UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECT OF GENOTYPE AND PLANT POPULATION ON GROWTH, NITROGEN FIXATION AND YIELD OF SOYBEAN (*Glycine max.* L. MERRILL) IN GUINEA SAVANNA AGRO-ECOLOGICAL ZONE OF GHANA.

KUMAH GIFTY

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BY

KUMAH GIFTY (BSc AGRICULTURE TECHNOLOGY)

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DECLARATION

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

(Student's Signature)……………………. Date ……………………………..

Name: Gifty Kumah

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

(Principal supervisor's Signature)…………………… Date…………………………

Name: Dr. Rufai Ahmed Mahama

(Co-supervisor's Signature)……………………….. Date…………………………

Name: Dr. Raphael Adu-Gyamfi

(External supervisor's Signature)………………….. Date…………………………

Name: Prof. Samuel Adjei-Nsiah

ABSTRACT

An experiment was conducted in the Savelugu/Nanton Municipality in the Guinea Savanna zone of Ghana from July 2015 to December 2015 to evaluate the **e**ffect of four soybean genotypes and three plant spacing on nitrogen fixation, growth and yield of soybean. The experiment was conducted in a split-plot design and replicated in four different communities. The main plots consisted of four soybean genotypes: TGX 1904-6F, TGX 1955-4F, Soung-pungun and Jenguma. The sub-plots were made up of three plant spacing: 45 by 10 cm, 60 by 10 cm and 75 by 10 cm. Seeds were planted two per stand. The number of days to 50% flowering was influenced by soybean genotype with Soung-pungun taking the shortest time to flower while Jenguma took the longest time to flower. Both the number of nodules per plant and nodule dry weight were not significantly influenced by genotype nor plant spacing ($p<0.05$). Biomass yield at mid-podding varied from 4324 kg/ha with Soung-pungun to 7163 kg/ha with TGX 1955-4F with significant differences among genotypes. Plant spacing also significantly influenced biomass yield. Biomass yield ranged from 4830 kg/ha with 75 x 10 cm spacing to 6769 kg/ha with the 45 x 10 cm spacing. There were no significant differences between genotypes or plant spacing with regard to percentage N fixed but the amount of N fixed differed significantly among genotypes and among plant spacing. Both grain and biomass yields at harvest were not significantly influenced by genotype or plant spacing. However, Jenguma appears to be better in terms of grain and biomass yield than the other genotypes. Giving the changing climate Soung-pungun appears to be better placed for adaptability due to its early maturing nature and its comparable yield with Jenguma.

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I wish to express my heartfelt gratitude to my pastor and his wife, Rev. and Mrs. Agbaku, my course mates, IITA workers (Tamale-Ghana), AGCM Nyankpala members and all friends who helped me in diverse ways.

DEDICATION

To my mother Beatrice Kunkah, father Simon Awayiwu and my uncle Clement Tengey.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Soybean (*Glycine max* (L) Merrill) is an important legume crop that grows in the tropical, subtropical and temperate climates (Thuzar *et al.*, 2010). Soybean belongs to the botanical family Leguminosae. It is an economically important crop grown worldwide and also one of the most important legume in Ghana (Plahar, 2006). The crop is well adapted to many soil types and climatic conditions. It is a native of eastern Asia, originally growing wild in China, Manchuria, Korea and Japan.

According to Ennin-Kwabiah and Osei-Bonsu (1993) cited by Ennin *et al.* (2002), it has high protein content, ranging from 36 to 56% of the dry weight which is approximately double the protein content of the indigenous legumes, cowpea (19% - 35%) and groundnut (25% - 30%). Therefore, Soybean has the potential of providing an inexpensive source of protein for both human consumption and animal feed preparation. Soybean, like most legumes, meet most of its nitrogen needs by establishing a symbiotic relationship with the bacterium *Bradyrhizobium japonicum*, and they can fix as much as 120 kg N/ha during a growing season (Giller, 2001).

According to Ugwu and Ugwu (2010), the benefits of soybean over other grain legumes such as groundnut and cowpea include lower susceptibility to pests and diseases, better storage quality and larger leaf biomass which translates into soil fertility benefits to subsequent crops. Even though soybean is a relatively new crop in Ghana (Akramov and Malek, 2012), it is increasingly playing an important role in the rural economy of farm households in Northern Ghana, and especially the eastern corridor of the Northern Region of the country. Northern region alone contributes about 70 percent of national land acreage cropped to soybean and about 77 percent of national production (SRID, 2012).

The introduction of soybean into Ghana through official channels began in 1909. The aim of the introduction was to get farmers to grow the soybean as an additional food and a possible export crop (Addai, 2001).

Etwire *et al.* (2013 a) reported that the crop is gaining popularity and acceptance among farmers in Ghana, mainly due to availability of ready market.

There has also been an increased interest in soybean production in Ghana for the past decade because of the government's policy to encourage its development, production and utilization in the country, within the framework of the Medium Term Agricultural Development Programme (Akramov and Malek, 2012). As such, soybean is becoming an important cash crop and is used in a variety of ways such as source of protein in local diets, vegetable oil, livestock feed and other industrial products (Dapaah *et al.*, 2005). According to Etwire *et al*. (2013 b) most agricultural interventions such as Youth in Agriculture Program, Northern Rural Growth Program, Savannah Accelerated Development Authority projects, Alliance for a Green Revolution in Africa (AGRA) projects, Danish International Development Authority projects, United States Agency for International Development projects, among others, are also promoting the production and utilization of the soybean crop mainly through value chain enhancements in the northern part of Ghana. Also Ghana’s Council for Scientific and Industrial Research (CSIR), Ministry of Food and Agriculture (MoFA) as well as its development partners have been promoting soybean production because of its potential to increase income and enhance nutritional status of households (Mbanya, 2011). While domestic production of soybean in Ghana currently stands at about 141,500 metric tons annually, total domestic demand is estimated at nearly 182, 100 metric tons per year giving a shortfall of about 40,600 metric tons (USAID, 2013).

In order to meet the country's domestic oil demand for household consumption and soymeal requirement for the fish and poultry industries, Ghana imports large quantities of soybean oil and soy meal annually. Although under field conditions, soybean could yield as much as 3 metric tons/ha, yields of soybean currently hovers around one metric ton/ha (Tweneboa, 2000) and this has been attributed to several factors including poor crop establishment, use of poor quality seeds, lack of effective nodulation, inherently low soil fertility levels and sub-optimal plant population (Lawson *et al.,* 2008). These factors can create a great challenge in meeting the soybean requirements of an increasing fish and poultry industry.

Other reasons attributed to the low yields of soybean in Ghana include low plant population per hectare for various cultivars of the crop, pod shattering, poor germination due to rapid loss of seed viability, poor nodulation and drought stress according to Addo-Quaye *et al* (1993). The low plant population is due to lack of adequate information on specific row spacing that will allow optimum plant population for the various soybean varieties cultivated locally.

Sowing rate or plant population density, sowing date, planting method and sowing depth are important factors that affect crop establishment and utilization of light, water and nutrients, thus, affecting the yield and productivity of a crop (Johnson, 1987). Grain yield was higher when soybean was planted at 45 cm than when planted at 60 cm or 75 cm (Dapaah *et al.*, 2005). Available research data on soybean planting systems give a broad range of spacing from 60 - 75 cm inter-row spacing and 5 - 10 cm intra-row spacing, giving an average of 299,999 plants ha^{-1} (MoFA and CSIR, 2005). This is irrespective of factors such as the maturity group, growth habit, soil condition and agro-ecological zone. This makes choice of optimal population densities among early and medium maturity soybean varieties difficult for farmers. Generally, legume seed yield is a function of plants per unit area, pods per plant, number of seeds per pod and weight per seed (Fageria *et al.,* 2010). Board *et al.* (2010) reported that soybean yield is equal among low, medium and high plant populations due to higher relative leaf expansion rates and increased light interception in the lower populations. Similar yield among different populations have been attributed to changes in dry matter partitioning in branches due to differences in light quality among the different plant populations (Board *et al.,* 2011).

Mbanya (2011) observed that many farmers in the Northern Region of Ghana do not use improved technologies such as row planting, fertilizer application and good management practices on their farms. Over the past decade some varieties of soybean have been released for cultivation by farmers.

With the release of new improved soybean varieties, knowledge on their potential and performance under different cultural practices are required. Thus there is a need for farmers to know the optimum plant spacing to use for specific varieties to achieve optimum yield. In soybean, optimum plant spacing is essential for achieving optimum plant stand at harvest. With their attendant effects on radiation interception and crop competition for growth resources, plant population density can limit yield of most crops.

In global agriculture, soil fertility is maintained through inorganic fertilizer application, but it costs two to six times more in Africa than anywhere else in the world at the farm gate (Sanchez, 2001). This leads to high cost of production and is expensive for smallholder farmers and therefore there is the need for an alternative to chemical fertilizers. Nitrogen is the key nutrient element, limiting crop production under most situations (Azarmi, 2001). Grain legumes can access atmospheric N through symbiosis with soil-inhabiting bacteria collectively known as rhizobia and therefore require minimal N fertilizer input.

Over the years, several legume crops were screened and adopted for inclusion into the farming systems for soil fertility improvement and restoration, but none has received the expected acceptance and inclusion like soybean by the smallholder farmers as it meets the food, fodder and fertilizer needs of the farmers (Aniekwe and Mbah, 2014). However, the amount of nitrogen contributed to the system depends on the amount of N fixed by the soybean genotype which also depends on the amount of biomass produced.

The study is aimed at evaluating the effect of plant population on the yield and yield components of different soybean genotypes and to evaluate the effect of plant population on growth, nodulation and nitrogen fixation in different soybean genotypes. This study also sought to evaluate the performance of different soybean genotypes in the southern Guinea Savanna Agro-ecological zone of Ghana. The high protein content of soybean which is double of other indigenous legumes (cowpea, groundnut), its ability to fix nitrogen and the high demand in the international market, makes the crop very important especially in the southern Guinea Savanna Agro-ecological zone of Ghana, which will enable farmers to improve their household income and also to improve the fertility of their soils.

1.2 Problem Statement and Justification

Farmers lack knowledge of the right population or planting distance of soybean for optimum yield. (Andrade *et al.*, 2005). This has led to low output per unit area of land. Also farmers lack specific knowledge on the various genotypes and their individual planting distances; they use one specific planting distance for all soybean genotypes, which might not favour some of the genotypes, hence their low output. Soybean genotypes are genetically different from each other and therefore their ability to fix nitrogen and use of nitrogen may be different. There is the need therefore to identify appropriate planting distance for each of the four selected genotypes, the amount of nitrogen fixed by each of them and at the end provide information that farmers may be able to utilise for sustainable cultivation of soybean in Northern Ghana for improved productivity and soil fertility.

1.3 Objectives

1. To evaluate the effect of plant population on the yield and yield components of different soybean genotypes

2. To evaluate the effect of plant population on growth, nodulation and nitrogen fixation in different soybean genotypes.

3. To evaluate the growth and yield performance of different soybean genotypes in the Guinea Savanna Agro-ecological zone of Ghana.

CHAPTER TWO

LITERATURE REVIEW

2.1 Family and Botany

Soybean (*Glycine max* (L) Merrill) like peas, beans, lentils and peanuts, belongs to the large botanical family Leguminosae, in the subfamily Papilionidae, and is well adapted to many soil types and climatic conditions. The genus *Glycine*, consists of two subgenera, *Soja* and *Glycine*. Subgenus *soja* includes *Glycine max* and its annual wild relative *Glycine soja* which are native to eastern Asia, throughout China, Japan, Korea and part of Russia (Chen *et al.,* 2015).

The crop grows well in the tropical, subtropical and temperate climates (Oyekanmi *et al.*, 2007). Plant breeders have argued that within the soybean species, there are varieties which react differently to photoperiod, and classified them as long day, short day and day neutral plants (Borget, 1992). Singh *et al.* (2007) described soybean as being typically a short day plant, physiologically adapted to temperate climatic conditions. However, some have been adapted to the hot, humid, tropical climate. This affects the extent of vegetative growth, flower induction, production of viable pollen, length of flowering, pod filling and maturity characteristics (Norman *et al.*, 1995).

Soybean plant has 46 chromosomes (2n=2x=40) and it is a self-fertile species with less than 1% out-crossing (Shurtleff and Aoyagi, 2007; IITA, 2009). The optimum temperature for soybean is 20 – 30^{0}C, with temperatures of 35^{0}C and above considered inhibitory to production. The optimum rainfall amount is between 350 mm and 750 mm, well distributed throughout the growth cycle (Ngeze, 1993). Soybean is a short day plant and therefore, flowers in response to shortening days. Each variety has a critical day length that must be reached before it will start to flower .The best time to plant soybeans is between early and late June depending on the rains in Northern Ghana. Soybeans prefer fertile, well drained, loamy soils. Drought is a major limiting factor for soybean in the early wet season in respect to germination (Luo *et al.*, 2013).

”Soya" (or "Soy" in the United States), is a dicotyledonous plant that exhibits epigeal emergence. During germination, the cotyledons are pushed through the soil to the surface by an elongating hypocotyl. Because of the energy required to push the large cotyledons through heavy soils, soybean generally emerges best if they are planted no deeper than 5 cm. After emergence, the green cotyledons open and supply the developing leaves with stored energy, while capturing a small amount of light energy (Fehr *et al.*, 1971). The first leaves to develop are the unifoliolate leaves. Two of these single leave appear directly opposite one another above the cotyledons. All subsequent leaves are trifoliolates, comprised of 3 leaflets (Mahama, 2011).

Soybean development is characterized by two distinct growth phases. The first is the vegetative stages that cover development from emergence through flowering. The second is the reproductive stages from flowering through maturation. Plant stages are determined by classifying leaf, flower, pod, and or seed development (Fehr *et al.*, 1971; Gary and Dale, 1997).

The flowers are either purple or white, and are borne in auxiliary racemes on peduncles at the nodes. The papilionaceous flower consists of a tubular calyx of five sepals, a corolla of five petals (one banner, two wings and two keels), one pistil and nine stamens with a single separate posterior stamen. The stamens form a ring at the base of the stigma and elongate one day before pollination, at which time the elevated anthers form a ring around the stigma and are self-pollinated (Acquaah, 2007).

The plant produces a large number of flowers, but only about two-thirds to three quarters of them produce pods (Acquaah, 2007). The pods are also pubescent and range in colour from light-yellow to black. They are usually straight or slightly curved in shape, vary in length from two to seven centimeters, and consist of two halves of a single carpel which are joined by a dorsal and ventral suture.

The pod usually contains one to three seeds (occasionally four) (Asafo-Adjei, 2005). The shape of the seed, usually oval, can vary amongst cultivars from almost spherical to elongated and flattened. The seeds are usually uncoloured and may be straw yellow, greenish-yellow green, brown, or black (Acquaah, 2007). Bicoloured seeds exist, such as yellow with a saddle of black or brown. The hilum is also coloured with various patterns such as yellow, buff, brown or black (Acquaah, 2007).

2.2 Origin and Distribution

Soybean is one of the oldest cultivated crops, but its early history is lost in antique. The first domestication of soybean has been traced to the eastern half of North China in the eleventh century B.C. or perhaps a bit earlier. Soybean has been one of the five main plant foods of China along with rice, wheat, barley and millet (Gibson and Benson, 2005). According to early authors (Hymowitz, 1984; Wilcox, 1987; Shurtleff *et al.,* 2014), soybean production was localized in China until after the Chinese-Japanese war of 1894-95, when the Japanese began to import soybean oil cake for use as fertilizer. Shipments of soybeans were made to Europe about 1908, and the soybean attracted world-wide attention. Europeans had been aware of soybeans as early as 1712 through the writing of a German botanist (Bertheau and Davison, 2011). It is believed that some soybean seed may have been sent from China by missionaries as early as 1740 and planted in France (Gibson and Benson, 2005).

The first written reference to soy appears in a list of Chinese plants from 2853 B.C. Soybean is also referred to many times in ancient writings as one of the five grains essential to Chinese civilization. Western contact with soybeans and soy foods was limited until Asians began to emigrate in large numbers to Europe and the U.S. in the 1800s. The crop grows in the tropical, subtropical and temperate climates regions (Evans, 1996).

Soy has been grown for three millennia in Asia and more recently, has been successfully cultivated around the world. Today, the world's top producers of soy are the United States, Brazil, Argentina, China and India (USDA, 2007).

Soybean was first introduced to Africa in the early 19th century, through Southern Africa (Ngeze, 1993) and is now widespread across the continent (Wikipedia, 2009). However, Shurtleff and Aoyagi (2007) have stated that, it might have been introduced at an earlier date in East Africa, since that region had long traded with the Chinese. The same report indicates that soybean has been under cultivation in Tanzania in 1907 and Malawi in 1909.

In Ghana, the Portuguese missionaries were the first to introduce the soybean in 1909. This early introduction did not flourish because of the temperate origin of the crop (Mercer-Quarshie and Nsowah, 1975). However, serious attempts to establish the production of the crop in Ghana started in the early 1970s. This was as a result of collaborative breeding efforts of Ghana's Ministry of Food and Agriculture (MoFA) and the International Institute of Tropical Agriculture (IITA) (Tweneboah, 2000).

A team from the International Soybean Programme (INTSOY) in Illinois, USA around 1977 prepared programme for soybean development in the country for the Grains and Legumes Development Board (GLDB) in Ghana and USDA. Their aim was to assist the Ghanaian government to design a five-year national soybean production, processing and utilization programme. GLDB and INTSOY projected that by 1978 about 4,800 ha of soybeans would be cultivated in Ghana and the nation would hence be self-sufficient in soy oil and meal and by 1982 over 50,000 acres of soybeans would be planted annually in Ghana respectively. (Mercer-Quarshie and Nsowah, 1975).

Soybean production in Ghana and Africa is low compared to other countries and continent. (Addai, 2001). According to FAO (1982), production of soybean in Africa is about 0.05% of the world total. While the United States, the leading soybean production in the world harvest an average of over 2,000 kg/ha on its 27 million hectares of land in 1981, Africa countries harvest just over 900 kg/ha on 300,000 ha.

The crop is cultivated mainly in the Northern, Upper West, Upper East, and Northern Volta regions in Ghana. Among these geographical regions, the largest production occurs in Northern Ghana, which lays within the Guinea savannah and Sahel agro-ecological zones (Lawson *et al.*, 2008).

