

UNIVERSITY FOR DEVELOPMENT STUDIES

**EFFECT OF MAIZE-SOYBEAN INTERCROP ON *STRIGA HERMONTHICA*
(DEL.) BENTH SEED BANK, CROP GROWTH, AND YIELD
IN THE BAWKU WEST DISTRICT OF THE UPPER EAST REGION**

AMOUT AKOLOBA DANIEL

2019



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IN THE BAWKU WEST DISTRICT OF THE UPPER EAST REGION**

BY

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(BSc AGRICULTURE TECHNOLOGY)

(UDS/MCS/0026/15)

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

MARCH, 2019



DECLARATION

I, Amout Akoloba Daniel, hereby declare that this thesis titled “Effect of maize -soybean intercrop on *Striga hermonthica* (Del.) Benth seed bank, crop growth and yield” has not been presented for a degree in any other university and it is entirely my own effort and help and references made therein are duly acknowledged.

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We, 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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Co-Supervisor’s Signature..... Date.....

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ABSTRACT

A field experiment was carried out at Gore in the Bawku West District of the Upper East Region during the 2016 cropping season to determine the effect of maize- soybean intercrop on *Striga hermonthica* seed bank, crop growth, and yield. The experiment was laid out in Randomized Complete Block Design with three replications on four drought and *Striga* tolerant maize varieties intercropped with and without soybean variety Afayak. Treatments reduced the initial *S. hermonthica* seed bank with a minimum of 5% and maximum of 26% for sole Omankwa and Wang data/Afayak respectively. At 12WAP, Omankwa, Aburohemaa, and Wang data intercrops promoted *Striga* emergence count and biomass production. Bihilifa/ Afayak supported the tallest plant height of maize whilst sole Omankwa gave the shortest. Days to 50% flowering of maize varied significantly with Aburohemaa/ Afayak, sole Omankwa and sole Bihilifa flowered early in 53 days whilst sole Aburohemaa flowered late in 56 days. Bihilifa/ Afayak produced the highest cob weight whilst Omankwa /Afayak produced the lowest. Highest grain yield of maize was obtained with Wang data/ Afayak (1149kg ha^{-1}) whilst sole Omankwa produced the lowest grain yield of 850kg ha^{-1} . Bihilifa/Afayak gave the highest grain yield of soybean whilst Omankwa /Afayak gave the lowest yield. The maize varieties proved tolerant to *Striga* infestation whilst the Afayak intercropped with any of the varieties could cause suicidal germination of *Striga* seeds, *Striga* seed bank depletion, and for improved crop growth and increased yield. Maize varieties intercropped with soybean (Afayak) have the potential to increase soil fertility.



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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
C: N	Carbon Nitrogen Ratio
CRI	Crops Research Institute of Ghana
CSIR	Council for Scientific and Industrial Research
CV	Coefficient of variance
DTMA	Drought tolerance maize for Africa
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agricultural Organization Statistics
GDP	Gross domestic product
ISSER	Institute of Statistical, Social and Economic Research
IITA	International Institute of Tropical Agriculture
IFDC	International Fertilizer Development Centre
LAI	Leaf Area Index
Lab	Laboratory
LSD	Least Significant Difference
MoFA	Ministry of Food and Agriculture
MT	Metric tons



M ha	Million of hectares
N	Nitrogen
NNP	Number of Nodules per Plant of Soybean
NPP	Number of Pods per Plant
PAR	Photosynthetic Active Radiation
RCBD	Randomize Complete Block Design
SARI	Savannah Agricultural Research Institute
SSA	sub- Saharan Africa
SEM	Standard Error of Mean
USA	United States of America
WWW, CIMMYT	World Wide Web, International Maize and Wheat Center
WAP	Weeks after Planting
%	Percent



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CHAPTER ONE

1.0 INTRODUCTION

Maize (*Zea mays* L.) belongs to the tribe *Maydeae* and the family *Poaceae*. It is one of the world's three most important cereal crops after wheat and rice, and in Ghana accounting for 74% of the total cereals (maize, rice, sorghum and millet) produced in 2005 (MOFA and CSIR 2005). Maize is grown under diverse environments than wheat and rice due to its greater adaptability (Kogbe and Adediran, 2003). It produces more grain yield than all the other cereals and is a wonder of efficiency in converting the energy of the sun into food energy.

In Ghana, maize is basically grown by small scale farmers, generally for subsistence as part of mixed farming. In sub-Sahara Africa (SSA), maize is consumed directly and serves as a staple diet for many people in the region (IITA, 2006). Maize has high carbohydrate content of about 71%, but low in essential amino acids such as lysine and tryptophan. However, the crop serves as the main source of carbohydrates for poultry industries worldwide. Also, it has industrial uses for example, starch from the grain could be made into fabrics and adhesives and production of alcoholic beverages (Yonli *et al.*, 2010). Maize is also an important livestock feed, ethanol production, and commodity for export (Yonli *et al.*, 2010).

In spite of the crucial roles maize plays in food security, yearly grain production of maize in Ghana could not meet the nation's demand, due to the threats posed by abiotic and biotic factors (MOFA, 2010). The major abiotic constraints include drought and declining



soil fertility (Vanlauwe *et al.*, 2006) while the biotic constraints comprise maize diseases, stem borers and *Striga* infestation (Kanampiu *et al.*, 2004).

Maize production particularly in the Guinea savannah zone of Ghana is negatively affected by the seed bank of *S. hermonthica*. *Striga hermonthica* which is a root parasitic weed of the genus *Striga* in the family *Orobanchaceae* inhibits host growth by competing for nutrients and impairing photosynthesis. It is one of the most important biological constraints to maize production in SSA. *Striga* acts by wounding the outer root tissues of maize and absorbing its supply of moisture, photosynthase, and minerals, which eventually leads to severe grain losses (30-90% yield loss) and to a greater extent total crop failure (Khan *et al.*, 2007; Amegbor *et al.*, 2017). Dzomeku and Murdoch (2007) also reported that average yield losses of 25 - 40% could occur but total crop failure under drought is not uncommon. Of the 23 *Striga* species prevalent in Africa, *S. hermonthica* has threatened about 44 million hectares of arable land and affecting the livelihoods of more than 100 million farmers (Mignouna *et al.*, 2013). Production losses due to *Striga* in African countries range from 20% - 90%, amounting to over 10 Mt of food lost annually. *Striga* infection is increasing to new areas even as farmers abandon the heavily infested fields. The problem is more serious in highly populated areas where soil fertility is low because of continuous cropping and lack of cereals (maize) – legumes (soybean) intercropping. According to Oswald (2005), continuous cropping which is likely to decrease the soil fertility further increases *Striga hermonthica* seed bank.

Striga is pernicious /harmful because of the large number of seeds it produces. A single *Striga* plant can produce up to 200,000 small dust-like seeds that survive in the soil for up



to 20 years (Ma *et al.*, 2004). The large number of seeds, dormancy of the seed in the soil, and the practice of continuously cropping cereals leads to a buildup of a big bank of seed mass in the soil.

Management of *Striga* should therefore aim at depletion of the *Striga hermonthica* seed bank in the soil, restraining development while underground, and preventing seed production. The adaptive mechanisms, the genetic plasticity of *Striga* and the wide diversity of biophysical and socio-economic environments in which farmers work imply that an integrated approach should be used. The use of host-plant resistance and tolerant varieties could stimulate the suicidal germination of *Striga hermonthica* seeds and therefore used to reduce the seed bank in the soil. Kling *et al.* (2000) reported that in researcher-managed trials with artificial infestation, resistant hybrid maize (CV.9022-13) yielded 2.5 t/ha of grain whereas the susceptible check variety (CV. 8338-1) produced only 0.7 t/ha. In this trial, the term resistant maize refers to the cultivar that show less attack in terms of the numbers of emerged *S. hermonthica*, as defined by Parker and Riches (1993).

Depletion of the soil *Striga* seed bank remains one of the most important options for *Striga* management. The effectiveness of leguminous trap crops in reducing the *S. hermonthica* seed bank was demonstrated by Sauerborn *et al.*, (1999) in field experiments in Ghana where annual double cropping of trap crops reduced the seed bank by around 30% each year. Trap crops such as soybean, cowpea, cotton, and groundnut are those crops that induce germination of *S. hermonthica* seeds but are not parasitized and consequently result in suicidal germination of *Striga* seeds (Parker and Riches, 1993;



Boatanga *et al.*, 2003). These crops may be used in cropping systems such as maize - soybean intercrop to deplete *Striga* seed bank in farmers' fields and increase the efficiency of land use through improved soil productivity (Parker and Riches, 1993; Kureh *et al.*, 2000). Thus use of legume trap crops to reduce *Striga* seed bank could even be more important as this could also help improve soil fertility through biological N fixation and act as a cheap source of proteins for improving the livelihoods of farmers. In Kenya, forage legume *Desmodium uncinatum* has been found to reduce *S. hermonthica* infestation by producing allelopathic root exudates that stimulate germination of *S. hermonthica* and inhibits growth of the *Striga* radicle (Khan *et al.*, 2002; Tsanuo *et al.*, 2003).

Mechanical weeding and hand pulling can control *Striga hermonthica* seed bank to a certain extent, although it is tedious and may not increase the yield of already infected plants. Ransom and Odhiambo (1994) found that, hand weeding of *Striga hermonthica* before seed set resulted in an increase in maize yield only after four seasons of implementation. Application of nitrogenous fertilizers increases the soil fertility and therefore reduces *Striga hermonthica* infestation (Watson and Ciotola, 1999). Fertilizers are however expensive and not economical to resource poor farmers.

