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DEPARTMENT OF CROP AND SOIL SCIENCES

GROWTH AND YIELD RESPONSE OF EARLY AND MEDIUM MATURITY SOYBEAN (*Glycine max* (L) Merrill) VARIETIES TO ROW SPACING

A thesis submitted to the Department of Crop and Soil Sciences, Faculty of Agriculture of the College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. This is in partial fulfilment of the requirement for the award of Masters of Science Degree in Agronomy.

BY

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DECLARATION

I hereby certify that this thesis has not been submitted for a degree to any other university and it is entirely my own work and all help and references have been duly acknowledged.

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(Student)

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Dr Joseph Sarkodie-Addo

(Supervisor)

DEDICATION

This Thesis is dedicated to my loving and supporting family who have always stood beside me and kept me in their thought and prayers throughout all my endeavours. I would also like to dedicate this work to the loving memory of my beloved parents whose short lives here on earth touched at many lives. Though gone to the creator, your love, care and wise counsel are ever present in my life.

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ABSTRACT

An experiment to investigate the effect of different row spacings on the growth and yield of three soybean varieties Ahoto, Anidaso and Nangbaar was conducted at the Plantation Crop Section of the Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology, Kumasi in 2008 and 2009.

The experimental design was a split plot, arranged in a randomized complete block design with three replications. The varieties were the main plots and row spacing, the subplots. Data collected were plant height, number of primary branches, shoot dry matter, leaf area index, crop growth rate, nodule count, nodule dry weight and effectiveness, number of pods per plant, number of seeds per pod, 100 seed weight, grain yield per hectare and percentage pod shattering. The data were analysed using ANOVA and means separated by LSD ($P<0.05$) using MSTAT-C.

The results showed significant ($P<0.05$) differences due to varieties for number of primary branches, leaf area index, number of pods per plant and grain yield (ton ha^{-1}). Row spacing effects were significant ($P<0.05$) on plant height (cm), leaf area index, number of leaves, dry matter yield kg ha^{-1} and grain yield (ton ha^{-1}). Correlation analysis showed significant positive correlation between number of pods per plant and grain yield ($r = 0.597$).

Under the conditions of this study, the Ahoto variety was the best in terms of grain yield, 3.15 ton ha^{-1}, and the row spacing of 40×5 cm resulted in the highest grain yield, 2.46 ton

ha^{-1}. Among the three varieties, therefore, Ahoto would give the highest grain yield to producers, and the spacing recommended to soybean farmers is 40×5 cm.

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CHAPTER ONE

1.0 INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is an important global legume crop that grows in the tropical, subtropical and temperate climates. Like peas, beans, lentils and peanuts, it belongs to the large botanical family, Leguminosae, in the subfamily Papilionideae. It has 40 chromosomes (2n = 2x = 40) and is a self-fertile species with less than 1% out-crossing (Shurtleff and Aoyagi 2007; IITA, 2009).

Soybean has many benefits, nutritionally for man and livestock, as well as other industrial and commercial uses. It is classified as an oilseed, containing significant amounts of all the essential amino acids, minerals and vitamins for human nutrition. It is therefore an important source of human dietary protein with an average of 40% content, 30% carbohydrate and oil content of 20% (Adu - Dapaah *et al*., 2004; MoFA and CSIR, 2005). In Ghana, the soy cake is an excellent source of protein feed for the livestock industry (MoFA and CSIR, 2005). The poultry, pig and fish farming industries especially, are benefiting tremendously from soybean as a cheap source of high quality protein feed.

Soybean oil is the world's most widely used edible oil, as it is low in cholesterol, with a natural taste and nearly imperceptible odour, which makes it the ultimate choice of vegetable oil for domestic and industrial food processing (Mpepereki *et al*., 2000; Addo-Quaye *et al.,* 1993). Almost all margarines, shortenings and salad dressings contain soy oil (Wikipedia, 2009). Soy oil has also become the most important raw material for the production of biodiesel, which is fast supplementing fossil fuels, a boom in the biofuel industry (Caminiti *et al.*, 2007). It has also found use in many products such as adhesives, lubricants, plastics, printing inks and health and beauty products (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, baby foods and 'dawadawa', a local seasoning product for stews and soups, (Abbey *et al.*, 2001). It is also used to fortify various traditional foods such as gari, sauces, stew, soups, banku and kenkey to improve their nutritional levels (MoFA and CSIR, 2005).

Soybean like all other legumes also improves soil fertility by converting atmospheric nitrogen from the soil for its own use, which also benefits subsequent crops in rotation. It therefore cuts down the amount of nitrogen fertilizer that farmers have to purchase to apply to their fields to improve productivity. This is a major benefit in Africa, where soils are poor in nutrients and fertilizers are expensive and not available for farmers (MoFA and CSIR, 2005; IITA, 2009).

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 and CSIR, 2005).

Ghana's current production is about 15,000 metric tons of soybean grain annually (MoFA and CSIR, 2005), but total domestic demand for cooking oil, seasoning and animal feed cake is estimated at nearly 30,000 metric tons per year (ADF, 2004).

Despite the numerous benefits of the soybean, the grain yield per unit area is low in Ghana, an average of 1.3 tons per hectare (Tweneboah, 2000). That of Africa is an average of 1.1 tons per hectare (IITA, 2009). Italy, Argentina, the USA and Brazil produce 3.32, 2.31, 2.30 and 2.00 tons per hectare on the average respectively (Norman *et al*., 1995).

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

Available research data on soybean planting systems give a broad range of 60-75cm inter-row spacing and 5-10cm intra-row spacing, giving an average of 19,750 plants ha^{-1} (MoFA and CSIR, 2005). This is irrespective of factors such as the maturity group, growth habit, soil condition and vegetational zone. This makes choice of optimal population densities among early and medium maturity soybean varieties difficult for farmers. Generally, legume seed yield is a function of plants per unit area, pods per plant, number of seeds per pod and weight per seed (Baligar and Jones, 1997).

The advantages for planting soybean in narrow rows are generally; increased grain yield, reduced soil erosion, increased harvesting efficiency and early crop canopy closure to help control weeds, and the convenience of using small grain equipment for some planting and harvesting operations, while the primary disadvantages are disease problems, seedling emergence problems if soil crusts easily and drought condition problems (Duane and Ted, 2003).