The optimum temperature for soybean is 20 - 30^{0}C, with temperatures of 35^{0}C, and above considered inhibitory to production. The optimum soil temperature for germination and early seedling growth is 25 to 30^{0}C.

Soybean can grow and yield with as little as 180 mm of in-crop rain but could expect a 40 - 60 percent yield decline compared to optimal conditions.

2.3 Importance of Soybean

Soybeans actually have hundreds of uses from industrial products like engine oil or crayons to food products and animal feeds. Soybeans are naturally rich in protein and oil and they have the highest natural source of dietary fiber, making them a very versatile crop in terms of how it is used. The soy cake is an excellent source of protein feed for the livestock industry in Ghana (MoFA and CSIR, 2005).

Aside from being a major source of quality protein and vitamin E, soy foods contain isoflavones, which seem to play a role in reducing the risk of heart attack, osteoporosis, breast cancer and prostate cancer (The Mirror, 2008). Packed with calcium, fiber and protein, soybeans are a healthy choice. The soybean, often referred to as the miracle crop, provides a sustainable source of protein and oil worldwide. Soy's properties allow its use in a variety of applications from animal feed and human consumption, to road fuel and other industrial uses (Abbey *et al.*, 2001; Caminiti *et al.*, 2007; Dugje *et al.*, 2009). Because soy grows throughout the world, it represents a viable and renewable replacement for petrochemicals. Soy oil is also used in industrial paint, varnishes, caulking compounds, linoleum, printing inks, and other products. A 27 kg of soybeans yields about 5 kg of oil and about 22 kg of meal (Gibson and Benson, 2005).

According to Masuda and Goldsmith (2009), soybeans are not only a valuable source of feed for livestock and fish but also a good source of protein for human diet. El- Agroudy *et al.* (2011) reported that soybeans contain 30 percent cholesterol free oil, 40 percent protein and also contain most essential vitamins required by human beings. As far as the soybean nutritional value is concerned, soybean serves as an excellent source of essential fatty acids, calcium, magnesium, lecithin, riboflavin, thiamine, fibre, foliate (folic acid), and iron. It aids in protecting the heart against oxidation (Page, 1998). Also, soybean powder is used for various preparations of food and drinks for babies and adult, such as mixing with pap for babies and even adults. According to Ennin-Kwabiah and Osei-Bonsu, (1993) cited by Ennin *et al.,* (2005), soybean has high protein content, ranging from 36 to 56% of the dry weight which is approximately double the protein content of the indigenous legumes, cowpea (19% - 35%) and groundnut (25% - 30%). Therefore soybean has the potential of providing an inexpensive source of protein both for human consumption and animal feed preparation. Soybeans, like most legumes, meet most of its nitrogen needs by establishing a symbiotic relationship with the bacterium *Bradyrhizobium japonicum.* Soybean like all other legumes also improves soil fertility by converting atmospheric nitrogen from the soil for its own use, which also benefits subsequent crops in rotation. It therefore reduces the amount of nitrogen fertilizer that farmers have to purchase to apply to their fields to improve productivity. This is an important benefit in Africa (Ghana; Southern Guinea Savanna), where soils are poor in nutrients and fertilizers are expensive and not available for farmers (MoFA and CSIR, 2005; IITA, 2009). They can fix as much as 120 kg N/ha during a growing season (Giller, 2001).

About 85 percent of the world's soybeans are processed, or "crushed," annually into soybean meal and oil (Reenberg and Fenger, 2011). Approximately 98 percent of the soybean meal that is crushed is further processed into animal feed with the balance used to make soy flour and proteins. Of the oil fraction, 95 percent is consumed as edible oil; the rest is used for industrial products such as fatty acids, soaps and biodiesel (Mpepereki *et al.,* 2000).

Promotion of the nutritional and economic values of the crop is being done in Ghana by the Ministry of Food and Agriculture, and this has resulted in rapid expansion in production (Sarkodie-Addo *et al.,* 2006). In West Africa, soybean has become a major source of high quality and cheap protein for the poor and rural households. It is used in processing soy meat, cakes, 'dawadawa' (a local seasoning product for stews and soups), and food for babies, (Abbey *et al.,* 2001). It is also used to fortify various traditional foods such as soups, gari, sauces, stew, kenkey and banku to improve their nutritional levels (MoFA and CSIR, 2005).

Soybean is beneficial in the management of *Striga hemonthica*, an endemic parasitic weed of cereal crops in the savanna zone of Ghana, which causes severe losses in crop yield of up to 70 - 100% of millet, sorghum and maize. Soybean is non-host plant to Striga, but it produces chemical substances that stimulate the germination of Striga seeds. Germinated seeds subsequently die off within a few days because they cannot attach their root system to that of the soybean plant to draw food substances and water (MoFA and CSIR, 2005).

2.4 Growth Requirements of Soybean

2.4.1 Soil and Moisture Requirement

Soil is a critical component in the germination, growth and survival of plants. Soybean is tolerant to a wide range of soil conditions but they prefer warm, moist, fertile, well drained, loamy soils that provide adequate nutrients and good contact between the seed and soil for rapid germination and growth (Hans *et al.,* 1997; Addo-Quaye *et al.,* 1993). However, such soils favour a wide range of other crops. Therefore soybean has to compete with alternative crops based on profitability (Gibson *et al.*, 2008). Different soils influence differently nutrient availability to plants. Soil nutrient availability varies depending on the soil types (Cambardella *et al.*, 1994). Clay, for instance, can retain more nutrients and can slow water movement through the soil, making nitrogen more available (Cambardella *et al.*, 1994). Sandy soil is less effective at holding nutrients, and therefore the soil with appreciable amount of sand particles will render nutrient unavailable for the plant uptake. The compacted soil will have impact on the nutrient availability. Soil compaction can make root permeability difficult for plants (Martono *et al.*, 2007). Aside from root penetration, compacted soil can make water and oxygen movement through the soil difficult (Lipiec and Hatano, 2003). Aerating the soil and mixing the top several inches can loosen the soil, improving soil permeability and increasing movement of water, air and nutrients through the soil. To fully exploit the genetic potential of soybean, it is empirical to provide it with the suitable condition for growth. Rienke and Joke (2002) reported high yields in loamy textured soil, and that if the seeds are able to germinate, they will grow better in clayey soils.

Soybean can be grown on a wide range of soils with pH ranging from 4.5 to 8.5 (measured in calcium chloride) with suitable management. However, soybeans prefer slightly acid soil with the optimal soil pH range of 5.5 to 6.5. They are not tolerant of strongly acid soils (below pH 4.5) as aluminum (Al) and manganese (Mn) toxicity are likely to be a problem on such soils. At the other end of the scale, it is not recommended to grow soybean in soils with pH greater than 8 as micronutrients such as zinc (Zn) and iron (Fe) become deficient (Lin *et al.*, 2005).

Ngeze (1993) reported that, soybean does well in fertile sandy soils with pH of between 5.5 and 7.0, and that the crop can tolerate acidic soils than other legumes but does not grow well in water logged, alkaline and saline soils. According to Ferguson *et al.* (2006), maintaining soil pH between 5.5 and 7.0 enhances the availability of nutrients such as nitrogen and phosphorus, microbial breakdown of crop residues and symbiotic nitrogen fixation.

Soybean plant has a nutrient dense, high protein seed, and therefore, requires high amount of nutrients for its growth (Lamond and Wesley, 2001). It is a legume that can meet its nitrogen needs by symbiotic relationship with nitrogen fixing bacteria of the species *Bradyrhizobia japonicum* from atmospheric nitrogen (Sarkodie-Addo *et al.,* 2006). Generally, soybean plant will not benefit from supplemental nitrogen fertilizer application, where there are indigenous populations of the appropriate Bradyrhizobia bacteria strains that cause effective nodulation of the roots and nitrogen fixation (Darryl *et al.*, 2004). According to Gary and Dale (1997), nitrogen fertilizer application circumvents the benefit of rhizobia bacteria, as the bacteria will not convert atmospheric nitrogen when soil nitrogen is readily available to the plant. However, where soybean has not been grown recently, inoculation of the seed with specific Bradyrhizobia strains is essential for effective nitrogen fixation (Darryl *et al.,* 2004).

Drought is a major limiting factor for soybean in the early wet season in respect to germination, but is not specific to any soil type. Soybean lacks drought tolerance as its roots are relatively shallow and the root structure limits water absorption during dry periods (Fenta *et al.*, 2014). Hence soybean performs poorly on sandy soils and soils with low water storage capacity, such as gravelly or shallow soils, due mainly to drought stress. Low rainfall on clay soils will reduce the chances of seed germination and plant establishment (Zahoor *et al.,* 2013). Jones and Jones (1989) defined water stress as the lack of the amount of soil water needed for plant growth and development, and which in certain cells of the plant may affect various metabolic processes. Direct impacts of drought stress to the physiological development of soybean depend on its water use efficiency (Earl, 2002). In soybean management, water use efficiency is an important physiological characteristic related to the ability of plants to cope with water stress. According to Pospíšilová (1997), grain yield is a function of the amount of water transpired, water use efficiency and harvest index. And soybean, as a C3 plant, is less efficient in water use due to high evapotranspiration and low photosynthetic rates. Pandey *et al.* (1984) observed that, increasing drought stress progressively reduced leaf area, leaf area duration, crop growth rate and shoot dry mater; thus limiting soybean yield. Sionit and Kramer (1977) also reported that, drought stress, during flowering and early pod formation causes greatest reduction in number of pods and seeds at harvest. Low soil moisture with high plant population may cause yield to decrease because of drought stress (Gary and Dale, 1997). Soybeans are susceptible to water logging between emergence and the four leaf stage (Morita *et al.,* 2004). However, after this stage soybean has good tolerance to water logging compared to other non-rice crops. Soybean may also tolerate flood irrigation techniques more effectively than other crops (Farquharson *et al.,* 2006). Adequate soil moisture is needed to initiate seedling growth, but too much or too little can adversely affect soybean emergence.

2.4.2 Temperature and Rainfall

Most legumes require an optimum temperature of between 17.5^{0}C and 27.5^{0}C for development (Ngeze, 1993). For soybean, the minimum temperature at which it develops is 10^{0}C, the optimum being 22^{0}C and the maximum about 40^{0}C. The seeds germinate well at temperatures between 15^{0}C and 40^{0}C, but the optimum is about 30^{0}C (Rienke and Joke, 2002). Addo-Quaye *et al.* (1993) have suggested the optimum temperature for growth as between 23 - 25^{0}C.

Soybean requires optimum moisture for seeds to germinate and grow well. The optimum rainfall amount is between 350 and 750 mm, well distributed throughout the growth cycle (Ngeze, 1993). Addo-Quaye *et al.* (1993) and Rienke and Joke (2002) have described two periods as being critical for soybean moisture requirement; from sowing to germination and from flowering to pod filling periods. During germination, the soil needs to be between 50% and 85% saturated with water, as the seed absorbs 50% of its weight in water before it can germinate. The amount of water needs increases, and peaks up at the vegetative stage, and then decreases to reproductive maturity. Large variation in the amount and distribution of soil water limits soybean yield.

According to Bohnert *et al.* (1995), there are two major roles of water in plants, as a solvent and transport medium of plant nutrients, and as an electron donor in the photosynthetic reaction processes. Heritage *et al.* (1993) reported that, soybean is quite susceptible to water stress, and usually respond to frequent watering by substantially increasing vegetative growth and yield.

Soybean is well adapted to wide range of climate and soil conditions. In Ghana, the best environments for soybean cultivation are the Forest-savanna transition and Guinea- savanna agro-ecological zones with well-drained fertile soils and annual rainfall not less than 700 mm distributed throughout the growing period (Asafo-Adjei *et al.,* 2005; Lawson *et al.,* 2008).

In addition to influencing soil conditions, rainfall and temperature play a critical role in the germination and growth of soybeans. Soil and air temperatures of 12.8 - 15°C are necessary for seed germination and seedling growth; and as temperatures increase (up to about 32.2° C), rate of germination and growth likewise increase (Catara *et al.*, 2016).

2.4.3 Photoperiod and Temperature

Soybean is a short day plant and, therefore, flowers in response to shortening days. Each variety has a critical day length that must be reached before it will start to flower. The best time to plant soybeans in Ghana is between late June and August in the south and between mid-June and mid-July in the north but sometimes cultivation also depends on the rainfall pattern in the year. When selecting varieties to grow, keep in mind that day length varies with latitude and this will affect varietal maturity (Olesen *et al.,* 2012). According to Boquet and Clawson (2007), soybeans exposed to days shorter than critical length, will progress rapidly to maturity. If this occurs before the plant reaches an adequate size, the soybean becomes stunted and gives low yield. Both increasing and decreasing rate of photoperiod change, as well as low levels of daily irradiance delays flowering in soybean (Cober *et al.,* 2001).

2.5 Cultural Requirements for Soybean Cultivation

2.5.1 Planting Date and Replanting

According to Morgan (2005), early planting can reduce the proportion of branch nodes that became fertile, while late planting can reduce branch node number in soybean. Early planting was also found to increase seed yield, while late planting increased seed mass (Pedersen and Lauer, 2004). Prasad *et al.* (2008) concluded that, the combination of the factors affecting soybean seed yield production emphasizes the complexity of individual soybean plant compensation and seed yield recovery, however, according to Conley *et al.* (2008) plants can recover yield loss at or before stage R1 if there is a at least a final plant population of 247,500 plants /ha. Planting date effect on emergence is related to weather and soil conditions (Rosenzweig *et al.,* 2001). As soil and air temperatures increase during the planting season, the percent of emergence also should increase (Licht and Al-Kaisi, 2005).

The soybean plant has a tremendous ability to compensate for missing plants. By developing more branches and podding more heavily, the effect of missing plants in the stand is often not detected in yields (Lichtenzveig *et al.,* 2006). Chauhan (2012) reported that, yield reduction that suffered with very poor stands may still be more profitable to the grower than a replanted field, which has additional costs associated with replanting and a reduced yield potential because of a delayed seeding date. Soybeans can compensate for missing plants when randomly placed gaps occur in the stand (Zaimoglu *et al.*, 2004). In field situation where poor stands are realized, management to control weeds is essential to prevent further yield losses due to the poor stand. The cost of maintaining the necessary weed control must be considered a cost of keeping a less than perfect stand. Growers who replant do so at a later planting date than is the optimum (Sacks *et al.*, 2010). A penalty to yield due to the delayed planting of 2 to 3 weeks is expected (Bastidas *et al.,* 2008). According to De Bruin and Pedersen (2009), plant density per meter of row achieved with replanting, along with possible gaps in a stand, will influence yield potential. Fernández *et al.* (2009) observed that, there will likely be less difference in emergence between early-and late-planted soybeans with high quality seed than with low quality seed.

2.5.2 Insect Pests

According to Abe *et al.* (2003) Soybean plants originated from the South Asia region, where several microorganisms and insects evolved ecological interactions. All soybean-producing countries in the world are located on the different continent, and this geographic distribution facilitates the spread of insect-pests and diseases (Murithi *et al.,* 2016). Hence, soybean can be attacked by many different organisms, ranging from viruses to nematodes and insects. These pathogens and pests can cause damage in seeds, roots, leaves, stems and pods, and usually are tissue-specific.

According to Shelton *et al.* (2002), the term pest is an arbitrary label that has no ecological validity. Some insects can be considered pests at certain times and beneficial at other times. An insect is usually considered a pest when it is in competition with humans for some resource, and when significant numbers are present (Flint and Van den Bosch, 2012). Because of the complexities of human society, it is usually impossible to eliminate pest problems by ceasing the activities that encourage them (Luckmann and Metcalf 1994). According to Oerke (2006) productivity of crops grown for human consumption is at risk due to the incidence of pests, especially weeds, pathogens and animal pests. Crop losses due to these harmful organisms can be substantial and may be prevented, or reduced, by crop protection measures (Oerke *et al.,* 2012). Soybeans have few serious insect pests compared to other cultivated crops (Pratt *et al.,* 2009). Soybean is a relatively new crop in Ghana and therefore has few recorded insect pest problems (Wagner *et al.*, 2008). In many locations, insect pest damage to soybean may be negligible but in some areas however, leaf eating caterpillars and pod-sucking bugs may cause serious yield losses if not controlled (Tutu, 2014). The pod-sucking bugs suck sap from the developing pods and seeds causing them to shrivel and drop-off (Asafo-Adjei *et al.,* 2005).

The legume pod borer, *Maruca vitrata* Fabricius is one of the major insect pests of grain legumes (e.g. pigeon pea, cowpea, mung bean and soybean) in the tropics and subtropics (Margam *et al.*, 2011).

The geographic range of *M. vitrata* extends from northern Australia and East Asia through sub-Saharan Africa (Sharma, 1998). The larval stages of M. vitrata are destructive within agricultural and forest eco-systems as they feed on the tender parts of the plant stems, peduncles, flower buds, flowers and pods (Singh and Jackai, 1988). Its common names include the Maruca pod borer, Bean pod borer, soybean pod borer, Mung moth, and the legume pod borer (Singh and Jackai, 1988). The soybean pod borer is considered one of the most destructive pests of beans, and is a major pest of cowpeas in most parts of Africa (Delmer, 2005). In cowpea, a typical infestation by M. vitrata can cause yield reductions of 20 to 80% (Singh *et al.,* 1990; Sharma, 1998).

González *et al.* (2009) reported that, an abundance of non-pest and beneficial insects are typically present in soybean fields. Beneficial insects usually keep harmful insect populations below economic thresholds. The potential for economic loss is possible each growing season, and growers should inspect fields regularly to check for insect damage (Dent, 2000). Good pest management is the result of sampling fields, evaluating plant damage, correctly identifying insects, and determining insect populations (Pratt *et al.,* 2009). Thresholds vary with the development of the crop. Treatment for insects should occur only when plant damage or insect counts exceed economic thresholds. Before employing chemical control measures for insects in soybeans, growers should be relatively sure that yield increases and/or the elimination of further damage will offset insecticide and application costs (Raymond *et al.,* 2011). Evaluation of the extent of insect infestations and timing insecticide applications are best accomplished by regularly surveying fields (Davies *et al.,* 2012). Economic thresholds establish for the major pests and applying insecticides should be based on careful scouting and using thresholds for the various pests (Luckmann and Metcalf 1994). Economic thresholds may be based on insect counts or plant damage (Dyer, 2002).

