UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECT OF GENOTYPE AND PLANT POPULATION ON GROWTH, NITROGEN FIXATION AND YIELD OF SOYBEAN [*Glycine max* (L.) Merrill] IN THE SUDAN SAVANNA AGRO-ECOLOGICAL ZONE OF GHANA

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DEPARTMENT OF AGRONOMY

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BY

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THESIS SUBMITTED TO THE DEPARTMENT OF AGRONOMY, FACULTY OF AGRICULTURE, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE

JULY, 2016

DECLARATION

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

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SIGNATURE DATE

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

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DEDICATION

To my family especially my father Alhaji Abudu Wuni and my mother Seini Safia Wuni; who have been a great source of inspiration for me.

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ABSTRACT

Soybean genotypes vary in growth characteristics and require different plant densities especially at different ecological zones. It is unacceptable to use one plant spacing recommendation for all varieties in different ecological zones. An experiment was conducted to determine the effect of plant population on the growth, nitrogen fixation and yield of four soybean genotypes **(**Jenguma, Soung-Pungun, TGX1904-6F and TGX 1955-4F) in the Binduri District in the Sudan Savanna zone of Ghana. The experiment was laid out in a split plot design with four communities serving as replicates. Genotype was the main plot and plant spacing (45 x 10 cm, 60 x 10 cm and 75 x 10 cm), the subplots. Data collected was plant height, days to 50 % flowering, number of nodules, nodule fresh weight and effectiveness, biomass weight, percentage nitrogen fixed, total nitrogen in plants, number of pods per plant, grain yield per hectare, 100 seed weight and fodder weight. The data collected was subjected to the analysis of variance. The results showed that plant height was not affected by genotype and plant spacing interaction; however, it influenced days to 50 % flowering, nodule count, biomass weight and grain yield. Flowering was earliest in Soung-Pungun while TGX1904-4F was last to flower. Soung-Pungun gave the highest grain yield of 0.953 ton ha^{-1} at plant spacing of 45 x 10 cm, followed by TGX1904-4F and Jenguma yielding 0.884 ton ha^{-1} and 0.838 ton ha^{-1} at plant spacing of 75 x 10 cm and 60 x 10 cm, respectively. TGX 1955-4F recorded the lowest grain yield of 0.590 ton ha^{-1}at plant spacing of 60 x 10 cm. Overall, Soung-Pungun could give the highest grain yield to producers in the Binduri district if the production goal is to maximize grain yield. Nitrogen fixing ability was different among the soybean genotypes, with TGX1904-4F recording the highest percentage nitrogen fixed followed by Jenguma. TGX1904-4F is recommended for farmers if the goal is to support N fixation. The spacing recommended to farmers is 45 x 10 cm for Soung-Pungun.

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CHAPTER 1: INTRODUCTION

1.1 Background of the study

Soybean (*Glycine max* (L.) Merrill) is an important legume crop that grows in the tropical, subtropical and temperate climates. In Ghana, soybean is cultivated mainly in the Northern, Upper West, Upper East, northern Volta and parts of Ashanti and Brong-Ahafo Regions. Among these geographical regions, the largest production occurs in northern Ghana, which lies within the northern and southern Guinea savannah agro-ecological zones. According to MoFA (2006), there is a very large number of recommended soybean cultivars in Ghana with seeding rates of 37.5 kg/ha and yields of 1.8 to 2.5 t/ha, compared to that of USA which was 4.6 t / ha (Lawson *et al*., 2008). Ghana produces about 15,000 metric tons of soybean grain annually (MoFA and CSIR, 2005). 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). Even though soybean is a relatively new crop in Ghana (Akramov and Malek, 2012), the increasingly important role the crop is playing in the rural economy of farm households in northern Ghana, and especially the eastern corridor of the Northern Region of the country, is overwhelming. Northern Region alone contributes about 70% of national soybean area and about 77% of national production (SRID, 2012).

Soybean serves as an excellent source of essential fatty acids, calcium, magnesium, lecithin, riboflavin, thiamine, fiber, foliate (folic acid), and iron (Adu - Dapaah *et al*., 2004; MoFA and CSIR, 2005). Soybean powder is used for various preparations of food and drinks for babies and adults, such as mixing with pap for babies and even adults. The main uses of Soybean are flour, protein products and animal feed. It is well known that soybean is an important source of high quality but inexpensive protein (about 40 %) and 20 % of highly digestible and no cholesterol oil content and also a source of superior amino acid profile. Soybean protein has great potential as a major source of dietary protein. There are diverse ways to consume soybean in Ghana which include soy milk, soy oil, soybean yogurt, dawadawa, and of course corn-soy blend. Awareness of soy-based products and the nutritional value of soybean is growing. Currently, Tom Brown is one of the most recognizable branded soybean products. It is a corn-soy blended product served to infants and pregnant women. The utilization of the crop in Ghana for food increased with the development and wide adoption by both small and medium-scale of various soybean-processing machines adapted for use in sub-Saharan Africa. Hence, over 100 food products with good nutritive value and consumer acceptability have been developed.

Soybean products are being used in hospitals for bio-fortified feeding of sick people and malnourished children. It also aids in protecting the heart against oxidation. Soybean remains the most important and preferred source of high quality vegetable protein for animal feed manufacture. Soybean meal, which is a by-product of oil extraction, has a high crude protein content of 44 % to 50 % and a balanced amino acid composition, complementary to maize meal for feed formulation (Ngeze, 1993; Abbey *et al*, 2001 and MoFA and CSIR, 2005). A high level of inclusion (30-40 %) is used in high performance monogastric diets. Soybean cake, a by-product from the oil production is used as a high-protein animal feed in Ghana. Apart from its nutritive value, soybean oil is used industrially for paints, linoleum, printing inks, soaps, insecticides, and disinfectants (Ngeze, 1993; Rienke and Joke, 2005 and Wikipedia, 2009). Soybean meal and soybean protein are used for synthetic fibre (artificial wool), adhesives, textiles, waterproofing, and firefighting foam.

Ugwu and Ugwu (2010) reported on the benefits of soybean over other grain legume (such as groundnut and cowpea) which included lower susceptibility to pests and diseases, better storage quality and larger leaf biomass which translates into soil fertility benefit to subsequent crops.

Sanginga *et al*. (2003) reported that some soybean varieties biologically fix 44 to 103 kg N ha^{-1} annually. However, this biological nitrogen fixation (BNF) process is primarily controlled by four principal factors: effectiveness of rhizobia-host plant symbiosis, ability of the host plant to accumulate nitrogen, amount of available soil nitrogen and environmental constraints (Van Kessel and Hartley, 2000). Soybean can fix atmospheric nitrogen through symbiosis with native rhizobia. However, it is specific with respect to the kind of rhizobia it forms symbiosis with and can only nodulate effectively with most *Bradyrhizobium japonicum* strains. *Bradyrhizobium japonicum* hardly exists in soils of Ghana since soybean is an introduced crop (Okogun and Sanginga, 2003). Promiscuous soybean varieties have been introduced to overcome specificity issues and to allow the plant to nodulate freely with the native rhizobia (Okogun and Sanginga, 2003).

Nitrogen fixation influences soybean yields significantly. The nitrogen requirement of a soybean crop is estimated at 350 kg N ha^{-1} (Abendroth *et al*., 2006). With adequate supply of P, soybeans can fix up to 450 kg N ha^{-1} (Unkovich and Pate, 2000) making it possible for the crop to satisfy its nutritional requirements and leave some residual nitrogen for use by associated crops. The amount of fixed nitrogen which is ultimately used by soybean crop is a function of available nitrogen, with the plants utilizing available soil nitrogen prior to fixed nitrogen (Salvagiotti *et al*., 2008).

Despite the numerous benefits of soybean, the grain yield per unit area is low in Ghana due to constraints such as declining soil fertility, low plant stand, erratic and unpredictable rainfall (often leading to periods of drought) (Addo-Quaye *et al*., 1993). In the tropics, most of the crops are near their maximum temperature tolerance; therefore, crop yield may decrease even with a minimal increase in temperature. Reductions in pod number caused by high temperature might decrease the effectiveness of pollination and fertilization, and consequently poor setting of pods (Prasad *et al*., 2002). Lindsey and Thomson (2012) reported that the optimum temperature range for soybean was 25-29 ^{o}C and pod setting seriously affected at temperatures above 37 ^{o}C.

In recent years, there has been a growing interest in the use of narrow row as well as narrow plant spacing for the production of soybean because of high labour energy and equipment requirements for cultivation (Jordan, 2010). Row spacing and seeding recommendations may vary for each growing region and soybean cultivar; thus, many studies have sought to determine optimum row spacing and plant density for soybean under different environmental conditions. Different agronomic settings are recommended for different locations because plant development and yield of soybeans depend on both environmental and genetic factors (Edwards *et al*., 2005). Available research data on soybean planting systems give a broad range of 60-75 cm inter-row spacing and 5-10 cm intra-row spacing, giving an average of 319,750 plants ha^{-1} (MoFA and CSIR, 2005), irrespective of factors such as the maturity group, growth habit, soil condition and vegetation zone.

In Nigeria, the leading soybean producer in Africa, the recommendation for planting soybean is by drilling at within row spacing of 5-6 cm and 60-75 cm inter-row spacing (IITA, 1990). Sowing rate or plant population density, sowing date, planting method and sowing depth are important factors that affect stand establishment and utilization of light, water and nutrients, thus, affecting the yield and productivity of a crop (Johnson, 1987). In the United States upper Midwest researchers hypothesized that narrow row spacing (38 cm) would produce greater yields than wide row spacing (76 cm) and economic advantages exist for narrow row soybean production (De Bruin and Pederson, 2008). A row spacing of 40 cm was recommended for early soybean production system in the mid-southern USA (Bowers *et al*., 2000), and a row spacing of <76 cm gave consistently higher yield than row spacing of >76 cm (De Bruin and Pedersen, 2008) in the USA mid-west and Southern Canada. Soybean yields in the primary growing region of the Midwest generally were 10-30 % greater in the narrow rows (Spilde *et al*., 1980). Row spacing is considered more important than tillage to get optimum plant population to maximize soybean yield potential (Pedersen, 2008). Osafo (1977) found in Kumasi (forest zone) that the yield of improved pelican soybean variety increased with reduced row spacing from 43 cm to 30.5 cm and decreased thereafter, while that of V/1 line increased with row spacing from 43 cm to 24.5 cm. Similarly, studies in 1977 at Kwadaso and Ejura showed the yields of Davis and F62-3977 increased as row spacing decreased from 65 cm to 50 cm to 35 cm to 20 cm (Anon., 1978). In Japan, Ikeda (1992) found that soybean seed yield decreased with increasing row widths and narrowing the within row spacing. At 70 cm row width, the twin-zigzag row arrangement yielded higher than the twin-rectangular ones.

1.2 Problem statement and justification

Despite the numerous benefits of soybean, the grain yield per unit area is low in Ghana due to lack of knowledge on the part of the farmers about the optimum plant population and/or row spacing for efficient utilization of light, water and nutrients, thus, affecting the yield and productivity of soybean crop. A number of recent studies have attributed low soybean yields in sub-Saharan Africa to poor yielding varieties, limited application of fertilizers and limited utilization of rhizobia inoculants in soils with no history of soybean production (Woomer *et al*., 2012). This still affects most smallholder farmers in Ghana because they have not discovered the high yielding varieties to maximize output.

Also some varieties do well at a particular plant spacing and population. Farmers do not have adequate knowledge on the varieties, row spacing and population density of soybean to maximize yields with low inputs.

1.3 Significance of the study

Several factors including declining soil fertility, use of poor yielding varieties, inappropriate planting distance, poor use of fertilizer etc, affect the grain yield of soybean in Ghana. The continues use of low yielding varieties by farmers in the Sudan savanna agro-ecological zone of Ghana have resulted in low yields of the crop. However, the potential to improve the grain yield of soybean per unit area is still there if only the farmers adopt the appropriate planting distance for improved and high yielding varieties of the crop.

Being a leguminous crop, soybean has the potential to fix atmospheric nitrogen into the soil to help improve the declining soil fertility problem. This is possible if the plant population per unit area allows the crop maximum utilization of available environment factors likes light, soil nutrients and available moisture to improve nodulation and nitrogen fixation. The introduction of a high yielding genotype with a strict planting distance will have a significant impact on the soybean yield per unit area. This study seeks to test new genotypes of the crop in the Sudan savanna agro-ecological zone of Ghana to come out with the best genotype and plant population for high yields and nitrogen fixation.

1.4 Objectives

The objectives of this study are to:

1. Evaluate the effects of plant population on the yield and yield components of soybean.
2. Evaluate the effects of different genotypes on the yield and yield components of soybean.
3. Determine the effects of genotype and plant population on nodulation and nitrogen fixation of soybean.

CHAPTER 2: LITERATURE REVIEW

2.1 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. According to early authors, soybean production was localized in China until after the Chinese-Japanese war of 1894-95, when the Japanese began to import soybean oil and 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. It's believed that some soybean seed may have been sent from China by missionaries as early as 1740 and planted in France (Gibson & Benson, 2005).

The first written reference to soy appears in a list of Chinese plants from 2853 B.C.; it 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 climatic regions.

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.

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 4800 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 50000 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). While the United States, the leading soybean production in the world harvest an average of over 2000 kg ha^{-1} on its 27 million hectares of land in 1981, Africa countries harvest just over 900 kg ha^{-1} 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 lies within the Guinea savannah and Sahel agro-ecological zones.

2.2 Botany

Soybean (*Glycine max* (L.) Merrill) is a legume plant belonging to the botanical family Leguminosae. Like all other peas, beans, lentils and peanuts, which include some 500 genera and more than 12,000 species, it belongs to the subfamily Papilionideae (Shurtleff and Aoyagi, 2007).

The genus *Glycine*, presently consist of two subgenera, *Glycine* consisting of wild species confined to Southeastern Asia; and Soja, comprising the domesticated and commercially important soybean, *Glycine max* and its wild ancestor, *Glycine soja.* Both are annuals and grow in the tropical, subtropical and temperate climates. They have 40 chromosomes (2n=2x=40) and are self-fertile species with less than 1% out-crossing (Norman *et al.*, 1995).