Research indicates that higher yields of soybean can be obtained in narrow rows if plant stands are well established and weeds are adequately controlled. Gary and Dale (1997), in an experiment comparing 75cm rows verses 30cm rows and 90cm rows verses 30cm rows, found the narrow rows yielding 28% and 31% respectively higher than the wider row spacing. In North Dakota, about 60% of soybeans are planted in narrow row spacing of 38cm or less if soil moisture is sufficient, and yields are often higher, an average of 3.5 tons per hectare (Gary and Dale, 1997).

Suitable land area for food production remains fixed or diminishing, yet farmers are faced with the task of increasing production to meet demand (Quainoo *et al*., 2000). Raising soybean production is possible through a more effective use of resources by appropriate row spacing adjustments.

Ennin and Clegg (2001) reported that there is interest in planting soybean in narrow rows to increase light interception for higher yields, especially of the determinate genotypes that tend to be short statured. There have been many studies conducted to evaluate the effect of narrow rows verses wide rows and the optimal seeded population on yield of soybean. However, the optimum varies greatly by geographic region and changes over time as new varieties are being released by breeders (Norsworthy and Oliver, 2002; IITA, 2009).

There is therefore, a need to research on row-spacing to obtain the optimum plant population densities to maximize yield of the local and new genotypes of soybean being released by breeders. The objectives of this project were to:

I. Determine the appropriate inter-row spacing to achieve the best plant population density that will give optimum yield of early and medium maturity soybean genotypes.

II. Compare agronomic characteristics of early and medium maturity soybean genotypes sown in various row spacing.

III. Determine whether both early and medium maturity soybean genotypes respond similarly to decreasing row spacing.

2.0 LITERATURE REVIEW

2.1 ORIGIN AND DISTRIBUTION

Soybean is native to Eastern Asia, mainly China, Korea and Japan, from where it spread to Europe and America and other parts of the world in the 18^{th} century (Ngeze, 1993). Evidence in Chinese history indicates its existence more than 5,000 year ago, being used as food and a component of drugs (Norman *et al.*, 1995). Some researchers have suggested Australia and Eastern Africa as other possible centres of origin of the genus *Glycine* (Addo-Quaye *et al.*, 1993). It is widely grown on large scale in both the temperate and tropical regions such as China, Thailand, Indonesia, Brazil, the USA and Japan; where it has become a major agricultural crop and a significant export commodity (Evans, 1996).

Soybean was first introduced to Africa in the early 19^{th} 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).

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 seven perennial 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).

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 20cm 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; CSIR and MoFA, 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 three to four leaflets per leaf. The fruit is a hairy pod that grows in clusters of three to five, each of which is five to eight centimetres long and usually contains two to four 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 (Wikipedia, 2009; Borget, 1992).

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. While the reproductive stage begins with flower bud formation, through full bloom flowering, pod formation, pod filling to full maturity.

2.4 CLIMATIC AND SOIL REQUIREMENTS

2.4.1 SOIL

Soybean is tolerant to a wide range of soil conditions but does best on warm, moist, and well drained fertile loamy soils, that provide adequate nutrients and good contact between the seed and soil for rapid germination and growth (Hans *et al.*, 1997; Addo-Quaye *et al.*, 1993). Ngeze (1993) stated that, soybean does well in fertile sandy soils with pH of between 5.5 and 7.0, and that the crop can tolerate acidic soils than other legumes but does not grow well in water logged, alkaline and saline soils.

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.

2.4.2 TEMPERATURE AND PHOTOPERIOD

Soybean is a legume species that grows well in the tropical, subtropical and temperate climates (IITA, 2007). Plant breeders have argued that within the soybean species, there are varieties which react differently to photoperiod, and classified them as long day, short day and day neutral plants (Borget, 1992).

Rienke and Joke (2005), described soybean as being typically a short day plant, physiologically adapted to temperate climatic conditions. However, some have been adapted to the hot, humid, tropical climate. In the tropics, the growth duration of adapted genotypes is commonly 90-110 days, and up to 140 days for the late maturing ones (Osafo, 1997). The relatively short growth duration is primarily due to sensitivity to the day length. This affects the extent of vegetative growth, flower induction, production of viable pollen, length of flowering, pod filling and maturity characteristics (Norman *et al.*, 1995).

Most legumes require an optimum temperature of between 17.5^{O}C and 27.5^{O}C for development (Ngeze, 1993). For soybean, the minimum temperature at which it develops is 10^{O}C, the optimum being 22^{O} C and the maximum about 40^{O}C. The seeds germinate well at temperatures between 15^{O}C and 40^{O}C, but the optimum is about 30^{O}C (Rienke and Joke, 2005). Addo-Quaye *et al.*, (1993) have suggested the optimum temperature for growth as between 23-25^{O}C.

2.4.3 MOISTURE REQUIREMENTS

Soybean requires optimum moisture for seeds to germinate and grow well. The optimum rainfall amount is between 350 and 750mm, 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. And during germination, the soil needs to be between 50% and 85% saturated with water, as the seed absorbs 50% of its weight in water before it can germinate. The amount of water needs increases, and peaks up at the vegetative stage, and then decreases to reproductive maturity.

Large variation in the amount and distribution of soil water limits soybean yield. According to Bohnert *et al*., (1995), there are two major roles of water in plants, as a solvent and transport medium of plant nutrients, and as an electron donor in the photosynthetic reaction processes.

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 certain cells of the plant may affect various metabolic processes. Direct impacts of drought stress to the physiological development of soybean depend on its water use efficiency (Earl, 2002).

In soybean management, water use efficiency is an important physiological characteristic related to the ability of plants to cope with water stress. According to 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) found 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).

2.5 FERTILIZER REQUIREMENT

Soybean plant has a nutrient dense, high protein seed, and therefore, requires high amount of nutrients for its growth (Lamond and Wesley, 2001). It is a legume that can meet its nitrogen needs by symbiotic relationship with nitrogen fixing bacteria of the species *Bradyrhizobia japonicum* from atmospheric nitrogen (Sarkodie-Addo *et al.*, 2006). And generally, the plant will not benefit from supplemental nitrogen fertilizer application, where there are indigenous populations of the appropriate *Bradyrhizobia* bacteria strains that cause effective nodulation of the roots and nitrogen fixation (Darryl *et al.*, 2004).

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. However, where soybean have not been grown recently, inoculation of the seed with specific *Bradyrhizobia* strains is essential for effective nitrogen fixation (Darryl *et al.*, 2004).