Further *Striga hermonthica* seed bank control benefits could be derived through the inoculation of the soybean seeds to promote N-fixation with consequential increase in soil fertility. The use of resistant crop varieties is the most effective, cost effective and practical for small scale farmers of Africa (Omanya *et al.*, 2004). There is a report on the adaptive and relative performance of these varieties (Aburohemaa, Omankwa, Wang



data, and Bihilifa) in integration with the trap-catch crop (Afayak) to deplete the *Striga hermonthica* seed bank in the Guinea and Sudan Savannah zones of Ghana.

1.1 Statement of the problem

Striga hermonthica is a main biotic constraint to cereal production in Africa and for that matter in Ghana. It is one of the major contributors to hunger, malnutrition, and food insecurity across SSA. The weed has contributed to halving of cereal yields in the infested areas (Watson *et al.*, 2007). Almost all the farm lands of every district in the northern parts of Ghana are infested with *S. hermonthica*. However, Runge-Metzger *et al.* (1997) stated that the state of knowledge with respect to the severity of *Striga hermonthica* infestation, its geographical distribution in northern Ghana and its current trend is still extremely unsatisfactory.

The actual *Striga hermonthica* infested area is estimated at 44 million hectares worldwide (Mignouna *et al.*, 2013). This parasite causes losses of up to 100% on farmers' fields, which often have to be abandoned due to their unproductivity. The problem is persisting due to continuous cultivation and this cropping system being mainly cereal based results in large quantities of *Striga hermonthica* seeds recharging the soil seed bank each season.

A number of control strategies have been suggested for the management of *Striga hermonthica* seed bank, but, farmers in *Striga*-infested areas have inadequate resources and cannot go for expensive control options. The *Striga* adaptive activities also mean that single strategies in isolation may be inadequate. An integrated approach that focuses on the development stage and depletion of the seed bank is ideal. Intercropping maize with any legume (non-host) plant such as soybean (Afayak) will help deplete the *Striga* seed



bank in the soil, preventing parasitism at the early crop growth stages and improve soil fertility.

1.2 Justification of the problem

As stand-alone technologies cannot effectively manage *Striga hermonthica*, there is the need to merge some of these technologies capitalizing on each of their individual strengths in an effort to manage the weed. Therefore, intercropping cereals with legumes, a common practice in most areas in Africa can be evaluated for the effectiveness. Intercropping is a potentially viable, inexpensive technology, which enable to address the twin important and interrelated problems of low soil fertility and *Striga hermonthica* seed bank.

The sub-optimal yields have been attributed to low soil fertility and weeds such as *Striga*, which sometimes cause maize yield losses up to 100%. Reducing these losses could significantly increase yield and improve the farmers' livelihood. *Striga* has different adaptive mechanisms that make its control difficult. A *Striga* plant can produce over 200,000 seeds that remain dormant in the soil for up to two decades or up to when stimulated to germinate. If *Striga* plants are allowed to flower and seed, a large number of seeds will be returned to the soil increasing the seed bank. The *S. hermonthica* problem is compounded by continuous cultivation of cereals, which contributes to decreasing soil fertility and increasing the *Striga hermonthica* seed bank. The control strategy must therefore focus on reducing *S. hermonthica* seed numbers in the soil, their development as well as increasing soil fertility.



Legumes such as soybeans can lure suicidal *S. hermonthica* seed germination, and increase the vigour and uniformity of the associated cereal crop by increasing soil organic matter and nitrogen content. This is useful because most farming systems, which suffer from *Striga* infestation, also have low soil fertility due to continuous cereal cropping.

1.3 Main objective

The main objective of this trial was to determine the effect of maize - soybean intercrop on *Striga hermonthica* seed bank, crop growth, and yield.

1.4 Specific objectives

The specific objectives of the experiment were to:

- identify the best performing *Striga* tolerant maize variety in terms of crop growth and grain yield.
- ascertain the most effective maize variety in integration with the soybean (Afayak) on yield components and yields of maize and soybean.
- assess the effect of maize-soybean integration on *Striga hermonthica* emergence and seed bank depletion.

1.5 Null hypothesis

- The maize varieties do not have equal level of tolerance against *S. hermonthica* in terms of crop growth and yield components when intercrop with the soybean (Afayak).
- The treatments will have no depletion on *Striga hermonthica* seed bank.



1.6 Alternative hypothesis

- The maize varieties have equal level of tolerance against *S. hermonthica* in terms of crop growth and yield components when intercropped with the soybean (Afayak).
- The treatments will have depletion on *S. hermonthica* seed bank.



CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Biology of maize

Maize (*Zea mays* L.) is a plant belonging to the tribe *Maydeae* of the grass family *Poaceae*. Maize is a versatile crop grown over a range of agro climatic zones (Doebley, 1990). It is a tall, determinate, monoecious, annual C₄ plant varying in height from 1 to 4 meters (Sleper and Poehlman, 2006; DOA, 2003). It produces large, narrow, opposite leaves, borne alternatively along the length of a solid stem. The lower leaves of maize are like broad flags, 50 – 100cm long and 5 - 10cm wide. The main stem is made up of clearly defined nodes and internodes. Internodes are wide at the base and gradually taper to the terminal inflorescence at the top of the plant. Leaf blades are borne alternatively along the length of the main stem.

The main stem terminates in a tassel, which bears spikelets. Tasseling begins immediately after knee height growth which generally occurs at 35 to 45 days after emergence. As the tassels open, spikelets (bearing anthers) are pushed out by elongating filaments and pollen grains are emptied from the extruded anthers (Sleper and Poehlman, 2006). Wind dispersed pollen usually remains viable for 10 to 30 minutes but can be preserved under favorable conditions (Simmond and Smartt, 1999). The reproductive phase begins when one or two axillary buds, present in the leaf axils, develop and form the pistillate inflorescence or female flower (Purseglove, 1972). The axillary buds undergo transformation forming cluster of leaves called the ear at a joint on the stalk on which flowers are borne (Acquaah, 2007). From each flower a style begins to elongate



towards the tip of the cob in preparation for fertilization. These styles form long threads, known as silks which may appear in different colours depending on the genotype. Silk emergence may be affected by temperature, soil moisture, and soil fertility. Adverse weather such as severe drought may also delay or cause complete cessation of silk emergence. As pollen receptors, each individual silk must be pollinated in order to produce a caryopsis. Pollen shed occurs over a 14 day period and its peak is during the first 5 days of shed (Sears *et al.*, 2000). Silks are receptive soon after emergence and remain receptive for up to about 10 days. Generally for each plant, pollen shed usually precedes silk emergence by about 1-3 days (Sleper and Poehlman, 2006). However, in prolific genotypes, silks may emerge before tassel begins to shed pollen (Hitchcock and Chase, 1971). A fertilized ear will always come in different shapes with an even number of kernel rows, usually eight or more rows arranged in different patterns (regular, irregular, mixed, straight and spiral) depending on the genotype (Acquaah, 2007).

The maize kernels consist of the embryo, endosperm, and the pericarp and may differ in colour, structure and chemical composition. The most common kernel colours are yellow and white though some landraces may have red, purple and black colours. Different colours on the same ear are often due to the out-crossing nature of the crop. Based on endosperm and glume characteristics, maize can be grouped into seven types, which are dent, flint, flour, pop, sweet, waxy, and pod corns. Depending on the farming area, different kernel textures are preferred by different groups of farmers. In West Africa, the flint and the dent types are the most widely grown and the most consumed. Dent maize (*Zea mays indentata*) is the most widely distributed maize type in the world. It is

characterized by a depression (dent) in the crown caused by rapid drying and shrinkage of the soft starch at the crown. The grain is characterized by an indentation at the distal end. Of the multiple colours available, the yellow or white dent kernels dominate commercial production. Flint maize (*Z. mays indurate*) on the other hand is comprised of corneous or hard starch that encloses the soft starch at the center. The kernels are smooth, hard, and usually rounded at the top. The starch composition gives the kernel a shiny surface. Flint varieties mature earlier, and its seeds store and germinate much better than dent varieties.

2.2 Importance of maize

Maize is an important crop in many countries in the world. It serves as food for a large population of the world and is among other things that are grown for its energy rich grain (Byerlee and Eicher, 1971). In SSA, maize is a staple food for an estimated 50% of the population and provides 50% of the basic calories. All parts of the crop can be used for food and non-food products (IITA, 2009) and as a versatile crop; maize has been put to a wider range of uses than any other cereal crop. According to Abdul Rahaman and Kolawole (2006) maize can be used alone or in combination with other food material as staple food or snacks in Nigeria. As a basic source of feed for animals (Prasanna, 2012), a raw material for many industrial products including starch, paints, pharmaceutical products, and thermoplastics, it also contributes greatly to the world's economy. It provides food and nutritional security in some of the world's poorest continents especially in Africa, Asia, and Latin America making it one of the most important crops in the world. In the developed world, maize is mostly used for livestock and poultry feed (70%) and only 5% is consumed by human beings. Undoubtedly, maize is preferred most



as staple in African region where over 300 million people depend on it as their main source of food (ABSF, 2010). It is an important stable food for more than 1.2 billion people in SSA and Latin America. The undeveloped countries consume about 62% of maize as food and 34% is used as feed. The manner in which maize is processed and consumed differs greatly from one country to another country, with maize flour and meal being the two most popular products (USAID, 2002). In Africa, the per capita consumption of maize ranges from 52 to 32 g per person per day (FAOSTAT, 2012). According to FAOSTAT (2012), the total consumption of maize in Ghana between 2007 and 2009 was estimated at 53 g per day. Maize production provides livelihood for millions of subsistence farmers in West and Central Africa. It accounts for about 45% of agricultural production which remains the main source of livelihood for most people in Ghana, giving employment to more than 60% of the population and contributes about 30% to GDP (ISSER, 2011). Acquah and Kyei (2012) reported that maize production contributes over 20% of the income earned by smallholder farmers in Ghana.