Rodents (especially rats, mice and wild rabbits) can cause serious damage by eating the seedlings and the maturing green pods late in the season (Fiedler, 1994). Rodent damage is most common in weedy fields and weedy surroundings. Birds (such as doves and crows) also pick seeds after planting; eat cotyledons or seedlings and immature seeds in pods (Asafo-Adjei *et al.,* 2005). Rodents and birds scaring can be done especially early in the morning and evenings. Weeds within the immediate vicinity of the farm should be cleared to destroy the hiding places of pests (Asafo-Adjei *et al.,* 2005).

2.5.3 Diseases

Diseases result in various symptoms such as stand loss, leaf spots, wilting, and premature plant death. Some diseases are minor and cause only cosmetic injury, while others can cause yield loss and poor seed quality (Tsitsigiannis *et al.,* 2008). The severity of disease is influenced by the presence and amount of the pathogen, variety selection, and environmental conditions (Pratt *et al.*, 2009). Quality seeds have less disease and insect problem (Pratt *et al.*, 2009). Fungi, bacteria, nematodes, and viruses are pathogens that cause the soybean diseases. These pathogens attack seed, seedlings, roots, foliage, pods, and stems (Pratt *et al.*, 2009).

Mathur *et al.* (2003) stated that seed-borne fungi that are capable of producing symptoms on young seedlings or even cause death are species of Alternaria, Ascochyta, Fusarium, Bipolaris, Colletotrichum, Macrophomina and Pyricularia. The vast majority of plant diseases are caused by fungal pathogens (Van-Gastel *et al.*, 1996). The authors further reported that any part of the plant is subject to disease, which may occur at any stage: seed, seedling, growing plants (Van-Gastel *et al.*, 1996). However, Jaiswal and Agrawal (1995) reported that seed borne microflora association with seed does not necessarily result in disease condition.

Maude (1996) reported that seed high in purity and germination but infected with seed-borne pathogens are of low planting value. Planting seed that is free of seed-borne pathogens is the primary means of limiting the introduction of pathogens, especially new pathogens, into a field. Nameth (1998) had pointed out that seed can serve as a vehicle for the dissemination of plant pathogens when they bear inoculums, which can result in disease outbreak through infection in the endosperm or embryo. The consequences of planting infected seed depend on the pathogen in question (Wright *et al.*, 1995). For those diseases that are primarily soil or residue-borne, planting infected seed is less important (Ratnadass *et al.*, 2006). Anderson *et al.* (2004) reported that, effects of seed-borne pathogens on plant health vary widely. Seed-borne pathogenic fungi may survive for long periods in storage and may attack seedlings during germination leading to poor emergence and a reduced seedling population

(Ashraf and Foolad, 2005). Pathogens may also be transmitted from the seed to the seedling causing disease symptoms and possible yield loss at a later stage of growth (Wright *et al.*, 1995). Some seed borne diseases can multiply rapidly from one generation to the next and seed crops can also become infected from neighboring diseased crops (Anderson *et al.*, 2004). In this way seed-borne disease can seriously affect the quality of both certified and farmer-saved seed (Wright *et al.*, 1995). Agrios (2005) indicated that for a disease to occur, the three components (host, pathogen and environment) must come into contact and interact. If any of the three components is zero, there can be no disease. Each of the three components can display considerable variability (Agrios, 2005). As one component changes, it affects the degree of disease severity within the host. The interaction of the three components of diseases generally referred to as the disease triangle. Each side of the triangle represents one of the three components (Agrios, 2005). In every infectious disease, a series of more or less distinct events occurs in succession and leads to the development and perpetuation of the disease and the pathogen. This chain of events is called a disease cycle. The primary events in a disease cycle are inoculation, penetration, establishment of infection, colonization (invasion), growth and reproduction of the pathogen, dissemination of the pathogen, and survival of the pathogen in the absence of the host (Agrios, 2005).

Disease management involves using cultural practices (crop rotation, residue management, etc), use of resistant varieties, and chemical control (fungicides) when needed (Pratt *et al.*, 2009). Crop management that integrates several different disease management strategies generally improves success and the potential for profitable soybean production (Pratt *et al.*, 2009). Monitoring soybean fields to detect the early stages of disease and pest outbreaks, and keeping good records on their occurrence and distribution allows for timely and economical application of management inputs. Correct identification of soybean diseases is essential for effective disease management (Pratt *et al.*, 2009).

2.5.4 Fertilizer Requirement

Nitrogen is one of the most important nutrient elements affecting the yield of soybean (Hungria and Vargas, 2000). According to West *et al.* (2005), Nitrogen requirement for soybean are typically met by a combination of soil-derived nitrogen and nitrogen provided through the process of symbiotic fixation from rhizobia bacteria in root nodules. The relative nitrogen supply from these two sources can change widely depending on soil nitrogen supply and conditions for nodule development (Gan *et al.,* 2003; West *et al.,* 2005). According to Gan *et al.* (2003) N fixation alone cannot meet the N requirement for maximizing soybean yield. Best timing for N top-dressing during reproduction is at the flowering stage, which increased seed yield by 19 and 21%, compared to the treatment without N top dressing (Gan *et al.,* 2003). Nitrogen increases yield by influencing a variety of agronomic and quality parameters. In general, there was an increase in plant height and dry matter accumulation per plant in soybean (Manral and Saxena, 2003). Adesemoye *et al.* (2009) reported an increase in plant height with the application of nitrogen fertilizer. Different nitrogen doses and plant densities significantly affected some important yield and yield characters in soybean. A rise in plant density and nitrogen rate increased plant height, lowest pod length, harvest index and seed yield (Mehmet, 2008).

Soybean plant has a nutrient dense, high protein seed, and therefore, requires high amount of nutrients for its growth (Lamond and Wesley, 2001). It is a legume that can meet its nitrogen needs by symbiotic relationship with nitrogen fixing bacteria of the species *Bradyrhizobia* *japonicum* from atmospheric nitrogen (Sarkodie-Addo *et al.,* 2006). And generally, the plant will not benefit from supplemental nitrogen fertilizer application, where there are indigenous populations of the appropriate rhizobia strains that cause effective nodulation of the roots and nitrogen fixation (Darryl *et al.*, 2004). Adesemoye and Kloepper (2009) have stated that, nitrogen fertilizer application circumvents the benefit of rhizobia bacteria, as the bacteria will not convert atmospheric nitrogen when soil nitrogen is readily available to the plant. However, where soybean have not been grown recently, inoculation of the seed with specific Bradyrhizobia strains is essential for effective nitrogen fixation (Darryl *et al.*, 2004). Malik *et al.* (2006) reported that, soybean seed inoculation with Rhizobium in combination with phosphorus application at 90 kg per hectare, performed better in yield under irrigated conditions. Soybean can produce maximum seed yield with relatively low levels of available phosphorus in the soil. Phosphorus application is not likely to increase seed yield at soil phosphate concentrations above 12 ppm P (Bray-1 test). Also, most soils seldom need potassium fertilizer for soybean production, since K levels are generally high in both surface soil and subsoil. Potassium fertilizer is not required if soil test shows more than 124 ppm (Ferguson *et al.,* 2006). Linderman and Glover (2003) have stated that, of the basic nutrients N, P and K, N is supplied by the symbiotic bacteria in the nodules, while the others come from the soil, and will be taken into the plant as it takes up water. Most farmers also apply Tripple Super Phosphat (TSP) to soybean crop (Tairo and Ndakidem, 2013).

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2.5.5 Weeds of soybean

The precise impact of weed competition on grain yield would be difficult to document since damage typically varies within fields, between fields, within and between regions, and between years (Buhler and Hartzler, 2004). The reduction in soybean yield due to weed infestation varies from 20 – 77% depending on the type of soil, season and intensity of weed infestation (Kurchania *et al.*, 2001; Daugovish *et al.*, 2003).

The higher reduction in seed yield due to weeds is high as compared to other factors limiting the soybean production. It has been estimated that soybean growers lose an average of 1.8 million US$ per year due to yield reductions from weed infestation (Jannink, 2000). In order to implement an adequate weed management strategy, it is essential to determine the period of soybean growth when weed interference is most detrimental (Ghersa *et al.*, 2000). Van Acker *et al.* (1993) addressed these issues at three locations in southern Ontario, Canada. Their work determined the critical period of weed control in soybean which consists of two parts: one being the critical weed-free period, and the second being the critical time of weed removal. They found the critical weed-free period to be consistent and relatively short. According to their research, when weed competition was eliminated from emergence to the fourth node growth stage, or approximately 30 days after emergence, yield losses were not more than 2.5%. However, the critical time for weed removal (CTWR) varied across locations and years, and ranged from V2 to R3, or approximately 9 to 38 days after emergence (DAE), to prevent a yield loss of more than 2.5%. If a 5% yield loss is deemed acceptable then the critical time for weed removal ranged from V3 to R3-R5, or 16 -50 days after emergence.

In addition, a 10% yield loss would have a critical time for weed removal range of V4 to harvest, or 22 - 74 days after emergence. Thus, one can conclude that yield losses from weed competition are evident early in the growing season, and depending on the level of yield loss deemed acceptable, weeds should be controlled before V4 and continue through harvest. Similar research was conducted by Knezevic *et al.* (2003) from 1999 to 2001 at two locations in Nebraska to determine the effect of row spacing on the critical time for weed removal (CTWR). This research found that the critical time for weed removal increases as row-spacing increases. These findings support conclusions by Van Acker *et al.* (1993), in that inter-specific competition begins early in the growing season. They also found that competition begins earlier in wide row soybeans versus narrow row soybeans, and that weeds allowed to compete all season long can reduce soybean yields by 44 to 84%. Harder *et al.* (2007) found out that, when weeds competed with soybean all season long and they reduced soybean seed yield by 46 – 66%. Knezevic *et al.* (2003) concluded that, soybeans in narrow rows are better competitors with weeds.

To further investigate weed interference on soybean seed yield, research was conducted by Nordby *et al.* (2007) to determine soybean cultivar competitiveness with weeds between different maturities and canopy characteristics. The authors found wide-canopy cultivars were not more competitive with weeds than narrow-canopy cultivars. However, later maturing cultivars were able to achieve higher yields even when weeds were removed later in the growing season compared to earlier maturing cultivars. They attributed the yield increase to the increased light interception, and increased canopy closure which reduced the amount of light reaching the soil surface thereby reducing weed seed germination and survival (Nordby *et al.*, 2007). It is suggested that in order to prevent yield losses to weed competition, weeds should be controlled early in the vegetative stages and remain controlled throughout the early part of the reproductive stages (Van Acker *et al.*, 1993). Inter-specific competition begins earlier in the growing season for soybean grown in wide rows versus narrow rows (Knezevic *et al.,* 2003), and late maturing cultivars tolerate weed competition better than early maturing cultivars (Nordby *et al.,* 2007). Soybeans respond to weed competition growing taller in an attempt to avoid shading (Green-Tracewicz, 20011), this can result in an increase in plant lodging and increasing harvest difficulties.

Controlling weeds is a vital step in the production of any crop but is especially important in successful soybean production (Coughenour, 2003). Weeds generally should be controlled within the first four weeks after soybean emergence to avoid yield loss (Knezevic *et al.*, 2002). In many instance, the best weed control program includes a combination of cultural, mechanical and chemical practices. Herbicides are commonly applied at the pre-emergence stage of soybean to control weeds in Ghana (Lehmann and Pengue, 2000). In soybean research, most work investigating the effect of competition has been on interspecies competition, or competition from weeds. It is common knowledge that competition between crops and weeds cause significant losses to soybean producers every year (Oerke and Dehne, 2004).

2.6 Nitrogen Fixation in Soybean

Extensive cereal cultivation with little or no fertilizer input, coupled with annual bushfires that remove the vegetation cover including crop stubble in the Guinea savanna has resulted in a decline in soil fertility (Braimoh and Vlek, 2006). Farmers therefore have to shift to relatively new and more fertile lands or increase the area under cultivation to meet the same production targets (Konlan *et al.,* 2013). These problems can be reduced when legumes including soybean are integrated in the farming system either through intercropping or crop rotation.

In the last decade, the use of leguminous crops has been widely promoted as an alternative strategy to enhance soil fertility in croplands (Lal, 2009). As with selecting the best genotype for yield, other management variables that increase yield should also increase the amount of N_2 fixed (Keyser and Li, 1992). Lupwayi *et al.* (2000) emphasized that, N is not always the primary limiting factor in soybean yield, but when it is not there, there will not be a response to inoculation. Other factors which limit soybean yield will then by definition also limit inoculation and N response (Salvagiotti *et al.,* 2008).

Postgate (1998) described nitrogen fixation as a process in which nitrogen (N_2) in the atmosphere is converted into ammonia (NH_3). Atmospheric nitrogen or molecular dinitrogen (N_2) is relatively inert: it does not easily react with other chemicals to form new compounds. The fixation process frees nitrogen atoms from their triply bonded diatomic form, N≡N, to be used in other ways. Nitrogen fixation, natural and synthetic, is essential for all forms of life because nitrogen is required to biosynthesize basic building blocks of plants, animals and other life forms (Augusto *et al.,* 2013).

Nitrogen-fixing bacteria have very close relationships with plants, referred to as symbiotic nitrogen fixation (Unkovich and Baldock, 2008). Biological nitrogen fixation is the process that changes inert N_2 to biologically useful NH_3 (Parsons *et al.,* 1993). This process is mediated in nature only by bacteria. Other plants benefit from nitrogen-fixing bacteria when the bacteria die and release nitrogen to the environment or when the bacteria live in close association with the plant (Maier *et al.,* 2009). In legumes and a few other plants, the bacteria live in small growths on the roots called nodules. Within these nodules, nitrogen fixation is done by the bacteria, and the NH_3 produced is absorbed by the plant (Parsons *et al.*, 1993). Nitrogen fixation by legumes is a partnership between a bacterium and a plant. However, nitrogen fixation by legumes can be in the range of 11 to 34 kg N/ha/yr in a natural ecosystem and several 100 kg in a cropping system (Lindemann and Glover 2003). Other grain legumes, such as peanuts, cowpeas, soybeans and faba beans are good nitrogen fixers and will fix most of their nitrogen needs other than that absorbed from the soil. These legumes may fix up to 279 kg N/ha and are not usually fertilized (Yusuf *et al.,* 2009). Soybeans usually do not respond to nitrogen fertilizer as long as they are capable of fixing nitrogen (Lindemann and Glover, 2003). Grain legumes can also fix about 15 - 210 kg N/ha seasonally in Africa (Dakora and Keya, 1997).

Legume nitrogen fixation starts with the formation of a nodule. A soil bacterium, *Rhizobium,* invades the root and multiplies within the cortex cells (Maier *et al.,* 2009). The plant supplies all the necessary nutrients and energy for the bacteria. Within a week after infection, small nodules are visible with the naked eye. In the field, small nodules can be seen 2 - 3 weeks after planting, depending on legume species and germination conditions. When nodules are young and not yet fixing nitrogen, they are usually white or gray inside. As nodules grow in size, they gradually turn pink or reddish in color, indicating nitrogen fixation has started. The pink or red color is caused by leghemoglobin that controls oxygen flow to the bacteria (Steenhoudt and Vanderleyden, 2000).

Nodules on soybeans are round and can reach the size of a large pea, they are short-lived and will be replaced constantly during the growing season. At the time of pod fill, nodules generally lose their ability to fix nitrogen, because the plant feeds the developing seed rather than the nodule (Maier *et al.,* 2009). Beans will generally have less than 100 nodules per plant, soybeans will have several hundred per plant and peanuts may have 1,000 or more nodules on a well-developed plant (Fehr *et al.,* 1971).

Legume nodules that are no longer fixing nitrogen usually turn green and may actually be discarded by the plant. Pink or red nodules should predominate on a legume in the middle of the growing season. If white, grey or green nodules predominate, little nitrogen fixation is occurring as a result of an inefficient *Rhizobium* strain, poor plant nutrition, pod filling or other plant stress ((Steenhoudt and Vanderleyden, 2000).

The nitrogen fixed is not free. The plant must contribute a significant amount of energy in the form of photosynthate (photosynthesis derived sugars) and other nutritional factors for the bacteria. A soybean plant may divert 20 - 30 percent of its photosynthate to the nodule instead of to other plant functions when the nodule is actively fixing nitrogen (Lindemann and Glover, 2003). Soybean is a known potent nitrogen fixer (Musiyiwa *et al.,* 2005; Zengeni *et al.,* 2006). Soybean can fix as much as 120 kg N/ha during a growing season (Giller, 2001). Soybean is capable of fixing between 60 kg and 168 kg of nitrogen per hectare per year under suitable conditions (Rienke and Joke, 2002).

Soybean nitrogen requirements are met in a complex manner, as it is capable of utilizing both soil nitrogen, in the form of nitrate and atmospheric nitrogen, through symbiotic nitrogen fixation. In the symbiotic relationship, carbohydrates and minerals are supplied to the bacteria by the plant, and the bacteria transform nitrogen gas from the atmosphere into ammonium and nitrate for use by the plant (Franzen, 2016).

Nastasija *et al.*, (2008) cited by Bebeley, (2013) outlined the following as limiting factors to nitrogen fixation:

- When soil N levels are too high, nodule number and activity decrease. Roots do not attract bacteria or allow infection; hence, nitrogen fixation is limited
- Poor plant growth does not allow the plants to sustain nodules and plant growth, therefore sacrificing nodule activity.
- If soil pores are filled with water, and not air, there will be no nitrogen to be fixed.
- A temperature of 16^0C to 27^0C is ideal, while levels above or below this reduce bacterial activity and slow the establishment of the N-fixing relationship.

Salvagiotti (2008) reported that soybean plant will effectively utilize soil residual nitrate and nitrogen mineralized from soil organic matter, obtaining 25 to 75 percent of plant nitrogen, with the balance supplied from symbiotic fixation.

2.7 Effect of Plant Population on Growth of Soybean

Among various agronomic factors limiting yield, plant population is considered of great importance. Plant population refers to the number of soybean plants emerged and established in the field which can contribute to overall crop performance (yield, competition with weeds, moisture use, etc.) (Delate *et al.,* 2012). It is usually expressed in terms of plants per acre or plants per hectare. Several researchers (Kasperbauer, 1987; Pons and Pearcy, 1994; Andrade *et al.,* 2002; Lone *et al.,* 2009) have different views on the effect of plant population on growth of soybean based on their research. Lone *et al.* (2009) stated that the optimum plant density with proper geometry of planting is dependent on variety, its growth habit and agro-climatic conditions. Adjusting planting density is an important tool to optimize crop growth and the time required for canopy closure, and to achieve maximum biomass and grain yield (Liu *et al.*, 2008).