Malik *et al*., (2006) reported that, soybean seed inoculation with *Rhizobium* in combination with phosphorus application at 90 kg per hectare, performed better in yield under irrigated conditions. Soybean can produce maximum seed yield with relatively low levels of available phosphorus in the soil. Phosphorus application is not likely to increase seed yield at soil phosphate concentrations above 12ppm 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 124ppm (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.

2.6 NITROGEN FIXATION

Soybean is a legume and 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 will fix nitrogen from the atmosphere, normally supplying most or all nitrogen needed by the plant. 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).

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 60kg and 168kg of nitrogen per hectare per year 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^{-1} 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, 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 percent 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^{o}C to 27^{o}C 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.

2.7 GROWTH AND YIELD RESPONSES TO ROW SPACING

There have been mixed reports on the effect of plant population on yield of soybean. Lueschen and Hicks (1977) have indicated that, soybean plants are capable of compensating for low plant densities by producing more branches and more pods per plant. Thus, yield levels remained relatively constant over a wide range of populations.

The amount of light intercepted by a crop, especially in the early stages of growth, is a simple function of plant population and row spacing (Charles-Edwards and Lawn, 1984). Board and Harville. (1994) have 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. James *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.

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), also demonstrated that soybean seed yields of two cultivars were consistently higher in narrow (50cm) rows than in wide (102cm) rows. Cooper (1977) reported yield increases of 10 to 20% from 17cm row spacing compared to 50 or 70cm rows. And early maturity cultivars showed greater response than late maturity cultivars. Costa *et al*., (1980) also found a 23% seed yield increase when 27cm rows were compared with 76cm rows spacing. (Alessi and Power, 1982). Also, determinate cultivars responded more positively to a reduction in row spacing than some indeterminate cultivars of the same maturity group (Cooper, 1981; Walker and Foritto, 1984).

Beatty *et al*., (1982) also adjusted plant population with row spacing and found that, early maturity cultivars planted early in 18cm rows with 600,000 seeds ha^{-1} and 48cm rows with 460,000 ha^{-1} seeds yielded more than late planting at any row spacing. Bouquet (1998) also found out 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 40cm) 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.

2.8 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 (Evan, 1996; Hunt, 1978). 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*., (2000) 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 LAI and NAR, 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 LAI 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), stated 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 lowermost leaves become heavily shaded that, photosynthetic contribution becomes less than respiration.

2.9 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).

Masuda and Goldsmith (2008), also gave the breakdown of world soybean production of 94 million hectares worldwide as follows: the U.S.A. accounted for over 30 million, Brazil for almost 22 million, Argentina for 15 million, China for 9.2 million, India for 8.2 million, Paraguay for 2.2 million and Canada for one million hectares respectively. 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 hectares), South Africa (150 000 hectares), Uganda (144 000 hectares), Malawi (68 000 hectares), and Zimbabwe (61 000 ha).

2.10 USES OF SOYBEAN

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 also contain about 20% oil on a dry matter basis, and this is 85% unsaturated and cholesterol-free.

Borget, (1992) has 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).

Rienke 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 one kilogram of soybean is equivalent to the quantity of proteins in three kilograms 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 can therefore be 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 (Rienke and Joke, 2005; Ngeze, 1993 and Wikipedia, 2009).

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 (Abbey *et al*, 2001; Ngeze, 1993; MoFA and CSIR, 2005). The haulms, after extraction of seed, also provide good feed for sheep and goats (Dugje *et al*., 2009).

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 (Rienke and Joke, 2005; Ngeze, 1993).

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).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 THE EXPERIMENTAL SITE

The field experiment was conducted at the Plantation Crops Section of the Department of Crop and Soil Sciences of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, between April and August 2008 and repeated at the same period in 2009. Kumasi is situated in the semi-deciduous forest vegetational zone of Ghana. It is about 356m above sea level on latitude 06° 43'N and longitude 01° 33'W (FAO/UNESCO legend, Asiamah, 1998).

3.2 CLIMATE

The rainfall is bimodal with an average annual rainfall of 1500mm. The major rainy season extends from mid-March to July, with a short dry period in August, while the minor rainy season extends from September to November. The main dry season also extends from late November to mid-March. The average relative humidity for 2008/9 varied from 97% (06 hours GMT) during the major and minor rainy seasons to as low as 20% (15 hours GMT) during the dry season (Metrological Station, KNUST, 2009).

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Annual average maximum and minimum temperatures for 2008/9 were 34.9°C and 21.2°C respectively. The mean daily maximum and minimum temperatures during the period of the experiment were 30.2°C and 21.8°C respectively, while the mean monthly rainfall recorded was 184.3mm and relative humidity, 78% (Metrological station, KNUST, 2009).

3.3 SOIL CHARACTERISTICS

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 (FAO/UNESCO legend, Asiamah, 1998).

Soil samples were taken from the experimental site to a depth of 0 – 15 and 0 – 30cm. These samples were taken to the laboratory to determine their physical and chemical properties. The samples were dried and sieved using a 2mm mesh sieve. The following properties were determined.

3.3.1 Organic Carbon

The Walkley-Black wet combustion procedure (Nelson and Sommers, 1982) was used to determine Organic carbon.

3.3.2 Organic Matter.

Percent organic carbon was multiplied by 1.724 (The Van Bemmelen factor) to get percent organic matter.

3.3.3 Soil pH.

This was measured in 1:2.5 soils to water suspension by the use of a glass Electrocalomel electrode (Mclean, 1962) pH metre.

3.3.4 Total Nitrogen

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

3.3.5 Potassium

The flame photometer method was used to determine the amount of potassium with ammonium acetate as the extractant.

3.3.6 Available phosphorous

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

3.3.7 Exchangeable Bases (Ca, Mg, K, Na)

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

3.4 LAND PREPARATION

The land was previously cropped to cowpea, maize, soybean and most recently groundnuts. The site for the experiment was manually cleared by slashing the vegetation with a cutlass, ploughed in the stubble for two weeks, before being harrowed with a tractor. The land was then levelled and the plots laid out using tape measure, garden line and pegs.

3.5 THE VARIETIES USED FOR THE EXPERIMENT

The seed of the soybean varieties used were obtained from the Crop Research Institute (CRI) of the Council for Scientific and Industrial Research (CSIR) at Fumesua, Kumasi. They included:

(a) Ahoto – 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).