According to Rosegrant *et al.*, (2009) the demand for maize in the developing countries will double in 2050. The growth in demand for maize consumption in the developing world is predicted to be 1.3% per annum until 2020. In addition, rising incomes are expected to result in a doubling of consumption of meat across the developing world (Naylor *et al.*, 2005), consequently, leading to an estimated growth in the demand for feed maize by 2.9% per annum.

Maize has the highest average yield per hectare and remains the third only after wheat and rice in total area of production in the world among the cereal crops grown



(FAOSTAT, 2012). Internationally, 765 metric tons (MT) of maize were harvested in 2010 from just less than 153 million hectares. The world area of maize production in 2012 was 17 million hectares whilst those of wheat and rice were 216 and 184 million ha respectively. However, maize surpasses both cereals in terms of productivity. In 2012 for example, the world maize production was 875 million tons, while wheat and rice were 606 million tons and 635 million tons, respectively (FAOSTAT, 2012).

In many of the developing countries, especially in SSA, where maize is highly an important staple food crop, yields are still below one ton per hectare which is among the lowest globally especially in comparison with countries such as USA, China, and South Africa.. This is as a result of climate change, poor soil fertility, erratic rains, high incidence of insect pests and diseases and weeds, farmers inadequate access to fertilizer, and lack of access to improve maize seed (Shiferaw *et al.*, 2011, Cairn *et al.*, 2012; Adu *et al.*, 2013). Due to population growth, increasing per capita income, urbanization, growing poultry and fish sectors in Ghana, maize demand was expected to rise steadily at a projected compound annual growth rate of over 1.83% (MTMA, 2013). It was estimated that demand will be more than production especially in developing countries in the coming years (FAO, 2013). As a net importer of maize, Ghana imported an average of nearly 33, 000 MT of maize at the cost of about US\$ 8.32 million per year between 2001 and 2010 (DTMA, 2013). The projected maize imported in Ghana was estimated to be 267,000 MT in 2015. Interventions are needed to increase maize productivity in Ghana on limited land resources.



2.3 Biology of soybean

Soybean is a legume plant belonging to the family *Leguminosae* and to the subfamily *Papilionideae*. The crop is grouped together with peas, beans, lentils and peanuts, and includes some 500 genera and more than 12,000 species (Shurtleff and Aoyagi, 2007). The genus *glycine*, currently consist of two subgenera, *glycine* consisting of species confined to Southeastern Asia, and Soja, comparing 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 as a useful plant, and has since become the valid name for this useful plant (Wikipedia, 2009). The optimum temperature for soybean is 20 – 30°C, with temperatures of 35°C and above considered inhibitory to production. The optimum rainfall amount is between 350 to 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 soybean is between early and late June depending on the rains in upper east region, Ghana. Soybean prefers 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 (Soy in the US), is a dicotyledonous plant that exhibits epigeal emergence. During germination, the cotyledons are pushed through the soil to the surface by elongating hypocotyls. As energy is required to push the large cotyledons through heavy soils, soybeans generally emerge best if they are planted no deeper than 5 centimeters. 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 this single leaf appears directly opposite one another above the cotyledons. All subsequent leaves are trifoliolates, comprised of three leaflets.

Soybean development is characterized by two distinct growth stages. The first is the vegetative stage that covers development from emergence through flowering. The second is the reproductive stage from flowering through maturation. Plant stages are determined 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 petals, 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 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 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 (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 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).

2.4 Importance of soybean

Soybean (*Glycine max* (L.) Merrill) is an important global legume crop that grows in the tropical, subtropical and temperate climates. Soybean has many benefits, nutritionally for people, livestock and poultry, food security, 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 required by human. 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; Mahasi *et al.*, 2011).

In Ghana, soybean 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 a lot from soybean as a cheap source of high quality protein feed. Soybean oil is the world most widely used edible oil, as it is low in cholesterol, with a natural taste



and nearly imperceptible odour. This makes it the ultimate choice of vegetable oil for domestic and industrial food processing (Mpepereki *et al.*, 2000; Addo- Quaye *et al.*, 1993). Soybean oil has become the essential 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 to 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 soybean 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).

When soybean is rotated with cereals it can contribute to yield increase of cereals by up to 25% (Sanginga, 2003; Mahasi *et al.*, 2011). This is because the bacterium (*Rhizobium japonicum*) harboured in the root nodules for the crop fix nitrogen contributing to improved soil fertility (Mathu *et al.*, 2012). Cheminingwa *et al.*, (2007), estimated that soybean fixes up to 200kg ha⁻¹ year under optimal field conditions. This, therefore, offers a quick way of improving soil fertility especially in densely populated areas such as western Kenya (Vanlauwe *et al.*, 2003). It therefore, also cuts down the amount of nitrogen fertilizer that farmers have to purchase to apply to their farms 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).

Soybean has the ability of reducing *S. hermonthica* seed bank, an endemic parasitic weed of cereal crops, when intercropped with cereal crops such as maize and sorghum (Carsky *et al.*, 2000). Soybean is a non-host plant to *Striga*, but it produces chemical substances that stimulate suicidal germination of *Striga* seeds. This is very important especially in northern Ghana where *Striga* is causing a lot of yield losses. Soybean also presents the farmers with the much needed alternative cash income source, thus reducing poverty. At national level, soybean helps in contributing to improvement of the agricultural sector which is one of the main pillars of Kenya's economy towards achieving the vision 2030 goals (Chianu *et al.*, 2008).

2.5 Origin, classification, and distribution of *Striga*

Striga weed is believed to have originated between Nubian hills of Sudan and Semien Mountains of Ethiopia (Atera *et al.*, 2011). The genus *Striga* comprises of obligate root hemi-parasites, which are serious pests to agriculture (Parker, 2009). *Striga* belongs to *Orobanchaceae* family, which has high numbers of parasitic species (Bennett and Mathews, 2006). Among the *Striga* genus, 30 species have been described to parasitize grass species (*Poaceae*) and one species, which parasitize legumes (Mohamed and Musselman, 2008). Currently, *Striga spp* of economic value are *S. hermonthica*, followed by *S. asiatica*, *S. gesnerioides* and less extent, *S. forbesi* and *S. aspera* (Parker, 2009).



Striga species are classified into two major groups, autogamous and obligate allogamy. *Striga asiatica* is classified as autogamous species; does not require pollinators while *S. hermonthica* and *S. aspera* are both allogamy; requires insects for pollination (Mohamed and Musselman, 2008). Genetic variation in sub population of *S. hermonthica* is contributed by its cross breeding nature (Berner *et al.*, 1997). Morphologically, *S. gesnerioides* is different from other species of *Striga* (Estep *et al.*, 2012) in that, haustoria of *S. gesnerioides* has branched vascular system and lack hyaline body. *Striga* weeds are extensively distributed all over the world however; they are generally innate in tropical and semi-arid areas of Africa (Ejeta and Gressel, 2007). *Striga curviflora*, *S. multiflora*, and *S. parviflora* are *Striga spp* native to Australia while *S. asiatica* was innate in tropical parts of Africa and Asia but now is found in Carolina in United States of America (Mohamed and Musselman, 2008). *Striga gesnerioides* is inborn in Asia, Africa, and Arabia but currently it is found in United States (Mohamed and Musselman, 2008) while *S. hermonthica* dominates semi-arid areas of Northern Tropical Africa, the Democratic Republic of Congo, South West Arabia and Southern tropical Africa (Parker and Riches, 1993). In Africa, 25 countries had been reported to be infested with *Striga* by year 2005 (De Groote *et al.*, 2008). *Striga* infests important staple crops including sorghum, maize, wheat, rice, sugarcane and cowpea which are of social and economic importance to local farmers in areas affected (Atera *et al.*, 2011). Plants infested by *Striga* weeds display severe symptoms characterized by chlorosis, leaf lesions, leaf desiccations, stunted growth and necrosis (Berner *et al.*, 1997). *Striga* in SSA has been estimated to affect the lifestyle of 300 million people per year and economic damage of about 7B USD (Waruru *et al.*, 2013).



2. 6 *Striga hermonthica* attachment and underground development

Contact between the tip of the radicle and the host root begins an attachment process that leads to the formation of a root structure called the haustorium. The haustorium links the xylem sap flow of the host root with that of the parasite and connects the parenchyma tissues of the host and the parasite (Kuijt, 1969). This connection allows *S. hermonthica* to withdraw water, nutrients and carbon assimilates from the host (Cechin and Press, 1994; Pageau *et al.*, 1998). Host recognition and haustorium development are mediated by chemicals, such as phenolic acids, quinones, and flavanoids (Yoder, 2001). Phenolics and allelopathic quinones are plant defence chemicals, which suggest that *Striga* spp., such as herbivorous insects, uses these defence chemicals as recognition cues (Atsatt, 1977).

The attached seedling causes damage to its host in two ways. The first direct negative effect on the host is as a result of competition for water, nutrients, assimilates and amino acids between the host (shoot) and the attached *Striga* seedling (Cechin and Press, 1994). The second, more indirect pathogenic effect from the attached seedling is a disruption of the host's hormonal balance (Frost *et al.*, 1997; Taylor *et al.*, 1996) and a reduction of the host's photosynthesis process (Graves *et al.*, 1989; Gurney *et al.*, 1995; Smith *et al.*, 1995; Watling and Press, 2001). This effect becomes evident several days after establishment of the haustorium. The attached seedling forms a sprout which grows towards the soil surface. From the time of attachment until emergence, *Striga* is fully dependent on the host for water, nutrients and assimilates, making it a holo-parasite during this stage of its life cycle.