Soybean plant densities of 400,000 plants/ha (Luca and Hungría, 2014) or even higher (National Soybean Research Laboratory, 2012) are recommended. However, at lower densities, interplant competition for water, nutrients and light could be mitigated (Blumenthal *et al.*, 1988; Andrade *et al.*, 2002). At high densities, shaded leaves may not contribute to canopy photosynthesis (Board *et al.*, 1990, 1992), and will likely senesce and/or be susceptible to disease (Pons and Pearcy, 1994). Changes in the red/infrared ratios through the canopy may deeply affect both photosynthesis (Kasperbauer, 1987) and the onset of nodule formation (Lie, 1969).

Ibrahim (1996) observed that leaf area index (LAI) and light interception (LI) increased with increasing plant density over a range of 7 to 21 plant m^{-2}. Ball *et al*. (2000) concluded that higher plant population facilitated maximum light interception that ultimately helped achieve higher crop growth rate (CGR) and total dry matter (TDM) of soybean.

Mellendorf (2011) believed there are two general concepts often used to explain the relationship between row spacing, plant density, and crop yield. The first concept is maximum crop yield which can only be achieved if the crop community is able to produce sufficient leaf area to provide maximum light interception during reproductive growth

(Jones *et al.*, 2003). The second is equidistant plant spacing maximizes yield because it minimizes interplant competition (Jones *et al.*, 2003).

According to Mellendorf (2011) Soybean plant population adjustment is made in order to produce a complete canopy that is capable of maximizing light interception, while maintaining adequate plant-to plant spacing. An advantage of high plant population is that it leads to an increase in canopy leaf area development and greater light interception earlier in the growing season (Shibles and Weber, 1966; Weber *et al.*, 1966). According to Johnson (1994) when light is the limiting factor in crop production, equidistant plant spacing results in maximum yields. Quicker canopy development is also an advantage of narrow-rows as this has been found to enhance weed management (Young *et al.* 2001; Buhler and Hartzler 2004; Heatherly and Elmore, 2004), decrease stored water loss due to evaporation (Hoeft *et al.* 2000), and increase plant establishment (Oplinger and Philbrook, 1992; De Bruin and Pedersen, 2008). However, other researchers have found that rapid canopy closure can increase the use of stored soil water, via transpiration, therefore, leaving less available water during the critical period of pod fill (Taylor, 1980; Johnson, 1994; Heatherly and Elmore, 2004).

Competition can be defined as two or more plants demanding common environmental resources in excess of supply (Porter and Van der Linde, 1995). In general, competition can be categorized into two types. Interspecific competition occurs between multiple species and is usually demonstrated as competition between a desired crop and weeds (Connolly and Wayne, 1996). Intra-specific, or interplant competition, is when common resources are limited for all the plants of a similar specie, such as between the established crop plants with a given crop canopy (Connolly and Wayne, 1996). Individual plant productivity is typically limited by competition for light, water, soil nutrients or a combination of each (Buhler and Hartzler, 2004). According to Weiner and Thomas (1986), competition for light exists when plants are large enough to shade one another, while competition for soil resources can begin soon after germination. Within a crop community, plants growing under a canopy not only experience a reduction in the amount of irradiance, but also a reduction in the quality of light as chlorophyll preferentially absorbs red (R) light and reflects far-red (FR) light, thereby the R : FR decreases as sunlight moves through the crop canopy (Kasperbauer, 1987). The decrease in the amount of R light in relation to the amount of far-red light thus results in an environmental cue for plants to detect neighbor plants before canopy closure (Green-Tracewicz *et al.,* 2011). Many plant species respond to a reduction in red: far-red with increased apical dominance, decreased branching, stem extension and internode elongation (Green-Tracewicz *et al.,* 2011). In contrast to aboveground competition for a single resource, light, plants compete for multiple soil resources, including water and other essential mineral nutrients. Competitive stress created by competition in plant stands may be expressed by increased mortality, reduced seed production, and reduced growth rate (Board, 2000). Green-Tracewicz *et al.* (2011) examined soybean shade avoidance and its effects on plant branching and on variability in biomass and yield per plant during the 2007 and 2008 growing season at the University of Guelph in Guelph Ontario, Canada. They observed a shade avoidance response in soybean seedlings due to a reduction in the red: far-red by comparing weedy and weed-free plots. Soybean plants grown in weedy conditions, or low red: far-red conditions had increased height, internode length, and shoot: root ratios. Plants grown in low red: far-red conditions also had less root biomass, total plant biomass, and leaf area.

2.8 Effect of Plant Population on Nitrogen Fixation in Soybean

Plant population is a production factor which affects light interception by plant canopy (Board, 2011). Improving the nitrogen fixation component for soybean has been identified as part of the overall strategy for increasing productivity (Hunter *et al.*, 1982; Scott and Aldrich, 1983; Anon, 1984; Russell *et al*., 1989).

Oljaca *et al.* (2000) observed that, intraspecific competition seems to be more intense in soybean plants than interspecific competition. Mehmet (2008) reported that an increase in plant population density and nitrogen rate increased plant height, decreased pod length, harvest index and seed yield, whiles number of branches per plant, pod number per plant, seed yield per plant and 100 seed weight decreased as plant density increased. Symbiotic nitrogen fixation consumes 6 - 12 g C/g of fixed N, representing about 20 - 30% of the total plant photosynthesis; however, this strong sink for C does not necessarily reduce yield, because it may modulate source activity (photosynthesis) (Kaschuk *et al.,* 2009, 2010, 2012).

Plant population is one factor that may influence how much residual nitrogen soybean is contributing to a cropping system. Estimated nitrogen fixation of determinate soybean is approximately, increased from 200 to 280 kg N/ha, when plant population is increased from 48,500 to 194,000 plants/ha respectively (Ennin and Clegg, 2001). Soybean had the potential to at least quadruple both photosynthesis and biological nitrogen fixation at lower plant densities according to (Luca, 2014).

Kapustka and Wilson (1990) found that an increase in soybean plant density reduces nodule number and dry weight per plant, but maintains high specific activity per nodule, which results in the same values of nitrogen fixation per plant. Shamsi and Kobraee (2012) stated that, at lower plant densities the photosynthetic rate per plant increased and, consequently, higher C supply to the nodules resulted in increases in nodulation and in nitrogen fixation rates. Regarding the efficiency of the nodules, Luca (2014) observed that soybean plant treatments with 40,000 and 160,000 plant/ha recorded higher values of N per unit of nodule dry weight than plants with 320,000 plants/ha.

At lower plant densities the photosynthetic rate per plant increased and, consequently, higher C supply to the nodules resulted in increases in nodulation and in nitrogen fixation rates **(**Luca, 2014).

2.9 Effect of Plant Population on Yield of Soybean

Plant population is an important agronomic factor that manipulates micro environment of the field and affects growth, development and yield formation of crops. There have been mixed reports on the effect of plant population on yield of soybean.

The ability of soybean plants to compensate yield is associated with many factors including vegetative growth and yield component adjustments, or a combination of both (Board, 2000). Board (2000) and Carpenter and Board (1997) reported an increase in individual plant performance related to vegetative adjustments in soybean and they attributed the performance to an increase in LIE and NAR in the lower populations that resulted in CGR equilibration by R1 and by equilibration of total dry matter production before seed fill initiation (R5). The was also a high increase in seed yield as a result of an increase in total dry matter that allowed more dry matter to be partitioned to branches thereby increasing the number of pods per branch (Mathew 2000; Carpenter and Board, 1997).

Rahman *et al.* (2011) concluded on a research on plant density effects on growth, yield and yield components of two soybean varieties under equidistant planting arrangement that, seed yield increased with increase of plant density up to 80 to 100 plants m^{-2} depending on variety and season and that the increase in plant density decreased yield components such as number of pods per plant, seeds per pod and 100-seed weight as well as seed yield per plant

Mahama (2011) stated that, row spacing effects are significant on plant height, leaf area index, number of leaves, dry matter yield kg/ha and grain yield (ton/ha).

Within certain limits, increase of plant population density (PPD) decreases the growth and yield per plant but the reverse occurs for yield per unit area (Caliskan *et al*., 2007).

Rahman *et al*. (2004) found out that, under the temperate environment of Canterbury, New Zealand, increase of plant population density (PPD) up to 40 plants m^{-2} gave the highest yield but above this PPD no yield advancement was achieved.

The optimum plant density to attain highest yield may vary with the genotype and geographical location. In the USA, the optimum plant density varies from 30 to 50 plants m^{-2} (Grichar, 2007). In South Korea, Kang *et al*. (1998) reported the highest yield at 33 to 53 plants m^{-2} while YoungSon and SokDong (2010) obtained highest yield at 66 plants m^{-2}. In India, a plant density of 40 to 60 plants m^{-2} was reported to be the optimum for soybean depending on the variety under cultivation (Rani and Kodandaramiah, 1997), while Singh (2010) reported the highest yield with 66 plants m^{-2}. In Turkey, Zaimoglu *et al*. (2004) found the highest yield at 12.8 plants m^{-2} while from the study of Mehmet (2008) it was 29 plants m^{-2}. The optimum plant density reported in Kenya was 45 plants m^{-2} (Misiko *et al*., 2008) while that in Ethiopia was 40 plants m^{-2} (Worku and Astatkie, 2011). In Iran, the highest yield of soybean is obtained at 60 plants m^{-2} (Daroish *et al*., 2005). In Bangladesh, the plant densities of 50 and 60 plants m^{-2} are suggested for rainy and dry seasons, respectively (Rahman *et al.*, 2011). Keyser and Li (1992) reported that, the bulk of future increased soybean production will have to come from yield improvements rather than increased planting area.

The above information explicitly indicates that optimum plant density for soybean could vary depending on geographical location.

Plant density affects yield in soybean by modulating leaf area and therefore, light interception and canopy photosynthesis (Wells, 1991). Board *et al.* (1992) concluded from their findings that, narrow row soybean gives higher yield than the wider row soybean because of greater light interception.

Board and Harville (1994) has reported that, soybean crops sown in narrow rows are able to achieve full light interception faster with lower leaf area index than those in wide rows, and consequently have higher yield potential.

Flénet *et al*. (1996) also concluded that, high plant population and narrow row spacing for early cultivars with sufficient duration to utilize the environmental factors effectively, combined with high yield potentials, produced substantially higher yield.

Ismail and Hall (2000) stated a decrease in grain yield of cowpea with increased spacing. Ball *et al.* (2000) reported that increasing plants population reduced yield of individual plants but increased yield per unit of area.

Other researchers (De Bruin and Pedersen 2009; Coulter *et al.,* 2010) also believe plant population is not critical yield factor for soybean and their reason is the plant has the ability to adjust growth and development to compensate for different plant populations. The plant produces branches and more pods per plant if the plant population is low and fewer branches and pods per plant if the plant population is high (DeWerff *et al.,* 2014).

Heatherly (1999) noted that, success of short maturity soybean production is contingent on higher population and more narrow rows, than those for late maturity types. Therefore plant population response data will help producers make better-informed decisions concerning management of both early and medium maturity groups.

Bullock *et al.* (1998) conducted research that focused on soybean yield response to row spacing. Soybeans were planted in 38 cm, 76 cm and 114 cm wide rows, and plant stands were thinned to 450,000 plants/ha between V1 and V2. They reported that seed yield increased as row spacing decreased, such that narrow rows (38 cm) out yielded 76 cm and 114 cm rows by 8 and 20%, respectively. In addition, 76 cm rows out yielded 114 cm rows by 12% (Bullock *et al.,* 1998). Egli (1988) also conducted research in Kentucky in 1985 and 1986 to determine the effect of plant density on both determinate and indeterminate cultivars on seed yield. Individual plants were grown in a variety of densities, ranging from 6,000 to 240,000 plants/ha. He found that seed yield increased linearly with increases in population up to 15,000 plants/ha in indeterminate cultivars, whereas determinate cultivars increased seed yield linearly in relation to increases in population up to 30,000 plants/ha. They observed that no interplant competition exists up to 15,000 plants/ha in indeterminate soybeans or 30,000 plants/ha in determinate cultivars. They also found out that, 95%

photosynthetically active radiation (PAR) interception at growth stage R5 was achieved at a density as low as 51,000 and 33,000 plants/ha in 1985 and 1986, respectively for the indeterminate cultivar. At these densities there was a sharp reduction in the rate of yield increase, suggesting that interplant competition has begun at some level. Maximum yield was achieved at 73,000 plants/ha. Therefore, one might assume that plant densities above those required to maximize light interception may be required for maximum yields. The determinate cultivar responded differently in that 95% photosynthetically active radiation interception was achieved by R5, and maximum yields were achieved at the same density of 61,000 plants/ha. Pedersen and Lauer (2003) found inconsistent response to row spacing in Wisconsin from 1997 - 2001. Their research focused on the influence of crop rotation sequence, tillage, and row spacing on soybean seed yield. There were inconsistent responses to row spacing between years resulting in at least one growing season where 19 cm, 38 cm and 76 cm rows each produced optimal yields (Pedersen and Lauer, 2003). That is in contrast to other reports (Egli, 1988; Bullock *et al.,* 1998; Elmore, 1998; Cox and Cherney, 2001; De Bruin and Pedersen, 2008).

The spatial distribution of plants within a crop community can influence soybean seed yield. Most research report a positive yield response to decreasing row spacing to less than 16 cm (Egli, 1988; Bullock *et al.*, 1998; Elmore, 1998; De Bruin and Pedersen, 2008; Cox and Cherney, 2011). Wiggans (1939) found out that, soybeans typically produce highest yields in a uniform distribution due to minimization of interplant competition. However, others reported no response to row spacing (Pedersen and Lauer, 2003), and suggests focusing on other strategies to increase soybean seed yield. In addition to the literature presented, Lee *et* *al.* (2008) came to the conclusion that economically optimum plant populations could be up to 33% less than the optimum plant populations due to increasing seed costs.

In general, soybean seed yield can be determined by the product of biomass (BM) and harvest index (HI). Acknowledging that soybean harvest index is constant in most environments (Spaeth *et al.*, 1984), maximizing biomass should produce the highest yields. This is consistent with work done by Duncan (1986), who proposed that, the greater the total dry matter (TDM) the greater the yield, as long as the total dry matter is produced before seed initiation.

It has been suggested that optimal crop growth rate (CGR), or dry matter (DM) production, resulted when leaf area index (LAI) is sufficient (3.0 - 3.5) to achieve near maximum light interception (LI), 95%, by R5 (Shibles and Weber, 1965; Weber *et al.*, 1966). Alternatively, yield can also be considered a function of four basic factors, commonly called 'yield components', which include seed mass, number of seeds per pod, number of pods per plant, and number of plants per given area. Identifying which yield components contribute the most to yield and yield compensation under given crop management situations would help understand necessary management options to achieve optimal yields. Moreover, an increased understanding of how yield components and growth dynamic factors regulate soybean yield in response to plant population could improve cultivar development to optimize yield at low populations. In addition, that could also provide producers with indicators of optimal populations (Carpenter and Board, 1997).

In order to determine which yield components contribute the most to yield or yield recovery Carpenter and Board (1997) conducted research in Louisiana on determinate growth soybeans in 1994 and 1995. This research focused on soybean branch yield components and how soybeans controlled yield stability across three plant populations (70,000; 164,000; and 234,000 plants/ha). They found that maximum yields were 4078 kg/ha and were achieved at 164,000 plants/ha. However, reducing that stand by 58% to 70,000 plants/ha only resulted in a 12% yield decrease.

On the other hand, increasing plant density by 43% to 234,000 plant/ha resulted in no yield increase. They found that yield stability in this experiment is explained by an increase in seed yield per plant. The seed yield increase per plant came from an increase in pod production per branch. The increase in branch pods resulted from an increase in branch dry matter per plant, where branch dry matter accounted for 13.6; 13.1; and 9.6% of the total dry matter at the low, medium, and high populations, respectively. Furthermore, the increase in branch dry matter was positively correlated with increased branch node number, and branch reproductive node number. Greater branch dry matter per plant was explained by greater dry matter per plant which could be associated with reduced interplant competition (Carpenter and Board, 1997). The higher plant densities showed a reduction in total plant dry matter that resulted in decreased dry matter partitioning to branches, and subsequently less branch nodes and reproductive nodes to produce seed yield.

In contrast to the many studies investigating competition between soybean and weeds, there has been very limited research on the effects of interplant competition, or competition between soybean plants on the performance on soybeans. Duncan (1986) advanced two postulates to explain the effect of soybean plant relations on seed yield. He proposed that; there is a range of plant densities where soybean seed yield increases with no increase in light interception by the crop canopy, and that, within limits, seed yield will increase with increases in vegetative mass during the seed initiation period, with all other conditions remaining the same. Duncan (1986) described three phases of soybean yield response to increased plant density; Phase I covers the range of plant densities where there is no interplant competition and seed yield is directly proportional to plant density, or yield per plant is constant, Phase II begins at a plant density great enough to intercept nearly all of the insolation at full canopy, and ends at a density where further increase in density results in no increase in seed yield whiles Phase III includes all plant densities where seed yield is not increased by an increase in density. Phase I and II are separated by that range of densities where interplant competition increases. These postulates provide a framework to evaluate seed yield response of a soybean community in relation to changing plant densities.

High soybean yields are possible with a wide range of plant populations because single plants of most varieties will utilize about 18 to 23 cm area in all directions around the main stem. Plants adjust to tow populations by producing more branches per plant and by increasing the number of pods on both the main stem and branches. There is, however, little change in seed size and in seed number per pod. While the production of more branches and pods per plant maintains the yield potential for soybeans, harvest losses may be greater in thin stands since the pods on the lateral branches will be close to the soil surface and branch lodging is apt to occur. Leaves on plants in a thin stand also take longer to produce a ground-covering canopy. This allows more weed competition and soil moisture evaporation. In contrast, a stand that is too thick may result in excessive early lodging which means reduced yields as well as increased harvest loss.