(b) Anidaso – 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).

(c) 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).

3.6 DESIGN AND EXPERIMENTAL LAY OUT AND TREATMENTS

The experimental design was a split-plot arrangement of treatments in a randomized complete block, with three replications (blocks). Main plot factor was soybean cultivars Ahoto (V1), Anidaso (V2) and Nangbaar (V3), and the sub-plot factor was inter-row spacing of 60cm (SP1), 50cm (SP2), 40cm (SP3) and 30cm (SP4), corresponding to plant population density of 333,333; 400,000; 444,444 and 500,000 plants per hectare respectively. The spacing between plants (intra row spacing) was 5cm.

Each block consisted of 12 plots, each of which measured 3m x 4m, giving a total of 36 plots, and total land area of 144m^2, with one metre alleys the between blocks.

The experiment was carried out during the major season, April to July, 2009. Seeds were drilled on the prepared flat seedbed on each plot, on the 16th April, 2009. Germination and emergence of seedlings took place five to ten days after sowing.

3.7. 0 CULTURAL PRACTICES

3.7.1 THINNING

Thinning out was done to approximately 5cm between plants in a row, 20 days after sowing, when the soil was moist and seedlings well established. This left a total of 20 plants per metre length of row.

3.7.2 WEEDING

Weeding was done manually by hand using a hoe, on the 3rd and 6th week after sowing to control weeds. Each weeding operation was completed on the same day for all the blocks on the day of weeding.

3.8 PESTS MANAGEMENT

There were incidences of pod suckers (*Riptortus dentipes*) and leaf rollers (garden webworms) at the pod filling stage, which warranted control measures, since the infestation reached the economic thresholds. The economic threshold is, an average of 10 plant-feeding pod suckers per one metre row and more than 10-12% of plants showing webbing for pod suckers and garden webworms respectively (Randall, 1997).

Spraying started at 100% flowering with Lambda Super 2.5 EC (containing 25g active ingredient of Lambda cyhalothrin per litre), at the rate of 600ml per hectare with a knapsack sprayer, at a recommended 14 days interval to control the insects, till when pods were completely filled. In all, there were two times of spraying.

3.9 GROWTH AND REPRODUCTIVE PARAMETERS

The agronomic parameters measured during the research period were:

- Mean plant height (cm)
- Mean number of primary branches per plant at maturity
- Number of leaves
- Mean number of nodules per plant 35 days after planting (DAP)
- % Nodule effectiveness
- Nodule dry weight (g)
- Shoot dry matter (kg ha^{-1})
- Leaf area index
- Crop growth rate
- Number of pods per plant
- Number of seeds per pod
- 100 seed weight (g)
- Grain yield (tons per hectare)
- Pod shattering percentage

3.10 DATA COLLECTION

3.10.1 VEGETATIVE GROWTH

Sampling for growth (vegetative) analysis started 28 days after sowing (DAS) and continued for eight weeks. This was done at three week interval, giving a total of three harvests at three growth stages. The growth stages were four weeks after planting (4WAP); seven weeks after planting (7WAP) and weeks after planting (10WAP). At each sampling period, six plants for each parameter were randomly selected using the simple systematic random sampling technique, as described by Gomez and Gomez, (1984).

By this technique, 24 plants were counted. And since six plants were to be sampled, 24 was divided by six (24/6), resulting to four. A number between one and four was picked to be the starting number. Then, after, every fourth plant was selected until the six plants were sampled.

The samples were taken from the second and last but one rows, next to the border rows in each plot. The plants were dug out and taken to the laboratory, where the roots were cut at the ground level.

3.10.1.1 PLANT HEIGHT

The plant height was measured from the ground level to the highest tip of the stem for the six sampled plants. This was done with the use of a metre rule at the various sampling periods and at harvest maturity. The average plant height was calculated for each treatment.

3.10.1.2 NUMBER OF PRIMARY BRANCHES

This was taken at the sampling periods and at physiological maturity, when all plants had ceased growth. Branches of six sampled plants from each plot were counted and the average computed.

3.10.1.3 LEAF AREA INDEX (LAI)

Leaf area index (LAI) was determined at 4WAP, 7WAP and 10WAP. This was done by detaching all opened leaves from six sampled plants from each plot. These were counted and the average computed. The leaves were then put in labelled envelopes and sent to the Crop Research Institute of the CSIR, Fumesua, where the leaf areas were estimated, using the leaf area meter. The average leaf area was the divided by the row spacing dimensions (inter row by intra row) to get the leaf area index per plant.

3.10.1.4 TOTAL DRY MATTER

The total dry matter was taken at the three sampling periods. Six sampled plants from each plot were put in labelled envelopes and oven dried to constant weight at 90 ^{o}C for 48 hours, and then weighed, and the average weight calculated.

3.10.1.5 CROP GROWTH RATE

Crop growth rate (CGR) was calculated using the formula (Radford, 1967):

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

Where, W1 and W2 are total dry matter of soybean plants at time t1 and t2, respectively. W1 was taken at 28 DAS, while (W2) was taken at 49 DAS. At each sampling period, six sampled plants were harvested, and the roots cut at the ground level. Samples from each plot were put in labelled envelopes and oven dried to constant weight at 90 °C for 48 hours, and the mean weight calculated.

3.10.1.6 NODULE COUNT AND EFFECTIVENESS

Other sets of six sampled plants from each plot were taken 35 days after sowing to assess nodulation. The samples were carefully dug out, retrieving detached nodules. The nodules were kept in labelled polythene bags and sent to the laboratory and washed, counted and the fresh weight taken. After which the nodules were cut opened to determine apparent effectiveness, using a knife and hand lens. Nodules with pink or reddish colour were considered effective and fixing nitrogen, while those with green or colourless, ineffective. After this, the percentage (%) effective nodules were calculated.

3.10.1.7 NODULE DRY WEIGHT

After the root nodules were assessed for effectiveness, they were oven dried to constant weight at 60 ^{O}C for 24 hours. These were weighed and the average weight calculated.

3.10.2 REPRODUCTIVE (HARVEST) DATA

At harvest maturity, when about 85% of pods had turned brown (Dugje *et al.*, 2009) and more than 75% of leaves shedded, one square metre area of plants from the central rows on each plot were harvested for the yield analysis. From this harvested lot, six plants each were sampled, for pod number, number of seeds per pod, 100 seed weight, shattering percentage and ultimately the seed yield per square metre; after all the used samples were returned to the harvested lot.