2.7 *Striga hermonthica* emergence

The time between attachment and emergence can vary from three to six weeks (Olivier *et al.*, 1991; Parker, 1965). Upon emergence of *Striga*, its leaves and stems turn green and start to photosynthesize. There is evidence for density dependent feedback mechanisms that regulate the maximum number of plants that can emerge and survive to maturity per host (Doggett, 1965; Van Delft *et al.*, 1997; Webb and Smith, 1996). Andrews (1945) and Doggett (1965) suggest that about 10–30% of the attached seedlings reach the soil surface.

2.8 *Striga hermonthica* survival to maturity

Striga plants start flowering between one to two months after emergence (Parker and Riches, 1993) and if not uprooted before seed set the seed bank would increase. Some studies have observed premature mortality of emerged plants but this process has only been quantified in one study (Webb and Smith, 1996). Flowering *S. hermonthica* plants are pollinated by bee-flies (*Bombyliidae*, *Diptera*) and butterflies (*Lepidoptera*). After pollination, a green capsule with seeds is formed within seven to ten days. A flowering *Striga* plant can bear from one to about 30 flower branches with flowers that are each 1 to 2 cm large. Flowers appear and open in sequence from the bottom of the flower branch upwards. Flowering is a continuous process and all stages, from flower buds to capsules that are already shedding seed, can be found simultaneously on one plant or flower stalk. Senescence sets in from the tip of the capsule downwards. Eventually, the capsule turns black and opens, shedding its seed.



2.9 *Striga hermonthica* fecundity

Estimates of fecundity that is number of seeds produced per mature *Striga* plant vary widely and may depend on growing conditions, host species and host variety which may lead to an increase of the seed bank (Andrews, 1945; Parker and Riches, 1993; Rodenburg *et al.*, 2006). Estimates of average fecundity range from 5,000 to 84,000 seeds per plant, while maximum fecundity is in the order of 200,000 seeds per plant. Seed production, or a proxy indicator for seed production, has only recently been related to control options (Rodenburg *et al.*, 2006; Van Ast and Bastiaans, 2006).

2. 10 *Striga hermonthica* (Del.) Benth seed bank

Striga hermonthica (Del.) Benth in the family *Orobanchaceae* is obligate (Berner *et al.*, 1995) chlorophyll bearing (Cook *et al.*, 1972) root parasite, which means that the weed is dependent on its host plant during its entire life cycle, from germination stage – flowering stage – reproduction stage. It is an obligate root parasite of cereal crops that inhibit normal host growth through three processes namely; competition for nutrients, impairment of photosynthesis (Joel, 2000), and a phytotoxic effect within days of attachment to its suitable host plants (Gurney *et al.*, 2006).

For yearly noxious weeds such as *Striga* spp., the persistence of the soil seed bank proves to be the main problem for control and management. *Striga hermonthica* seed bank being small rapidly increases in subsequent cropping seasons when suitable host plants (crops or weeds) grow in the field (Lopez-Granados and Garcia-Torres 1999). Control of this weed (*Striga*) has become a difficult task considering the seed production rate of 10,000



– 100,000 seeds/plant, which can even remain viable in the soil for up to 20 years and germinate in the presence of suitable conditions (Ikie *et al.*, 2006). This can lead to seed shed rates of over 1,000,000 seeds m⁻² per year (Kroschel and Muller- Stover, 2004) and thereby leading to a rapid buildup of *S. hermonthica* seed bank in the soil, once fields have been contaminated (Van Mourik *et al.*, 2005). This is one of the reasons why many of the soils in *Striga* endemic areas of sub- Saharan Africa have extra high *Striga* seed densities.

Semi-arid tropical farming in sub-Saharan Africa suffers from increasing land pressure due to human population growth. This results in continuous mono cropping of (cereal) hosts in the same field for long periods even more than 10 years. Where previously the seed bank would decrease to tolerable levels of *Striga hermonthica* after a fallow period, a reduction in length of fallow periods has favoured the development of high levels of infestation (Samaké *et al.*, 2005, 2006; Weber *et al.*, 1995). Also, mono cropping of cereal hosts with little or no specific measures against *Striga* has resulted in huge amounts of seeds accumulating in the seed bank. The soil seed bank plays a very important role in population dynamics and when seed production is unreliable, the seed bank is important for the survival of annual plant populations (Silvertown and Charlesworth, 2001).

Technologies to deplete the *Striga hermonthica* seed bank or reduce it to tolerable levels are imperative for food security in Africa (Van Mourik *et al.*, 2008). Seed ageing, attack by pathogenic fungi, germination and seed predation are steps that deplete the soil seed bank. It is known that *Striga* seeds can stay viable for long periods in the soil and



germinate under favourable conditions. High depletion rates of seed bank of over 50% over one or two rainy seasons reported in several studies in Africa can, therefore, not only be attached to seed ageing (Oswald and Ransom, 2001; Gbèhounou *et al.*, 2003; Murdoch and Kunjo, 2003).

Oswald and Ransom (2001) and Murdoch and Kunjo (2003) suggested that germination in response to root exudates was the main cause of *Striga hermonthica* seed bank depletion whereas Gbèhounou *et al.* (2003) suggested that microbial activity leading to germination or infection of seeds caused seed bank depletion. In both studies, the cause of seed death or the relative importance of different processes leading to seed bank depletion could not be clarified because of the method used.

Striga seeds need a chemical stimulant to trigger germination after a period of preconditioning (Vallance, 1950). Roots of hosts or suitable crops (Parker and Riches, 1993) and non-hosts (Egley, 1972) exude these chemicals. When a non-host plant causes the germination of *Striga* seeds, the seedling will be unable to attach to the roots and dies which is known as suicidal germination. The potential of crop rotation with non-host plants to deplete the *Striga hermonthica* soil seed bank by suicidal germination has been assessed in the laboratory (Khan *et al.*, 2002; Emechebe and Ahonsi, 2003; Gbèhounou and Adango, 2003; Olupot *et al.*, 2003) and in the field (Oswald and Ransom, 2001; Khan *et al.*, 2002; Gbèhounou and Adango, 2003; Murdoch and Kunjo, 2003).

There was great variability in seed germination found during *invitro* experiments in the laboratory (Emechebe and Ahonsi, 2003) and consistent comparisons between trap and host crops were many times lacking (Gbèhounou and Adango, 2003). When trap and host



crops were compared, seed germination was higher in response to host roots. That was in maize and sorghum, than trap crop roots of cowpea, soybean and *Celosia argentia* L., except for cotton and *Desmodium* spp. (*Desmodium uncinatum* and *D. intortum*) that evoked germination responses comparable to sorghum and maize (Khan *et al.*, 2002; Emechebe and Ahonsi, 2003; Olupot *et al.*, 2003). It has been suggested that the variation in depletion of the *Striga hermonthica* seed bank in the soil is accounted for these differences in the stimulation of germination (Oswald and Ransom, 2001; Khan *et al.*, 2002; Abunyewa and Padi, 2003; Murdoch and Kunjo, 2003). However, a clear comparison could often not be made between a host crops, trap crop and a mix of host crop and trap crop, because *S. hermonthica* was allowed to flower and shed seed on the host crop. In all cases, except for the intercrop with *silverleaf desmodium* this seed shed led to increase in the seed bank density. Only Murdoch and Kunjo (2003) compared *Striga hermonthica* seed bank depletion under a cereal and a trap crop while preventing seed production completely under the cereal crop by weeding. In this manner, a true comparison between *Striga hermonthica* seed bank depletion as caused by germination in response to a trap crop and a host crop could be determined.

2.11 *S. hermonthica* seed bank importance on maize production

S. hermonthica (Del.) Benth is one of the most widespread and the most economically significant species that parasitizes on sorghum (*Sorghum bicolor* L. Moench), pearl millet (*Pennisetum glaucum* L.), maize (*Zea mays* L.), and rice (*Oryza sativa* L.). Particularly, *S. hermonthica* is the most serious biotic problem to cereal production (Babiker 2007).



The production of cereals in the Northern Regions of Ghana is menaced by the threat of low productivity as a result of the parasitic weed, *S. hermonthica* seed bank (Sauerborn, 1991). The damage it causes is major and the harvest losses are clear (De Groote *et al.*, 2007). This parasitic angiosperm threatens the lives of over 100 million people in Africa, seriously in 17 countries and moderately in 25 (Mboob, 1986). Yield losses caused by the parasitic weed generally result from competition for limited resources such as light, water and soil nutrients. The extent of yield loss is related to the incidence and severity of attack, the host's susceptibility to *Striga*, environmental factors (edaphic and climatic) and the management level at which the crop is produced (Esilaba, 2006). A conservative estimate of crop losses due to *Striga* species in Africa is 40 percent, representing an annual loss of cereals worth US\$ 7 billion (Mboob, 1986). The losses, however, vary with countries depending on the ecological zones. In Gambia, a two year study was conducted, crop losses due to *S. hermonthica* were found to range from 20 to 35 percent (Carson, 1986). In Nigeria, losses of 10 to 91 percent with an average loss of 35 percent, in sorghum and maize yields have been attributed to *S. hermonthica* (Parkinson, 1985).