When grown under high populations, individual plants produce fewer pods, fewer branches, grow taller, and pod higher off the soil surface than when grown at low populations. Yield potential is maintained with high populations since there are more plants per acre. Soybean populations that are too high also undergo a natural thinning process due to the intense competition between plants, which reduces the stand to a more acceptable level. In other words, plants are eliminated after emergence. In summer, soybean populations can vary perhaps as much as 50 percent from recommended levels without affecting yields, as long as missing plant spaces are not too large and weeds are controlled.

There are varietal differences in soybean response to over- or under-population. Taller varieties that are lodging prone are likely to have reduced yields if populations are too high. Shorter varieties are more likely to have reduced yields if populations are too low. In general, fewer problems occur when stands are established at or near recommended levels.

2.10 Effect of Genotype on Yield of Soybean

Harvestable yield is an important characteristic to consider when selecting a soybean variety. Soybean yield is influenced by planting date, pattern and density of seeding but varieties differing in growth habit may vary in response to cultural treatments and environmental conditions (Madanzi *et al.,* 2012).

The soybean varieties selected for planting will directly affect yield potential and income. Mike Staton from Michigan State University Extension recommends selecting varieties on the basis of yield, pest and pathogen resistance, maturity, lodging and quality (Bakar *et al.,* 2015). A variety must be able to remain erect throughout the growing season. Lodging during the vegetative or reproductive growth will disrupt the light penetration into the plant canopy and may reduce seed yield. Lodging late in the season may also reduce harvest efficiency and increase harvest losses. Increasing plant population causes the stems of soybean plants to become taller, more slender, And more prone to lodging (Xiang *et al.*, 2013). The knowledge of genetic variability is the most important aspect of plant improvement program. It is of equal importance for a soybean breeder to evaluate soybean genotypes from different genetic backgrounds under different environments. Baker (1988) suggested that evaluation of soybean genotypes under different planting dates is vital in boosting production. According to Ngalamu *et al.* (2012), varietal screening and selection for adaptation under local conditions can be considered of prime importance.

While varieties differ in their ability to resist lodging, environmental conditions greatly influence the tendency to lodge (Bakar *et al.*, 2015). Factors such as irrigation and high fertility tend to promote Vegetative development and increase lodging (Sonderegger, 2013).

There are also new improved varieties that are disease and pest resistance. Example is the Afayak variety in Ghana which is able to resist striga infestation. Other varieties are more yielding than others.

From a research conducted by Tan *et al.* (2016) in Eastern Ethiopia they concluded that, the main effect of soybean variety significantly affects yield components of soybean such as number of pod per plant, 100 seed weight and harvest index.

The performance of any variety will vary from year to year and from location to location depending on factors such as weather, management practices, and variety adaptation

(Enete and Onyekuru, 2011).

Plant height at harvest, number of pods per plant, weight of 100 seeds and seed yield were used to assess the performance of improved varieties of soybean. The newly recommended improved varieties of soybean have a wide range of maturity and diverse morphology (Olufajo, 1992 and Adeniyan and Ayoola 2006). Similarly it was reported by Jin *et al.* (2010) that the yield increase is correlated with increasing pod number, while seed size and seeds per pod does not change greatly over time. Khan *et al.* (2000) studied heritability and correlation among yield determining components of 86 genotypes in Pakistan and reported that seed yield had a significant positive relationship with all yield components except pod height.

2.11 Effect of Genotype on Growth of Soybean

Many varietal characteristics, such as maturity, lodging, and disease resistance, must be considered when selecting varieties to complement a production area (Enete and Onyekuru, 2011).

Growth, development, and yield of soybeans are all a result of a given variety's genetic potential interacting with its environment (Sjamsijah *et al.*, 2016)

Cultivars of soybean are broadly grouped into three according to the number of days to maturity (early maturing (125 - 130 days), medium maturing (140 - 150 days) and late maturing (150 - 160 days) cultivars, which increase with increase in latitude, day light and cool conditions (Aniekwe and Mbah, 2014).

Soybean plants are sensitive to day length or photoperiod. The plants' response to day length controls the timing of the transition from vegetative to reproductive or floral development and the rate of physiological development. Varieties differ in their responses to day length. Some varieties flower under relatively short days while others flower under longer days. Varieties have been classified for photoperiod Response based upon the ability of the variety to effectively utilize the length of the growing season in a region (Yin *et al.*, 1997).

2.12 Effect of Genotype on Nitrogen Fixation in Soybean

Nitrogen is an abundant element and its deficiency results in changes in root formation, photosynthesis and production according (Krapp *et al.*, 2011). Mineral N can be absorbed by plants root from the soil or obtained from the atmospheric N_2 through the process of biological nitrogen fixation (Masson-boivin *et al.,* 2009).

The amount of nitrogen that a plant can fix depends on the variety, the productivity of Rhizobium bacteria, the soil and the climatic conditions. Soybean is capable of fixing between 60 kg and 168 kg of nitrogen per hectare per year under suitable conditions (Rienke and Joke, 2002).

The amount of nitrogen actually fixed by a legume does not only depend on the genetics of the bacteria but also on the host plant. The factors which control the amount of N fixed include available soil N, genetic determinants of compatibility in both symbiotic partners and lack of other yield-limiting factors (Bohlool *et al.,* 1992). Van Kessel and Hartley (2000) also observed that, increased soil moisture increases the potential of biological nitrogen fixation. The rich N content of Soybean grain coupled with soil N meets the seedling stage demand, while biologically fixed N takes care of the needs at later crop stages under favourable conditions (Hellal and Abdelhamid, 2013). Thus, the crop rarely shows N deficiency symptoms, but it does show the symptoms of deficiency with failure of biological nitrogen fixation (BNF) and in N-deficient soils. (Hellal and Abdelhamid, 2013).

Omondi *et al.* (2014) reported that, there are significant differences in nitrogen fixed among the soybean varieties but the difference in nitrogen fixed among soybean varieties was attributed to differences in soil moisture within the experimental plots which probably enhanced activity of rhizobia at different sites and the genetic ability within the different varieties. Different growth habit and maturity period of soybean varieties have different nitrogen fixation ability (Mahama, 2011).

Keyser and Li (1992) stated that the late maturing cultivars fix more N, and yield more than earlier types due to a longer reproductive phase, when rates of N_2 fixation and seed biomass accumulation are high and this had earlier been confirmed by (Patterson and LaRue, 1983; George *et al.,* 1988) from previous studies. However, from their results it appears that the proportion of total N derived from fixation remains fairly constant for cultivars of different maturity at a given site. There is tremendous germplasm diversity in soybean, and using a genotype well adapted to a given site is probably one of the best and simplest strategies for improving BNF, through improving yield (Keyser and Li, 1992).

Ogoke *et al.* (2003) observed a positive N balance by soybean crop and they accredited the result to the effect of increased crop duration (late maturing varieties) and N application. From their findings, late maturing soybean varieties are able to fix more N_2 than early and medium maturing varieties. According to Wondimu *et al.* (2016), late maturing soybean varieties are able to give higher N benefit compared to early and medium varieties for the improvement of the cropping systems.

Phillips and DeJong (1984) reported that, traditional legume breeding programs have not included enhancement of biological nitrogen fixation as a direct objective. A review of the reports on soybean, examining the relationship between total N fixed and yield, shows them to be positively and highly correlated (Leffel, 1989). It appears that direct selection for yield improvement in soybean has indirectly included improved capacity to fix N_2. The potential for yield increase due directly to increased biological nitrogen fixation exists (Imsande 1989; Burias and Planchon, 1990). The one preliminary report that shows differences between biological nitrogen fixation in soybean genotypes of equal yield and maturity is that of (Rotundo *et al.,* 2009). They found that selected high seed-protein genotypes attained higher total N from higher N, fixation compared to normal genotypes. Soybean genotypes have recently been identified which have greater numbers of nodules in the presence of high mineral N (Herridge *et al*., 1988; Herridge *et al.,* 1998). Similar studies have been conducted on a smaller scale (Gibson and Harper, 1985; Danso *et al.,* 1987). The benefit of this approach is that soybean would fix more at a given level of mineral N, thus saving or 'sparing' that soil N for subsequent crops.

2.13 N Nutrient depletion in soils

Nutrient is a source of nourishment such as food that can be metabolized by an organism to give energy and build tissue. As plants use the available nutrients in the soil for their growth and production purposes, there is the need for the soils to be replenished for continuous cropping (Stewart *et al.,* 2005).

Ghana has one of the highest rates of soil nutrient depletion among sub-Saharan African countries with annual projected losses of 35 kg N, 4 kg P and 20 kg K/ha. The extent of nutrient depletion is widespread in all the agro-ecological zones with nitrogen and phosphorus being the most deficient nutrients (Fosu-Mensah *et al.,* 2012). Nutrients that have been removed from the soils by crop harvest have not been replaced through the use of corresponding amounts of plant nutrients in the form of organic and inorganic fertilizers. MoFA (2015) reported that, Ghana has one of the highest soil nutrient depletion rates in Sub Saharan Africa; it has one of the lowest rates of annual inorganic fertilizer application of only 8 kg/ha. Therefore, compared to most other African countries with fragile soils, sustainable forms of agricultural intensification in Ghana will require explicit attention to soil nutrient replacement.

The extent of nutrient depletion in Ghana is widespread in all the agro-ecological zones with nitrogen and phosphorus being the most deficient nutrients. These deficiencies are, however, more pronounced in the coastal, Guinea and Sudan Savannah zones where organic matter content is low and the annual burning and removal of crop residues further prevent the build-up of organic matter.

Most of Ghana's soils are developed on thoroughly weathered parent materials. They are old and have been leached over a long period of time (Banson *et al.,* 2015). Their organic matter content is generally low, and is of low inherent fertility. The two most deficient nutrients are nitrogen and phosphorus particularly because of the very low organic matter content (Fernandes *et al.*, 2012).

Incidentally, the tropical soils in Africa do not respond well to some of the temperate farming practices like heavy use of fertilizers, herbicides and pesticides (Houngnandan *et al.,* 2000). Therefore the need for soil fertility management practices to amend the depleted soils.

Bessah *et al.* (2016) reported that, status of total N in soils of guinea savanna ranges between 0.05 - 0.12 mg/L In Ghana, annual depletion rate of 30 kg N, 3 kg P and 17 kg K/ha were recorded for the period 1982 – 1984 and projected for year 2000; 35 kg N, 4 kg P and 20 kg K/ha. Among the nutrient been depleted N ranked the most depleted in soils, and this show it's the most used and most needed by plant. Soil fertility management is a crucial yet under-appreciated dimension of sustainable productivity growth. If soil fertility problems remain unaddressed, Ghana's agricultural growth will be impeded, its agricultural lands will become increasingly degraded, its use of inorganic fertilizer will continue to be low, and it is likely to become more dependent on food imports as the rate of growth of population or consumption outstrips that of food production (MOFA, 2015).

Among legumes, soybean is considered most suitable for integration into the traditional intercropping systems and in crop rotation due to its outstanding features, such as short growth duration, adaptability to short spells of moisture deficiency, high yield potentials, soil fertility restoration through nitrogen fixation and easy ploughing as it leaves the soil friable (Aniekwe and Mbah, 2014).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Site

The experiment was conducted in four different communities (Bunglung, Langa, Kukuo, Sandu) in Savelugu/Nanton Municipality in the Northern region of Ghana. Savelugu/Nanton Municipality falls within the Guinea Savanna agro-ecological zone of Ghana which is characterized by vast, low-lying areas of semi-arid grassland interspersed with savannah woodland, a dry and hot climate and a uni-modal rainfall patter (Wiredu *et al*., 2010; Ellis-Jones *et al*., 2012). The land is generally flat with gentle undulating low relief. The altitude ranges between 121 to 244 m above sea level with the southern part being slightly hilly and sloping gently towards the North. The area receives an annual rainfall averaging 1100 mm, considered enough for a single farming season. The rainy season starts from May to October with peak in August/September and a long dry season from November to April. The annual rainfall during the year 2015 in Tamale was 855.3 mm. Temperatures are usually high, averaging 34^0C. The maximum temperature could rise as high as 42^0C and the minimum as low as 16^0C. The low temperatures are experienced from December to late February (Dietz *et al.,* 2004).

3.2 Geology and Soils

The soils in the area which developed over voltaian sandstones, shales and mudstones give rise to laterite, ochrosols, sandy soils, alluvial soils and clay and are classified as Savanna-ochrosols (Tay, 2012). The organic matter content is low and is increasingly worsened by the extensive bush burning and the top soil has little capacity to retain moisture. The soils are porous and friable and underlain with iron concretions (Tay, 2012).

3.3 Land Preparation and Experimental Layout

The experimental fields were generally previously cultivated to maize. The fields were ploughed using a tractor and harrowed with hoes. The study was conducted as a two factor experiment laid out in a split plot design with genotype as the main plot and plant population as sub-plot in four communities. The communities served as replicates. The main plots consisted of four soybean genotypes: TGX 1904-6F, TGX 1955-4F, Soung-pungun and Jenguma. The sub-plots were made up of three plant spacing: 45 by 10 cm at 2 seeds per stand giving a plant population of 444,444 plants/ha; 60 by 10 cm at 2 seeds per stand giving a plant population of 333,333 plants per hectare and 75 by 10 cm at 2 seeds per stand giving a plant population of 266,666 plants per hectare. Each sub-plot measured 6 by 5 m with 1 m between two sub-plots. The genotypes TGX 1904-6F and TGX 1955-4F were obtained from the International Institute of Tropical Agriculture (IITA), Kano in Northern Nigeria while the genotypes Jenguma and Soung-pungun were obtained from the Savanna Agricultural Research Institute (SARI) at Nyankpala. The seeds were inoculated with the inoculants (Nodumax) containing 10^8 cells/g of *Bradyrhizobium japonicum* strain USDA 110. Triple super phosphate fertilizer (46% P_2O_5) was applied at a rate of 30 kg P/ha at planting to only soybean plants. The fertilizer was banded 10 cm away from the planting line, in a 2 - 5 cm deep trench and covered.

Maize (Abontem) was planted within each subplot to serve as a reference crop for nitrogen fixation. Maize was planted at 75 x 40 cm. fertilizer was not applied to any of the maize plant.

3.4 Soil Sampling and Analysis

Before clearing the land, soil samples were taken from 0 – 20 cm depth for both physical and chemical analysis. Core soil samples were collected randomly from the 0 – 20 cm depth on the site using a soil auger. Soil was then mixed thoroughly and a composite sample was taken to the laboratory, air–dried and sieved to pass through a 2 mm screen for chemical analysis. Soils were analysed for pH (1:1- soil : H_2O), organic C (Walkley-Black), total N (Kjeldahl), Mehlich P and exchangeable K, Ca and Mg (IITA, 1981).

Table 1: Physico-chemical properties of soils at the four (4) communities

Soil parameter	Community levels			
	Bunglung	Sandu	Kukuo	Langa
pH (H_2O)	5.8	6.2	5.7	5.9
Organic carbon (%)	0.37	0.45	0.44	0.28
Available Nitrogen (%)	0.075	0.046	0.042	0.023
MehP (ppm)	47.11	19.46	112.02	22.54
Exchangeable bases				
Calcium (Cmol/kg)	2.62	1.87	1.68	0.73
Magnesium(Cmol+/kg)	0.65	0.66	0.54	0.25
Potassium (Cmol/kg)	0.13	0.11	0.28	0.09
CEC (Cmol/kg)	3.49	2.70	2.58	1.16
Particle size distribution (%)				
Sand	68	68	52	66
Clay	18	15	15	13
Slit	14	17	33	21

3.5 Data Collection

3.5.1 Plant Height

The heights of ten tagged plants were taken in each treatment at 50% flowering. Measurement was made from the base of the plants (above ground) to the highest growing point using a straight edge stick attached with a measuring tape.

3.5.2 Nodule Count

At 50% flowering, ten soybean plants were randomly uprooted; the nodules were removed, washed and counted.

3.5.3 % of Effective Nodule

Nodules were cut into two with a sharp edge and the effectiveness was determined by looking at the colour. The colours, pink and red were regarded as effective while white, gray, green and black were regarded as non-effective. Effective nodule % was determined at 50% flowering.

The effective nodule % was then calculated as:

$$\text{Effective nodule \%} = \frac{Effective\ nodule}{Total\ number\ of\ nodule} \times 100$$

3.5.4 Nodule Dry Weight

Nodules were oven dried at $60^{o}C$ for two days and the weights were determined by weighing them on an electronic balance.

3.5.5 Number of Pods per Plant

Ten plants were sampled from each subplot, the pods were then counted and the average recorded.

3.5.6 Number of Seeds per Pod

Ten plants were sampled from each subplot, the seeds in each pod were counted and the average was recorded.

3.5.7 Days to 50% Flowering

Each variety was observed closely and carefully from the day of emergence to the day half of the plants in each subplot flowered. The days to 50% flowering was then calculated by counting the number of days from emergence to flowering.

3.5.8 Grain Yield

An area of 12 m^2 per subplot was harvested, threshed and winnowed. The grains were then air dried and weighed at 12% moisture content**.**

3.5.9 Hundred Seed Weight

Hundred seeds of soybean grains were picked randomly and the weight was taken.

3.5.10 Biomass Sampling

At mid pod filling stage which was approximately 50 days after planting, soybean plants were taken from an area of 3 m^2 from each sub-plot. The fresh weight was taken. A sub-sample of 500 g was taken and then oven dried at 60^0C for three days to constant weight. The same area of the maize plot was also sampled, weighed and sub-sample of 500 g taken, oven-dried at 60^0C for three days to constant weight.

3.5.11 Nitrogen Fixation (planting non N fixing plant such as maize)

N difference method was used to determine the amount of N fixed (Unkovich and Pate, 2000).

500 g of the pods and shoot of soybean were oven-dried at 60^0C for 72 hours to determine the dry matter content after which samples were grounded and sieved with one mm mesh and analysed for N.

500 g of the maize cobs and shoot were oven-dried at 60^0C for 72 hours to determine the dry matter content after which samples were grounded and sieved with one mm mesh and analysed for N.