3.10.2.1 NUMBER OF PODS PER PLANT

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

3.10.2.2 NUMBER OF SEEDS PER POD

The number of seeds per pod was also determined by taking six random plants from the harvested plants. All pods were plucked and counted. Pods were shelled; and seeds were counted, the average calculated.

3.10.2.3 100 SEED WEIGHT

The 100 seed weight was determined by counting 100 seeds from the threshed and oven dried seeds from each plot. These were weighed to represent the mean seed weight.

3.10.2.4 POD SHATTERING PERCENTAGE

With the shattering percentage, pods of six sampled plants were plucked, counted and put in labelled envelopes and oven dried at 40 ^{O}C for 24 hours. Pods that opened to release the seeds or opened but not released seeds were considered shattered. The shattering percentage was therefore calculated as:

$$\text{Shattering percentage} = \frac{\text{number of shattered pods}}{\text{total number of pods}} \times 100$$

3.10.2.5 GRAIN YIELD (TONS PER HECTARE)

Grain yield per hectare was determined by threshing the harvested plants from the central one square metre of each plot. These were put in labelled envelopes and oven dried to a constant weight at 60 ^{O}C for 48 hours, and then weighed. The resulting weights, in grams (g) per metre square were then scaled up to tons per hectare basis to get the average grain yield per hectare.

3.11 DATA ANALYSIS

All data was analyzed using the Analysis of Variance (ANOVA) and the MSTAT-C statistical package. Treatment differences were compared using the Least Significant Difference (LSD) procedure at 5% level of probability.

CHAPTER FOUR

4.0 RESULTS

4.1 SOIL CHEMICAL ANALYSIS

Table 4.1 shows the results of the chemical analysis of the soil at the experimental site.

Table 4.1 Results of soil chemical analysis of experimental site

<table>
<tr><th colspan="2">Sample Identification</th><th>0 -15cm</th><th>15 -30cm</th></tr>
<tr><td colspan="2">% Organic Carbon</td><td>0.6185</td><td>0.3990</td></tr>
<tr><td colspan="2">% Organic matter</td><td>1.066</td><td>0.6879</td></tr>
<tr><td colspan="2">% Total nitrogen</td><td>0.182</td><td>0.168</td></tr>
<tr><td rowspan="4">Exchangeable Cations -Cmol/kg/ Mc/100g</td><td>Potassium</td><td>0.146</td><td>0.103</td></tr>
<tr><td>Sodium</td><td>0.248</td><td>0.232</td></tr>
<tr><td>Calcium</td><td>2.5</td><td>2.1</td></tr>
<tr><td>Manganese</td><td>0.9</td><td>0.8</td></tr>
<tr><td>Available phosphorus (ppm)</td><td colspan="2">29.74</td><td>25.22</td></tr>
<tr><td>pH</td><td colspan="2">6.24</td><td>6.16</td></tr>
</table>

The results of the soil chemical analysis shown in (Table 4.1) above, compare with the standard for soybean, recommended by Ferguson *et al*. (2006). The average pH value of 6.20, available Phosphorus of 27.48ppm and Potassium of 0.13ppm are within the recommended standard of pH between 5.5-7.0, available P concentration above 12ppm (Bray-1 test) and K concentration of above 0.124ppm.

4.2 PLANT HEIGHT

The results of plant height are presented in Table 4.2. The results did not show significant differences (P>0.05) among soybean varieties at all sampling occasions. Row spacing effect was however, significant at all sampling days. At 4 WAP, effect of SP1 treatment

Table 4.2. Variety and row spacing effect on plant height (cm) at three sampling occasions.

Treatment	4WAP	7 WAP	10 WAP
Variety			
Ahoto	13.21	25.64	41.73
Anidaso	13.41	26.20	43.85
Nangbaar	12.37	24.62	37.92
LSD (5%)	NS	NS	NS
Spacing (cm)			
SP1	13.98	28.91	44.38
SP2	12.88	25.54	42.31
SP3	12.50	23.44	40.57
SP4	12.63	24.06	37.42
LSD (5%)	1.19	2.18	2.10
CV (%)	9.2	8.6	5.1

NS = not significant

was significantly higher than those of the SP3 and SP4 treatments. All other treatment differences were not significant.

At 7 WAP, treatment effect of SP1 was significantly higher (P<0.05) than all other treatment effects. All other treatment effects were statistically similar. Sampling at 10 WAP showed that the effect of the SP4 treatment was significantly lower than all other treatment effects. Additionally, the effect of the SP3 treatment was significantly lower than that of the SP1 treatment. All other treatment differences were not significant at 5% level of probability.

4.3 LEAF AREA INDEX ON SOYBEAN PLANTS

Results of leaf area index of the various varieties of soybean plants at 4WAP, 7WAP and 10WAP are presented in Table 4.3. Varieties had significant effect on LAI on all occasions. At 4WAP, Anidaso produced the highest value of LAI, 2.39, and this was significantly (P<0.05) higher than that of Nangbaar, which recorded the lowest value of LAI of 2.01. At both 7 and 10 WAP, LAI of the Ahoto and Anidaso varieties were similar, but either effect was significantly higher than that of the Nangbaar variety.

Row spacing effect on plant was significant at all sampling occasions (Table 4.3). At 4 WAP, LAI of the SP3 and SP4 treatments were similar, but either effect was significantly higher than those of the SP1 and SP2 treatments, which had similar effects. At both 7 and 10 WAP, results showed that the SP4 treatment produced the greatest LAI, which was significantly higher than all other treatment effects. Treatment effects of the SP3 treatment was also significantly higher than that of the SP1 and SP2 treatments on both occasions, but treatment effect of both SP1 and SP2 were similar on both occasions.

Table 4.3. Effect of variety and row spacing on LAI at three sampling periods.

Treatment	4WAP	7 WAP	10 WAP
Variety			
Ahoto	2.22	3.37	6.79
Anidaso	2.39	3.20	6.56
Nangbaar	2.01	2.75	5.41
LSD (5%)	0.25	0.31	0.53
SPACING (cm)			
SP1	2.05	2.84	5.59
SP2	2.05	2.88	5.78
SP3	2.29	3.16	6.33
SP4	2.44	3.55	7.31
LSD (5%)	0.18	0.19	0.39
CV (%)	8.30	6.10	6.30

NS = not significant

4.4. LEAF NUMBER PER PLANT

Results of leaf number per plant as affected by varieties and row spacing are presented in Table 4.4. Leaf production was not significantly affected by soybean variety (P>0.05) on all sampling occasions. Notwithstanding, the Ahoto variety produced numerically greater

Table 4.4 Variety and row spacing effect on the number of leaves per plant at three sampling periods.

