied and where no inputs were applied. Similar results have also been reported by other scientists (Tsvetkova and Georgiev, 2003; Tahir *et al*., 2009; Bekere *et al*., 2012). The non-significant effect of nitrogen application on number of nodule is in line with the finding of Seneviratne *et al*. (2000) that the presence or absence of nitrogen in the soil does not significantly impact nodulation of the crop. Chen *et al.* (1992) also found that N fertilizer reduces nodulation.

5.6 Number of Primary Branches and Leaves

The highest number of leaves recorded by Jenguma throughout the sampling periods might be due to genotypic characteristics among the genotypes. The greater number of leaves in Tsp + inoculant + nitrogen compared to other treatments may be that booster N fertilizer supplied nitrogen until efficient biological N_2-fixation began. This means N was available throughout the crop season for this treatment resulting in increased number of leaves. The crop's nitrogen requirement when seedling are developing prior to the formation of nodule is critical to the growth and development of soybean (Hatfield *et al.,* 1974) since N_2- fixation usually begins 14 days after sowing (Hardy *et al.,* 1971). The significant influence of N fertilizer on the number of branches is in line with the findings of Bekere *et al.* (2013) in Ethiopia and Siam *et al*. (2012) in Egypt where N fertilization of soybean significantly affected number of branches of soybean throughout the sampling period. N is important in increasing chlorophyll content and photosynthetic rate of soybean (Zhang *et al.,* 2011). Researchers like Varon *et al*. (1984), Ahmed *et al*. (2013) and Umeh *et al*. (2011) have all reported increase in branch production and leaf area following availability of N in crop production. The highest number of primary branches produced by N19 might be connected to the genetic characteristics of the individual genotypes. This is in accordance with the findings of Umeh *et al*. (2011). All treatment combinations containing nitrogen produced relatively higher number of primary branches than the other treatment combinations. The presence of inoculant and Tsp also made a great impact in the number of primary branches with Tsp + inoculant + nitrogen recording the highest which did not significantly differ from Tsp + nitrogen. This is an indication that the presence of mineral fertilizer is necessary for the functioning and productive performance of soybeans and agrees with the report of Abdul and Saud (2012) who showed that application of P resulted to high number of soybean branches.

5.7 Biomass Weight

The non-significant differences in biomass weight among soybean genotypes are in agreement with Lambon (2016) who discovered no significant difference in biomass among varieties. The trend in biomass weight was Tsp + inoculant + nitrogen > Tsp + nitrogen > Tsp+I > and shows that nitrogen, and/or Tsp improved vegetative growth. This implies that omission of N and Tsp from soybean production could reduce biomass yield as suggested by Bekere *et al.* (2012) and, Bekere and Hailemariam (2012).

5.8 Number of pods per plant and Pod weight

Higher pod number was observed on genotype N19, N102 and N105 respectively. However, N19 genotype produced statistically greater number of pods per plant than other genotypes. This observation can be attributed to its growth habit and its genetic make-up which gave it a slight superiority over others in terms of pod number. This is in consonance with the report by Bouquet (1998) that, genotype selection is one of the most important factors for increasing pod yield in soybean. Ahmad and Mohammed (2004) also reported inherent genotypic differences among seed number per pod in pigeon pea. The finding of this study agrees with the work of Umeh *et al*. (2011) who observed that, the varieties of soybean used in the Guinea Savanna zone of Nigeria responded differently to the number of pods.

The pod weight was influenced statistically ($P=0.042$) by mineral fertilization and inoculant application (Figure 20). The greatest pod weight by Tsp + inoculant could be attributed to the presence of Tsp in the treatment combination as the treatments which contained Tsp produced heavier pods than the other treatment combinations. Nitrogen usage did not positively affect dry weight and number of pods per plant. Jalaluddin

(2005) support this finding. Khan (2000) reported that Phosphorus utilization and Rhizobium inoculation statistically enhance formation of pods, grain yield and production of dry matter as compared with un-inoculated treatments.