The genus name *Glycine* was originally proposed by Linnaeus in his first edition of Genera Plantarum; with the cultivated Species first appearing in the edition, 'Species Plantarum', under the name *Phaseolus max* L. The combination, *Glycine max* (L.) Merr.) was proposed by Merrill in 1917, and has since become the valid name for this useful plant (Wikipedia, 2009).

The optimum temperature for soybean is 20-30^{o}C, with temperatures of 35^{o}C and above considered inhibitory to production. The optimum rainfall amount is between 350 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. http://www.timeanddate.com/worldclock/sunrise.html

”Soya" (or "Soy" in the United States), is a dicotyledonous plant that exhibits epigeal (above the surface) 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, soybeans generally emerge best if they are planted no deeper than 2 inches. After emergence, the green cotyledons open and supply the developing leaves with stored energy, while capturing a small amount of light energy. The first leaves to develop are the unifoliolate leaves. Two of these single leaves appear directly opposite one another above the cotyledons. All subsequent leaves are trifoliolates, comprised of three leaflets.

Soybean development is characterized by two distinct growth phases. The first is the vegetative stages (V) that cover development from emergence through flowering. The second is the reproductive (R) stages from flowering through maturation. Plant stages are determined by classifying leaf, flower, pod, and or seed development.

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 *et al.*, 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).

2.3 Morphological description

Soybean is an annual, erect hairy herbaceous plant, ranging in height of between 30 and 183 cm, depending on the genotype (Ngeze, 1993). Some genotypes have prostrate growth, not higher than 20 cm or grow up to two metres high (Wikipedia, 2009).

There are two types of growth habit of the soybean: determinate and indeterminate types with six approved varieties grown in Ghana (Ngeze, 1993; MoFA and CSIR, 2005). The determinate genotypes grow shorter and produce fewer leaves, but produce comparatively more pods, while the indeterminate types grow taller, produce more leaves and more pods right from the stem to shoot. Also, the flowers are small, inconspicuous and self-fertile; borne in the axils of the leaves and are white, pink or purple (Ngeze, 1993).

The stem, leaves and pods are covered with fine brown or gray hairs. The leaves are trifoliate, having 3 to 4 leaflets per leaf. The fruit is a hairy pod that grows in clusters of 3 to 5, each of which is 5 to 8 cm long and usually contains 2 to 4 seeds (Rienke and Joke, 2005).

Soybean seeds occur in various sizes, and in many, the seed coat colour ranges from cream, black, brown, yellow to mottle. The hull of the mature bean is hard, water resistant and protects the cotyledons and hypocotyls from damage (Borget, 1992; Wikipedia, 2009).

Gary and Dale (1997) have described soybean growth and development in two main stages: the vegetative stage and the reproductive stage. The vegetative stage starts with the emergence of seedlings, unfolding of unifoliate leaves, through to fully developed trifoliate leaves, nodes formation on main stem, nodulation and the formation of branches. The reproductive stage begins with flower bud formation, through full bloom flowering, pod formation, pod filling to full maturity.

2.4 Soil requirements

Soybean is tolerant to a wide range of soil conditions but does best on warm, moist and well drained fertile loamy soils, which 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 (2005) reported high yields in loamy textured soil, and that if the seeds are able to germinate, they will grow better in clayey soils.

Ngeze (1993) stated that, soybean does well in fertile sandy soils with pH 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.

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 (Ferguson *et al.,* 2006). Rienke and Joke (2005) reported high yields in loamy textured soil, and that if the seeds are able to germinate, they grow better in clayey soils.

2.5 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 (deplete) the available nutrients in the soil for their growth and production purposes, there is the need for the soils to be replenish for continuous cropping.

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^{-1}(MoFA, 2015). The extent of nutrient depletion is widespread in all the agro-ecological zones with nitrogen and phosphorus being the most deficient nutrients. 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 only 8 kg ha^{-1}. Therefore, even 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 (Bationo and Waswa, 2011). 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.
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.

Bationo and Waswa (2011) reported that, status of total N in soils of Guinea savanna ranges between 0.05 - 0.12. In Ghana, annual depletion rate of 30 kg N, 3 kg P and 17 kg K ha^{-1} were recorded for the period 1982 –1984 which projected for year 2000 were 35 kg N, 4 kg P and 20 kg K ha^{-1}. Among the nutrient being depleted N ranked the most depleted in soils, 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 (Na Lampang, 1981) and in crop rotation due to its outstanding features, such as short growth duration (100 ± 20 days), 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.

2.6 Moisture requirements

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). Rienke and Joke, (2005) and Addo-Quaye *et al.* (1993) have described two periods as being critical for soybean moisture requirement; from sowing to germination and flowering, and pod filling periods. Inadequate soil moisture at this stage can result in reduction in yield.

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 then decreases to reproductive maturity. It has been shown that 10% reduction in soil moisture use by soybean results in an 8% reduction grain yield potential while the same reduction in soil moisture use during pod filling results in 10% grain yield loss (Godsey, 2012).

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. Troedson *et al*. (1985) reported that soybean is quite susceptible to water stress and usually respond to frequent watering by substantially increasing vegetative growth and yield. 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 the metabolic processes of certain cells of the plant may be affected. 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 Passioura (1997), grain yield is a function of the amount of water transpired, water use efficiency and harvest index. And soybean, as a C_3 plant, is less efficient in water use due to high evapotranspiration and low photosynthetic rates.

Pandy *et al*. (1984) observed that increasing drought stress progressively reduced leaf area, leaf area duration, crop growth rate and shoot dry mater; hence, limits soybean yield. Drought stress, during flowering and early pod formation causes greatest reduction in number of pods and seeds at harvest (Sionit and Kramer, 1977). Low soil moisture with high plant population may cause yield to decrease because of drought stress (Gary and Dale, 1997).

2.7 Cultural requirements for soybean cultivation

2.7.1 Planting date and replanting

According to Morgan *et al*. (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 emphasizes the complexity of individual soybean plant compensation and seed yield recovery.

However, according to Conley *et al.* (2008) soybean 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^{-1}. 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 situations 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 metre 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.

2.7.2 Insects pests control

According to Abe *et al.* (2003) Soybean plants originate from the South Asia region, where several microorganisms and insects evolved ecological interactions. Soybean-producing countries are located on different continents, 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.

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 % (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).

2.7.3 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 (Agrios, 2005).

The interaction of the three components of diseases is 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 (Agrios, 2005). 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).

2.7.4 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 requirements 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, lowered 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 *Bradyrhizobium 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 Bradyrhizobia bacteria 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 has 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 ha^{-1} 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 Ndakidemi, 2013).

Gary and Dale (1997) 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.

2.7.5 Weeds

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 more 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 *et al.,* 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 generally consists of two parts: first the critical weed-free period, and the second, 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 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, 2011) which 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 instances, 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 inter-species 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).

2.8 Nitrogen fixation

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. Farmers therefore have to shift to relatively new and more fertile lands or increase the area under cultivation to meet the same production targets (Kolan *et al.*, 2013). These problems can be solved when legumes, including soybean are intercropped or added to crop rotation and mixed cropping systems.

Soybean is a known potent nitrogen fixer (Musiyiwa *et al.*, 2005; Zengeni *et al.*, 2006). 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, $N \equiv N$, to be used in other ways (Keyser and Li, 1992).

Biological nitrogen fixation is the process that changes inert N_2 to biologically useful NH_3. This process is mediated in nature only by bacteria. Biological nitrogen fixation involves association of rhizobia and legumes. The rhizobium-legume symbiosis plays an important role in agriculture, because it offers the ability to convert atmospheric molecular nitrogen into forms useable by the plant (Jensen and Nielsen, 2003). 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) due to their ability to fix atmospheric nitrogen. 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). Soybean grown on soil where well nodulated soybean has been grown in recent years will probably not require inoculation; however, if there is any question about the presence of *Rhizobium* bacteria, inoculation is recommended (Darryl *et al.,* 2004; Nastasija *et al*., 2008).

Singh *et al*. (2003) reported that relative to early maturing soybean varieties, medium and late maturing varieties produce more biomass, fix more nitrogen and consequently contribute positively to the nitrogen balance of the soil. Most of the research to optimize symbiotic nitrogen fixation and to increase the use of legumes in crops systems has been in part stimulated by the increasing fertilizer prices and by environmental concerns (Sanginga *et al*., 2003).

Soybean normally provides itself nitrogen, through a symbiotic relationship with nitrogen fixing bacteria of the species, *Bradyrhizobium japonicum* (Sarkodie-Addo *et al.,* 2006; Nastasija *et al.*, 2008). Bacteria present in soybean root nodules can fix nitrogen from the atmosphere, normally supplying most or all nitrogen needed by the plant. Soybean can obtain up to 80% of its total nitrogen requirement from biological nitrogen fixation (Salvagiotti *et al*., 2008). Sanginga *et al*. (2003) reported that some soybean varieties can fix 44 to 103 kg N ha^{-1} annually. However, the quantity of biologically fixed nitrogen can be reduced if the crop is supplied with starter nitrogen above 50 kg N ha^{-1} and or if soil available N is far below 10 kg ha^{-1} (Van Kessel and Hartley, 2000). Other nutrients influencing biological nitrogen fixation include: P, Ca, Mg, and Zn (Hungria and Vargas, 2000). Inoculation of soybean with rhizobia in areas with low or ineffective native rhizobia is also reported to increase biological nitrogen fixation (Abaidoo *et al*., 2007). Inoculated late and medium maturing soybean cultivars exhibit increased nitrogen content and dry matter in seed and vegetative parts (stem and leaves), nitrogen harvest index and seed yield (Sogut, 2006). However the same parameters can be reduced in quantity and quality if the native or indigenous rhizobia are substantial reducing the effective establishment of rhizobial strains in the inoculant (Abaidoo *et al*., 2007).

The amount of N_2 fixed is primarily controlled by four principal factors: the effectiveness of rhizobia-host plant symbiosis, the ability of the host plant to accumulate N, the amount of available soil N and environmental constraints to N_2 fixation (Van Kessel and Hartley, 2000). Soil environments is influenced by a combination of factors including acidity (leading to toxicities of Al and Fe), salinity, alkalinity (including high concentrations of Ca and B) soil temperature, moisture, fertility (including nutrient deficiencies), and soil structure (Hungria and Vargas, 2000). Legumes should have effective root rhizosphere associations for effective N_2 fixation. Successful inoculant strains must be able to rapidly colonize the soil and tolerate environmental stresses, as well as compete with other soil micro-organisms (Slattery *et al*., 2001).

More conservative estimates suggest that the uptake of fixed nitrogen can meet 60-89% of total demand. (Abendroth *et al*., 2006; Tien *et al*., 2002). The amount of fixed nitrogen used by a plant is often largely dependent on N availability in the soil, with the plants utilizing available soil N prior to fixed N (Salvagiotti *et al*., 2009). Other researchers have reported more conservative estimates of the amount of plant N derived from nitrogen fixation; ranging from 220 kg N ha^{-1} to 300 kg N ha^{-1} (Abendroth *et al*., 2006; Bezdicek *et al*., 1978; Keyser and Li, 1992; Lindemann and Glover, 2003).

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. 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.

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 kilograms of nitrogen per acre per year in a natural ecosystem and several hundred kilograms in a cropping system (Linderman 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 113 kg of nitrogen per acre and are not usually fertilized. Soybeans usually don't respond to nitrogen fertilizer as long as they are capable of fixing nitrogen (Linderman and Glover, 2003). Grain legumes can also fix about 15 - 210 kg N ha^{-1} seasonally in Africa Dakora & Keya (1997).

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/ha/yr of nitrogen under suitable conditions (Rienke and Joke, 2005). 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 (Frazen, 1999).

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 was approximately, increased from 200 to 280 kg ha^{-1}, when plant population was increased from 48,500 to 194,000 plants/ha respectively (Ennin and Clegg, 2001).

The process of nitrogen fixation requires the presence of the right species of the nitrogen fixing bacteria in the soil, and they are often attracted to the roots by chemical signals from the soybean root (Rienke and Joke, 2005). Once in contact with the root hairs, a root compound binds the bacteria to the root hair cell wall. The bacteria release a chemical that causes curling and cracking of the root hair, allowing the bacteria to invade the interior of the cells, and begin to change the plant cell structure to form nodules. The bacteria live in compartments of up to 10,000 in a nodule, called bacteroids. The nitrogen fixation is aided by an enzyme called, nitrogenase which takes place in an environment without oxygen, through a transfer compound, leghemoglobin. And this results in a pink-red colour of nodule interiors, an indication of active fixation of nitrogen (Lindermann and Glover, 2003). Ferguson *et al*. (2006) reported that soybean plant will effectively utilize soil residual nitrate and nitrogen mineralized from soil organic matter, obtaining 25% to 75% of plant nitrogen, with the balance supplied from symbiotic fixation.

Legume nodules that are not fixing nitrogen usually turn white, grey or green and may actually be discarded by the plant. This may be as a result of inefficient *Rhizobium* strain, poor plant nutrition, pod filling or other plant stresses. Nastasija *et al*. (2008) have outlined the following as limiting factors to N-fixation:

- A temperature of 16^oC to 27^oC is ideal, while levels above or below this reduce bacterial activity and slow the establishment of the N-fixing relationship.

- 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.

Ferguson *et al.* (2006) 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.

2.9 Measurement of biological nitrogen fixation

Measurement of biological nitrogen fixation is critical as it enables establishment of the amount of nitrogen fixed by different legumes and their potential on improving soil fertility. Several methods have been put forward such as the nitrogen balance method, nitrogen difference method, ureides method, ^{15}N isotope technique, acetylene reduction method, hydrogen evolution method and ^{15}N natural abundance method (Unkovich *et al*., 2008). ^{15}N natural abundance method was the technique used in this study.