According to Saueborn (1991) records of losses caused by *Striga hermonthica* in Northern Ghana in 1991 indicated that yield losses amounted to 16% for maize, 31% for millet and 29% for sorghum, representing a total economic loss of US\$25 million for the three crops. Preliminary surveys at the farmer level in Mali showed that crop losses due to *Striga* species ranged from 25 to 100 percent (Konate, 1986). In East Africa, Doggett (1975) estimated a 20-95 percent total yield loss for sorghum and millet. Experiments conducted in Sudan indicate that *Striga* infestations can cause almost complete crop failure while soil fertility is still adequate (Leroy, *et al*, 1977). The authors also noted that



upland rice growing in areas of southern India has been stopped because of 80 to 90 percent crop losses from *Striga* species.

Striga is not like other weeds; it attaches to the vascular system of the host plant and diverts carbohydrates produced by the host. It has been estimated that about 20 percent of the yield reduction in the host can be attributed to loss of fixed carbon diverted to the attached *Striga species*. The symptoms of *Striga* parasitism on the host plant suggest a phytotoxic effect (Graves *et al.*, 1989). In cereals such as maize and sorghum *S. hermonthica* causes stunting, drought like leaf wilting, chlorotic lesions and leaf rolling even under high moisture condition. *S. hermonthica* has been noted to reduce leaf, stem and root growth of infected susceptible maize plant which also showed completely moribund shoots, with no green leaves at 76 days after planting (Stewart *et al.*, 1991).

Stewart and Press (1990), have observed the growth inhibiting effects of *Striga* species on its host, and speculated that a toxin produced by the parasite is responsible for the symptoms.

After *Striga* has spread to a field, the damage it causes increases every planting season if nothing is done to combat it (Khan *et al.*, 2006). Farmers who have too much *Striga* emergence in their farm lands due to high *Striga* seed bank find it easier to abandon them and start cropping somewhere else.

2.12 Management strategies of *Striga hermonthica*

Striga seed banks in many of the areas in SSA where *Striga* is endemic are extremely high. The primary objective of many research programmes is to reduce the *Striga* load by initiating suicidal *Striga* germination using chemicals (Worsham, 1987), killing seeds by



fumigation, and roots of some legumes such as soybean (Afayak) to cause suicidal germination. Research aim at *Striga* control has been carried out for a long time and a wide range of technologies have been developed (Atera *et al.*, 2011). Despite efforts made to control *Striga* problem, it has persisted and increased in magnitude prompting to research aimed at preventing infestation. *Striga* has a high fecundity, it uses the host plants nutrients and the seed is asynchronous. These characteristics make the weed difficult to control (Andrianjaka *et al.*, 2007; Worsham and Egley, 1990). According to Haussman *et al.* (2000), *Striga* control strategies can be broadly classified into three major categories that have different impacts on a *Striga* population: reduction of the *Striga* seed bank, limitation of *Striga* seed production, and reduction or prevention of *Striga* seed dissemination to uninfested fields.

Today there are several methods available when it comes to *Striga* control: soil preparation, hand-weeding, hoeing, herbicides, push-pull technology, resistant crop varieties, N-fertilization, biological control, germination stimulants and crop seed treatment (Radi, 2007). However, synthetic compounds are not the best option. It is not sustainable and the farmers can't easily afford it. Techniques which include a changed cropping system are a sustainable solution which can ensure a proper yield (Abunyewa and Padi, 2003).

2.12.1 Hand pulling

Hand pulling is done through the normal weeding process, which involves uprooting the *Striga* (witch weed) by hand. Hand pulling has two objectives: to reduce damage to the current crop, and to prevent seeding of the weed and so reduce future infestation or



deplete the *Striga* seed bank. Hand pulling of *Striga* has been shown to reduce its infestation, but only if done before seed set, (Parker and Riches, 1993).

Although much of the damage from *S. hermonthica* is done before the weed emerges, it is often possible to show a benefit from hand pulling emerged *Striga* plants (Carson *et al.*, 1989), and even from the destruction at the time of *Striga* flowering. Removal of *Striga* at the early vegetative stage is likely to be more beneficial in terms of yield than later removal (Ogborn, 1984). But the general experience is that there is rapid regrowth, presumably from the broken shoot bases below ground and farmers find it very discouraging to go through crop farms repeatedly many times to uproot the weed. The method is however time consuming and labour intensive (Khan *et al.*, 2003). It is also only effective in reducing the weed infestation during preceding seasons since most of the damage by *Striga* occurs before the weed emerges from the ground.

Striga also continues to mature in the field after maize has been harvested (Woomer and Savala, 2008), which is a time when hand weeding is not done. This therefore leads to further flowering and shedding of seeds which increases the *Striga* seed bank in the soil.

2.12.2 Intercropping cereals with trap crops

Trap crops cause suicidal germination of the weed, which reduces the seed bank in the soil. Some varieties of soybean, cowpea, and groundnut have the potential to cause suicidal germination of *S. hermonthica* and improve soil fertility (Carsky *et al.*, 2000; Schulz *et al.*, 2003). The use of trap crop such as soybean triggers suicidal germination of



Striga and therefore reduces the *Striga* seed bank in the soil when intercropped with maize (De Groote *et al.*, 2010).

The efficient way of reducing *Striga* seed germination is the use of trap crops. A study done in the savannah zone of Ghana by Abunyewa, (2003) gave a negative correlation between nitrogen content and *Striga* seed in the top soil (0-15cm). When legumes were cultivated the number of *Striga* seed in the seed bank decreased from 28 183 seeds /m² to 8 185 seeds/ m². However, when cereals were cropped the number of seeds increased from 9 383 seeds/ m² to 16 696 seeds m². Legumes can function as a trap crop since it induces germination of the *Striga* seed but do not allow it to attach and live on the root. Sole cereal cultivation also gave a 100 percent increase in *Striga* seed in the soil, while the legume cultivation decreased the *Striga* seed bank (Abunyewa and Padi, 2003). *Desmodium* has also been reported to be an effective and sustainable management program for depleting the *Striga* seed bank, and have additional soil improvements such as; increasing nitrogen in the soil, organic matter and conserving moisture (Khan *et al.*; 2006, Khan *et al.*, 2008). Van Mourik *et al.*, (2011) compared *Striga hermonthica* seed bank depletion rates, attained under bare or weedy fallow and mono or intercropping with a non-host crop, to the rates attained under cereal (sorghum or millet) mono-cropping. They observed that seasonal depletion rates of the soil seed bank under continuous mono-cropping of the host crop (75–82 % under sorghum depending on variety and 74 % under millet) were higher than when intercropped with a non-host crop (49–66 %). This in turn depleted the soil seed bank more than when the non-host crop was grown as mono-crop (35–43 %) or when the soil was under a weedy fallow (47 %) or left bare (28–43 %). These results suggested that preventing parasitic weed seed production (e.g. timely hand



weeding and growing a suitable host crop) can actually be more effective in reducing the weed seed bank than growing a non-host crop as mono- or intercrop or leaving the field fallow.

The trap crops advantage is the stimulating germination of *Striga* or other root parasites without themselves being parasitized. Some varieties of cowpea, groundnut and soybean have the potential to cause suicidal germination of *S. hermonthica* and improve soil fertility (Carsky *et al.*, 2000; Schulz *et al.*, 2003). The use of trap crops such as soybean causes suicidal germination of the *Striga* seedlings which do not attack the soybean later, the *Striga* is ploughed off before flowering thereby reducing the seed density of *Striga* in the soil (Umba *et al.*, 1999). In IITA, about 40 lines of soybean were screened for their ability to stimulate *Striga hermonthica* seeds germination. Nicholas *et al.*, (2012) reported that to minimize the effects of *S. hermonthica* on maize, improved lines that are efficacious as trap-crop such as Afayak (TGX 1834-5E) and Songda (TGX 1445-3E) can be used with the aim to increasing maize productivity. Hess and Dodo (2003) also found that the use of leguminous trap crops that include varieties of groundnut, soybean, cowpea, and sesame stimulate suicidal germination of *Striga* is another technology to control *Striga*. De Groote *et al.*, (2010) found that soybean triggers suicidal germination of *Striga* and reduces the *Striga* seed bank in the soil when intercropped with maize.

Leguminous trees and shrubs such as *Sesbania sesban*, *Markhamia lutea* and *Leucaena diversifolia* encourage suicidal germination of *Striga* seed during the fallow phase (Oswald *et al.*, 1996; Rao and Gacheru, 1998). In addition to the increased amounts of mineral N in the topsoil and higher levels of N mineralization in the subsequent cropping phase improves crop performance in this intercropping system. However, the prevailing



scarcity of land as a result of population increase has resulted in intensive land use and a shift from this method (Berner *et al.*, 1996, Kureh *et al.*, 2000). Inclusion of trap crops in a rotation system can result in a significant reduction of the *Striga* seed bank in the soil but, the high population pressure on the available land implies the method is no longer practicable (Massawe *et al.*, 2001). Oswald *et al.* (1999) found that farmers rated crop rotation as third option after intercropping and catch cropping even though it was technically superior to the other options.

Intercropping which entails growing two or more crops simultaneously on the same field (Charles, 1986) results in insurance against crop failure, economic use of farm inputs, soil erosion control and soil fertility maintenance. Brian (1986) suggested that the varied distribution of growth factors in space and time in many agricultural environments could be absorbed completely and usefully by a mixed stand of crops. Intercropping cereals with leguminous plants improve soil fertility by biological nitrogen fixation in addition to utilizing nutrients in the unoccupied niches by other plants. The vegetation diversity in intercropping has also been used in the management of insect pests, weeds and plant disease (Perrin, 1980). The associated crops can function as trap crops, source of natural enemies, produce toxicant, anti-feeding, and growth disruption or masking stimuli, act as physical barriers to insect pests, or modify micro-environmental climate to the disadvantage of the onset of disease (Charles, 1986). The rhizo-deposits from some of the crops may enhance soil fungistasis and antibiosis to control soil borne pathogens in addition to influencing the microbial community structure (Maguel and Matt, 1986).