5.9 100 grain weight

The least 100 seed weight recorded by N19 though it produced the highest number of pods could be linked to the fact that N19 is a late maturing genotype and was affected by climatic conditions. There was water stress during pod filling stage; N19 could not fill its pods before the draught set in because it's late maturing genotype. Turk *et al.* (1980) in their work indicated that individual seed weight was mostly impacted by genetic make-up except in cases of extreme drought and hot desiccating winds causing forced maturity. Konlan *et al.* (2013) reported low 100 weight grain because of water stress at pod filling stage. The results also agreed well with the work of Masoumi *et al.* (2011) and Behtari and Abadiyyan (2009) who reported that soybean yield could significantly be decreased due to reduction in availability of soil moisture during flowering and pod filling periods.

Genotypes N135, N119 and Jenguma variety are early maturing types which flowered earlier than genotype N19. The significant difference exhibited by the genotypes in this study is similar to earlier observations by Tamiru *et al.* (2012) who found that variety showed significant difference in 1000 seed weight but contrary to their findings, Alam *et al*. (2009) stated that variety did not show significant difference in 100 seed weight

5.10 Grain yield

Grain yield is a function of interaction among various yield components such as number of pods produced which are affected differently by the growing conditions and crop management practices. Genotypic difference played a significant role on the grain yield in the first phase since the only variable factor was the different genotypes while every other factor was the same. The greatest grain yield by N119 during the screening phase could be attributed to its ability to utilize environmental conditions as an early maturing genotype.

The significant interaction between soybean genotypes and fertilization could be attributed to differences in response of genotype to fertilizer regimes. Jenguma gave the highest grain yield when treated with Tsp combined + inoculants (4.062 t/ha) which is statistically similar to Jenguma treated with Tsp + inoculant + nitrogen (3.862 t/ha). The result of this experiment is in agreement with the findings of Ebenezer *et al*. (2019) in relation to Jenguma who reported that soybean variety treated with Tsp combined with inoculant recorded higher grain yield per hectare than other treatment combinations. The findings of Ebenezer *et al.* (2019) contradicts this studies result in relation to N19, N135 and N119 because these genotypes combination with Tsp + N, Tsp + N and Tsp + N +I, respectively gave the highest grain yield. However, generally, Tsp, N or I, a combination of two or three enhanced grain yield. Similar research that supports findings of this study is Jalaluddin (2005). Khan (2000) stated that pod formation and grain yield are significantly enhanced with the application of phosphorus and rhizobium inoculant as compared with un-inoculated treatments.

5.11 Economic cost analysis

Information on costs and benefits of treatments is a prerequisite for adoption of technical innovation by farmers (Das *et al.,* 2010). The use of booster N in the production of soybean was connected with the least production cost among the technologies used except for the control. Tsp + inoculant + N recorded the highest revenue generation and also the highest cost. Rhizobia inoculants + Tsp treatment on soybean resulted in greater yields and is comparatively cheaper than Tsp + inoculant + booster N application while the control gave the least cost ratio but a higher benefit than sole N fertilizer (Table 4). From the observations on comparative analyses of the technologies used in soybean production, it is advisable for farmers to go for Tsp + inoculants as soybeans treatment since this will give a higher yield with reduced cost. The higher the yield the greater the income. The findings of this research is contrary to Adegeye and Dittoh (2011) who stated that, the higher the benefit: cost ratio, the higher the gain derived from the use of the given production system.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusions

The experiment was carried out in two phases. The first phase was to screen high-yield soybean genotypes under optimum phosphorus fertilizer and the second phase was to determine the effect of nitrogen and phosphorus mineral fertilization and rhizobium inoculation on screened and selected high-yield soybean genotypes in Northern Ghana. Data were collected on the following parameters: plant height days to 50% flowering, leaf area, number of primary branches, percentage effective nodules, number of nodules, nodule dry weight, biomass dry weight, number of pods per plant, pod weight, 100 seed weight and grain yield.