This technique involves two plants; a non N_2 fixing plant and a N_2–fixing plant, which is the legume. The ^{15}N natural abundance method applies the principle that where N_2–fixing plant is grown in a medium free of combined N (mineral N and or organic N) it is completely reliant upon symbiotic N_2 fixation for growth. The isotopic composition of the legume would be expected to be similar to that of atmospheric N_2 ($\delta\ ^{15}N$ %). On the contrary, if the non N_2 fixing plant is grown in a soil containing mineral N, its $\delta^{15}N$ value should be equal to that of soil mineral N taken up by the plant from the soil. The amount of N_2 fixed biologically is calculated in terms of % Ndfa (Unkovich *et al*., 2008).

^{15}N natural abundance method has several advantages over the other methods such as: it can be applied in glasshouse or field experiments, it allows N_2 fixation to be assessed in almost any situation where both N_2–fixing and non N_2–fixing plants are present at the same location. Its disadvantages are: complexity in choosing a non N_2 fixing reference species, the need to adjust isotopic fractionation within legume, the magnitude and variability in ^{15}N abundance of plant available soil N. To reduce variability due to the disadvantages; a non N_2 fixing reference plant should exploit the same N pool as the legume, have similar duration of growth and pattern of N uptake as the legume and receive no significant transfer of fixed N from the legume if they are growing in close association.

2.10 Factors influencing nitrogen fixation in legumes

2.10.1 Environmental factors

Establishment of effective N_2 fixing symbioses between legumes and compactible bacteria is dependent upon many environmental factors, and can be greatly influenced by farm management practices (Peoples *et al.,* 1989). Additionally, there are several environmental factors affecting BNF: Severe environmental conditions such as salinity, unfavorable soil pH, nutrient deficiency, mineral toxicity, extreme temperature conditions, low or extremely high levels of soil moisture, inadequate photosynthates, and disease conditions can affect fixation. As a result of these factors, even persistent rhizobium strains will not be able to perform root infection and N fixation in their full capacity (Panchali, 2011).

Moisture stress can adversely affect the nodule functioning. Drought conditions can reduce nodule weight and nitrogenase activity. After exposure to the moisture stress for 10 days, the nodule cell wall starts to degrade resulting in senescence of bacteroids (Ramos *et al*., 2003). The accumulation of Na^+ reduces plant growth, nodule formation, and symbiotic N fixation capacity under salinity conditions (Sousssi *et al*., 1998; Kouas *et al.*, 2010). High salt level can directly affect the early interaction between the rhizobium and legume in nodule formation (Singleton and Bohlool, 1984). The plant nitrogenase activity reduces dramatically as a result of formation of ineffective nodules at high temperature (40 ^{o}C) (Hungria and Franco, 1993). Rhizobial colonization in the legume rhizosphere can be reduced by extreme soil pH. Nitrogen fixation can be inhibited by low soil pH (Van Jaarsveld *et al*., 2002). Characteristics of highly acidic soils (pH < 4) are low level of phosphorous, calcium, and molybdenum along with aluminum and manganese toxicity, which affects both plant and the rhizobia. As a result, under low soil pH conditions, nodulation and N fixation are more severely affected than plant growth. Highly alkaline (pH > 8) soils tend to be high in sodium (Na^+), chloride (Cl^-), bicarbonate (HCO_3^-) and borate (BO_3^-) which reduce N fixation (Bordeleau and Prevost, 1994).

2.10.2 Management factors

In addition to environmental factors, agricultural management factors influence percentage of N_2 derived from the atmosphere (% Ndfa) as well. Management factors which include inoculation, P-fertilization, choice of variety and plant density affect the plant growth and development (Roner and Franke, 2012). The need for inoculation depends on the presence of compatible rhizobia in the soil and their effectiveness. If a legume is promiscuous, it can form nodules with many rhizobium strains which are often present in soil, and will rarely respond to inoculation (e.g. cowpea or groundnut). In grain legumes, a response to inoculation is most commonly seen in soybean. Many varieties are highly specific and do not always nodulate with indigenous rhizobia in Africa (Giller, 2001).

2.10.3 Different varieties

Also, some varieties are more specific than others, or are better adapted to local environmental circumstances. In general, long duration, indeterminate species fix more N_2 due to their longer period of growth than determinate, short-duration varieties. Phosphorus fertilization improves nodulation and plant growth where P is limiting (Roner and Franke, 2012). Legumes in intercropping often show a higher percentage of nitrogen from N_2 fixation than legumes in a mono-cropping system, since cereals like maize or sorghum, grown as main crops, has a high N demand. With less N available in the soil, legumes in intercropping rely more on N_2 fixation (Vesterager *et al*., 2008; Rusinamhodzi *et al*., 2006). Higher plant population density show either a positive for percentage of nitrogen from N_2 fixation due to increased competition for soil N, or negative as a result of competition for other nutrients and moisture (Naab *et al*., 2009; Makoi *et al*., 2009).

2.11 Effect of plant population on nitrogen fixation in soybeans

Soybean nitrogen (N) demands can be supplied to a large extent via biological nitrogen fixation, but the mechanisms of source regulating photosynthesis/nitrogen fixation in high yielding cultivars and current crop management arrangements need to be investigated.

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 was increased from 200 to 280 kg N ha^{-1}, when plant population was increased from 48,500 to 194,000 plants ha^{-1} respectively (Ennin & Clegg, 2001).

Kapustka & Wilson (1990) found that an increase in soybean plant density reduced nodule number and dry weight per plant, but maintained high specific activity per nodule, which resulted in the same values of nitrogen fixation per plant. Shamsi & 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.

2.12 Effect of genotype on nitrogen fixation in soybean

The amount of fixed nitrogen used by a plant is often largely dependent on N availability in the soil, with the plants utilizing available soil N prior to fixed N (Salvagiotti *et al*., 2009). N nutrient can be absorbed by plants root from the soil or obtained from the atmospheric N2 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 N ha^{-1} yr^{-1} under suitable conditions (Rienke & Joke, 2005).

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. Van Kessel & Hartley (2000) also observed that, increased soil moisture increases the potential of biological nitrogen fixation. The nitrogen content of a Soybean seed coupled with soil nitrogen meets the requirements of the plant at the seedling stage, while biologically fixed nitrogen takes care of the crop's needs at later stages under favourable conditions. Thus, the crop rarely shows nitrogen deficiency symptoms, but it does show the symptoms of deficiency with failure of biological nitrogen fixation (BNF) and in N-deficient soils Hellal & Abdelhamid (2013).

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

Keyser & 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 & LaRue (1983) and George *et al.*, (1988). 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.

Ogoke *et al.* (2003) observed a positive N balance by soybean crop and they attributed the result to the effect of increased crop duration (late maturing varieties) and N application. From their findings, late maturing soybean varieties were able to fix more N_2 than early and medium maturing varieties, similarly according to Bekele *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.

2.13 Varietal differences in growth and yield in soybean

Soybean [*Glycine max* (L.) Merrill] is an important grain crop in the Africa. Soybean yield can be achieved through cultural practices and breeding. The increasing importance of the crop in our daily lives has resulted in the need to develop high yielding varieties and improved ways of cultivation to achieve high yields. Bouquet (1998) stated that, genotype selection is one of most important factors for increasing pod yield in soybean.

According to the CRI (2010), soybean production increased from 1000 to 10,000 t between 1979 and 1992 as a result of farmers' adoption of improved cultivars and production technologies, yet Soybean imports continued to increase (198,000 t import, versus 96,050 t production in 2009 (MoFA, 2009). This is as a result of slow adoption on the part of farmers to the new varieties and improved farming practices.

According to MoFA (2006) and the Savannah Agricultural Research Institute (SARI, 2006), there is a very large number of recommended soybean cultivars in Ghana with seeding rates of 37.5 kg/ha and yields of 1.8 to 2.5 t/ha. The examination of genetic diversity is important for plant breeding in general and particularly in a new crop like soybean in Ghana. Introduced genotypes are an important source to help us meet our national food/oil demand.

Soybean genotypes play a significant role in increasing grain yield per hectare. Khanghah and Sohani (1999), Muhammad and Shah (2003) showed significant difference among varieties in terms of traits likes pods/plant, seeds/plant, plant height, days to flowering, days to pod initiation, 100 seed weight, grain yield/plant and seeds/pod indicating the existence of genetic variation among varieties. Turk *et al.* (1980) reported that individual seed weight was highly affected by genetic factors except in case of severe water stress and hot desiccating winds causing forced maturity.

Karikari (2000) observed that early maturing varieties under rain-fed conditions were high yielding because they emerged rapidly, flowered earlier and had probably enough time to fill the pods. Soybean genotypes are made up of different genetic constitution which affects their growth and performance on the field. Choudhry *et al*., (1999) also revealed that all cultivars varied significantly in yield components. Jagdish *et al.,* (2000) and Jain and Ramgiri (2000) reported that seed yield per plant, biological yield, pods per plant and plant height showed high heritability with high genetic advance as a percentage of mean. Verma *et al.* (2009) reported varying growth patterns in some groundnut genotypes which they attributed to differences in their genetic makeup. Salisbury and Ross (1992) stated that dry matter production shown by genotypes of the same crop under similar growth conditions is indication of similar potential. Chand (1999) performed experiments on different varieties of soybean and revealed that the genotypic correlation coefficients for all characters studied were higher than the phenotypic and environmental correlation coefficient.

IITA had released a total of 21 tropical bred soybean varieties for Africa by the year 2011 (Tefera, 2011). The grain yields ranged from 1 - 2.1 t ha^{-1} for the early maturing varieties depending on locations. For medium maturing varieties grain yields ranged from 1 - 2.7 t ha^{-1}. In the case of late maturing varieties grain yields ranged from 1.3 - 2.3 t ha^{-1}.

TGX 1740-2F also called SB19 is an example of the early maturing varieties released by IITA which matures within a period of 92 – 96 days. It has more pods per plant up to the top of the plant, performs well under poor and erratic rainfall, and has better lodging resistance (Tefera, 2011). Its grain yield is between 1761 – 2232 kg ha^{-1}. Another variety TGX 1448-2E which is also called SB20, matures within a period of 115 – 117 days and has grain yield ranging between 2403 – 2458 kg ha^{-1} (Tefera, 2011).

Management practices for example tillage methods, sowing method, weeding and pest and disease control are specific to a farmer and differ from one location to another although they can be manipulated to increase the yield potential of a crop. This has a far reaching influence on the climatic variability; for example better tillage methods will increase soil water holding capacity (Landers, 2007), soil organic matter among other benefits hence increase in soybean yields. Cooper (1977) also stated that, yield success of early maturity soybeans is contingent on cultivar characteristics. Bouquet (1998) stated that, genotype selection is one of most important factors for increasing pod yield in soybean. Ahmad and Mohammed (2004) also reported inherent varietal differences in seed number per pod in pigeon pea.

Many varietal characteristics, such as maturity, lodging, and disease resistance, must be considered when selecting varieties to complement a production area (www.bookstore.ksre.ksu.edu/pubs/c449.pdf). Growth, development, and yield of soybeans are all a result of a given variety's genetic potential interacting with its environment (www.agron.iastate.edu/soybean/beangrows.html).

Cultivars 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 & 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. 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 (www.bookstore.ksre.ksu.edu/pubs/c449.pdf).

The Crop Research Institute (CRI) of the Council for Scientific and Industrial Research (CSIR) at Fumesua, Kumasi also use genotypes like Ahoto and Nangbaar

Ahoto is an early maturity genotype, of medium seed size, rounded and yellow seed colour, with mean 100 seed dry weight of 13.60g. It is resistant to pod shattering, good cereal- *Striga* management and promiscuous nodulator with the native *Rhizobia.* Grain yield is 1.9 -2.9 tons per hectare. It matures in about 95 days, and was released by CRI in 2005 (MoFA and CSIR, 2005).

Anidaso is a medium maturity genotype, small seed size, rounded and yellow seed colour, with mean 100 seed dry weight of 13.0g and matures in 110 days. It is resistant to pod shattering, fairly good cereal *Striga* management and promiscuous nodulator with the native *Rhizobia.* Grain yield is 1.2 -1.8 tons per hectare. It was released in 1992 by CRI (MoFA and CSIR, 2005).

Nangbaar – An early maturity dwarf type genotype with large seed size of mean 100 seed dry weight of 16.0g. The seeds are oval and creamy-yellow in colour. It is also resistant to pod shattering, fairly good cereal- *Striga* management and very promiscuous nodulator with native *Rhizobia*. Grain yield is 1.5-2.5 tons per hectare. It matures in 90 days, and was also released in 2005 by CRI (MoFA and CSIR, 2005).

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. 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 to become taller, more slender, and more prone to lodging (www.bookstore.ksre.ksu.edu/pubs/c449.pdf).

While varieties differ in their ability to resist lodging, environmental conditions greatly influence the tendency to lodge. Factors such as irrigation and high fertility tend to promote vegetative development and increase lodging.

There are also new improved varieties that are disease and pest resistant. An 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 affected 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 (www.bookstore.ksre.ksu.edu/pubs/c449.pdf.).

2.14 Growth and yield responses to row spacing

In recent years, there has been a growing interest in the use of narrow row as well as narrow plant spacing for the production of soybean because of high labour energy and equipment requirements for cultivation (Jordan, 2010). Row spacing (RS) and seeding recommendations may vary for each growing region and soybean cultivar; thus, many studies have sought to determine optimum row spacing and plant density for soybean under different environmental conditions. Different agronomic settings are recommended for different locations because plant development and yield of soybeans depend on both environmental and genetic factors (Edwards *et al*., 2005). However, the magnitude of the response depends on many variables such as location, year, cultivar, planting date, and tillage system.

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).

Narrow (<76 cm) and wide-row (≥ 76 cm) soybean production systems are employed throughout the United States. According to the USDA-NASS (2009), around 18 % of soybeans produced in the United States in 2009 were grown in row widths less than 25 cm, 43 % were grown in widths ranging from 25 to 47 cm, 11 % were grown in row widths between 47 to 72 cm, 25 % were grown in row widths of 72 to 88 cm, and 3 % were grow in row widths greater than 88 cm. Economic factors, such as equipment costs, often play a large role in the decision to convert from a wide-row system to a narrow-row system even though the literature generally concludes that narrow rows often result in higher yields or more yield stability (Bullock *et al.,* 1998; Cooper, 1977; De Bruin and Pederson, 2008; Ethredge *et al*., 1989; Janovicek *et al*., 2006; Taylor, 1980;

Weber *et al*., 1966). When narrow row widths show a yield advantage over wide row widths it is generally thought that an increase in light interception is responsible.