Treatment	4WAP	7 WAP	10 WAP
Variety			
Ahoto	6.33	11.42	17.42
Anidaso	5.92	10.42	16.58
Nangbaar	5.33	10.92	16.33
LSD (5%)	NS	NS	NS
SPACING (cm)			
SP1	6.78	13.56	19.11
SP2	6.78	12.44	18.00
SP3	5.22	9.33	15.89
SP4	4.67	8.33	14.11
LSD (5%)	0.94	1.46	1.43
CV (%)	16.30	15.90	8.60

NS = not significant

number of leaves on sampling occasions. On the other hand, row spacing had significant effect on leaf production. On all occasions, treatment effect of SP1 and SP2 spacings was statistically similar, but either effect was significantly higher than those of the SP3 and SP4 treatments. The SP3 and SP4 treatment effects were statistically similar at 4 and 7WAP, but at 10 WAP, the effect of the SP3 treatment significantly higher than that of the SP4 treatments.

4.5 NUMBER OF PRIMARY BRANCHES

Results of the effect of the number of primary branches per plant at 4, 7 and 10 WAP are presented in Table 4.5. At 4WAP, number of primary branches per plant was not affected by varieties of soybean. The treatment effects of the three varieties were statistically ($P>0.05$) similar. The row spacing effect on the number of primary branches showed significant difference among the treatment means. Row spacing SP1 and SP2 treatment effects were statistically similar, but were significantly ($P<0.05$) higher than the effects of SP3 and SP4 treatments. Treatment difference between SP3 and SP4 was non-significant.

Number of primary branches of soybean plants was significantly affected by varieties and row spacing at 7WAP. The effect of the Ahoto variety, (5.42) and the Anidaso variety, (5.17) was statistically similar but either was significantly higher than the effect of Nangbaar variety which recorded the lowest value of 4.08 branches. The SP1 and SP2 treatments recorded the greatest number of primary branches of 5.89 and 5.67, respectively and these were statistically higher than the values recorded by the SP3 and SP4 treatments. Treatment difference between SP3 and SP4 was not significant. Variety and row spacing showed significant ($P<0.05$) effect on the number of primary branches per plant at 10WAP. Ahoto and Anidaso varieties produced the greatest number of branches of 8.00 and 7.67 respectively, and this was significantly higher than the number of branches produced by the Nangbaar variety. Row spacing effect was highest with the SP1 treatment of with 8.56 branches, followed by SP2 of 7.68 branches. These effects were statistically higher than the effects of SP3 and SP4 treatments.

Table 4.5 Effect of variety and row spacing on number of primary branches at three sampling periods.

Treatment	4WAP	7 WAP	10 WAP
Variety			
Ahoto	2.58	5.42	8.00
Anidaso	2.58	5.17	7.67
Nangbaar	2.42	4.08	5.75
LSD (5%)	NS	0.55	1.53
SPACING (cm)			
SP1	3.00	5.89	8.56
SP2	3.11	5.67	7.68
SP3	2.11	4.33	6.67
SP4	1.89	3.67	5.67
LSD (5%)	0.68	1.08	1.18
CV (%)	27.20	22.40	16.7

NS = not significant

The effects between SP1 and SP2 treatments, as well as between SP3 and SP4 treatments were not significant.

4.6 NODULE NUMBER, EFFECTIVENESS AND DRY WEIGHT

Root nodule number of the varieties ranged between 13 and 16 per plant (Table 4.6). There was no significant difference (P>0.05) among varietal and row spacing. Percentage nodule effectiveness was neither affected by soybean varieties nor the row spacing of plants at the various sampling periods as shown in Table 4.6. Similarly, nodule dry weight did not show significant effect due to varietal or spacing differences.

Table 4.6 Variety and row spacing effect on nodule number, percent nodule effectiveness and nodule dry weight (g)

Treatment	Nodule number	% nodule effectiveness	Nodule dry wt. (g)
Variety			
Ahoto	13	88.58	0.118
Anidaso	14	89.25	0.155
Nangbaar	16	90.83	0.133
LSD (5%)	NS	NS	NS
Row spacing (cm)			
SP1	15	91.44	0.158
SP2	12	91.22	0.093
SP3	13	90.00	0.128
SP4	16	85.56	0.161
LSD (5%)	NS	NS	NS
CV (%)	56.76	15.11	53.38

NS= not significant

4.7. TOTAL PLANT DRY MATTER

Results of plant dry matter are presented in Table 4.7. On all sampling occasions, soybean variety did not significantly (P>0.05) affect dry matter production. Row spacing did not significantly affect dry matter production at 4 and 7 WAP. However, at 10 WAP, dry matter from the SP4 treatment was significantly higher than those of the SP1 and SP2 treatments only. All other treatment effects were statistically similar.

Table 4.7. Variety and row spacing effect on total dry matter yield (kg /ha)

Treatment	4WAP	7 WAP	10 WAP
Variety			
Ahoto	1093	2279	4420
Anidaso	1074	2230	4491
Nangbaar	1114	2216	4378
LSD (5%)	NS	NS	NS
SPACING (cm)			
SP1	1002	2254	4212
SP2	1029	2111	4259
SP3	1174	2162	4343
SP4	1093	2439	4904
LSD (5%)	NS	NS	640.9
CV (%)	23.6	18.5	14.8

NS = not significant

4.8 CROP GROWTH RATE, NUMBER OF PODS PER PLANT AND POD SHATTERING PERCENTAGE

Results presented in Table 4.8 indicated that crop growth rate was not significantly affected by either soybean variety or row spacing differences. The results of the number of pods per plant are presented in Table 4.8. Ahoto variety produced the greatest number of 68 pods per plant, and this was significantly higher than the effect of only the Nangbaar variety. Treatment effects of Anidaso and Nangbaar varieties were statistically similar.