The results show that the tallest plants were observed in genotype N19. Jenguma recorded the highest percentage of effective nodule. Tsp + inoculant + nitrogen recorded the highest biomass dry weight at 8th week after planting. Triple superphosphate + nitrogen + inoculant recorded the greatest number of leaves and biomass. Triple superphosphate + inoculant gave the greatest number of nodules and effective nodule percentage.

The interaction between genotype N19 treated with Tsp + inoculant + nitrogen recorded the largest leaf area on 6 and 10WAP. The same combination also recorded the highest number of primary branches per plant. There was interaction effect between genotype and fertilization (*P=0.039*) on grain yield. Triple superphosphate + inoculant on Jenguma recorded the highest grain yield (4.062 t/ha) which was significantly similar to Tsp + nitrogen + inoculant application on Jenguma (3.863 t/ha) followed by Tsp + inoculant application on genotype N135.

The findings indicate that generally, combinations of two or three of triple superphosphate, booster nitrogen and inoculant enhanced grain yield depending on genotype used. For this study, combination of triple superphosphate plus inoculant is required for maximum growth and yield of Jenguma soybean. From the observations on comparative analyses of technologies used in this study, it is advisable for farmers to go for Tsp + inoculant with the Jenguma variety; this will give a higher yield with reduced cost and result in increased profitability.

6.2 Recommendations

As genotype N135 performed better in terms of yield, when genotype N135 was treated with Tsp + booster nitrogen (3.743 t/ha), further research work should be conducted on the genotype N135 for subsequent release as a variety in Ghana and for cultivation by the farmers in the Guinea Savanna Agro-Ecological Zone of Ghana. Irrespective of the genotype used, farmers are recommended to use either triple superphosphate or inoculant or booster nitrogen and its combination to improve yield. Finally, further study is recommended over a period in the study area to confirm and validate the findings of this research.

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APPENDICES

Appendix 1: Plant height at maturity

Source of variation	**d.f**	**s.s**	**m.s**	**v.r**	**F pr.**
ID	99	52288.44	528.17	17.03	<.001
Residual	200	200	6204.41	31.02	
Total	299	58492.85			

Appendix 2: Days to 50% flowering

Source of variation	**d.f**	**s.s**	**m.s**	**v.r**	**F pr.**
ID	99	5078.667	51.300	14.66	<.001

Residual	200	700.000	3.500
Total	299	5778.667	

Appendix 3: Leaf area index

Source of variation	d.f	s.s	m.s	v.r	F pr.
ID	99	1.613899	0.016302	2.12	<.001
Residual	200	1.535922	0.007680		
Total	299	3.149822			

Appendix 4: Number of pods

Source of variation	d.f	s.s	m.s	v.r	F pr.
ID	99	84763.3	856.2	4.72	<.001
Residual	200	36274.4	181.4		
Total	299	121037.6			

Appendix 5:100 grain yield

Source of variation	d.f	s.s	m.s	v.r	F pr.

ID	96	2.468E-03	2.571E-05	10.68	<.001
Residual	183	4.403E-04	2.406E-06		
Total	279	2.908E-03			

Appendix 6: Grain yield

Source of variation	**d.f**	**s.s**	**m.s**	**v.r**	**F pr.**
ID	99	17688317	178670	4.26	<.001
Residual	200	8388327	41942		
Total	299	26076644			

Appendix 7: Plant height at 6 weeks after plant (WAP)

Source of variation	**d.f**	**s.s**	**m.s**	**v.r**	**F pr.**
REP stratum	2	2.31	1.16	0.02	
REP.FERTILIZER stratum					
FERTILIZER	6	553.85	92.31	1.67	0.212
Residual	12	664.15	55.35	5.01	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	224.99	75.00	6.79	<.001
FERTILIZER.VARIETY	18	33.12	18.40	1.67	0.087
Residual	42	463.88	11.04		
Total	83	2240.31			

Appendix 8: Plant height at 8 weeks after planting (WAP)