Intercropping has potential as a means of weed control because it offers the possibility of a mixture of crops capturing a greater share of available resources hence pre-empting



their use by weeds. Allelopathic potential of some crops also offer an attractive alternative to chemical weed suppression. Such alternatives are increasingly important in the face of environmental pollution, ground water contamination and increased resistant of weeds to herbicide. *Striga* seeds in the soil have been observed to reduce by the use of trap crops or catch crops in an intercropping system (Pieterse and Pesch, 1983). Carson (1989) observed reduced *S. hermonthica* densities under sorghum/ groundnut (*Arachis hypogaea*) intercrop.

Intercropping sorghum with dolichos lablab (*Lablab purpureus*) resulted in suppressed *S. hermonthica* emergence and growth and increased yield of sorghum (Babiker *et al.*, 1993). The spreading vegetation of trap crops such as *Mucuna* has also been shown to smother emerging *Striga* plants before flowering (Kabambe, 1995). In Uganda, intercropping sorghum and *Celosia argentea* (Amaranthaceae) has been shown to reduce *Striga* seed bank by 55 % (Olupot *et al.*, 2003). In Kenya, silverleaf *Desmodium* has been found to suppress *Striga* by stimulating seed germination and inhibiting haustorium development and has been successfully modeled into 'push-pull' control system (Khan *et al.*, 2001; Tsanuo *et al.*, 2003).

Success of the intercropping system depends on the environment and crops used (Kabambe, 1995). Farmers' acceptance of any trap crop will depend on its economic value. One of the options would be to introduce a high nutritious and priced food legume. Currently many soybean accessions have been recommended for the diverse-ecological zones of Kenya and are being grown (Nassiuma *et al.*, 2002). Expanding the horizontal use of soybean would increase potential for adoption and integration into existing cropping systems. This is because the acceptance of a technology by farmers depends on



its suitability to the wide diversity of biophysical and socio-economic environments in which subsistence farmers' work (Oswald *et al.*, 2002; Marley *et al.*, 2004; Franke *et al.*, 2005). Kureh *et al.* (2000) found that sole hybrid maize supported significantly higher *Striga* incidence and infestation than when intercropped with selected soybean lines (that is TGX 1019-2E and TGX 1440-1E) in Northern Nigeria. Intercropping *Striga* tolerant maize and selected soybean varieties led to 46% reduction in *Striga* seed bank and 88% increase in maize production (Schulz *et al.*, 2003; Franke *et al.*, 2005). Studies have shown that there are differences in production of chemical stimulants among non-host crops and within crop cultivar in their ability to stimulate *Striga* seed germination and between *Striga hermonthica* populations to respond to germination stimulant (Kureh *et al.*, 2000).

2.12.3 Crop rotation

Crop rotation is a low technology and addresses the problem of low soil fertility and *Striga* infestation. It can be an effective way of reducing the *Striga* seed bank, particularly when the rotating crop can serve as trap crop for the parasite (Oswald and Ransom 2001). It is effective in reducing the seed bank mainly because it interrupts the seasonal production of parasitic seed weeds; it improves the *Striga* suppressive capacity of the soil (Parkinson *et al.*, 1987) and it can cause suicidal germination of *Striga* seeds.

Crop rotation is the easiest control measure of *Striga* to implement because it requires only commitment and planning (Shank, 2002). For heavily infested fields, trap crops for example soybean can accelerate the depletion of the reservoir of *Striga* seeds in the soil (Mloza-Banda and Kabambe, 1997). Rotating a cereal crop with legumes such as soybean



can be a highly effective method of reducing the amount of *Striga* seeds in the soil. To ensure the effectiveness of the rotation crop, the cultivars which are most effective in stimulating *Striga* must be included. A more desirable option is the use of leguminous non-host crops, which stimulate *Striga* germination, but do not support its growth but lead the weed to death. These non-hosts can significantly deplete the soil seed bank by inducing suicidal germination of *Striga* (Berner *et al.*, 1997). Rotating the infested maize or sorghum areas to wheat/barley, pulses, or groundnuts are viable and effective options in Ethiopia. A season of non-host cropping allows for a large portion of the *Striga* seeds to deteriorate into non-viability. Seriously infested areas should be rotated to non-host crops for two years followed by closely supervised weeding.

In Ethiopia two years of cropping to a non-host was reported to reduce *Striga* infestation by 50% (Shank, 2002). In Sahel the results of a four year experiment in bush fields indicated that one season cowpea in 1998, had a positive effect on subsequent millet grain yields, soil organic carbon and nitrogen, and reduced *Striga* infestation. The increase in yields due to millet-cowpea rotation was 37% in 1999 compared to 3-5 years continuous millet cropping (Samake, 2003). Farmers might find many of these cropping system alternatives impractical or not sufficiently profitable. So suitable legumes should therefore at least combine parasitic weed control characteristics with an additional economic benefit to increase the likelihood to be acceptable to farmers (Becker and Johnson 1999; Ransom 2000), and they should possess good environmental adaptation.

By including fallow in the crop rotation, two positive effects occur (De Groote *et al.*, 2007). The first one is that the soil fertility increases which makes the conditions less favourable for *Striga* seeds germination. The second effect is that the *Striga* seed bank in



the soil decreases which lead to a smaller effect of *Striga* during the next season. Due to an increase in population the use of fallow has decreased (Berner *et al.*, 1995). As more people need to be fed, the farmers have not been able to put land aside for a season.

2.12.4 Resistant crop varieties

The use of host-plant resistance and tolerant varieties could stimulate the suicidal germination of *Striga* seeds and therefore reduce the seed bank in the soil.

Tolerant crop varieties are able to reduce the negative effects of parasitic weed infestation on crop yields but do not prevent seed production by the parasite (Rodenburg and Bastiaans 2011; Badu-Apraku *et al.*, 2007). Some crop varieties are resistant to parasitic weeds. Resistant varieties, while able to reduce immediate damage to the crop (in particular when combined with tolerance), are unlikely to significantly reduced the seed bank simultaneously in a similar way as trap crops. When the natural seasonal seed bank depletion is 46 %, the production of only 8 seed capsules per meter square for *S. hermonthica* would fully replenish a low-density seed bank of 30,000 seeds per meter square during one season.

In all other cases, the estimated production of *Striga* seed greatly surpassed replenishment of the seasonal losses and hence increased the soil seed bank (Rodenburg *et al.*, 2006).

In maize, *Striga* tolerant varieties, which are either open pollinated, or hybrid varieties such as WS909, WH502 and KSTP94 and local variety Nyamula have been identified (Odongo *et al.*, 1997). The CSIR – SARI and CSIR –CRI have developed and released



new varieties that are resistant / tolerant to *Striga* infestation (Adu *et al.*, 2014). These varieties include Wang–Data, Bihilifa, Omankwa, Abontem, and Aburohemaa.

Reports of genetic resistance to *Striga* have been documented in rice (Gurney *et al.*, 2006), and sorghum (*Sorghum bicolor*) (Rich *et al.*, 2004). However, the major problem associated with the use of resistant/tolerant cultivars is the lack of universal resistance, because of the existence of different biotypes of *S. hermonthica* since it is cross-pollinated (Koyama, 2000). Such variation has been observed in variable response of *S. gesnerioides* to germination stimulation (Berner and Williams, 1998). As a result of variation, field screening for *Striga* resistance cultivars is often unreliable and slow because of the inconsistency nature of infestation within and between field, and across years (Vogler *et al.*, 1995).

Also, the resistance genotype was found to lower the *Striga* seed bank only at very low infestation levels (Rodenburg *et al.*, 2005). Further-more, reliance on host resistance alone is not ideal because so far complete resistance against *Striga* cannot be attained through breeding (Gurney *et al.*, 2002), and usually the newly developed varieties may not fulfill farmers preference traits (Adugna, 2007). The production of tolerant and resistance varieties can be improved if they are used as major component of integrated *Striga* control packages.

2.12.5 Soil fertility

Several studies have shown that *Striga* infestation is correlated with low soil fertility and that improved soil fertility would lead to a reduction of the infestation (Lagoke *et al.*, 1991; Weber *et al.*, 1995; Ransom, 1999; Debrah *et al.*, 1998). One of the weeds most



contributing factors for development is low soil fertility and cropping systems in SSA with no external inputs (Cardoso *et al.*, 2010). According to a study in Benin, focus should only be on *Striga* management when soil fertility is more than a threshold value. Otherwise, resources will be used without improvement in yields (Abunyewa and Padi, 2003). Declining soil fertility has led to the increase of *Striga* infestation due to the lack of nitrogen (N). N is said to have the effect of reducing *Strigolactone* production from the host plants and therefore also inhibit germination of *Striga* seeds. N also increases vegetative growth of the host plant, which strengthens it and protects the plant from *Striga* parasitism (Gacheru and Rao, 2011). When N has been applied to the crop, several studies indicate that *Striga* infestation is reduced and the crop yield increases (Sjögren *et al.*, 2009). Total soil N content has showed to be negatively correlated with *Striga* seed density in the soil. Results have shown that both soil N and organic C is correlated with reduction of *Striga* seed density in the soil. With a low C: N ratio, *Striga* seed density is significantly lower in the soil than where the C: N ratio is high.