There are two general concepts often used to explain the relationship between row spacing, plant density, and crop yield. Most soybeans in the Midwest and southern Canada are grown in rows spaced 18 to 76 cm apart. Typically, plant to plant spacing within a row is adjusted according to row to row spacing (row width) so overall plant density remains constant. This 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 narrow row spacing is more equidistant plant spacing that leads to an increase in canopy leaf area development and greater light interception earlier in the growing season (Shibles, 1966; Weber *et al*., 1966). Quicker canopy development is also an advantage of narrow-rows as this has been found to enhance weed management (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 **(**Heatherly and Elmore, 2004).

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

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 plant^{-1}, seeds pod^{-1} and 100-seed weight as well as seed yield plant^{-1}. Mckenzie *et al.* (1992) reported that the amount of solar radiation intercepted into the canopy depends on plant arrangement and plant density where the higher plant population density speeds up canopy closure and increases interception of photo-synthetically active radiation (PAR) needed for carbohydrate production and higher biomass in the plants.

Mahama (2011) stated that, row spacing effects are significant on plant height, leaf area index, number of leaves, dry matter yield kg ha^{-1} and grain yield (ton ha^{-1}). Kumaga *et al.* (2002) reported that bambara groundnut (*Vigna subterranea* L) produced greater number of leaves (67.2) at the lower population densities (150,000 plants/ha). Kueneman *et al.* (1978) also reported that the low plant population tended to enhance vegetative growth of dry bean resulting in the development of large leaf area compared to the high and moderate plant populations resulting in sink limitation to photosynthesis.

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*. (2011) found out that, under the temperate environment of Canterbury, New Zealand, increase of 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 Young Son & 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 Kodandaramaiah, 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 & 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 kharif II (rainy) and rabi (dry) seasons, respectively (Rahman *et al.,* 2011).

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. Virk *et al*. (2005) and Abdullah *et al.* (2007) reported that, increased plant density decreased number of pods per plant and as plant density decreased, number of pods per plant increased. Similarly, increased number of pods per plant with increasing plant spacing observed in this investigation concurs with many researchers in different crops (El Naim and Jabereldar, 2010). They reported that closer spacing reduced the number of pods per plant in cow pea and sesame.

Board & 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. Worku & Astatkie, (2011) also observed an increase in 1000 seed weight of two varieties with narrow row spacing.

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 & Hall (2002) stated a decrease in grain yield of cowpea with increased spacing.

Ball *et al.* (2000a) reported that increasing plants population reduced yield of individual plants but increased yield per unit of area.

Others researchers 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.

Weed control is essential in soybean production to ensure maximum crop yield (Buhler and Hartzler, 2004). Most farmers in Ghana do not plant in rows, and in most crops the plant populations are usually low, leaving wide gaps for weed growth and thus giving very low yields at harvest. Berglund and Helms (2003) reported that row spacing is a critical determinant of yield in soybean production, because appropriate spacing can ensure effective weed control.

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.

Research conducted in Minnesota, USA, has shown that soybean seed yield increased as row spacing is reduced (Johnson, 1987). Lehman and Lambert (1960) observed that soybean seed yields of two cultivars were consistently higher in narrow (50 cm) rows than in wide (102 cm) rows. Worku and Astatkie (2011) also observed an increment in seed yield per unit area as row spacing decreased, but it did not identify optimum plant density for high yield, nodulation and weed control.

However, a recent study on the responses of early and late maturing varieties to planting density in south-western Ethiopia showed less weed growth and greater yield and yield components per m^2 as row spacing decreased from 70 to 50 cm and plant spacing from 10 to 2.5 cm or as plant density increased from 14 to 80 plants/m^2 (Worku and Astatkie, 2011). Beatty *et al.* (1982) also adjusted plant population with row spacing and found that, early maturity cultivars planted early in 18 cm rows with 600,000 seeds/ha and 48 cm rows with 460,000 seeds/ha yielded more than late planting at any row spacing. Bouquet (1998) concluded that, planting date and genotype selection were the most important factors for increasing yields, while row spacing was less significant. However, when early maturity genotypes were compared with medium maturity genotypes under drought stress, narrow rows did show increased yield.

Researchers in Louisiana and Texas, summarized 21 field experiments conducted over 14 years to determine the effect of row spacing on seed yield in soybean planting systems. For all environments tested, narrow rows (less than 40 cm) yielded equal to or greater than wider rows. They concluded that narrow rows should be used to optimize yield in early maturity soybean cultivars (Bowers *et al*., 2000). Hans *et al*. (1997) have stated that, since early-maturing soybean varieties generally do not produce a dense canopy, the planting rate should be increased to ensure early canopy closure so as to maximize light interception.

Among various agronomic factors limiting yield, plant population is considered of great importance. Several researchers 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^{-1} (Embrapa Soja, 2011) 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 & Pearcy, 1994). Changes in the red/infrared ratios through the canopy may deeply affect both photosynthesis according to 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*. (2000b) 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.

2.15 Growth analysis (functions)

Plant growth analysis is an explanatory, holistic and integrative approach to interpreting plant form and function. It uses simple primary data in the form of weights, areas, volumes and contents of plant components to investigate processes within and involving the whole plant

(Evans, 1996). The most common growth functions are crop growth rate (CGR), leaf area index (LAI), leaf area duration (LAD), net assimilation rate (NAR), leaf area ratio (LAR) and relative crop growth rate (RCGR). These are normally calculated from total shoot dry weights and leaf area indexes recorded over a given period (Clawson *et al*., 1986).

Crop growth rate is a dynamic character that determines the final yield in cereal and legume crops. Ball *et al*. (2000a) have reported that, high population of soybean ensures early canopy closure, maximizes light interception, crop growth rate and crop biomass, resulting in increased yield potential. Crop growth rate depends on leaf area index and net assimilation rate, the later depending on light-intercepting efficiency and photosynthetic efficiency of the leaf (Kokubun, 1988). Increasing plant population reduces the amount of time that, it takes to reach 95% light interception levels that correspond to leaf area index levels of 3.2 to 3.5 (Higley, 1992).

Pod and seed number are the most important yield components of soybean. However, leaf area index, leaf area duration and dry matter accumulation during the reproductive period strongly influence the yield components (Liu *et al*., 2004). Malone *et al*. (2002) have reported that, leaf area index values of at least 3.5-4.0 in the reproductive stages are required for maximum potential yield of soybean. Stern and Donald (1961) concluded that leaf area index influences crop growth rate and that dry matter production by a crop also increase as the leaf area index increases until a maximum value is attained; thereafter as the leaf area index increases further, the rate of dry matter production will decline. This is because, the lowest leaves become heavily shaded that, photosynthetic contribution becomes less than respiration.

2.16 World production

Soybean production is increasing rapidly all over the world as a result of the numerous benefits derived from the crop. Current world production of soybean is 220 million metric tons of grain per annum, of which the seven leading producers are the USA (32 %), Brazil (28 %), Argentina (21 %), China (7 %), India (4 %), Paraguay (3 %), Canada (1 %) and others (4 %) (USDA, 2007). According to FAO data for 2005, total land area under soybean cultivation in the world was 95.2 million hectares per annum and total production was 212.6 million tons annually. The three major producing countries were USA (29 million hectares), Brazil (23 million hectares), and Argentina (14 million hectares) (IITA, 2009).

In relation to Sub-Saharan Africa, the same source showed that, soybean was grown on an average of 1.16 million hectares with an average production of 1.26 million tons of grain in 2005. African countries with the largest area of production were Nigeria (601 000 ha), South Africa (150 000 ha), Uganda (144 000 ha), Malawi (68 000 ha) and Zimbabwe (61 000 ha).

2.17 Uses of soybean

Borget (1992) stated that, soybean contributes to the feeding of both humans and domestic animals. And that, it has various nutritional and medicinal properties as well as industrial and commercial uses; and agronomic values such as soil conservation, green manure, compost and nitrogen fixation. Soybean can be cooked and eaten as a vegetable as well as processed into soy oil, soy milk, soy yogurt, soy flour, tofu and tempeh (Rienke and Joke, 2005; MoFA and CSIR, 2005).

According to Dugje *et al*. (2009), soybean is more protein-rich than any of the common vegetable or legume food sources in Africa. It has an average protein content of 40 %. The seeds contain about 20 % oil on a dry matter basis (about 85 % unsaturated and cholesterol-free oil). Reinke and Joke (2005) reported that soybean contains a lot of high-quality protein and is an important source of carbohydrates, oil, vitamins and minerals. Research has shown that the quantity of proteins in 1 kg of soybean is equivalent to the quantity of proteins 3 kg of meat or 60 eggs or 10 litres of milk. And comparatively, the cost of buying one kilogram of soybean is much less than buying a similar quantity of meat or eggs (Ngeze, 1993).

It is therefore an excellent substitute for meat in developing countries, where animal protein-rich foods such as meat, fish, eggs and milk are often scarce and expensive for resource poor families to afford. Soybean oil is also rich and highly digestible, odourless and colourless, which does not coalesce easily. It is one of the most common vegetable cooking oil used in food processing industries, all over the world. And it is also heavily used in industries, especially in the manufacture of paint, soap, typewriter ink, plastic products, glycerine and enamels (Ngeze, 1993; Rienke and Joke, 2005 and Wikipedia, 2009).

Lecithin, a product extracted from Soybeans oil, is a natural emulsifier and lubricant used in many food, commercial, and industrial applications. As an emulsifier, it can make fats and water compatible with each other. For example, it helps keep the chocolate and cocoa butter in a candy bar from separating. It is also used in pharmaceuticals and protective coatings Reinke and Joke (2005).

The cake obtained from soybean after oil extraction is also an important source of protein feed for livestock such as poultry, pig and fish. The expansion of soybean production has led to significant growth of the poultry, pig and fish farming (Ngeze, 1993; Abbey *et al.*, 2001 and MoFA and CSIR, 2005). The haulms, after extraction of seed, also provide good feed for sheep and goats (Dugje *et al.*, 2009). The high protein meal remaining after extraction can be processed into Soybeans flour for human food or incorporated into animal feed. Soybeans protein helps balance the nutrient deficiencies of such grains as corn and wheat, which are low in the important amino acids, lysine and tryptophan.

Soy flour and grits, made from grinding whole soybeans, are used in the commercial baking industry to aid in dough conditioning and bleaching.

Soybean is said to contain some anti-nutritional substances that reduce the nutritional value of the beans and are dangerous to health and therefore, need to be removed before they can be eaten. This is not a problem since these substances can be removed by simply soaking and/or 'wet' heating the beans; leaving a valuable product that is not harmful to humans (Ngeze, 1993; Rienke and Joke, 2005).

Soybean is also reputed to have many health benefits. It has been reported that, regular intake of soy foods may help to prevent hormone-related cancers such as breast cancer, prostate cancer and colon cancer (Wikipedia, 2009). It also relieves menopausal symptoms, due to the oestrogen like effect of soy isoflavones. Research also suggest that, regular ingestion of soy products reduces the rate of cardiovascular diseases, by reducing total cholesterol, low density lipoprotein cholesterol and preventing plaque build-up in arteries which could lead to stroke or heart attack (The Mirror, 2008). The high quality protein, low cholesterol oil and other nutritional values are beneficial in the treatment of nutritional diseases in children (MoFA and CSIR, 2005), diabetics and also very important protein for vegans (Wikipedia, 2009).

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 & CSIR, 2005).

It is also 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 & CSIR, 2005).

CHAPTER 3: MATERIALS AND METHODS

3.1 Experimental site

The experiment was conducted during the 2015 cropping season in the Binduri district, located in the Upper East region of Ghana. The Upper East Region (UER) covers a land surface area of 8860 km^2 which is about 4 % of the country (238534 km^2). The experimental sites were in four communities (Kaadi, Tansia, Tetako and Sakpenatinga) located on the northeastern corner of Ghana on latitude 11° 03. 243^o North and longitude 000° 26. 755^o West for Kaadi, latitude 10^o 94. 055^o North and longitude 000^o 32. 046^o West for Tansia, latitude 10^o 93. 167^o North and longitude 000^o 31. 775^o West for Tetako and latitude 10^o 93. 798^o North and longitude 000^o 32. 116^o West for Sakpenatinga.

There is only one rainy season, which builds up gradually from little rains in April to a maximum in August-September and then declines sharply, coming to a complete halt in mid-October when the dry season sets in. Rainfalls are very torrential and range between 850 mm and 1150 mm per annum with irregular dry spells occurring in June or July (Boateng and Ayamga, 1992).

The area has mean monthly temperatures ranging between 21.9 ^oC and 34.1 ^oC. The highest temperatures are recorded in March and this can rise to 45 ^oC, whereas the lowest temperatures are recorded in January. The dry season is characterised by dry harmattan winds and wide diurnal temperature ranges.

The vegetation of the area is characterised by savannah woodland and consists mostly of deciduous, widely spaced fire and drought resistant trees of varying sizes and density with dispersed perennial grasses and associated herbs. There exist trees of economic value like baobab, acacia, sheanut and the dawadawa in the Districts.

The soil at the experimental site is well drained, sandy loam overlying reddish-brown and gravelly light clay. It belongs to the Kumasi series, Ferric Acrisol developed over deeply weathered granite rocks (Asiamah, 1998). The majority of soils in the Upper East Region are infertile, except soils occurring in seasonally flooded areas. This is typical of savannah zones, which have low accumulation of organic matter in the surface horizons owing to the high temperatures that cause rapid decomposition rates. The annual burning of the vegetation cover throughout the area also reduces the amount of organic matter in the soils (Boateng and Ayamga, 1992). Table 1 highlights the physio-chemical properties of the soil at the experimental site.