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	21.91	10.96	0.09	
REP.FERTILIZER stratum					
FERTILIZER	6	1088.73	181.45	1.46	0.273
Residual	12	1496.25	124.6	6.63	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	1172.95	390.98	20.79	<.001
FERTILIZER.VARIETY	18	668.58	37.14	1.98	0.065
Residual	42	789.85	18.81		
Total	83	5238.27			

Appendix 9: Plant height at 10 weeks after planting (WAP)

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	16.78	8.39	0.07	
REP.FERTILIZER stratum					
FERTILIZER	6	822.9	137.16	1.07	0.433
Residual	12	1543.72	128.64	3.35	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	7903.50	2634.50	68.53	<.001
FERTILIZER.VARIETY	18	725.4	40.30	1.05	0.432
Residual	42	1614.64	38.44		
Total	83	12627.04			

Appendix 10: Days to 50% flowering

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	13.649	6.824	1.41	
REP.FERTILIZER stratum					
FERTILIZER	6	36.363	6.061	1.25	0.349
Residual	12	58.226	4.852	0.96	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	4542.08	1514.027	299.07	<.001
FERTILIZER.VARIETY	18	93.232	5.180	1.02	0.456
Residual	42	212.625	5.063		
Total	83	4956.176			

Appendix 11: Leaf area at 6 weeks after planting (WAP)

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	295.8	147.9	0.29	
REP.FERTILIZER stratum					
FERTILIZER	6	10994.9	1832.5	3.57	0.029
Residual	12	6166.6	513.9	3.24	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	3893.5	1297.8	8.19	<.001
FERTILIZER.VARIETY	18	4499.8	250.0	1.58	0.111
Residual	42	6654.5	158.4		
Total	83	32505.1			

Appendix 12: Leaf area at 8 weeks after planting (WAP)

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	748.8	374.4	0.80	
REP.FERTILIZER stratum					
FERTILIZER	6	14783.7	2463.9	5.28	0.007
Residual	12	5596.8	466.4	2.32	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	8310.5	2770.2	13.80	<.001
FERTILIZER.VARIETY	18	3668.8	203.8	1.02	0.463
Residual	42	8428.3	200.7		
Total	83	41536.8			

Appendix 13: Leaf area at 10 weeks after planting (WAP)

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	946.03	473.01	0.82	
REP.FERTILIZER stratum					
FERTILIZER	6	12208.60	2034.77	3.51	0.031
Residual	12	6955.64	579.64	7.50	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	9943.72	3314.57	42.90	<.001
FERTILIZER.VARIETY	18	1517.96	84.33	1.09	0.393
Residual	42	3245.96	77.27		
Total	83	34817.14			

Appendix 14: Number of nodules

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	2809.0	1404.0	1.05	
REP.FERTILIZER stratum					
FERTILIZER	6	53710.0	8952.0	6.72	0.003
Residual	12	15990.0	1333.0	1.12	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	5401.0	1800.0	1.51	0.226
FERTILIZER.VARIETY	18	30033.0	1668.0	1.40	0.182
Residual	42	50088.0	1193.0		
Total	83	158031.0			

Appendix 15: Effective nodules percentage

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	0.07326	0.03663	0.37	
REP.FERTILIZER stratum					
FERTILIZER	6	1.81734	0.30289	3.09	0.045
Residual	12	1.17539	0.09795	3.51	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	0.51631	0.17210	6.17	0.001
FERTILIZER.VARIETY	18	0.74963	0.04165	1.49	0.141
Residual	42	1.17094	0.02788		
Total	83	5.50286			

Appendix 16: Number of leaves at 6 weeks after planting (WAP)

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	101.04	50.52	0.56	
REP.FERTILIZER stratum					
FERTILIZER	6	1154.81	192.47	2.15	0.123
Residual	12	1076.47	89.71	2.18	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	2300.19	766.73	18.67	<.001
FERTILIZER.VARIETY	18	1284.07	71.34	1.74	0.071
Residual	42	1724.74	41.07		
Total	83	7641.32			