Determination of nitrogen fixation

The N difference method is based on the difference in total N between the N_2–fixing legume and the reference crop which in this study was maize. Thus the amount of N_2 fixed was estimated by the N difference method as:

$$\text{N from nitrogen fixation} = N_{legume} - N_{maize}$$

And the % N derived from N_2–fixation was calculated as:

$$\%\ \text{N from nitrogen fixation} = \frac{(N_{legume} - N_{maize})}{N_{legume}} \times 100$$

Amount of N fixed per hectare was calculated as:

$$\text{N fixed (kg/ha)} = \frac{\% \, N\{legume\}}{100} \times BW \, \{Legume \; kg/ha\} - \frac{\% \, N\{Maize\}}{100} \times BW \, \{Maize \; kg/ha\}$$

Where BW stand for biomass weight

3.5.12 Statistical Analysis

Data collected was subjected to the Analysis of Variance (ANOVA) model using Genstat Statistical package (12^{th} edition), and treatment means compared using Fisher test Least Significance Difference (LSD) at 5% probability level.

CHAPTER FOUR

RESULTS

Results on germination percentage, days to 50% flowering, plant height, nodule count, nodule dry weight, % of effective nodules, weight of dry biomass at mid podding, nitrogen fixation (%), amount of nitrogen fixed (kg/ha), number of pods per plant, number of seeds per pod, grain yield, hundred seed weight and dry weight of biomass at harvest, are presented in this section.

4.1 Germination percentage (%)

The result of the germination % for the different plant spacing is shown in Figure 1. The interaction between plant spacing and genotype was not significant. Planting distance significantly affected germination percentage (*P=0.011*). Germination was significantly higher in closer plant spacing (45 x 10 cm) than the other two plant spacings (Figure 1). Genotype did not significantly (*P=0.114*) influence germination percentage.

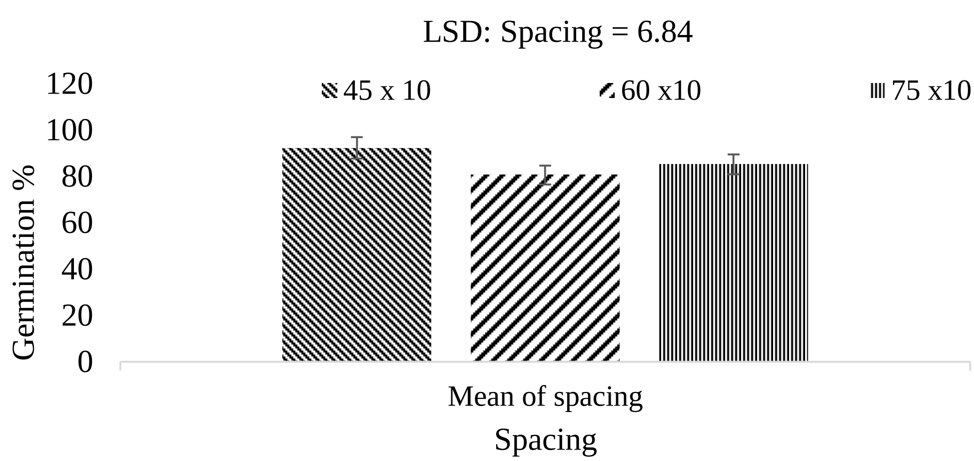

Figure 1: Effect of plant spacing on germination %. Error bars represent standard error of means (SEM)

4.2 Days to 50% flowering

Figure 2 shows the number of days to 50% flowering. Earliness to flowering was significantly (*P=0.001*) influenced by interaction between plant spacing and genotype. Jenguma at wider spacing (75 x 10 cm) flowered earlier than when closely spaced (45 x 10 cm and 60 x 10 cm). Soung-pungun at closer spacing (45 x 10 cm) flowered earlier than when widely spaced (60 x 10 cm and 75 x 10 cm). TGX 1904-6F also flowered earlier when closely spaced than when broadly spaced. TGX 1955-4F flowered earlier when spaced at 60 x 10 cm than when spaced at 45 x 10 cm and 75 x 10 cm. planting distance and genotype were also significant.

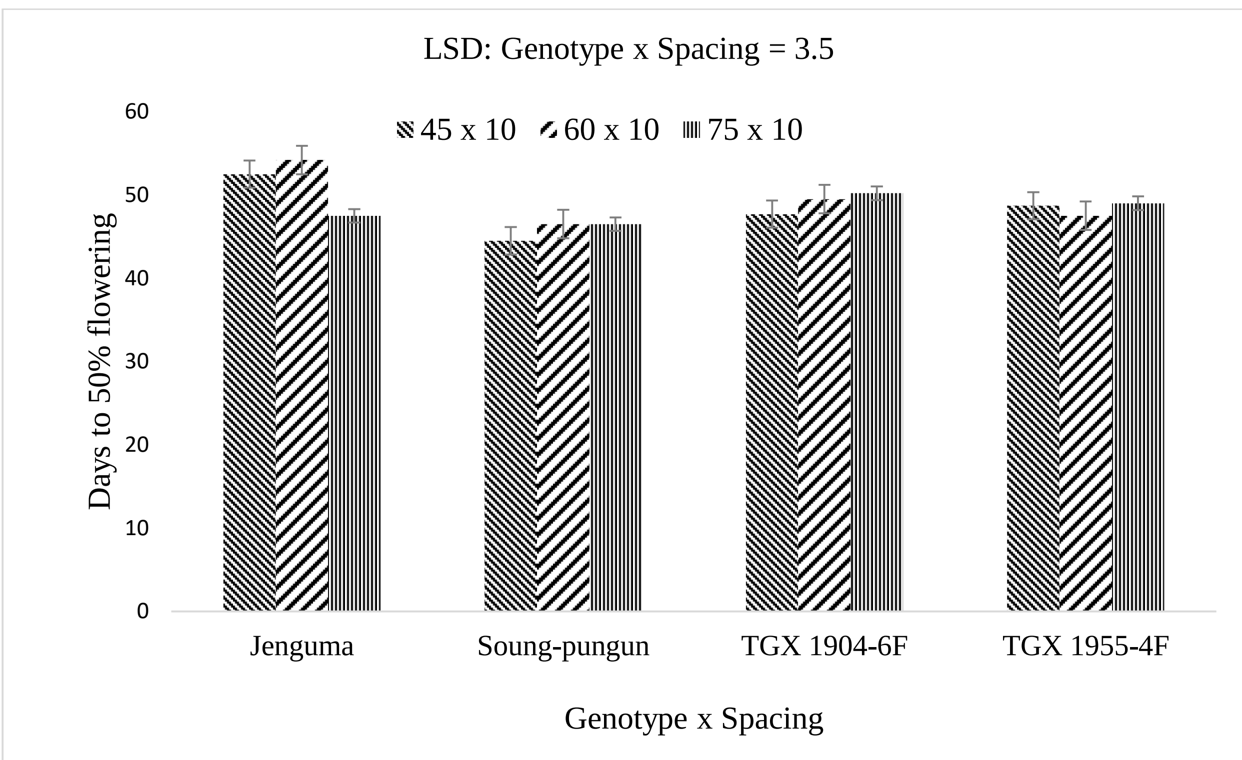

Figure 2: Effect of interaction between soybean genotype and spacing on days to 50% flowering. Error bars represent standard error of means (SEM)

4.3 Plant height at flowering

Table 2 shows plant height at flowering for 4 genotypes of soybean planted at 3 plant spacing in the Guinea Savanna ecological zones of Ghana. There was no significant effect of plant height on interaction between genotypes and plant spacing. Genotypes and plant spacing were not significantly affect plant height.

Table 2: Effect of interaction between soybean genotype and spacing on plant height

		Spacing		
Genotype	45 x 10	60 x 10	75 x 10	Mean of Genotype
		Plant height (cm)		
Jenguma	57.8	62.0	63.9	61.2
Soung-pungun	56.6	54.1	56.9	55.9
TGX 1904-6F	59.7	60.6	56.9	59.1
TGX 1955-4F	58.7	60.1	58.8	59.2
Mean of spacing	58.2	59.2	59.1	
CV (%)		9.1		

4.4 Number of nodules per plant

Figure 3 shows the results of the effect of genotype and plant spacing on the number of nodules at flowering. The interaction between genotype and spacing for nodule number was not significant. The number of nodules at flowering was not significantly different among the different genotypes and plant spacing.

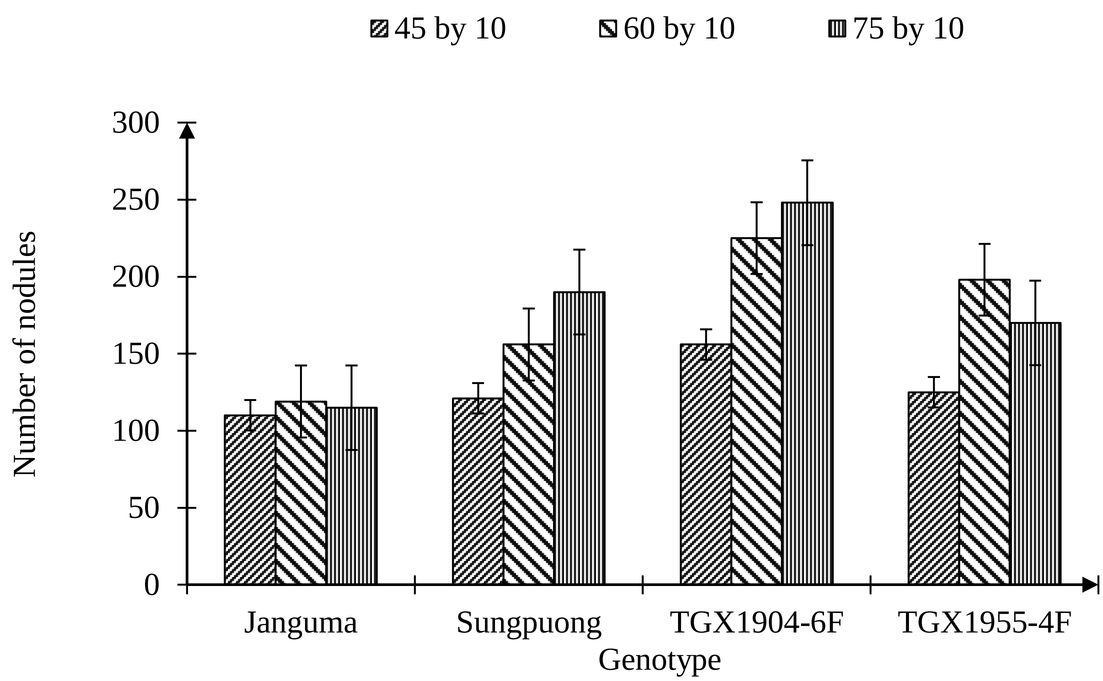

Figure 3: The Effect of soybean genotype and plant spacing on the number of nodules at flowering. **Error bars represent standard error of means (**SEM)

4.5 Nodule dry weight

Figure 4 shows the results of the effect of genotype and plant spacing on dry weight of nodules per plant. Interaction effect between genotype and spacing was not significant. Nodule dry weight was not significantly different among genotype and plant spacing.

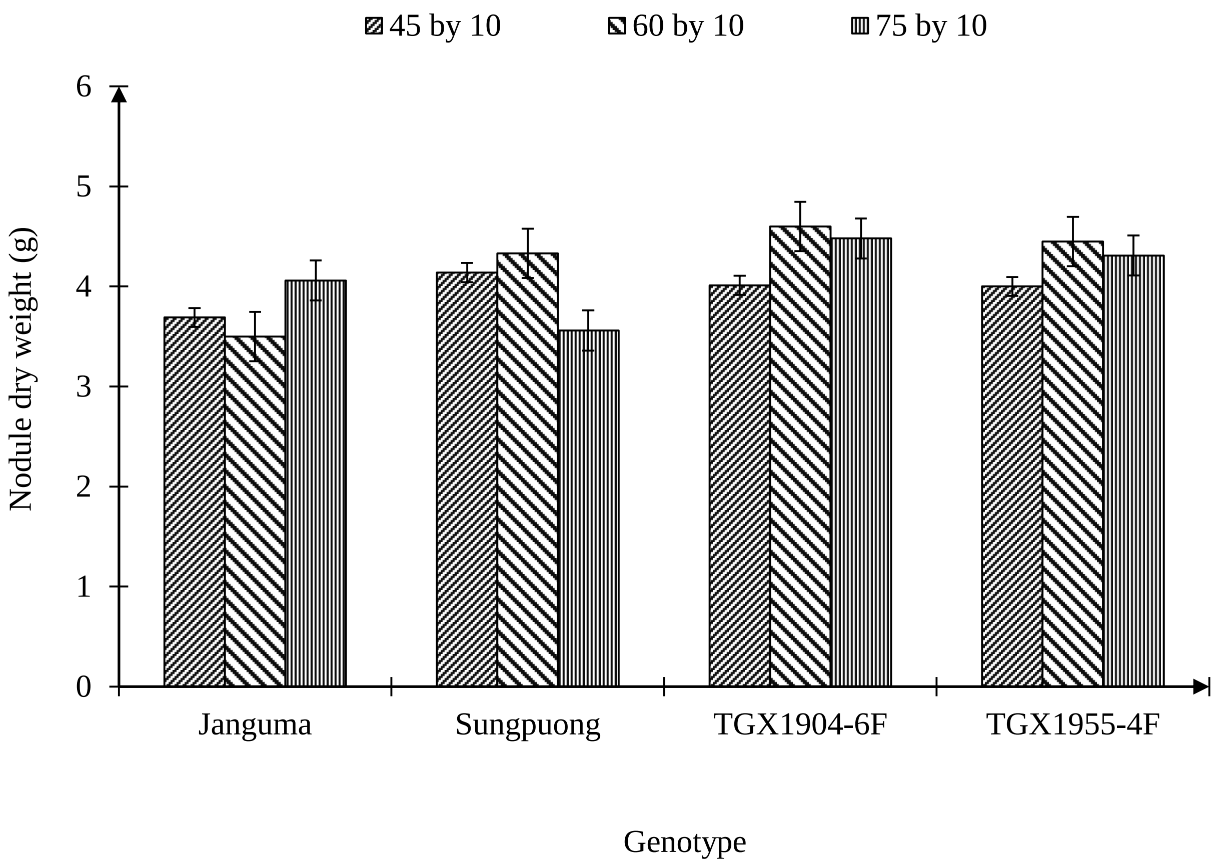

Figure 4: Effect of soybean genotype and spacing on nodule dry weight. Error bars represent standard error of means (SEM)

4.6 Percentage of effective nodules

Figure 5 represents the result for percentage number of effective nodules as influenced by genotype and plant spacing. Interaction between genotype and spacing was not significant. Both genotype and spacing did not significantly influence the percentage number of effective nodules at flowering.

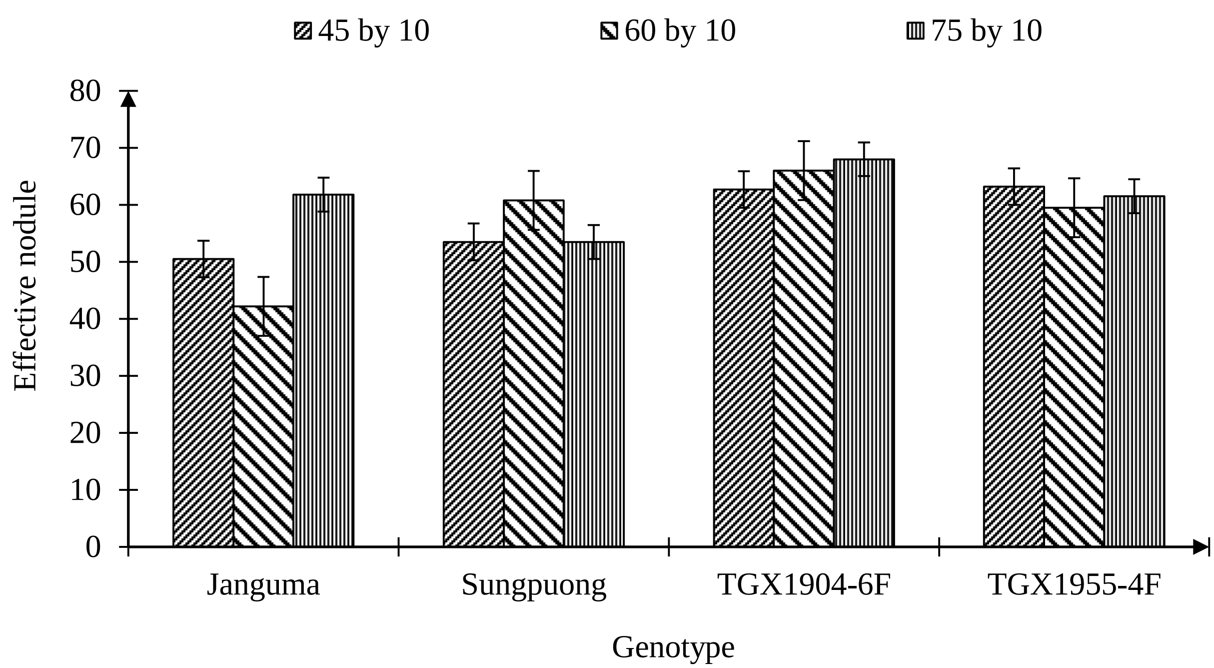

Figure 5: Percentage of effective nodules as affected by soybean genotype and plant spacing. Error bars represent standard error of means (SEM).

4.7 Dry weight of biomass at mid podding

There was significant interaction between genotype and plant spacing with regards to biomass at mid podding. TGX 1904-6F with 45 x 10 cm produced the highest biomass at mid podding than the other genotypes with their various spacing. TGX 1955-4F performed well with spacing 45 x 10 cm while Jenguma and soung-pungun performed better with spacing 60 x 10 cm and 45 x 10 cm respectively.

There was no significant difference between genotype with respect to above ground biomass yield at mid podding (Figure 6). Plant spacing also had significant effect on weight of dry biomass. Spacing 45 x 10 cm gave the highest value whilst 75 x 10 cm gave the least.