When the soil is highly degraded and infertile, application of N fertilizers seems to trigger *Striga*. Repeated use of N fertilizer would, however, most likely reduce the amount of *Striga* as the soil N content gradually increases (Schulz *et al.*, 2002). In a study done in Western Kenya a higher fertilization input on *Striga* infested fields increased the yields, but not enough to cover the cost for the extra amount of fertilizer needed (De Groote *et al.*, 2010). Studies done on rice (*Oryza sativa*) shows that integrated soil fertility strategies which involves the use of N- fixation legumes, little chemical, fertilizer and a *Striga* resistant genotype of rice prevent soil fertility degradation and improve rice



productivity. In Western Africa higher rice production and weed suppression have been achieved by the use of nitrogen fixating legumes (Becker and Johnson 1998, 1999). Promiscuous soybeans in combination with mineral fertilizer (N) in maize have showed to increase the yield and provide sustainability in the cropping system. The study showed that promiscuous soybean cultivars significantly had higher dry matter and N accumulation in soils with low soil fertility. Soybeans have a large portion of underground biomass which releases nitrogen due to decomposition (Oikeh *et al.*, 2008).

A good supply of N in the soil is a good way of *Striga* control. A study done by Ayongwa (2011) showed that roots with an increased N content led to a reduction of *Striga* germination. Moreover, the study showed proof of a strong correlation between germination stimulants from the roots and the level of N in the roots. Different types of nitrogen fertilization suppress *Striga* either by the inhibition of *Striga* germination or the production of germination stimulants from the host plants. Chicken manure for an example delayed *Striga* emergence on sorghum but only at high rates (Ayongwa, *et al.*, 2011). However, Ikie *et al.*, (2007) stated that urea had a greater effect on reduction of *Striga* emergence than chicken manure had. Some studies indicate that an increased use of fertilizer should not have a direct link to *Striga* control, though it has other benefits (Berner *et al.*, 1995). Other studies indicated that direct application of phosphate would decrease the exudation of *strigolactone* and therefore reduce *Striga* germination and also *Striga* infection (Cardoso *et al.*, 2010). However, the use of fertilizer is expensive and not an alternative to most farmers in Africa (Ransom, 2000).



2.12.6 Weeding/sanitation

Although weeding the small *Striga* plants is a tedious task and may not increase the yield of already infected plants, it is necessary to prevent seed production and re - infestation of the soil. Weeding must begin at the first sign of flowering because pod formation and seed setting will soon follow. New shoots may sprout out below the soil from infected plants requiring a second weeding before crop maturity (Shank, 2002). Weeding with the hoe remains the most common practice of weed control in most African countries. Farmers will normally weed twice; the second time is through the banking operation where the soil is pulled-up the ridge. Inconsistent results have been obtained in Malawi on the effectiveness of hoe-weeding for *Striga* control (Mloza-Banda and Kabambe, 1997). Sanitation consists of taking care to note infested areas and to isolate them. Wind, rainwater, ploughing, and soil on tools or root crops can spread seeds in the soil. Seedpods on *Striga* plants attached to maize or sorghum plants pulled for forage will infest manure and feeding areas. It is suggested that a *Striga* disposal pit be constructed to prevent seed maturation of green or drying plants that are pulled (Shank, 2002). According to Woomer (2004) who reported that if *Striga* has formed flowers and matured, farmers should dig a hole about 70 cm deep, burn the plant and bury them. As the practice of uprooting *Striga* plants with already mature seed and placing them on the roads and footpaths instead of burning them, further help in increasing seed bank in the ecosystem.



2.12.7 Biological control

Fusarium fungus that is found at low levels under normal conditions in some African soils can be applied by coating cereal seeds first with Arabic gum and then with dry fungal powder. It is a seed technology rather than herbicide technology. The advantage with this approach is that Fusarium can colonize the soil and lie in wait for *Striga* germination. According to Eberlee (2000) when *Striga* attacks the crops, it is killed by the Fusarium. Researchers at McGillbio pesticides research laboratory discovered a fungus (*Fusarium oxysporum*) in the soil in Mali that can suppress the weed's growth (Watson *et al.*, 1998).

Also, the larvae of the butterfly *Junonia orithya* feeds on the foliage while that of the fly *Ophiomia strigalis* and the beetle *Smicronyx spp.* feed on gall seeds of the *Striga*. These predators have their natural enemies and appear to be poly-phagous and consequently have limited potential as biological control agents (Greathead, 1984). Mycoherbicidal organisms like *Fusarium oxysporum* (Marley *et al.*, 1999; Ciotola *et al.*, 2000; Marley *et al.*, 2004) and bacteria (Berner *et al.*, 1999; Miche *et al.*, 2000) have been cited as biocontrol agents. Jasmonates and fungal metabolites cotylenin and fusicoccins have also been found to induce germination of *S. hermonthica* and *Orobancha minor* seeds under experimental conditions but have not been packaged for use in field conditions (Yoneyame *et al.*, 1998). Ethylene producing bacteria *Pseudomonas syringae* pv. *glycinea* have also been identified as possible for controlling *Striga* spp. (Berner *et al.*, 1999). The pathogenicity effect of these bacteria on the environment needs to be studied before they are recommended for use.



2.12.8 Chemical control

Certain chemical control measures that have been practised in the western hemisphere are not practical or are too risky for several reasons. Soil sterilization by means of stimulating *Striga* seed germination with non-host plants (cotton or soybeans) or chemical stimulants (*strigol* and ethylene) is not practical in developing countries because of cost and the resulting delay in planting the food crop in areas where the season length is already limited by moisture (Shank, 2002). Pre-emergence herbicides against *Striga*, such as oxyfluorfen and dinitroaniline compounds, form a barrier in the top few centimeters of the soil and kill *Striga* as it emerges (Berner *et al.*, 1997).

Since *Striga* is a broadleaf plant, pre-plant herbicides such as atrazine, goal, and flex show some effect though not efficient enough to be justified (Shank, 2002). Post-emergence use of 2, 4-D is effective when sprayed on the *Striga* leaves. Though low in cost, this herbicide is quite volatile and drifts to nearby sensitive broadleaf crops (legumes, pepper and tomato) and could be devastating. Also, maize and sorghum are vulnerable to stalk twisting and lodging if 2, 4-D is sprayed into the leaf whorl. Spraying should only be done after users have been trained and cautioned to these hazards. Experimentally, anti-transparent type herbicides applied only to the base of the row of sorghum-*Striga* or maize-*Striga* were very effective (Shank, 2002). Herbicides such as Trifluralin and Pendimethalin have been effective against *S. Asiatica* when incorporated shallowly in a layer above the cereal seed by inhibiting shoot growth of the parasite (Mloza-Banda and Kabambe, 1997). Traore *et al.* (2001) reported that use of herbicides is more cost effective than mechanical weeding and it enhanced *Striga* control. Use of 2,4-



D cannot work in the smallholder sector where maize is often intercropped with cowpea, cucumber, and melons, and herbicide technology has largely not yet been introduced to these farmers.



CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

The experiment was conducted at Gore in the Bawku West District of the Upper East Region of Ghana from June to November 2016 during the planting season where *Striga* is a serious problem. The experimental site is located on latitude $10^{\circ} 48''\text{N}$ and $0^{\circ} 28''\text{W}$ and longitude $0^{\circ} 33'' 1''\text{W}$ (IFDC personal communication 2016). The vegetation is Sudan savannah grassland which is characterized by shrubs and few scattered trees. The area is characterized by high temperature and low humidity during most parts of the year.

The District shares boundaries with Burkina Faso to the North, East Mamprusi District to the South, Bawku Municipality to the East, and Talensi/Nabdam District to the West. Two important tributaries of the Volta River namely the White and Red Volta ran contiguous to the Districts' Eastern and Western boundaries respectively. The District covers an area of approximately 1,070 square kilometers, which constitutes about 12% of the total land area of the Upper East Region.

The rainfall pattern is monomodal and erratic with an annual mean of 1100mm which mostly begins in April - May and ends in October (MoFA, 2016). In 2016, the district experienced a total of 1112mm of rainfall with 51 wet days (Table 1).



Table 1: Amount of rainfall and number of wet days in Bawku west district

Month	Rainfall amount (mm)	Number of wet days
January	0.0	0.0
February	0.0	0.0
March	16.6	2
April	73.1	2
May	27.6	4
June	125.6	6
July	230.9	12
August	279.2	12
September	271.8	12
October	25.4	1
November	0.0	0.0
December	0.0	0.0
Total	1112mm	51

Source: MoFA Office, Zebilla, 2016.

3.2 Experimental design and treatments details

This experiment was laid out in randomized complete block design (RCBD) with eight treatments and three replications. The treatments were obtained from the combination of four maize varieties intercropped with and without soybean variety Afayak. A replication was made up of eight plots, each plot and replication was separated by 1m and 2m spacing respectively. Plot size of 10m x 10m was used with a total land experimental area of 2780.50m² (67.0m × 41.5m).

The varieties of maize used were: Omankwa, Wang Data, Bihilifa, and Aburohemaa, and the soybean variety Afayak. Seeds of Bihilifa and Wang data were obtained from SARI, Maize Section in Nyankpala whilst Omankwa and Aburohemaa were obtained from CRI in Fumesua. The maize cultivars were early maturing (90 days). The soybean variety was obtained from SARI. Treatments details are provided in Table 2.



Table 2: Entries for Researcher managed trial in 2016 at Gore

S/No	Maize Variety	Soybean (Inoculated)	Intercrop
1	Bihilifa	Soybean (Afayak)	Bihilifa/soyabean
2	Bihilifa	-	Bihilifa monocrop
3	Wang data	Soybean	Wang data/soybean
4	Wang data	-	Wang data monocrop
5	Omankwa	Soybean	Omankwa/soybean
6	Omankwa	-	Omankwa monocrop
7	Aburohemaa	Soybean	Aburohemaa/Soybean
8	Aburohemaa	-	Aburohemaa monocrop

3.3 Cultural operations

3 3.1 Land preparation and planting

Bullocks were used for the land preparation and ridges made across the slope followed by using pegs, a garden line, and a measuring tape to layout the experimental plots. The seeds of maize and soybean (Afayak inoculated) were planted on 6th and 20th July, 2016 respectively. Two to three seeds per hill were planted. The spacing was 75cm x 40cm for maize and 75cm x 20cm for the soybean. Twelve plots of maize were intercropped with soybean (Afayak) inoculated. The remaining twelve plots were *Zea mays* mono cropped.