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

Soil parameter	**Community levels**			
	Tansia	**Kaadi**	**Tetako**	**Sakpenatinga**
pH(H_2O)	5.5	6.2	6.0	5.8
Organic carbon (%)	0.31	0.47	0.36	0.56
Available Nitrogen (%)	0.047	0.065	0.056	0.032
MehP (ppm)	24.38	17.42	21.51	17.42
Exchangeable bases				
Calcium ($Cmol_{(+)}\ kg^{-1}$)	1.87	2.44	3.19	1.11
Magnesium ($Cmol_{(+)}\ kg^{-1}$)	0.37	0.64	0.81	0.35
Potassium ($Cmol_{(+)}\ kg^{-1}$)	0.16	0.20	0.15	0.16
CEC ($Cmol_{(+)}\ kg^{-1}$)	2.46	3.37	4.21	1.71
Particle size distribution (%)				
Sand	74	76	70	72
Clay	14	12	14	13
Silt	12	12	16	15

3.2 Experimental treatments and design

The experiment was laid out in a split plot design replicated in four communities. The experiment was conducted as two factor experiment with soybean genotypes (four) serving as the main plot factor and plant population or plant spacing (three) serving as the sub-plot factor. The four soybean genotypes used were Jenguma, TGX 1904-6F, TGX 1955-4F and Soung-Pungun.

The three planting distances were 45 x 10 cm, 60 x 10 cm, and 75 x 10 cm at 2 seeds per stand giving plant population of 444,444, 333, 333 and 266,666 plants/ha respectively. A maize plot was established within each replicate plot as a reference crop for the determination of Nitrogen derived from atmosphere (Ndfa) using the N- difference method (People *et al.,* 1989). The maize was planted at 75 cm x 40 cm.

The size of each sub-plot was 6 m x 5 m with 1 m interval between each sub-plot, making a total main plot of 48 m x 13 m. The four soybean genotypes were obtained from the International Institute of Tropical Agriculture (IITA).

3.3 Planting and experimental procedure

The site was cleared with a cutlass before ploughing with a tractor. The field was then harrowed with a hoe and demarcated into respective plots using a tape measure, garden line and wooden pegs.

Planting was done on the 17th of July 2015 at the three planting distances stated in the treatment; 45 x 10 cm, 60 x 10 cm and 75 x 10 cm. The reference crop (maize) was planted at 75 cm x 40 cm.

The seeds were inoculated with Nodumax inoculant containing 10^8 cells g^{-1} of *Bradyrhizobium japonicum* strain of United State Department of Agriculture (USDA 110) at the rate of 7 g/1 kg seeds. The inoculated seeds were air-dried for 20 minutes and planted immediately into the dibbled holes at three seeds per hole. A basal rate of Triple Super Phosphate (TSP) fertilizer was applied immediately after planting to all treatments at the rate of 30 kg P ha^{-1} in furrows of 3 cm depth and 5-10 cm away from the planting lines and covered with soil.

Five plants were randomly selected in each sub-plot and tagged for observation and data collection.

3.4 Cultural practice

The experiment was conducted under rain fed conditions. Thinning out was done after germination to reduce plants to 2 plants per stand. Weeding was done by hand pulling depending on their appearance and using a hoe after every 2 weeks. Each weeding operation was completed on the same day for all the sub-plots on the day of weeding.

3.5 Data collected

3.5.1 Days to 50 % flowering

It was recorded as the number of days after planting to the date when 50 % of the plants in a plot produced at least one flower.

3.5.2 Biomass weight at 50 % flowering stage

Plants samples were harvested at 50 % flowering stage and weighed to determine their fresh weight (biomass).

3.5.3 Nitrogen fixation

Crop biomass was randomly sampled on each sub-plot at 50 % flowering for the assessment of nitrogen fixation. 500 g of pods and shoot of the soybean were oven-dried at 60 ^{o}C for 72 hours to determine the dry matter content after which samples were grounded and sieved with one mm mesh and analyzed for N.

500 g of the reference crop (maize cobs and shoot) were oven-dried at 60 ^{o}C for 72 hours to determine the dry matter content after which samples were grounded and sieved with one mm mesh and analyzed for N.

N difference method was used to determine the amount of N fixed.

3.5.4 Determination of nitrogen fixation using the N difference method

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

$$\text{N from nitrogen fixation} = N_{Legume} - N_{maize} \text{ --------- Equation 1}$$

And the percentage (%) N derived from N_2-fixation was calculated as

$$\text{\% N from nitrogen fixation} = \frac{(N_{Legume} - N_{maize}) \times 100}{N_{Legume}} \text{ --------- Equation 2}$$

Unkovich *et al*., 2008.

3.5.5 Plant height

Plant height was taken at 8, 10 and 12 weeks after planting (WAP) using a calibrated wooden ruler. Measurement was done from the ground level to the growing point of the plant.

3.5.6 Weed density score

Weed samples were taken from 5 diagonal spots in every plot using a 1 x 1 m^2 quadrat. The samples were packed in well labelled polythene bags and taken to the laboratory where they were sorted out into individual species and scored to determine the density of weed species present. Where the weediness of a field was quantified based on a scale of 0 – 4.

That is, 0 = 0 Species not seen, 1 = 1 Species is rare, 2 = 1-5 Occasional occurrences of species, 3 = 6-19 Common species and 4 = 20 Abundant species (Anderson *et al*. 2005).

3.5.7 Fresh weight of weeds

The fresh weight of each weed species was measured before oven drying.

3.5.8 Dry weight of weeds

The dry weight was also measured after oven drying at 70 ^{o}C for 48 hours.

3.5.9 Nodule count at flowering

10 plants were selected at random from each plot and dug out with their roots and nodules. The roots were cut from the plants and then packed in well labelled polythene bags and taken to the laboratory. Nodules were separated from roots and washed before counting.

3.5.10 Fresh weight of nodules

The fresh nodules were weighed after counting using an electronic scale (Sartorius TE612) to get the fresh weight.

3.5.11 Nodule colour

The nodules were sliced into two using a sharp blade and their colour was assessed as either good (>75 % nodules per root system; pink in colour), moderate (25 % – 75 % nodules per root system; pink in colour) and poor (<25 % nodules per root system; pink or white in colour or >25 % nodules but white in colour) (Alemayehu, 2009).

3.5.12 Dry weight of nodules

Dry weight of the nodules was recorded after oven drying to a constant weight at 60 ^{o}C for 24 hours using the scale Sartorius TE612.

3.5.13 Number of pods per plant

Ten plants were randomly selected from each plot and the number of pods on each plant was counted and recorded.

3.5.14 Number of seeds per pod

The number of seeds per pod was also counted from the previously selected 10 plants.

3.5.15 Biomass of vines and pods

An area of 3 m x 4 m was harvested from each plot to determine the total biomass for individual plots before threshing.

3.5.16 Grain weight

threshing was done on individual plots and the grains collected and weighed. Grain yield per hectare was determined using the equation:

$$\text{Grain yield per hectare} = \frac{yield\ in\ kg\ x10000}{harvested\ area} \text{ ------------ Equation 3}$$

3.5.17 100 seed weight

100 seeds were counted out from each lot and weighed.

3.6 Data analysis

Data collected was subjected to the Analysis of Variance (ANOVA) model using GenStat statistical package 12 Edition. Means were separated using Least Significant Difference (LSD) at 5 %. Results are presented in graphs and tables in chapter four.

CHAPTER 4: RESULTS

4.1 Plant Height

The planting spacing at which the genotypes were planted had no significant (P = 0.05) effect on plant height at 8 to 12 weeks after planting (WAP). Genotype TGX1955-4F planted at planting space of 60 x 10 cm recorded the tallest height at week 8 and 12, while Jenguma consistently recorded the shortest plant height (Table 2). TGX 1904-6F and Soung-Pungun planted at 45 x 10 cm and 75 x 10 cm respectively recorded a steady increase in plant height at 10 to 12 WAP (Table 2). The shortest heights were recorded by Jenguma planted at 45 x 10 cm and 75 x 10 cm, Soung-Pungun planted at 75 x 10 cm and TGX1955-4F planted at 45 x 10 cm

Table 2: Effect of soybean genotype response to spacing on plant height (cm) at 8, 10 and 12 WAP.

Genotype	Spacing	8 WAP	10WAP	12WAP
JENGUMA		35.25	40.50	40.45
SOUNG-PUNGUN		42.75	44.10	43.65
TGX1904-6F	45 x 10	39.95	44.60	44.20
TGX1955-4F		35.60	41.45	40.85
JENGUMA		38.40	44.40	43.80
SOUNG-PUNGUN		39.25	42.65	41.55
TGX1904-6F	60 x 10	39.75	44.35	44.95
TGX1955-4F		43.30	47.50	48.40
JENGUMA		37.20	38.50	39.00
SOUNG-PUNGUN		41.50	40.70	40.20
TGX1904-6F	75 x 10	39.30	45.00	46.15
TGX1955-4F		39.30	44.10	43.85
LSD (0.05)		8.09(NS)	8.03(NS)	8.33(NS)
CV (%)		11.2%	10.1%	10.7%

NS: Not significant

4.2 Days to 50 % flowering

Genotype and plant spacing interaction significantly (P < 0.001) influenced days to 50 % flowering. Soung-Pungun generally took shorter period (or number of days) to record 50 % flowering at the three plant spacing (Figure 1). TGX1904-6F at 45 x 10 cm and 60 x 10 cm recorded significantly longer time to flower but at the widest spacing of 75 $\boldsymbol{x}$ 10 cm it recorded early flowering which was comparable with Soung-Pungun. Jenguma and TGX1955-4F at the three plant spacing behaved similarly in days to 50 % flowering (Figure 1).

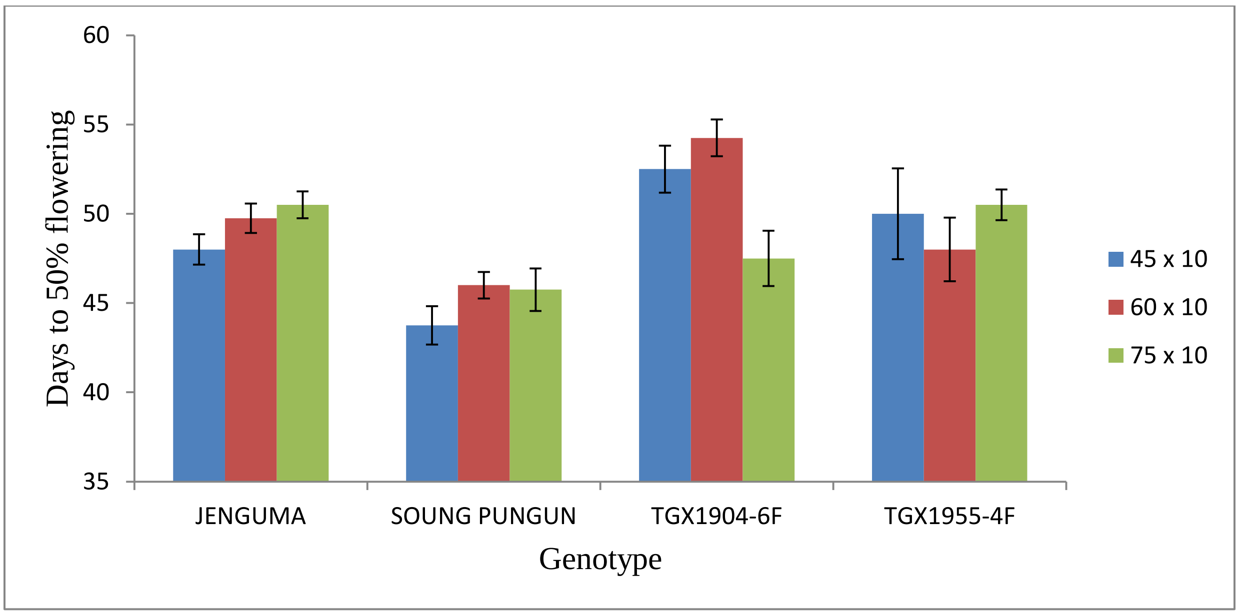

Figure 1: Effect of soybean genotype response to spacing on days to 50 % flowering. Error bars represent standard error of means SEM.

4.3 Number of nodules

Nodulation was significantly influenced by the genotype (P = 0.003). Soung-Pungun recorded the highest number of nodules followed by TGX 1904-6F and Jenguma (Table 3). TGX 1955-4F produced the least number of nodules, about 42 %, less than Soung-Pungun. Plant spacing however had no significant effect on nodulation.

Table 3: Influence of genotype on the number of nodules formed per plant at flowering

Genotype	Nodule number
JENGUMA	20
SOUNG-PUNGUN	27
TGX1904-6F	22
TGX1955-4F	15
LSD (0.05)	Genotype = 5.56
CV (%)	31.9 %

4.4 Number of effective nodules per plant

Genotype and spacing interaction showed no significant difference (P = 0.862) with regards to the number of effective nodules (Table 4). All the genotypes recorded similar number of effective nodules. Plant spacing also did not significantly influence (P = 0.160) the number of effective nodules.

Table 4: Effects of genotype, spacing and their interaction on the number of effective nodules (%).

		Spacing		
Genotype	$45 \, x \, 10$	$60 \, x \, 10$	$75 \, x \, 10$	Mean of Genotype
JENGUMA	100.0	80.0	92.5	90.8
SOUNG-PUNGUN	100.0	100.0	100.0	100
TGX1904-6F	100.0	87.5	95.0	94.2
TGX1955-4F	100.0	95.0	100.0	98.3
Mean of Spacing	100.0	90.6	96.9	
LSD (0.05)	Genotype = 11.38	Spacing=9.86	Genotype x Spacing= 19.72	
CV (%)			14.3 %	

4.5 Nodule fresh weight

Nodule fresh weight was significantly (P = 0.017) influenced by genotype. Soung-Pungun recorded the highest nodule fresh weight followed by TGX 1904-6F while Jenguma recorded the least weight (Figure 2).