Appendix 17: Number of leaves at 8 weeks after planting (WAP)

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	955.5	477.8	0.96	
REP.FERTILIZER stratum					
FERTILIZER	6	19166.9	3194.5	6.43	0.003
Residual	12	5961.6	496.8	2.19	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	5425.8	1808.6	7.99	<.001
FERTILIZER.VARIETY	18	3378.2	187.7	0.83	0.658
Residual	42	9509.9	226.4		
Total	83	44397.9			

Appendix 18: Number of leaves at 10 weeks (WAP)

Source of variation	**d.f**	**s.s**	**m.s**	**v.r**	**F pr.**
REP stratum	2	497.9	248.9	0.24	
REP.FERTILIZER stratum					
FERTILIZER	6	10306.3	1717.7	1.65	0.217
Residual	12	12512.5	1042.7	3.22	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	3872.0	1290.7	3.99	0.014
FERTILIZER.VARIETY	18	10282.4	571.2	1.77	0.065
Residual	42	13583.2	323.4		
Total	83	51054.2			

Appendix 19: Number of primary branches

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	0.6270	0.3135	0.43	
REP.FERTILIZER stratum					
FERTILIZER	6	20.8307	3.4718	4.74	0.011
Residual	12	8.7804	0.7317	1.22	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	27.3796	9.1265	15.22	<.001
FERTILIZER.VARIETY	18	6.1852	0.3436	0.57	0.899
Residual	42	25.1852	0.5996		
Total	83	88.9881			

Appendix 20: Biomass dry weight at 10 week (WAP)

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	99.91	49.95	1.55	
REP.FERTILIZER stratum					
FERTILIZER	6	816.26	136.04	4.22	0.016
Residual	12	386.98	32.25	0.64	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	45.08	15.03	0.30	0.827
FERTILIZER.VARIETY	18	477.37	26.52	0.53	0.929
Residual	42	2119.39	50.46		
Total	83	3944.98			

Appendix 21: Number of pods per plant

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	3317.0	1659.0	0.20	
REP.FERTILIZER stratum					
FERTILIZER	6	37582.0	6264.0	0.75	0.619
Residual	12	99709.0	8309.0	1.87	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	33048.0	11016.0	2.48	0.074
FERTILIZER.VARIETY	18	37087.0	2060.0	0.46	0.960
Residual	42	186531.0	4441.0		
Total	83	397274.0			

Appendix 22: Pod weight

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	0.0013160	0.0006580	2.27	
REP.FERTILIZER stratum					
FERTILIZER	6	0.0054875	0.0009146	3.16	0.042
Residual	12	0.0034713	0.0002893	2.34	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	0.0001860	0.0000620	0.50	0.683
FERTILIZER.VARIETY	18	0.0021379	0.0001188	0.96	0.517
Residual	42	0.0051842	0.0001234		
Total	83	0.0177830			

Appendix 23: 100 grain weight

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	1.826E-05	9.129E-06	0.53	
REP.FERTILIZER stratum					
FERTILIZER	6	1.162E-04	1.937E-05	1.12	0.405
Residual	12	2.071E-04	1.726E-05	2.23	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	3.609E-04	1.203E-04	15.51	<.001
FERTILIZER.VARIETY	18	7.536E-05	4.187E-08	0.54	0.920
Residual	4	3.180E-04	7.755E-06		
Total	82	1.016E-03			

Appendix 24: Grain yield

Source of variation	d.f	s.s	m.s	v.r	F pr.
REP stratum	2	5.9879	2.9940	1.26	
REP.FERTILIZER stratum					
FERTILIZER	6	23.3147	3.8858	1.64	0.220
Residual	12	28.4639	2.3720	4.50	
REP.FERTILIZER.VARIETY stratum					
VARIETY	3	64.9604	21.6535	41.10	<.001
FERTILIZER.VARIETY	18	18.4847	1.0269	1.95	0.039
Residual	41	21.5996	0.5268		
Total	82	151.4902			