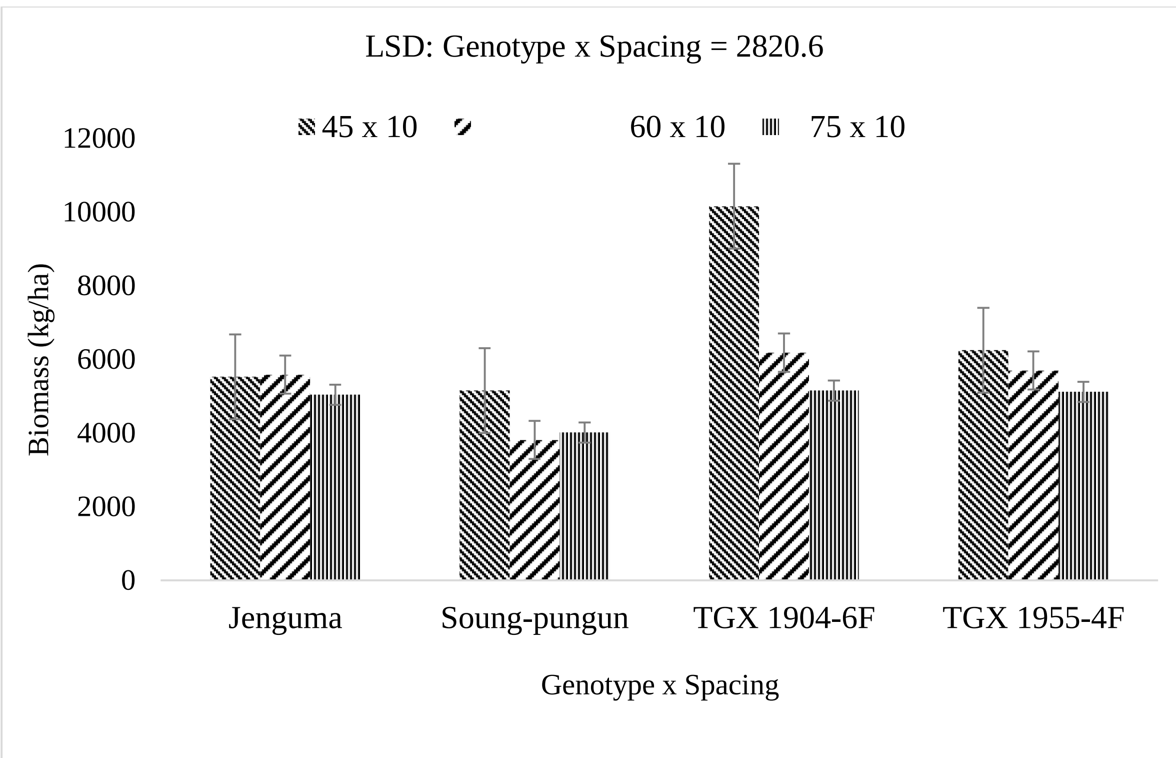

Figure 6: Effect of soybean genotype and plant spacing on biomass yield at mid podding. Error bars represent standard error of means (SEM)

4.8 Nitrogen fixation in soybean as affected by genotype and plant spacing

The percentage of nitrogen fixed by soybean as influenced by genotype and spacing are shown in Table 3. Interaction between genotype and spacing was not influenced by Nitrogen fixed statistically. There was no significant differences in the percent nitrogen fixed between the different soybean genotypes and also between the different plant spacings.

Table 3: Influence of soybean genotype and plant spacing on % nitrogen fixation in soybean

	Spacing (cm)			
Genotype	45 x 10	60 x 10	75 x 10	Mean of Genotype
	Nitrogen fixed (%)			
Jenguma	65.4	69.2	63.2	66.0
Soung-pungun	70.8	70.3	69.6	70.3
TGX 1904-6F	68.5	64.0	65.8	66.1
TGX 1955-4F	62.1	59.7	64.2	62.0
Mean of spacing	66.7	65.8	65.7	
CV (%)			6.1	

4.9 Amount of nitrogen fixed as affected by genotype and plant spacing

The amount of nitrogen in kg/ha fixed by soybean as influenced by genotype and spacing are presented in Figure 7. Interaction between plant spacing and soybean genotype significantly influenced the amount of nitrogen fixed (*P<0.006*). TGX 1904-6F was able to fix the highest amount of N when spaced at 45 x 10 cm. Jenguma, TGX 1955-4F and soung-pungun with spacing 60 x 10 cm, 45 x 10 cm and 45 x 10 cm respectively was able to fix high amount of N than the other spacing. Plant spacing was also influenced by amount of nitrogen fixed (*P<0.026*) but there were no significant differences in the amount of N fixed between the different soybean genotypes.

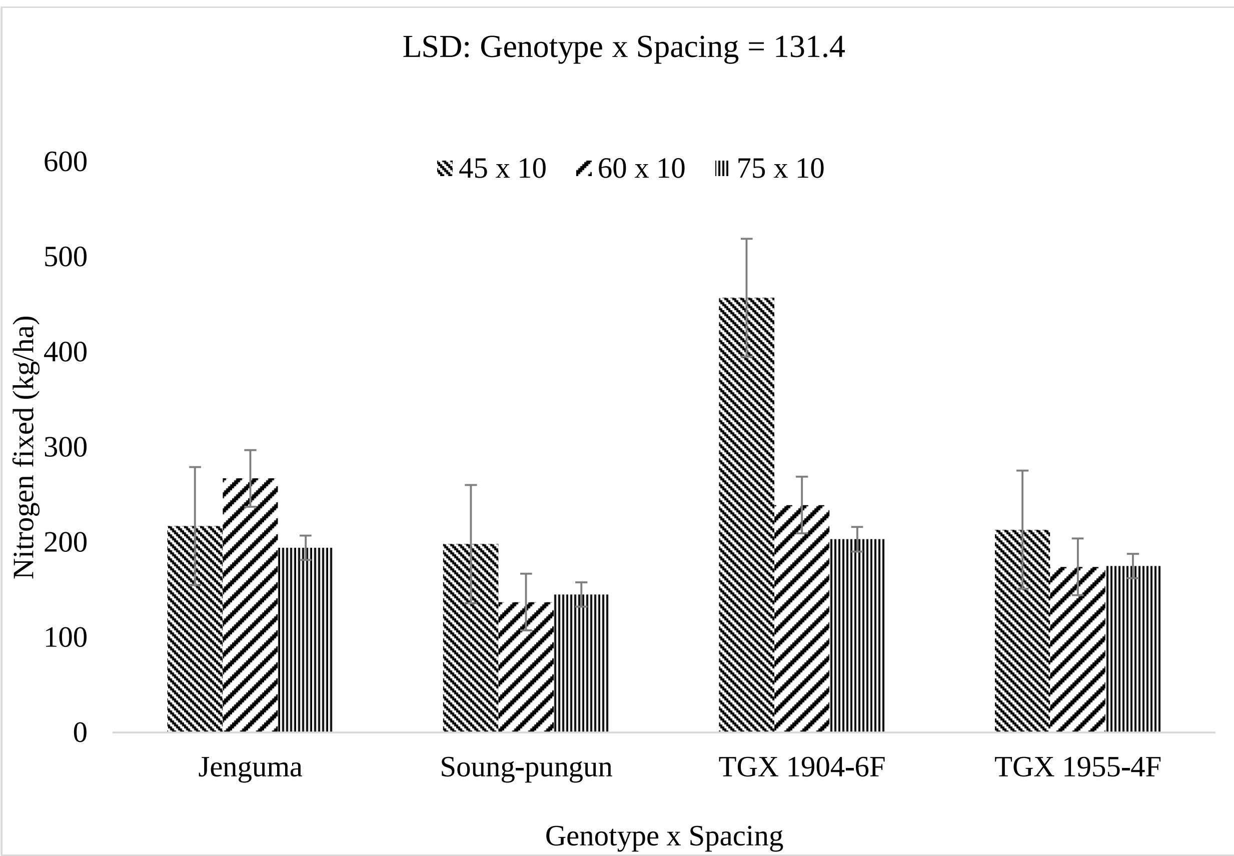

Figure 7: Effect of soybean genotype and spacing on amount of N fixed by plant. Error bars represent standard error of means (SEM)

4.10 Number of pods per plant

Figure 8 represents the results of the number of pods per plant as influenced by genotype and plant spacing. Interaction effect between genotype and plant spacing was significant. Soung-pungun with spacing 75 x 10 cm produced the highest number of pods while TGX 1955-4F with spacing 45 x 10 cm produced the lowest number of pods per plant. There was significant (*P<0.05*) difference between genotype with respect to the number of pods per plant. The number of pods per plant ranged from 30 with TGX1904-6F to 44 with Jenguma. Spacing did not significantly affect the number of pods per plant.

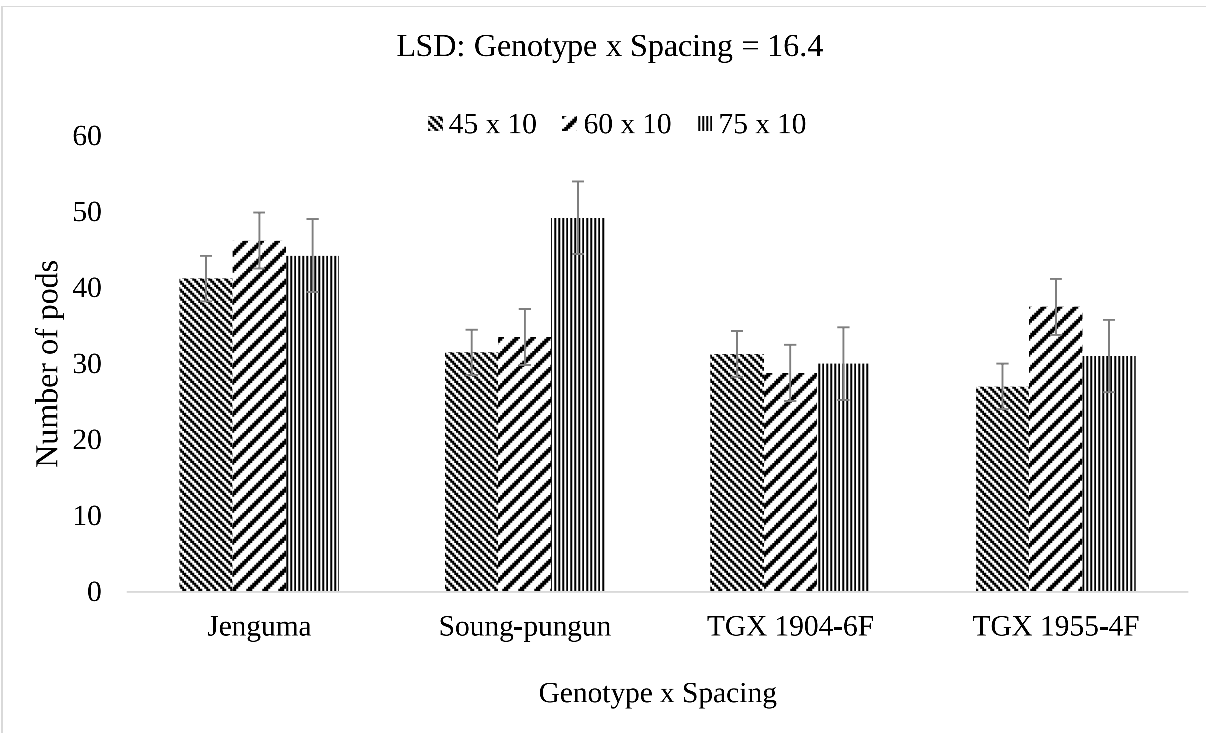

Figure 8: Effect of soybean genotype and spacing on number of pods per plant. Error bars represent standard error of means (SEM)

4.11 Number of seeds per pod

Results of number of seeds per pod as affected by genotype and plant spacing are presented in Table 4. Interaction between spacing's and genotype had no significant influence on number of seeds per pod. There was no significant (*P>0.05*) difference between genotype and spacing's.

Table 4: Effect of soybean genotype and spacing on number of seeds per pod

		Spacing (cm)		
Genotype	45 x 10	60 x 10	75 x 10	Mean of Genotype
Jenguma	2.7	2.5	2.7	2.7
Soung-pungun	2.5	2.2	2.2	2.3
TGX 1904-6F	2.2	2.5	2.5	2.4
TGX 1955-4F	3.0	2.7	2.7	2.8
Mean of spacing	2.6	2.5	2.6	
CV (%)			19.5	

4.12 Hundred seed weight

Table 5 shows the results of hundred seed weight as influenced by genotype and plant spacing. The interaction between genotypes and Plant spacing with respect to the mean of 100 seeds weight was significant. TGX 1955-4F with spacing 60 x 10 cm recorded the highest hundred seed weight while Jenguma with spacing 75 x 10 cm recorded the least.

Genotypes were significantly different but plant spacing had no significant effect on hundred seed weight.

Table 5: Effect of soybean genotype and plant spacing on hundred (100) seed weight (g)

		Spacing (cm)	
Genotype	45 x 10	60 x 10	75 x 10
Jenguma	7.6	7.9	7.1
Soung-pungun	8.5	8.5	8.8
TGX 1904-6F	7.8	7.9	7.9
TGX 1955-4F	8.8	9.2	8.3
LSD	Genotype x Spacing = 718		
CV (%)	7.2		

4.13 Grain yield at harvest

Grain yield at harvest did not significantly affect the interaction between spacing and genotype (Table 6). There was also no statistical different between genotypes and plant spacing.

Table 6: Effect of soybean genotype and plant spacing on grain yield of soybean in the Guinea Savanna ecological zone of Ghana.

		Spacing (cm)		
Genotype	45 x 10	60 x 10	75 x 10	Mean of Genotype
	Yield (kg/ha)			
Jenguma	1887	2363	1533	1928
Soung-pungun	1736	1620	2267	1874
TGX 1904-6F	2002	2014	1538	1851
TGX 1955-4F	1794	2083	1544	1807
Mean of spacing	1855	2020	1721	
CV (%)	26.8			

4.14 Dry biomass yield at harvest

From figure 9, biomass yield at harvest has no significant influence on the interaction between plant spacing and genotype. There was also no significant difference among genotypes or plant spacing. However Jenguma produced the highest biomass yield while Soung-pungun produced the least. Spacing 60 x 10 cm recorded the highest biomass yield while spacing 45 x 10 cm recorded the least.

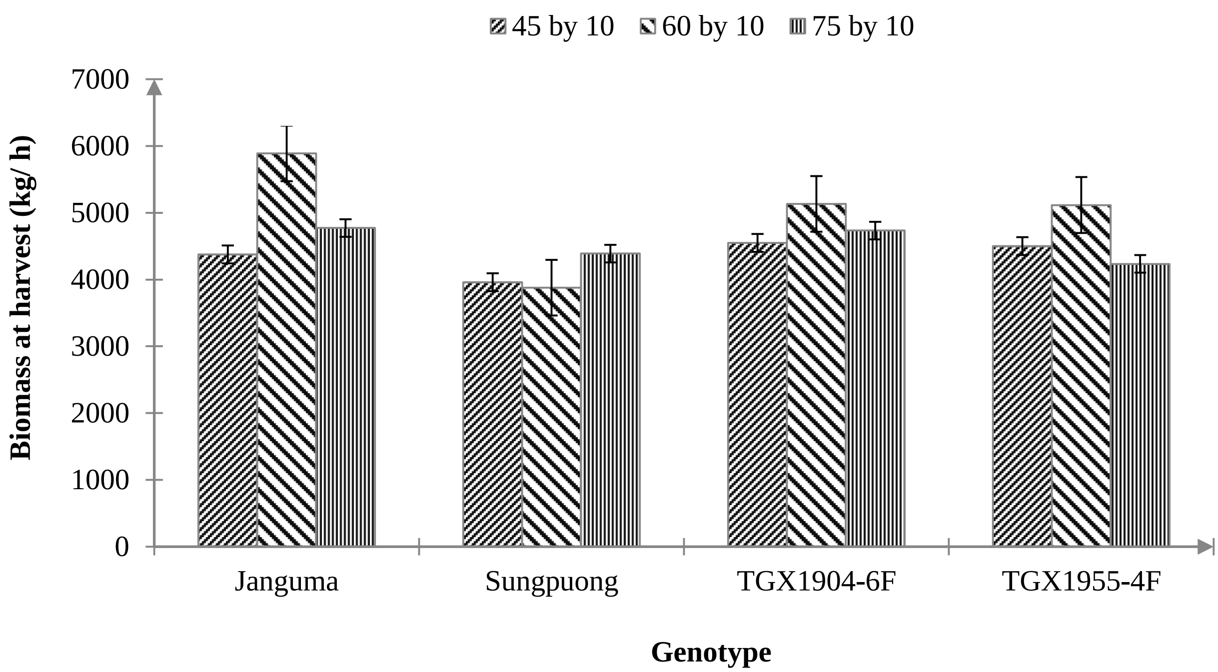

Figure 9: Effect of soybean genotype and plant spacing on biomass yield. Error bars represent standard error of means (SEM)

CHAPTER FIVE

DISCUSSION

5.1 Effect of Genotype and Plant Population Density on Growth

Plant population density, genotype and their interaction significantly affected the number of days it took the soybean plants to reach 50% flowering. The earliest variety to reach 50% flowering was Soung-pungun, followed by TGX 1955-4F, TGX 1904-6F and Jenguma in that order and the differences may be due to the differences in their genetic makeup. Sjamsijah *et al.* (2016) stated that, growth, development, and yield of soybeans are as a result of a given variety's genetic potential interacting with its environment. Ishag (2000) observed differences in flowering patterns between cultivars of groundnut while Kaba *et al.* (2014) also reported significant differences in flowering patterns among groundnut varieties.

The genotypes flowered earlier when spaced at 75 x 10 cm than when spaced at 45 x 10 cm or 60 x 10 cm and this agrees with the findings of Rahman *et al.* (2011) who observed that, within certain limits, increases in plant population density (PPD) results in prolong number of days to flowering. Jenguma flowered earlier when plant population was reduced to 266,666 plants/ha (75 x 10 cm); the number of days to flowering increased when population was increased to 333,333 plants/ha (60 x 10 cm) but number of days to flowering reduced when population was further increased to 444,444 plants/ha (45 x 10 cm). Soung-pungun and TGX 1904-6F flowered earlier at higher plant population (444,444 plants/ha) but flowered late at lower plant population (266,666 plants/ha). TGX 1955-4F also flowered earlier at a spacing of 60 x 10 cm but flowering duration increased as plant population was increased to 444,444 plants/ha and as plant population was reduced to 266,666 plants/ha.

Interaction between genotype and plant spacing was not significant. Germination percentage was significantly affected by plant spacing. Germination of soybean was significantly higher in closer plant spacing (45 x 10 cm) than when spaced 75 x 10 cm and 60 x 10 cm respectively. Germination percentage was higher when soybean plant population was increased from 333, 333 plants/ha to 444, 444 plants/ha but there was a decline when population was increased from 266,666 plants/ha to 333, 333 plants/ha. From the study, increase in plant population density (PPD) within certain limits, results in the reduction of germination percentage in soybean plant. There was no significant difference between genotypes in percent germination.