Table 4.8. Variety and row spacing effect on crop growth rate, number of pods per plant and pod shattering percentage

Treatment	CGR ($g/m^{-2}d^{-1}$)	No. of pods $plant^{-1}$	Pod shattering (%)
Variety			
Ahoto	0.37	68	31.25
Anidaso	0.38	52	28.33
Nangbaar	0.37	38	28.75
LSD (5%)	NS	16.72	NS
Row spacing (cm)			
SP1	0.40	55	36.67
SP2	0.41	56	23.33
SP3	0.40	56	27.22
SP4	0.37	45	30.56
LSD (5%)	NS	NS	NS
CV (%)	18.1	13.63	41.05

NS= not significant

Row spacing did not significantly affect pod numbers in soybean plants. Pod shattering was not significantly affected by both soybean variety and plant spacing differences (Table4.8).

4.9 NUMBER OF SEEDS PER POD, 100 SEED WEIGHT AND GRAIN YIELD

Number of seeds per pod as well as 100 seed weight is presented in Table 4.9. Soybean varietal and row spacing effects were not significant. Grain yield results as presented in Table 4.9 was significantly affected by varietal differences.

Table 4.9 Effect of variety and row spacing on number of seeds per pod, 100 seed weight (g) and grain yield (ton ha^{-1})

Treatment	No. of seeds pod^{-1}	100 seed weight	Grain yield
Variety			
Ahoto	2.0	13.74	3.15
Anidaso	2.0	12.85	1.58
Nangbaar	2.0	13.66	1.84
LSD (5%)	NS	NS	0.40
Row spacing (cm)			
SP1	2.0	13.72	1.98
SP2	2.0	13.46	2.17
SP3	2.0	13.38	2.46
SP4	2.0	13.11	2.14
LSD (5%)	NS	NS	0.47
CV (%)	0.0	6.84	21.80

NS = not significant

The Ahoto variety produced the greatest grain yield of 3.15 ton ha^{-1}, and this was statistically ($P<0.05$) higher than the yields of Anidaso and Nangbaar. However, grain yield differences between the latter two varieties were not significant.

Row spacing significantly affected grain yield. The greatest grain yield was recorded in the SP1 treatment, 2.46 ton ha^{-1}, but this was significantly ($P<0.05$) higher than the effect of the SP1 treatment only. All other treatment differences were not significant.

4.10 CORRELATION MATRIX

The results of the correlation matrix for CGR, number of primary branches 10 WAP, pods per plant, LAI at 10 WAP, plant height at 10 WAP, dry matter yield at 10 WAP and grain yield are presented in Table 4.10.

Table 4. 10: Coefficient of selected parameters.

	CGR	Bran/plt	Pods/plt	LAI	Plt ht	DM	Grain yld
CGR	1.000						
Bran/plt	0.313	1.000					
Pod/plt	0.187	0.560*	1.000				
LAI	- 0.207	-0.016	-0.278	1.000			
Plt ht	0.406	0.406	0.437	-0.194	1.000		
DM	0.662*	-0.146	-0.351	0.209	0.038	1.000	
Grain yld	-0.077	0.200	0.597*	0.172	0.211	-0.137	1.000

*= significant at 5%

The results showed significant positive correlation between number of pods per plant and grain yield, (r = 0.597); pods per plant and number of branches per plant, (r = 0.560) and dry matter yield and crop growth rate (r = 0.662).

CHAPTER FIVE

DISCUSSION

5.1 EFFECT OF VARIETIES AND ROW SPACING ON PLANT HEIGHT

Plant height was affected by row spacing at the various growth periods. Plants from the SP1 treatment were consistently and significantly ($P<0.05$) the tallest, at all sampling periods. Plants of SP1, the widest row spacing of 60×5cm, might had had effective utilisation of available environmental resources like light, water and nutrients, as a result of less intra plant competitive effect. And this might have accounted for the greater plant height for the growth periods. Staggenborg *et al*., (1996) reported significant increase in plant height in wider row spacing of 30-inch as against narrow row spacing of 18-inch, at high-yielding environments.

5.2 VARIETY AND ROW SPACING EFFECT ON LEAF AREA INDEX

Leaf area index was affected significantly ($P<0.05$) by soybean varietal differences at all the growth periods. Ahoto produced the highest LAI values of 3.37 and 6.79 at 7WAP and 10WAP respectively. These values were significantly higher than the Nangbaar's value of 2.75 at 7WAP and 5.41 at 10WAP respectively. The highest value of 2.39 at 4WAP was produced by Anidaso and this was significantly higher than Nangbaar's value of 2.01. Anidaso's LAI values at 7WAP and 10WAP were also significant to Nangbaar's values of 2.75 and 5.41 respectively.

The differences in LAI exhibited by the varieties at the various growth periods might have been due to genotypic characteristics. However, all the three varieties exceeded the minimum recommended LAI value of 3.5 – 4.0 by the 10WAP when the plants had 100% flowered (Westgate, 1999; and Board and Harville, 1992). This is a vital condition for the reproductive stages for greatest soybean yield. This observation corroborates with the statement by Malone *et al*, (2002) that early maturing soybean genotypes achieve minimum LAI values required for maximum potential yield by the early reproductive stage of growth.

LAI was significantly ($P<0.05$) affected by row spacing at all the growth periods. The results show an increase in LAI to reduced row spacing in soybean plants. This observation agrees with the report of Higley, (1992) that, increasing plant population in soybean reduces the amount of time the plants take to reach 95% light interception levels that correspond to LAI levels of 3.2 – 3.5. Previous works carried out on the grain yield of soybean and some of its agronomic parameters by Lehman and Lambert (1960), also showed that, leaf area index and dry matter accumulation increase with plant population from narrow spacing.

5.3 NUMBER OF PRIMARY BRANCHES AS AFFECTED BY VARIETY AND ROW SPACING

Varieties showed significant effect on number of branches produced per plant at 7WAP and 10WAP. Ahoto produced the greatest number of branches of 5.42 and 8.00, respectively for 7WAP and 10WAP. This was followed by Anidaso, 5.17 branches at

7WAP and 7.67 branches at 10WAP. These values were significantly ($P<0.05$) higher than the values recorded by Nangbaar variety. Genotypic characteristics might have accounted for these significant differences observed in the branches of the varieties, as they were grown under similar environment.

The results showed that, wider- spaced plants produced the greatest number of branches on all sampling periods. As indicated earlier, wider spacing means less competition among plants for growth resources as water, nutrients and solar radiation. This will mean more assimilates would be available to growth, and hence, greater allocation for more branching. This observation is in agreement with the report of Caliskan *et al*., (2007) that, plants in wider row spacing are capable of partitioning more resources to increase branch number in response to plant density.