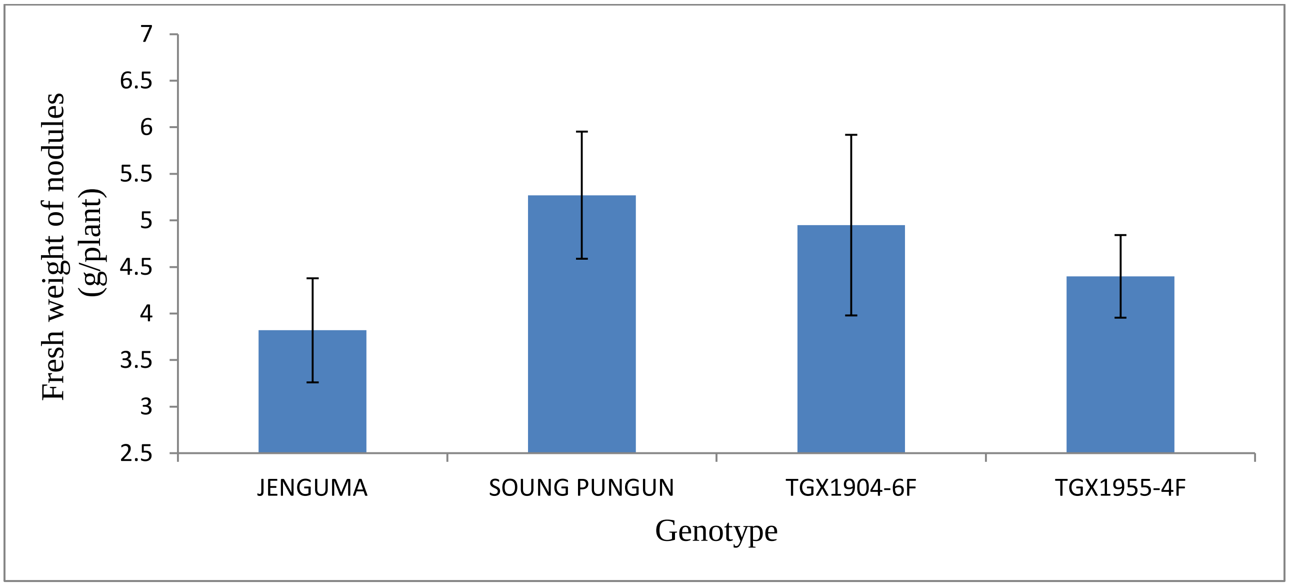

Figure 2: Effect of soybean genotype on nodule fresh weight (g) per plant. Error bars represent SEM.

4.6 Nodules dry weight

Nodules dry weight was significantly (P = 0.019) affected by genotype. TGX 1904-6F recorded the highest nodules dry weight followed by Soung-Pungun and TGX 1955-4F (Figure 3). Jenguma recorded the lowest nodules dry weight**,** about 39 %, less than TGX 1904-6F, which was the highest.

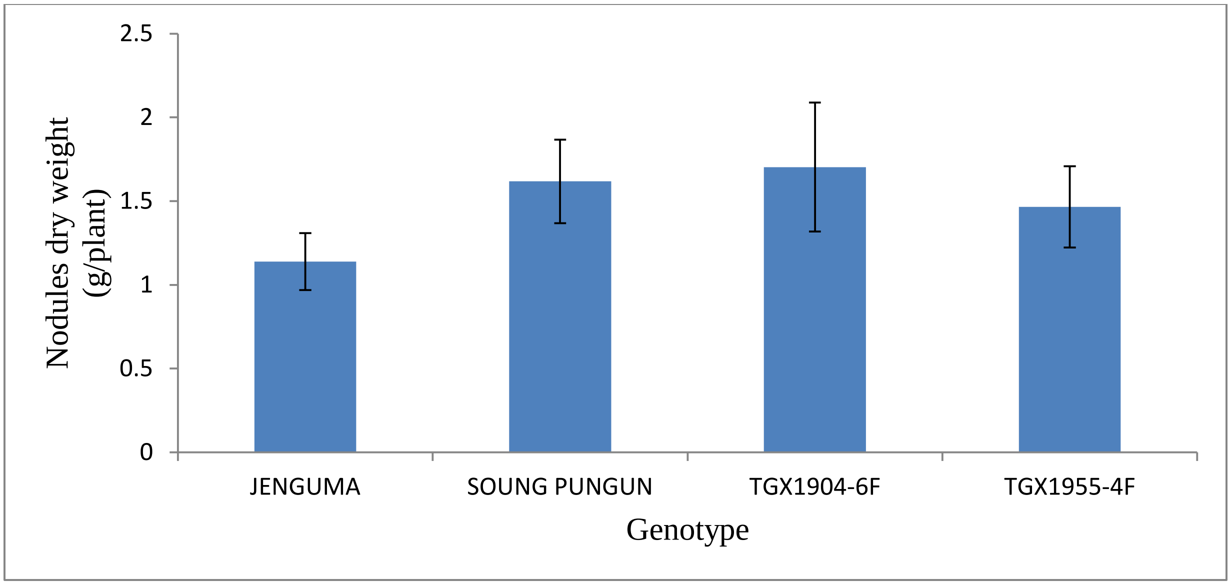

Figure 3: Effect of genotype on nodules dry weight (g) per plant after oven drying. Error bars represent SEM.

4.7 Soybean biomass weight at 50 % flowering

Soybean genotypes, plant spacing and their interaction did not significantly influence (P = 0.069) the biomass weight at 50 % flowering (Table 5). It is significant to note that Jenguma recorded the highest biomass weight at 45 x 10 cm and 60 x 10 cm. Soung-Pungun and TGX1955-4F recorded the least biomass weight at 50 % flowering.

Table 5: Main effects of genotype, spacing and their interaction on biomass weight at 50 % flowering (kg/ha).

	Spacing			
Genotype	45 x 10	60 x 10	75 x 10	Mean of Genotype
JENGUMA	2.250	2.270	1.773	2.097
SOUNG-PUNGUN	1.974	1.188	1.424	1.528
TGX1904-6F	2.107	1.728	1.794	1.876
TGX1955-4F	2.157	1.824	1.518	1.833
Mean of Spacing	2.122	1.752	1.627	
LSD (0.05)	Genotype= 0.5021	Spacing= 0.4349	Genotype x Spacing= 0.8697	
CV (%)			33.0 %	

4.8 Percentage (%) nitrogen fixed from atmosphere

Soybean genotypes showed no significant (P = 0.119) difference in the percent nitrogen fixed. TGX 1904-6F recorded the highest percentage of nitrogen fixed followed by Jenguma. Soung-Pungun and TGX 1955-4F recorded the lowest percentage of fixed nitrogen (Table 6).

Table 6: Effect of soybean genotype on percentage (%) nitrogen fixed from atmosphere.

Genotype	Mean of Genotypes
JENGUMA	44.0
SOUNG-PUNGUN	34.4
TGX1904-6F	48.4
TGX1955-4F	24.5
LSD (0.05)	Genotype = 21.11
CV (%)	67.2 %

Plant spacing did not significantly affect (P=0.737) percentage nitrogen fixed from the atmosphere (Table 7). On nominal scale, plant spacing 60 x 10 cm recorded the highest percentage of fixed nitrogen followed closely by plant spacing 45 x 10 cm and 75 x 10 cm (Table 7).

Table 7: Effect of soybean population on percentage (%) nitrogen fixed from atmosphere

Spacing	Mean of Spacing
45 x 10	37.1
60 x 10	41.6
75 x 10	34.7
LSD (0.05)	Spacing = 18.28
CV (%)	67.2 %

4.9 Total nitrogen in plants

Soybean genotypes, plant spacing and their interaction did not influence the total amount of N in the soybean plant at 50 % flowering (Table 8). It is significant to note that TGX 19904-6F recorded the highest total nitrogen in plants at 45 x 10 cm and 60 x 10 cm (Table 8).

Table 8: Main effects of genotype, spacing and their interaction on total nitrogen in plants (kg ha^{-1}) at 50% flowering.

	Spacing			
Genotype	45 x 10	60 x 10	75 x 10	Mean of Genotype
JENGUMA	90.6	79.8	66.6	79.0
SOUNG-PUNGUN	35.1	67.6	79.4	60.7
TGX1904-6F	94.9	95.8	74.8	88.5
TGX1955-4F	66.7	57.5	21.6	48.6
Mean of Spacing	71.8	75.2	60.6	
LSD (0.05)	Genotype = 44.9	Spacing= 38.9	Genotype x Spacing= 77.8	
CV (%)			28.9 %	

4.10 Number of pods

Plant spacing x genotype interaction significantly ($P < 0.001$) affected number of pods per plant. Soung-Pungun, TGX1904-6F and TGX1955-4F recorded similar number of pods at plant spacing 45 x 10 cm. The highest number of pods was produced by Soung-Pungun planted at 60 x 10 cm, it was however, statistically similar to the number of pods produced by Jenguma and TGX1904-6F planted at 60 x 10 cm and 75 x 10 cm (Figure 4). The least number of pods was produced by TGX1904-6F, Jenguma, Soung-Pungun, and TGX1955-4F planted at 60 x 10 cm, 75 x 10 cm, 45 x 10 cm and 75 x 10 cm, respectively (Figure 4).

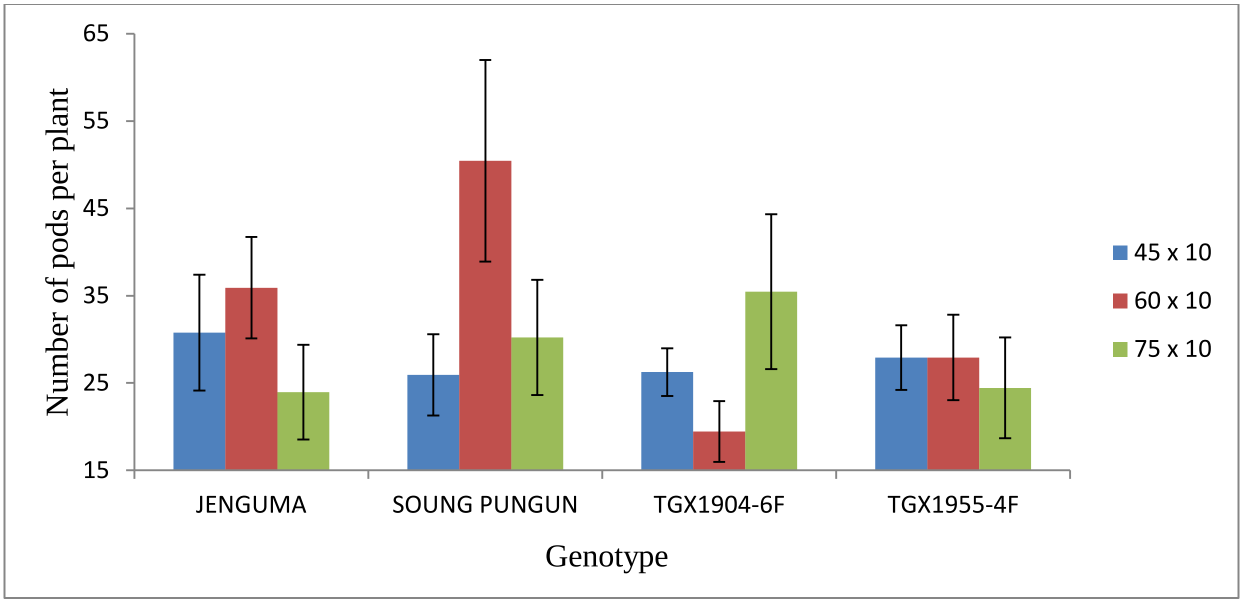

Figure 4: Effect of soybean genotype response to spacing on number of Pods. Error bars represent SEM.

4.11 Grain yield

The kind of soybean genotype used significantly (P = 0.006) influenced grain yield. Soung-Pungun, TGX 1904-6F and Jenguma recorded similar grain yields which were higher than that of TGX 1955-4F (Figure 5).

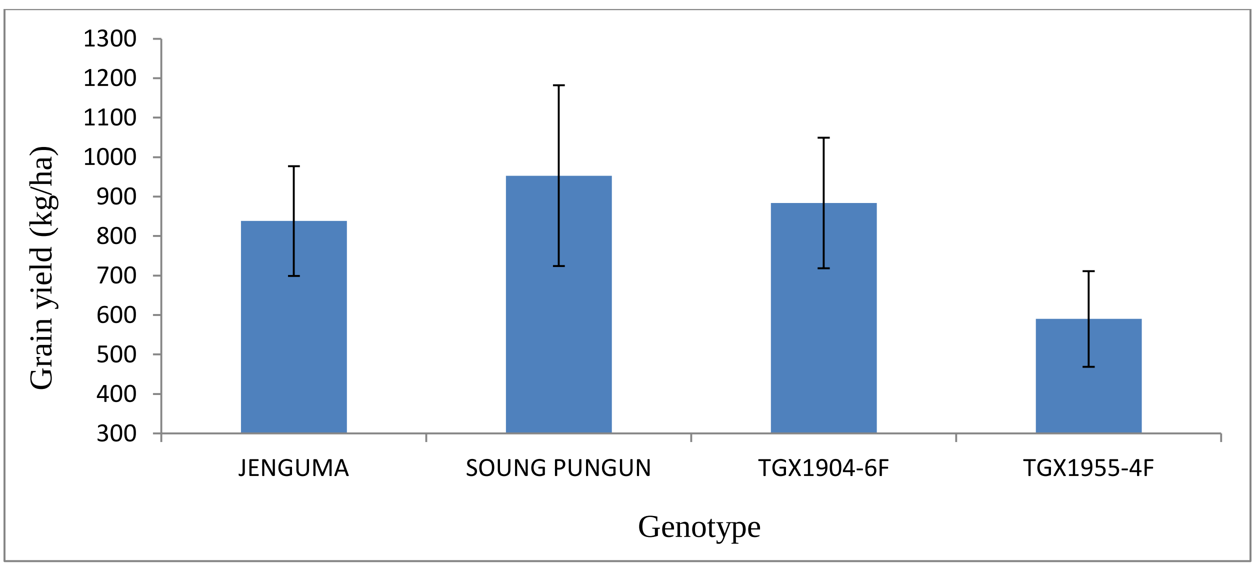

Figure 5: Effect of soybean genotype on grain yield (kg/ha). Error bars represent SEM.

4.12 Hundred seed weight

Genotype significantly ($P < 0.001$) influenced hundred seed weight. Soung-Pungun, TGX 1904-6F and TGX 1955-4F recorded similar hundred seed weight (Figure 6). Jenguma however recorded the lowest hundred seed weight (Figure 6).