From the result, genotype, plant spacing and their interaction had no significant effect on plant height. However, it can be deduced from the result that, Jenguma produced the tallest plants followed by TGX 1955-4F, TGX 1904-6F and Soung-pungun. Plant population of 333,333 plants/ha (60 x 10 cm) also produced the highest plant height followed by 266,666 plants/ha (75 x 10 cm) and 444,444 plants/ha (45 x 10 cm) respectively. Mahama (2011) observed an increase in plant height when soybean plants were spaced at 60 x 5 cm than when spaced at 50 x 5 cm, 40 x 5 cm and 30 x 5 cm respectively. Plant height followed the trend of grain yield. This is in line with Caliskan *et al.* (2007) who stated that, within certain limits, increase in plant population density (PPD) results in the reduction in growth and yield per plant but the reverse occurs for yield per unit area. Sa *et al.* (2006) also observed an increase followed by decrease in plant height with increasing population density in sunflower plants. Spacing 60 x 10 cm might have effective utilisation of available environmental resources like light, water and nutrients, as a result of less intra plant competition. This might have accounted for the greater plant height. Staggenborg *et al.*

(1996) reported significant increases in plant height in wider row spacing of 76 cm as against narrow row spacing of 46 cm, at high-yielding environments.

5.2 Effect of Genotype and Plant Population Density on Nodulation and Nitrogen Fixation

From the result, TGX 1904-6F had the highest number of nodule per plant followed by TGX 1955-4F, Soung-pungun and Jenguma in that order. Spacing of 75 x 10 cm recorded the highest number of nodule per plant while 60 x 10 cm and 45 x 10 recorded the least respectively. It was observed that, as plant population increases, the number of nodules per plant decrease and this agrees with what Shamsi and Kobraee (2012) observed. They stated that, at lower plant densities the photosynthetic rate per plant increases and, consequently, higher carbon (C) supplied to the nodules resulted in an increase in nodulation and in nitrogen fixation rates. Kapustka and Wilson (1990) also found out that, an increase in soybean plant density reduced nodule number. Genotype TGX 1904-6F performed well in terms of number of nodules per plant with spacing 75 x 10 cm while TGX 1955-4F, Soung-pungun and Jenguma also performed well with spacing 60 x 10 cm, 75 x 10 cm and 60 x 10 cm in that order with respect to number of nodules per plant.

There was no significant difference between genotypes for nodule dry weight per plant. There was also no significant interaction between spacing and genotype. However, spacing 60 x 10 cm, recorded the highest nodule dry weight per plant followed by 75 x 10 cm and 45 x 10 cm while TGX 1904-6F, also produced the highest nodule dry weight per plant followed by TGX 1954-6F, Soung-pungun, Jenguma in that order (Figure 4). Kapustka and

Wilson (1990) stated that an increase in soybean plant density reduced nodule number and dry weight per plant.

TGX 1904-6F recorded the highest percentage of effective nodule followed by TGX 1955-4F, Soung-pungun and Jenguma respectively. Spacing 75 x 10 cm (266,666 plants/ha), recorded the highest percentage of effective nodule per plant while 45 x 10 cm (444,444 plants/ha) and 60 x 10 cm (giving 333,333 plants/ha) gave the least. As plant population increases, the effectiveness of the nodules decreases but the nitrogen accumulated by plant increases as plant population increase and this was reflected in the amount of nitrogen fixed.

There was significant difference between genotypes with respect to above ground biomass yield at mid podding. TGX 1904-6F produced the highest dry weight biomass followed by Jenguma, TXG 1955-4F and Soung-pungun. Spacing had significant effect on weight of dry biomass yield and there was no significant interaction between genotype and spacing. Spacing 45 x 10 cm, gave the highest biomass yield followed by 60 x 10 cm while 75 x 10 cm gave the lowest biomass yield at mid podding. The result indicates that, soybean biomass increases as plant density increases at the vegetative stage of soybean plant. TGX 1904-6F produced the highest dry biomass at mid podding but at harvest Jenguma produced the highest dry biomass and this may be as a result of TGX 1904-6F shedding most of its leaves thus resulting in a lower biomass at harvest. This observation of rapid dry matter accumulation in plants, especially during the vegetative phase has been made by several workers (Gardner *et al.,* 1985; Evan, 1996; Mahama, 2011).

There were no significant differences in the percent nitrogen fixed between soybean genotypes, However, Soung-pungun fixed the highest percentage of N (70.27) compared to the other genotypes; TGX 1904-6F (66.12) Jenguma (65.96), and TGX 1955-4F (61.99). Spacing 45 x 10 cm produced the highest % of N fixed while 60 x 10 cm produced the lowest. The trend in % of N fixed is different from that of the amount N fixed in kilogram per hectare because of the differences in biomass production. Omondi *et al.* (2014) reported that the difference in percentage nitrogen fixed among soybean genotypes could be due to the genetic ability of different genotypes to fix nitrogen.

The amount of N_2 fixed in the soybean genotypes from the study ranged from 187-226 kg N/ha which compares favourably with values reported by Ennin and Clegg (2001) who obtained a range of 200 - 280 kg/ha in Ghana. However our values are higher than those reported by (Ogoke *et al.*, 2006; Giller, 2001; Yusuf *et al.*, 2009) but lower than what was obtained by Salvagiotti *et al.* (2008).

There was no significant difference in the amount of nitrogen fixed among soybean genotypes. However, the genotype TGX 1904-6F fixed the highest amount of N, while Soung-pungun fixed the least amount of N. Plant spacing and interaction between spacing and genotype significantly influenced the amount of nitrogen fixed ($P<0.006$, $P<0.026$). Spacing 45 x 10 cm, fixed the highest amount of N while spacing 75 x 10 cm recorded the least amount of N fixed. TGX 1904-6F with spacing 45 x 10 cm fixed the highest amount of N followed by Jenguma 60 x 10 cm, TGX 1955-4F 45 x 10 cm and Soung-pungun 45 x 10 cm in that order. As soybean plant population density increases, amount of nitrogen fixed in kilogram per hectare also increased. This finding is in line with Ennin and Clegg (2001) who observed that estimated nitrogen fixation of determinate soybean was approximately, increased from 200 to 280 kg N/ha, when plant population was increased from 48,500 to 194,000 plants/ha respectively.

5.3 Effect of Genotypes and Plant Population Density on Yield and Yield Component

The grain yields of the genotypes of soybean used in this study ranged from 1807 kg/ha with TGX 1955-4F to 1928 kg/ha with Jenguma with no significant differences between the genotypes. The yields obtained in this study compares favourably with yields obtained in other studies under the same environmental conditions in Northern Ghana. For instance in similar environment in Northern Ghana, Aziz *et al.* (2016) obtained grain yields of soybean ranging between 1500 and 1800 kg/ha when they evaluated the response of three soybean varieties to rhizobium inoculation and phosphorus application. Yields obtained in this study are however higher than those obtained by Lamptey *et al.* (2014) who reported of yields of between 1044 and 1062 kg/ha in Northern Ghana. Although there was no significant differences among the four genotypes, Jenguma appeared to perform slightly better than the other genotypes. Jenguma is a genotype that has been grown in Northern Ghana for a long time and has become adapted to the environment.

Grain yield of Jenguma was higher by 25% when soybean plant population was increased from 266,666 plants/ha (75 x 10 at 2 seeds per hole) to 333, 333 plants/ha (60 x 10 cm at 2 seeds per hole) although the difference was not significantly different. Further increase in population to 444, 444 plants/ha (45 x 10 cm at 2 seeds per hole) however resulted in decline in yield by 54%. Within certain limits, increase in plant population density (PPD) results in the reduction in growth and yield per plant but the reverse occurs for yield per unit area according to Caliskan *et al*. (2007). This finding is in line with Ball *et al.* (2000) and Madanzi *et al.* (2012) who reported that, an increase in plant population in soybean can only influence yield to a certain point, reaching a maximum beyond which an increase in population will not result in further increase in yield but can lead to a decline in yield. The various genotypes performed differently with regards to yield at different spacing. Genotypic characteristics of the genotypes might have accounted for the grain yield differences. The results confirm with the findings of Cooper (1977) and Mahama (2011) who stated that, yield success of early maturity soybeans is contingent on cultivar characteristics. Bouquet (1998) also found that, cultivar selection and planting date were the most important factors for increasing soybean yield. Except for the genotype Soung-pungun which appeared to perform better at the population of 266, 666 plants per hectare, all the genotypes performed best at population of 333, 333 plants per hectare. Thus the results of this study which suggest the population of 333,333 plants per hectare to be optimum confirms the population of 333,333 plants per hectare which is recommended by the National Agricultural System.

Jenguma produced the highest dry biomass at harvest while Soung-pungun produced the least. Soung-pungun is a grain type and early maturing genotype with low biomass production while Jenguma is a dual purpose late maturing genotype with high biomass production. Also spacing 60 x 10 cm produced the highest biomass weight followed by 75 x 10 cm and 45 x 10 cm respectively. Anderson (2014) and James *et al.* (1996) stated that, high population in narrow row spacing for early maturing cultivars potentially increase growth and yield components, as they are able to utilize environmental factors more effectively. However, in this study, Soung-pungun which is an early maturing genotype had lower biomass production even at narrow spacing than at wider spacing (Figure 9).

Kapustka and Wilson (1990) found that an increase in soybean plant density reduced dry weight per plant but from the results, increase in plant density in soybean positively influenced biomass at harvest to a certain point, reaching a maximum beyond which increase in population did not result in increase in biomass but led to a decline in biomass.

There was significant difference between genotypes with respect to number of pod per plant but there was no statistical difference between spacing. The number of pods per plant ranged from 30 with the genotype TGX1904-6F to 45 with Jenguma and this maybe a contributory factor to the highest grain yield obtained by Jenguma. Spacing 60 x 10 cm, recorded the highest value of number of pods per plant followed by 75 x 10 cm and 45 x 10 cm respectively. Although the effect of spacing did not significantly influence the number of pods per plant, there was a decrease in the number of pods per plant as plant population increased to a certain limit. Board and Harville (1994) and Madanzi (2012) reported a decrease in number of pods per plant as plant density increases.

There was no significant difference between genotype and between spacing with respect to number of seed per pod; however TGX 1955-4F produced the highest number of seeds per pod while Soung-pungun produced the least. Spacing 45 x 10 cm produced the highest number of seed per pod while 60 x 10 produced the least. From the results, number of seed per pod increases as population increases which is in contrast with observation made by Rahman and Hossain (2011) who stated that, increase in plant density decreased yield components such as number of pods plant per plant and number of seeds per pod. From the study only number of pods per plant confirmed their findings but not number of seed per pod.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From the study it was found that, the range of soybean genotypes used in the study performed differently with the various spacing used.

Results from the study show that yield components such as number of pod per plant decreases as plant density increases but yield and number of seed per plant did not decrease as plant density increases.

Yield was not influenced by spacing but soybean plant population of 333,333 plants per hectare (60 x 10 cm) appears to be the optimum spacing due to its tendency to give higher yields. Thus the results of this study which suggests the population of 333,333 plants per hectare to be optimum, confirm the population of 333,333 plants per hectare which is recommended by the National Agricultural System. Farmers can therefore go ahead and plant at 60 x 10 cm irrespective of the genotype used.

Spacing 45 x 10 cm was able to support more amount of N fixation compared to 60 x 10 cm and 75 x 10 cm. The best spacing for each genotype with regards to amount of N fixed was Jenguma, 60 x 10 cm; Soung-pungun, 45 x 10 cm; TGX 1904-6F, 45 x 10 cm and TGX 1904-6F, 45 x 10 cm. Plant population is one factor that may influence how much residual nitrogen, soybean is contributing to a cropping system.

Although there was no significant difference in grain yield among the genotypes, Jenguma appears to be better in terms of grain and biomass yield than the other genotypes. However, because of the changing climate Soung-pungun appears to be better due to its early maturity and its yield is also not significantly different from that of Jenguma.

6.2 Recommendations

- Farmers will be better off when they plant Soung-pungun especially in situations when rainfall stops earlier than is anticipated.
- TGX 1904-6F should be considered by farmers when selecting genotype of soybean for soil fertility improvement because besides having the highest amount of N fixed it also has high biomass that can be used as mulching or compost material.
- Since this is a preliminary study, it is recommended that the study should be repeated at the same and other agro-ecological zones in the country to evaluate the effect of nitrogen fixation, growth and yield of soybean which will be very beneficial to farmers.

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APPENDIX

Appendix 1: Analysis of variance for effect of genotype and spacing on germination percentage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	9756.7	3252.2	5.0	
Genotype	3	5122.9	1707.6	2.6	0.114
Residual	9	5840.7	648.9	7.4	
Plant distance	2	959.0	479.5	5.5	0.011
Genotype x Plant distance	6	1004.8	167.5	1.9	0.121
Residual	24	2106.8	87.8		
Total	47	24790.9			

Appendix 2: Analysis of variance for effect of genotype and spacing on days to 50% flowering.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	180.7	60.2	21.6	
Genotype	3	250.7	83.6	29.9	<.001
Residual	9	25.1	2.8	2.5	
Plant distance	2	9.4	4.7	4.1	0.029
Genotype x Plant distance	6	128.1	21.3	18.9	<.001
Residual	24	27.2	1.1		
Total	47	621.2			

Appendix 3: Analysis of variance for effect of genotype and spacing on plant height.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1123.1	374.4	2.9	
Genotype	3	174.5	58.2	0.5	0.718
Residual	9	1142.9	126.9	4.4	
Plant distance	2	10.2	5.1	0.2	0.84
Genotype x Plant distance	6	121.7	20.3	0.7	0.652
Residual	24	695.3	28.9		
Total	47	3267.7			

Appendix 4: Analysis of variance for the effect of genotype and plant spacing on the number of nodules at flowering.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	432685	144228	20.2	
Genotype	3	55039	18346	2.6	0.12
Residual	9	64342	7149	1.2	
Plant distance	2	26435	13217	2.2	0.13
Genotype x Plant distance	6	12204	2034	0.3	0.907
Residual	24	142590	5941		
Total	47	733295			

Appendix 5: Analysis of variance for effect of genotype and spacing on nodule dry weight.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	5.6	1.9	4.1	
Genotype	3	2.7	0.9	1.9	0.188
Residual	9	4.1	0.4	0.8	
Plant distance	2	0.5	0.3	0.5	0.623
Genotype x Plant distance	6	2.6	0.4	0.8	0.612
Residual	24	13.7	0.6		
Total	47	29.3			

Appendix 6: Analysis of variance for Percentage of effective nodules as affected by genotype and plant spacing.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	3	343.6	114.5	0.3	
Genotype	3	1371.7	457.2	1.3	0.325
Residual	9	3098.9	344.3	1.6	
Plant distance	2	161.3	80.6	0.4	0.684
Genotype x Plant distance	6	829.7	138.3	0.7	0.681
Residual	24	5012.3	208.8		
Total	47	10817.5			

Appendix 7: Analysis of variance for Effect of genotype and plant spacing on biomass yield at mid podding.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	29502239	9834080	1.8	
Genotype	3	49415679	16471893	2.9	0.089
Residual	9	49796410	5532934	1.9	
Plant distance	2	32553163	16276582	5.6	0.010
Genotype x Plant distance	6	30720474	5120079	1.8	0.149
Residual	24	69532256	2897177		
Total	47	261520223			

Appendix 8: Analysis of variance for Influence of genotype and plant spacing on % nitrogen fixation in soybean.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	890.1	296.7	1.9	
Genotype	3	411.6	137.2	0.9	0.470
Residual	9	411.6	149.2	9.1	
Plant distance	2	9.9	4.9	0.3	0.742
Genotype x Plant distance	6	145.1	24.2	1.5	0.231
Residual	24	394.8	16.4		
Total	47	3194.5			

Appendix 9: Analysis of variance for effect of genotype and spacing on amount of N fixed by plant.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	49647	16549	1.3	
Genotype	3	132749	44250	3.4	0.066
Residual	9	116015	12891	2.2	
Plant distance	2	72204	36102	6.3	0.006
Genotype x Plant distance	6	102374	17062	2.9	0.026
Residual	24	137958	5748		
Total	47	610947			

Appendix 10: Analysis of variance for Effect of genotype and spacing on number of pod per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	505.4	168.5	1.4	
Genotype	3	1444.4	481.5	3.9	0.049
Residual	9	1112.7	123.6	0.9	
Plant distance	2	283.2	141.6	1.1	0.363
Genotype x Plant distance	6	760.8	126.8	0.9	0.481
Residual	24	3215.3	134.0		
Total	47	7321.9			

Appendix 11: Analysis of variance for effect of genotype and spacing on number of seed per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.4	0.1	0.4	
Genotype	3	1.8	0.6	1.9	0.186
Residual	9	2.8	0.3	1.3	
Plant distance	2	0.1	0.1	0.2	0.781
Genotype x Plant distance	6	0.5	0.1	0.4	0.896
Residual	24	6.0	0.2		
Total	47	11.8			

Appendix 12: Analysis of variance for Effect of genotype and plant spacing on grain yield.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	6.8	2.3	6.1	
Genotype	3	0.1	0.1	0.1	0.959
Residual	9	3.3	0.4	1.4	
Plant distance	2	0.5	0.3	0.9	0.399
Genotype x Plant distance	6	3.4	0.6	2.1	0.092
Residual	24	6.5	0.3		
Total	47	20.7			

Appendix 13: Analysis of variance for Effect of genotype and plant spacing on hundred (100) seed weight.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	151.5	50.5	283.4	
Genotype	3	12.5	4.2	23.3	<.001
Residual	9	1.6	0.2	0.5	
Plant distance	2	1.0	0.5	1.4	0.254
Genotype x Plant distance	6	2.1	0.4	1.0	0.442
Residual	24	8.5	0.3		
Total	47	177.2			

Appendix 14: Analysis of variance for effect of genotype and plant spacing on dry biomass yield at harvest.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	33675271	11225090	5.2	
Genotype	3	5827890	1942630	0.9	0.478
Residual	9	19408039	2156449	1.4	
Plant distance	2	3681187	1840594	1.2	0.326
Genotype x Plant distance	6	4214017	702336	0.4	0.839
Residual	24	37633380	1568058		
Total	47	1.0			