5. 4 VARIETY AND ROW SPACING EFFECT ON DRY MATTER PRODUCTION

Total dry matter production did not vary among all soybean varieties on each sampling occasion. This shows that, the varieties studied had equal growth and dry matter production potential. This is because the conditions of growth were similar, so producing similar dry matter attest to the fact that, the growth potentials are similar in these varieties. Dry matter production shown by varieties of the same crop under similar growth conditions is indication of similar potential (Salisbury and Ross, 1992).

Dry matter production increased between sampling periods in all varietal and spacing treatments. Indeed, dry matter almost doubled between 4 and 7 WAP and also between 7 and 10 WAP (Table 4.7) in all varieties and spacing treatments. This observation of rapid dry matter accumulation in plants, especially during the vegetative phase has been made by several workers (Evan, 1996; Gardner *et al*., 1985).

Among the various spacings treatments, SP4, that is the 30cm inter row spacing, produced the greatest amount of dry matter at both 7 and 10 WAP. The closest inter row spacing of this treatment means that, this treatment had the greatest population density of 500,000 plants per hectare. This really resulted in the greatest dry matter produced from this treatment. PHI (2009) has made similar report on soybean row spacing. James *et al*. (1996) also stated that, high population in narrow row spacing for early maturing cultivars potentially increase growth and yield components, as they are able to utilize environmental factors more effectively.

5.5 VARIETY AND ROW SPACING EFFECT ON NUMBER OF PODS PER PLANT

Ahoto variety produced the highest number of pods per plant of 68 pods. This was significantly ($P<0.05$) higher than 38 pods per plant produced by Anidaso. The effects between Nangbaar and Ahoto, and Anidaso respectively were non-significant. Genetic factors of the varieties might have contributed to the significant effect in pod yield, with Ahoto being the best performer and Nangbaar the least. This corroborates with the report of Bouquet (1998) that, genotype selection is one of most important factors for increasing pod yield in soybean. Also yield data available at CRI indicates Ahoto as the highest yielder among the three varieties (MoFA and CSIR, 2005).

Row spacing treatments means did not show significant differences ($P>0.05$) on the number of pods per plant. This result also agrees with Lueschen and Hicks (1977) that, soybean plants are capable of compensating for low densities by producing more branches and pods, resulting in yield levels remaining relatively constant over a wide range of populations.

5.6 VARIETY AND ROW SPACING EFFECT ON GRAIN YIELD (ton ha^{-1})

Ahoto produced the greatest grain yield of 3.15 ton ha^{-1} followed by Nangbaar, 1.84 ton ha^{-1} and Anidaso 1.58 ton ha^{-1}. Ahoto yielded significantly ($P<0.05$) higher than the yields of Nangbaar and Anidaso. This observation followed a similar trend observed in the number of pods per plant.

The result demonstrates that, number of pods per plant is an important index of grain yield and this agrees with the work of Osafo (1977). Ahoto is therefore the best performer in terms of grain yield, with Anidaso and Nangbaar being at par in their performance. Genotypic characteristics of the varieties might have accounted for the significant grain yield differences. The results corroborate with many reports, including that of Cooper (1977) that, yield success of early maturity soybeans is contingent on cultivar characteristics. Bouquet (1998) also found that, cultivar selection and planting date were the most important factors for increasing soybean yield.

The grain yield recorded for the various row spacings ranged from 1.98 ton ha^{-1} to 2.46 ton ha^{-1}. SP3 (40×5 cm) recorded the highest grain yield of 2.46 ton ha^{-1}, and this was statistically ($P<0.05$) higher only to SP1 (60×5 cm) value of 1.98 ton ha^{-1}. The effects of SP2 and SP4 were not significant.

The results showed that, SP3 performs best in grain yield, with the rest of the row spacings having statistically ($P>0.05$) similar capabilities of grain yield production. Heatherly (1999) and James *et al.* (1966) made similar reports that, high plant population and narrow row spacing for early soybean cultivars increases grain yield. In addition, Johnson (1987), reported soybean grain yield increase as row spacing was reduced in early maturing varieties.

5.7 CORRELATION ANALYSIS OF GRAIN YIELD AGAINST CGR, NUMBER OF BRANCHES, PODS PER PLANT, LAI, PLANT HEIGHT AND TOTAL DRY MATTER

From the correlation analysis, it is observed that, only number of pods per plant had significant ($P<0.05$) positive correlation to grain yield per hectare of soybean, with r value of 0.597. The results showed a positive linear relationship between grain yield and number of pods per plant across varieties and row spacings. This is an indication that, the higher the number of pods per plant, the greater the grain yield. Phakamas *et al* (2008) reported similar observation that, number of pods per plant was positively correlated to seed yield in peanut varieties. Ali and Tahir (1999), also made similar observation in chickpea genotypes. The results also confirm the report of Baligar and Jones (1997) that, legume seed yield is a function of number of pods per plant.

There was a positive linear correlation between the number of primary branches produced per plant and the number of pods produced per plant (r = 0.560). This observation is not unexpected as soybean pods are formed on both central stem and the branches. Hence, a plant with more branches will likely yield greater than where the branches are few. A significant positive correlation between crop growth rate and dry matter production is also not surprising, as greater growth means more dry matter availability for both sustained growth and storage.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

The results of this study revealed that variety and row spacing affect soybean response to growth and yield performance. Significant differences in grain yield of the varieties indicate that, recommendations for soybean varietal selection could be based on expected yield goals. The results indicate field based empirical evidence that, Ahoto variety is superior in terms of yield performance, yielding significantly high of 3.15 ton ha^{-1} of grain. It is therefore recommended over Anidaso and Nangbaar for producers if the expected goal is to achieve higher yields.

This study also illustrated substantial grain yield increase by decreasing row spacing from 60×5cm to 40×5cm, and no yield increase by further decreasing the row spacing to 30×5cm. Narrow row spacing (SP3) of 40×5cm, with plant population density of 444,444 plants ha^{-1} should be recommended over SP1, SP2 and SP4 for recording the highest row spacing grain yield of 2.46 plants ha^{-1}. Yield increase in narrow rows was mainly due to increased number of pods per plant. It is therefore recommended that, for greater seed yield, farmers should adopt the 40 ×5cm spacing.

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