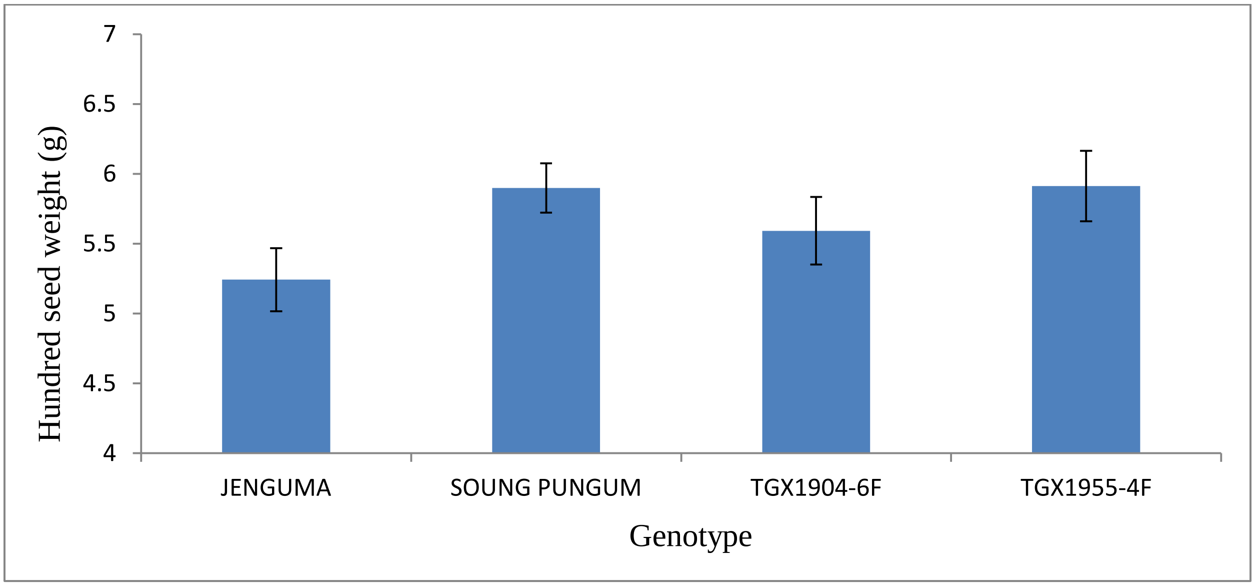

Figure 6: Effect of soybean genotype on hundred seed weight. Error bars represent SEM.

4.13 Total biomass at harvest

Genotypes showed significant effect ($P = 0.048$) on the biomass weight at harvest. TGX1904-6F, Soung-Pungun and Jenguma produced similar biomass with grain weight and that was significantly higher than that of TGX1955-4F (Figure 7). Spacing did not show significant effect ($p=0.476$) on biomass with grain weight. The genotype and spacing interaction also had no significant effect ($P = 0.243$) on biomass weight.

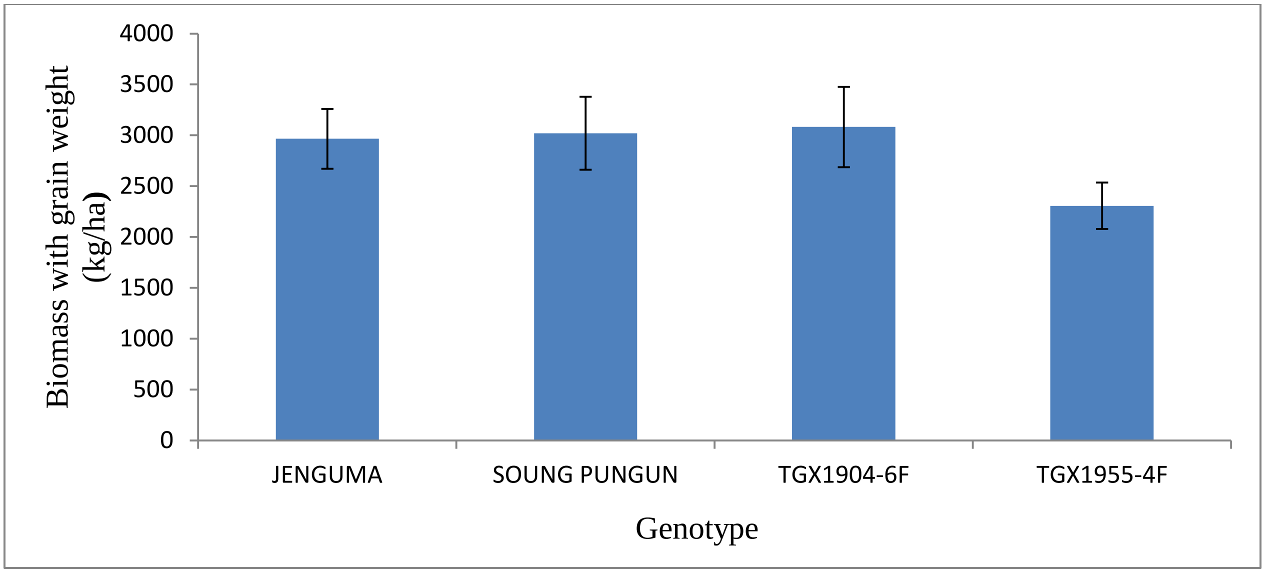

Figure 7: Main effects of genotype on the biomass with grain weight (kg/ha). Error bars represent SEM.

4.14 Fodder weight at harvest

Soybean genotypes, plant spacing and their interaction had no significant (P = 0.218) effect on the fodder weight at harvest. Jenguma and Soung-Pungun recorded the same fodder weight at harvest. TGX 1955-4F recorded the lowest fodder weight at harvest (Table 9).

Table 9: Main effects of genotype, spacing and their interaction on fodder weight at harvest.

		Spacing		
Genotype	45×10	60×10	75×10	Mean of Genotype
JENGUMA	2134	2199	2049	2127
SOUNG-PUNGUN	2273	1887	2040	2067
TGX1904-6F	2646	1921	2027	2198
TGX1955-4F	1523	2194	1433	1717
Mean of Spacing	2144	2050	1887	
LSD (0.05)	Genotype= 492.5	Spacing= 426.5	Genotype $\times$ Spacing= 853.1	
CV (%)			29.3 %	

4.15 Weed fresh and dry weight

The soybean genotype used did not significantly influence weed fresh weight (P = 0.470) (Table 10) and dry weight (P = 0.370) (Table 11). TGX1904-6F recorded the lowest weeds fresh weight though not significantly different from other genotypes. The plant spacing also did not significantly affect the fresh and dry weight of weed (Table 10 and 11 respectively). Genotype and plant population interaction showed no significant (P = 0.231) effect on the weeds fresh weight. The highest weeds fresh weight was recorded in plots planted to Jenguma at 75 x 10 cm.

Table 10: Main effects of genotype, spacing and their interaction on the weeds fresh weight (g/m^2)

		Spacing		
Genotype	45 x 10	60 x 10	75 x 10	Mean of Genotype
JENGUMA	0.0450	0.0287	0.0675	0.0471
SOUNG-PUNGUN	0.0312	0.0487	0.0500	0.0433
TGX1904-6F	0.0510	0.0412	0.0375	0.0432
TGX1955-4F	0.0612	0.0600	0.0475	0.0562
Mean of Spacing	0.0471	0.0447	0.0506	
LSD (0.05)	Genotype = 0.0189	Spacing=0.0164	Genotype x Spacing= 0.0328	
CV (%)			48.0 %	

Table 11: Main effects of genotype, spacing and their interaction on the weeds dry weight (g/m^2)

	Spacing			
Genotype	45 x 10	60 x 10	75 x 10	Mean of Genotype
JENGUMA	0.02325	0.01600	0.02450	0.02125
SOUNG-PUNGUN	0.01525	0.02250	0.02100	0.01958
TGX1904-6F	0.01875	0.01700	0.01775	0.01783
TGX1955-4F	0.02125	0.02375	0.02200	0.02233
Mean of Spacing	0.01963	0.01981	0.02131	
LSD (0.05)	Genotype =0.005441	Spacing=0.004712	Genotype x Spacing=0.009425	
CV (%)			32.4 %	

CHAPTER 5: DISCUSSIONS

5.1 Days to 50 % flowering

It was recorded as the number of days after planting to the date when 50 % of the plants in a plot produced at least one flower. TGX1904-6F took the longest time to achieve 50 % flowering while Soung-Pungun was the earliest to flower. The differences observed among the soybean genotypes in relation to days to flowering is attributable to the difference in growth characteristics among the genotypes. Verma *et al.* (2009) reported varying growth patterns in some groundnut genotypes which they attributed to differences in their genetic makeup. It could have also been as a result of effective utilization of available environmental resources like light, water and nutrients.

Plant spacing did not influence earliness to flowering and this agrees with the findings of Kueneman *et al.* (1978) who stated that, date of 50 % flowering is not significantly affected by increasing and/or decreasing plant density of soybean. TGX1904-6F planted at 60 x 10 cm took the longest days to 50 % flowering and this could have been as a result of its genetic makeup which prevents it from flowering early. Flowering could have also been delayed as a result of the genotypes inability to utilize environmental resources like light, water and nutrients due to the spacing. The results agree with that of Ahmad *et al.* (2002) who reported that sesame from the lower plant densities flowered significantly later than that of higher plant density. Alessi *et al.* (1977) also reported significantly delayed flowering of sunflower planted at wider plant spacing than those in the narrow plant spacing. On the other hand, increased plant density in faba bean did not significantly affect the days to flowering but hastened uniformity in maturity (Amato *et al.*, 1992).

5.2 Number of nodules

Nodule number was affected significantly by soybean genotypes. The highest number of nodules recorded by Soung-Pungun shows its genetic superiority over the other genotypes in this study. Adequate soil moisture enabled rhizobial activities beneath the roots of plants and consequently led to the number of nodules produced by Soung-Pungun. Soybean plant may divert 20 - 30 % of its photosynthates to the production of nodules instead of to other plant functions when the nodules are actively fixing nitrogen (Mir, 2012).

Also the level of nitrogen in the soil (Table 1) could have also played a role in the number of nodules produced. Nastasija *et al.* (2008) outlined that when soil N levels are too high, nodule number and activity decreases. Plant spacing however did not influence the nodule number in this study at the stage of sampling.

5.3 Fresh nodule weight

Significant effects of genotypes on nodule fresh weight was recorded by Soung-Pungun and TGX1904-6F which had the heaviest fresh nodules. The results obtained can be attributed to their genetic variation from Jenguma and TGX1955-4F which recorded the least nodule fresh weight. Genetic variation plays a significant role in dry matter accumulation though climatic and edaphic factors often add up to determine dry matter accumulation in crops. Canopy closure could have also enabled an ideal environment for rhizobial activities and hence production of fresh and active nodules. Soung-Pungun and TGX1904-6F developed faster during the vegetative stage and had wider canopies which enabled moisture retention for an ideal environment for nodule production. Mckenzie *et al.* (1992) reported that the amount of solar radiation intercepted in to the canopy depends on plant arrangement and plant density where the higher plant population density speeds up canopy closure and increases interception of photo-synthetically active radiation (PAR) needed for carbohydrate production and higher biomass in the plants.

5.4 Biomass weight at 50 % flowering

Genotypes and plant spacing showed no significant effect on the biomass weight at 50 % flowering in this study. All the genotypes produced similar amount of biomass at the stage of sampling and this can be attributed to the fact that they have similar growth potential as they were all grown under similar field conditions. Salisbury and Ross (1992) stated that dry matter production shown by genotypes of the same crop under similar growth conditions is indication of similar potential.

Plant spacing as stated earlier did not significantly affect the biomass weight in this study at the time of sampling and this result is contrary to work done by Kumaga *et al.* (2002) who reported that bambara groundnut (*Vigna subterranea* L) produced greater number of leaves (67.2) at the lower population densities (150,000 plants/ha). It was also contrary to work of Kueneman *et al.* (1978) who also reported that the low plant population tended to enhance vegetative growth of dry bean resulting in the development of large leaf area compared to the high and moderate plant populations resulting in sink limitation to photosynthesis.

5.5 Percentage nitrogen fixed from atmosphere

Plant spacing x genotype did not show interaction effect on the percentage nitrogen fixed. Although the statistical analysis was not significant, TGX1904-4F planted at 60 x 10 cm and 45 x 10 cm recorded the highest percentage nitrogen fixed. Jenguma, Soung-Pungun and

TGX1904-4F all recorded similar percentage nitrogen fixed at plant spacing 75 x 10 cm. Nitrogen fixation could have been influenced by the genetic variability of genotypes or the levels of inherent nitrogen in the soil (Table 1). 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.

Nastasija *et al.* (2008) outlined that when soil N levels are too high, roots do not attract bacteria or allow infection; hence, nitrogen fixation is limited. Temperature fluctuation and other environmental factors could have also played a role in the reduced percentage nitrogen fixed from the atmosphere. Nastasija *et al.* (2008) again outlined that a temperature of 16 ^{o}C to 27 ^{o}C is ideal for N-fixation, while levels above or below this reduce bacterial activity and slow the establishment of the N-fixing relationship. The results from this study could have also been influenced by periods of drought and reduced soil moisture which affected rhizobial activity and hence affecting the N-fixing process. Van Kessel and Hartley (2000) reported that increased soil moisture increases the potential of biological nitrogen fixation.

5.6 Number of pods per plant

Pod number per plant is one of the most important yield components of soybean. Higher pod number was observed on Soung-Pungun and Jenguma planted at 60 x 10 cm. However Soung-Pungun being an early maturing variety than the other genotypes, produced significantly higher number of pods per plant. This observation can be attributed to its growth habit and also its genetic makeup which gave it a slight superiority over the others in terms of pod number. This is in consonance with the report made by Bouquet (1998) that, genotype selection is one of most important factors for increasing pod yield in soybean.

Ahmad and Mohammed (2004) also reported inherent varietal differences in seed number per pod in pigeon pea. Soybean population density recorded a significant (P = 0.045) effect on the number of pods per plant. Plant spacing of 60 x 10 cm recorded the highest number of pods per plant. This spacing enabled the plants to utilize available soil water and nutrients to increase its growth and pod production. Virk *et al*. (2005) and Abdullah *et al.* (2007) reported that, increased plant density decreased number of pods per plant and as plant density decreased, number of pods per plant increased. Similarly, increased number of pods per plant with increasing plant spacing observed in this investigation concurs with many researchers in different crops (El Naim and Jabereldar, 2010). They reported that closer spacing reduced the number of pods per plant in cow pea and sesame.

5.7 Grain yield

Grain yield is a function of interaction among various yield components such as days to flowering and the number of pods produced which are affected differently by the growing conditions and crop management practices. Genotype difference played a significant role on the number of days to flowering and the number of pods per plants. Soung-Pungun being an early maturing genotype as compared to the others in this study took the least number of days to flower and also recorded the highest number of pods produced per plant. This performance by the genotype resulted in it producing a significant (P = 0.006) amount of grain yield at the plant spacing used. Karikari (2000) observed that early maturing varieties were high yielding because they emerged rapidly, flowered earlier and had probably enough time to fill the pods. Soybean genotypes are made up of different genetic constitution which affects their growth and performance on the field. This has resulted in the differential grain yield produced by the different genotypes in this study. Plant population density did not have any significant effect on the grain yield in this experiment.

The results therefore contradicts the findings of Bowers *et al*. (2000) who observed that narrow rows should be used to optimize yield in early maturity soybean cultivars. Although three different plant spacings were used, inter plant competition at all planting distance for nutrients and environmental factors like light and water did not have any significant effect on grain yield.

The weeding regime adopted also reduced weeds competition with plants at all the plant spacing used. Hence allowing the crops to perform well under any spacing and only the superior genotype produced the highest grain yield. Contrary to the findings of this study is work done by Board and Harville (1994) who observed 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 enhanced higher yields. They attributed this reduction to inter plant competition for assimilates and low pod yield when beyond optimum plant population is used.

5.8 Hundred seed weight

Soybean genotypes had significant ($P < 0.001$) effects on the hundred seed weight. Maximum 100 seed weight was produced by Soung-Pungun, while Jenguma recorded the lowest seed weight (Figure 10). Plant spacing had no significant effect on seed weight in this experiment and this agrees with Lemlem (2011) who also obtained no significant effect of plant density on hundred seed weight of soybean. However the results goes against work of Worku & Astatkie (2011) who observed an increase in 1000 seed weight of two varieties with narrow row spacing. Genetic constitution of some soybeans gives them a slight edge over others and this resulted in the differential seed weight recorded by genotypes in this study. The crops vigor and ability to utilize available resources on the field eventually results in high grain yield and seed weight. Turk *et al.* (1980) reported that individual seed weight was highly affected by genetic factors except in case of severe water stress and hot desiccating winds causing forced maturity.

Weeds control measures adopted proved effective in reducing weeds competition with crops at all plant spacing, hence allowing crops to utilize available resources on the field to maximize yield and hence seed weight. The results however did not agree with those obtained by Solomon (2003) on haricot bean, who reported that hundred seed weight decreased with increase in plant density. Moreover, Turk and Tawaha (2002) and Matthews *et al*. (2008) reported that hundred seed weight of faba bean was negatively related with plant density.

5.9 Weeds dry weight

Genotypes and plant spacing interaction showed no significant ($P = 0.395$) effect on the weeds dry weight. All the plots recorded similar amount of weeds at the stage of sampling and this can be attributed to the fact that they were all grown under similar field conditions. The lowest dry weeds weight was recorded in plots planted with Soung-Pungun at 45 x 10 cm spacing. The weeding regime adopted also prevented weeds resurgence in both narrow and wider rows. Indicating that plant spacing has no significant effect on weeds infestation if the weeding regime is reliable. However, Worku & Astatkie (2011) stated that the lowest dry weeds weight for soybeans planted in narrower rows than in wider ones is due to greater ground-covering canopy of the soybean plants, which did not allow additional weed growth and establishment. Their finding supports the hypothesis that a thin plant stand or wide plant stands allows more weed growth and establishment as a result of less ground-covering canopy. The results in this study goes contrary to the results of Yelverton and Coble (1991) who observed highest weed resurgence in wide row spacings.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Conclusions

The experiment was conducted to determine the effects of different genotypes and plant population density on the growth, yield, nodulation and nitrogen fixation of soybean in the Sudan Savanna Agro-Ecological Zone of Ghana. Data were collected on the following parameters: plant height, days to 50 % flowering, number of nodules, Fresh nodules weight, biomass weight at 50 % flowering, numbers of pods per plant, grain yield, 100-seed weight and weeds dry weight. The results indicated that different genotypes significantly affected soybean response to growth and yield performance.

The tallest plants were observed in TGX1904-6F planted at 60 x 10 cm while the shortest heights were recorded by Jenguma planted at 45 x 10 cm spacing. Although not significant, the analysis showed that genotype difference affected plant height at different population densities. Significant effects of genotypes were recorded on days to flowering, nodulation, number of pods, grain yield and the hundred seed weight. Soung-Pungun recorded the least number of days to 50 % flowering followed by Jenguma. It also recorded the highest nodule and pod count per plant and eventually recording the highest grain yield per hectare. These results indicate that Soung-Pungun is the superior genotype among other genotypes in this study.

Plant population density significantly influenced the number of pods produced in this study. Plant spacing of 60 x 10 cm recorded the highest number of pods with Soung-Pungun, followed by spacing of 75 x 10 cm and 45 x 10 cm. This indicates that high population density is required for maximum number of pods production. Plant population density however showed no significant effect on the rest of the above listed parameters.

Plant spacing x genotype interaction showed no significant difference on the percentage nitrogen fixed from the atmosphere, however TGX1904-4F planted at 60 x 10 cm recorded the highest percentage nitrogen fixed and TGX1955-4F recorded the lowest at plant spacing 75 x 10 cm, followed by Soung-Pungun planted at 45 x 10 cm. The results therefore suggests that TGX1904-4F planted at 60 x 10 cm is superior among other genotypes in the fixation of atmospheric nitrogen.

6.2 Recommendations

Significant differences in grain yield of the genotypes indicate that, recommendations for soybean varietal selection could be based on achieving higher yields. The result obtained in this experiment indicates that Soung-Pungun is superior in terms of yield performance, yielding about 0.953 tonnes ha^{-1} of grain. Soung-Pungun is therefore recommended over Jenguma, TGX1904-6F and TGX1955-4F for farmers in the Sudan Savanna Agro-Ecological Zone of Ghana if their goal is to achieve higher yields.

Also, this study illustrated substantial increase in the number of pods per plant, by increasing the population density through reduced row spacing of 60 x 10 cm. It is therefore recommended that, for greater number of pods, farmers should adopt the 60 x 10 cm spacing. Finally, it is recommended that further experiments be carried out in the study area to confirm the findings of this research.

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APPENDICES

Appendix 1: Plant height at 8 weeks after planting (WAP)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	781.91	260.64	4.90	
Rep. Genotype stratum					
Genotype	3	102.92	34.31	0.65	0.605
Residual	9	478.50	53.17	2.78	
Rep. Genotype. Spacing stratum					
Spacing	2	31.87	15.93	0.83	0.446
Genotype. Spacing	6	178.57	29.76	1.56	0.203
Residual	24	458.45	19.10		
Total	47	2032.21			

Appendix 2: Plant height at 10 weeks after planting (WAP)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	554.37	184.79	3.53	
Rep. Genotype stratum					
Genotype	3	98.42	32.81	0.63	0.616
Residual	9	471.29	52.37	2.78	
Rep. Genotype. Spacing stratum					
Spacing	2	61.98	30.99	1.64	0.214
Genotype. Spacing	6	107.77	17.96	0.95	0.477
Residual	24	452.67	18.86		
Total	47	1746.50			

Appendix 3: Plant height at 12 weeks after planting (WAP)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	742.44	247.48	4.51	
Rep. Genotype stratum					
Genotype	3	136.33	45.44	0.83	0.511
Residual	9	493.49	54.83	2.58	
Rep. Genotype. Spacing stratum					
Spacing	2	60.49	30.24	1.42	0.260
Genotype. Spacing	6	135.53	22.59	1.06	0.411
Residual	24	509.40	21.23		
Total	47	2077.67			

Appendix 4: Days to 50 % flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	180.750	60.250	38.05	
Comm.*Units* stratum					
Genotype	3	250.750	83.583	52.79	<.001
Spacing	2	9.375	4.688	2.96	0.066
Genotype. Spacing	6	128.125	21.354	13.49	<.001
Residual	33	52.250	1.583		
Total	47	621.250			

Appendix 5: Number of nodules

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	1605.18	535.06	11.95	
Comm.*Units* stratum					
Genotype	3	774.13	258.04	5.76	0.003
Spacing	2	46.93	23.46	0.52	0.597
Genotype. Spacing	6	170.50	28.42	0.63	0.702
Residual	33	1477.86	44.78		
Total	47	4074.59			

Appendix 6: Number of effective nodules

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	350.0	116.7	0.62	
Comm.*Units* stratum					
Genotype	3	616.7	205.6	1.09	0.365
Spacing	2	729.2	364.6	1.94	0.160
Genotype. Spacing	6	470.8	78.5	0.42	0.862
Residual	33	6200.0	187.9		
Total	47	8366.7			

Appendix 7: Nodules resh weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	0.85873	0.28624	22.99	
Comm.*Units* stratum					
Genotype	3	0.14692	0.04897	3.93	0.017
Spacing	2	0.00197	0.00099	0.08	0.924
Genotype. Spacing	6	0.05608	0.00935	0.75	0.613
Residual	33	0.41087	0.01245		
Total	47	147.457			

Appendix 8: Nodules dry weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	5.5237	1.8412	9.40	
Comm.*Units* stratum					
Genotype	3	2.2249	0.7416	3.79	0.019
Spacing	2	0.0207	0.0103	0.05	0.949
Genotype. Spacing	6	1.0504	0.1751	0.89	0.511
Residual	33	6.4658	0.1959		
Total	47	15.2855			

Appendix 9: Biomass weight at 50 % flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	11003730.	3667910.	11.71	
Comm.*Units* stratum					
Genotype	3	1693034.	564345.	1.80	0.166
Spacing	2	1814608.	907304.	2.90	0.069
Genotype. Spacing	6	825928.	137655.	0.44	0.847
Residual	33	10340438.	313347.		
Total	47	25677738			
Total	47	29.9505			

Appendix 10: Nitrogen percentage (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	6246.3	2082.1	3.22	
Comm.*Units* stratum					
Genotype	3	4073.6	1357.9	2.10	0.119
Spacing	2	397.3	198.6	0.31	0.737
Genotype. Spacing	6	2478.9	413.1	0.64	0.698
Residual	33	21322.4	646.1		
Total	47	34518.4			

Appendix 11: Total nitrogen in plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	14413.	4804.	1.64	
Comm.*Units* stratum					
Genotype	3	11586.	3862.	1.32	0.284
Spacing	2	1870.	935.	0.32	0.729
Genotype. Spacing	6	9183.	1530.	0.52	0.787
Residual	33	96549.	2926.		
Total	47	133599.			

Appendix 12: Number of pods

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	4216.89	1405.63	31.49	
Comm.*Units* stratum					
Genotype	3	598.36	199.45	4.47	0.010
Spacing	2	305.73	152.86	3.42	0.045
Genotype. Spacing	6	1899.95	316.66	7.09	<.001
Residual	33	1473.20	44.64		
Total	47	8494.12			

Appendix 13: Grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	2261133.	753711.	12.31	
Comm.*Units* stratum					
Genotype	3	897576.	299192.	4.89	0.006
Spacing	2	27680.	13840.	0.23	0.799
Genotype. Spacing	6	700970.	116828.	1.91	0.109
Residual	33	2020129.	61216.		
Total	47	5907489.			

Appendix 14: Hundred seed weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	2.3360	0.7787	5.01	
Comm.*Units* stratum					
Genotype	3	3.5991	1.1997	7.71	<.001
Spacing	2	0.3964	0.1982	1.27	0.293
Genotype. Spacing	6	1.0955	0.1826	1.17	0.344
Residual	33	5.1330	0.1555		
Total	47	12.5600			

Appendix 15: Biomass with grain weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	30766521.	10255507.	19.19	
Comm.*Units* stratum					
Genotype	3	4682243.	1560748.	2.92	0.048
Spacing	2	810492.	405246.	0.76	0.476
Genotype. Spacing	6	4499679.	749946.	1.40	0.243
Residual	33	17636871.	534451.		
Total	47	58395806.			

Appendix 16: Fodder weight at harvest

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	16359491.	5453164.	15.51	
Comm.*Units* stratum					
Genotype	3	1643768.	547923.	1.56	0.218
Spacing	2	540713.	270356.	0.77	0.472
Genotype. Spacing	6	2417689.	402948.	1.15	0.358
Residual	33	11603986.	351636.		
Total	47	32565647.			

Appendix 17: Weeds fresh weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	0.0057734	0.0019245	3.70	
Comm.*Units* stratum					
Genotype	3	0.0013459	0.0004486	0.86	0.470
Spacing	2	0.0002850	0.0001425	0.27	0.762
Genotype. Spacing	6	0.0044743	0.0007457	1.43	0.231
Residual	33	0.0171574	0.0005199		
Total	47	0.0290360			

Appendix 18: Weeds dry weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	0.00017217	0.00005739	1.34	
Comm.*Units* stratum					
Genotype	3	0.00013950	0.00004650	1.08	0.370
Spacing	2	0.00002737	0.00001369	0.32	0.729
Genotype. Spacing	6	0.00027763	0.00004627	1.08	0.395
Residual	33	0.00141633	0.00004292		
Total	47	0.00203300			

Appendix 19: Maize dry weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Comm stratum	3	59076.	19692.	1.48	
Comm.*Units* stratum					
Genotype	3	21340.	7113.	0.54	0.670
Residual	9	119620.	13291.		
Total	15	200035.			