3.3.2 Gap filling and thinning

Gap filling was carried out in a week after sowing to maintain optimum plant population.

Thinning was done fourteen days after sowing by retaining two healthy seedlings per hill.

3.3.3 Weed management

Weeding was done manually using hoe on 2nd and 5th week after sowing that was on 20th July, 2016 and 10th August, 2016 respectively, followed by hand – pulling of other weeds other than *Striga* at 9WAP. Each weeding operation was completed on the same day for all the blocks.

3.3.4 Inorganic fertilizer application

Basal application of compound fertilizer, NPK (15:15:15) kg/ha was applied to sole and intercropped maize for all the twenty four plots on 20th July 2016 at 2 WAP. Top dressing was done using sulphate of ammonia at the rate of 125kg as the second application on 10th August, 2016 that was in 5 weeks after planting (WAP) for all experimental plots. Fertilizer application targeted maize hills only.

3.3.5 Harvesting and threshing

Maize was harvested on 15th October, 2016 when the leaves had turned yellowish and fallen off which were signs of leaf senescence and cob maturity (Ijoyah and Jimba, 2009). The harvesting was done on net area/ plot (8m × 8.7m size) of each treatment demarcated after leaving out of two rows on each side of the plot to minimize the edge effect. The entire plants on each plot were harvested by cutting at the ground level. Maize cobs were manually separated from the straw, sundried, and packed in bags before threshing.



Soybean was harvested on 2nd November, 2016 when the pods have turned brown (Dugie *et al.*, 2009). Net plot size of 8m × 8.7m was used for the harvesting. Haulm was dried for seven days in the sun, threshed, winnowed, and grain yield per plot was then taken, similarly haulm weight was taken. Both maize and soybean were converted to grain yield and reported in kilograms per hectare.

3.4 Sampling procedure

Five plants from each net plot were randomly selected, tagged and crop growth parameters were recorded at 2 weeks intervals (3WAP, 5WAP, 7WAP, 9WAP and at harvest).

3.5 Data collection on maize

3.5.1 Plant height

Plant height of maize crops was measured at 3, 5, 7, 9WAP and at harvest. This was done by measuring the height from the soil surface to the arch of the uppermost leaf that was at least 50% emerged. Tape measure was used to measure the plant height and the averages were noted.

3.5.2 Plant stand

The stand count per plot was recorded from the net plot area (8 m x 8.7 m) after thinning and at harvest. Plant stand of maize from the net plot area was converted to kilogram per hectare.



3.5.3 Leaf count

Total number of fully opened leaves per plant was counted from the five plants tagged. It was counted at 3, 5, 7 and 9 WAP

3.5.4 Leaf area (LA)

The leaf area was determined by measuring three leaves of the tagged plant (lower, middle and upper leaves) from the bases to the tips and the average leaf length was taken. The measurements were taken at 7 and 9WAP using a fine tape measure. The leaf width was determined by measuring the widest portion of three leaves (lower, middle and upper leaves) of each of the tagged plants and the averages computed. The length multiplied by the breadth provided a measured leaf area. The true leaf area was obtained by multiplying the measured leaf area by a factor of 0.72 as used by Norman and Campbell (1989).

3.5.5 Days to 50% flowering

The days to 50% flowering on anthesis was recorded on the day at which 50% of the maize plants in each experimental unit flowered.

3.5.6 Straw weight

When cobs were separated from stocks at harvest, each plot's stocks were tied and weight taken by a hanging scale. The straw weight of maize was determined on per hectare basis as follows:

Straw weight of maize (Kg/ha) = Weight of straw $\times$ 10000m²/Net area



3.5.7 Cob weight

Each plot's cobs were put in bags and weight taken by the use of a hanging scale and averages recorded. The cob weight of maize was determined on per hectare basis as follows:

Cob weight of maize (Kg/ha) = Weight of cobs $\times$ 10000m²/Net area

3.5.8 Maize grain yield

At physiological maturity, maize was harvested from each net plot area of 8m $\times$ 8.5m. The cobs were then dried, threshed, winnowed and grains weighed. The maize grain yield was determined on per hectare basis as follows:

Grain yield (Kg/ha) = Weight of grains $\times$ 10000m²/Net area

3.5.9 Hundred seed weight

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

3.6 Data collection on soybean (Afayak)

3.6.1 Plant height

Plant height of soybean crops was measured at 3, 5, 7, 9WAP and at harvest. The plant height was measured from the ground level to the highest tip of the stem for the five sampled plants. This was done with the use of a tape measure at the various sampling periods and at harvest. The average plant height was calculated for each treatment.



3.6.2 Plant stand count

The number of seedlings was counted after establishment and at harvest from the net plot area and converted to per hectare basis.

3.6.3 Number of leaves per plant

Total number of leaves per plant on each plot was counted from the five plants tagged in every two weeks. It was measured at 3, 5, 7 and 9 WAP

3.6.4 Leaf area (LA)

The leaf area was determined by measuring three leaves of the tagged plant (lower, middle and upper leaves) from the bases to the tips and the average leaf length was taken. The measurements were taken at 7 and 9WAP using a fine tape measure. The leaf width was determined by measuring the widest portion of three leaves (lower, middle and upper leaves) of each of the tagged plants and the averages computed. The length multiplied by the breadth provided a measured leaf area. The true leaf area was obtained by multiplying the measured leaf area by a factor of 0.72 as used by Norman and Campbell (1989).

3.6.5 Nodule count per plant

Ten consecutive soybean plants were randomly taken from each plot at 35 days after sowing to assess number of nodules per plant and nodulation. The plants were harvested from the row next to the border row and roots gently dug out. They were washed with clean tap water to remove all attached soil from the roots. The nodules were then detached from the roots, counted and the mean value of ten plants was recorded. 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.

3.6.6 Number of pods per plant

For pods number, five plants were taken from each plot and all the pods plucked. These were then counted manually and the average pod number was calculated and recorded. This was done at harvest from net plot area.

3.6.7 Haulm weight

At harvest, soybean haulm in each plot was tied and weight taken using a hanging scale.

3.6.8 Grain yield

Harvesting of the soybean (Afayak) was done in a net plot area of 8m×8.7m from each plot at physiological maturity, air dried, threshed, winnowed and dry weight recorded. The grain yield per hectare at 14% moisture content was determined as follows;

Grain yield/ha = Grain yield per plot 10,000 m²/Net plot Area (m²)

3.7 Data collection on *Striga*

3.7.1 *Striga* emergence count

The number of emerged *Striga* seedlings in each of the net plot area (8m × 8.5m) was counted and converted to kg/ha. The counting was done at 5, 7, and 9 weeks after planting of maize.



3.7.2 Cumulative *Striga* emergence count

It was done at 12WAP to determine the number of the parasites recorded in each net area plot and converted to kilogram per hectare.

3.7.3 *Striga* fresh weight and biomass

This was assessed at the time that maize was matured. All the *Striga* plants in each of the plots were uprooted, well packed in envelopes, and the right label put on each and weight taken using a fine beam balance in the acid Lab at UDS on 22nd September, 2016.

After taken the fresh weight of the *Striga*, the materials were then enveloped and neatly arranged in a calibrated oven. The temperature of the oven was then set to a maximum and constant level of eighty degrees Celsius (80°C) for twenty four hours and the dry weights taken with the same balance and the weights recorded.

3.7.4 Initial, postharvest, and percent reduction in *Striga hermonthica* seed bank

100g of soils were taken before planting and after harvest from each experimental unit for analysis of *Striga hermonthica* seed bank related to crop productivity.

3.8 Field day

Field day was organized for the farmers at the site (Gore). Both male and female farmers from the surrounding community were invited. The aim was to gather information on their appreciation of performance of the four maize varieties to drought and tolerance for *S. hermonthica* infestation. The farmers visited the demonstration plots and had the



opportunity to learn by seeing the performance of recommended practices adopted by the field worker (the student) in the management of the plots.

During questions and answers time, farmers identified *Striga* infestation, erratic rainfall, drought and low levels of soil fertility as the major constraints to maize production. Also, 25 out of the 65 farmers (male and female) chose Wang data intercropped with soybean as the most preferred, followed by Bihilifa (19) and Aburohemaa (17) intercrops with soybean while the least was sole and Omankwa intercropped with soybean for one and three farmers respectively. To mitigate the effect of these constraints, the farmers were urged to use improved planting materials tolerant to drought and *Striga* and to also adopt best practices in maize cultivation.

3.9 Data analysis

Count data collected was transformed using square root transformation ($\sqrt{x+0.5}$) to homogenize the variance before subjecting them to analysis of variance (ANOVA) using Genstat statistical package (12th edition). Where x is a number to be transformed and 0.5 is a constant. Significant differences among treatment means were separated using Fisher least significant difference test (LSD) at 5% significant level. Correlation analysis was run to establish relationships among some parameters.

CHAPTER FOUR



4.0 RESULTS

4.1 General observation

It was observed that the maize varieties were resistant/ tolerant to *Striga* infestation as *Striga* emergence was high but crop growth and other yield components were not affected as a result of *Striga*. *Striga* emergence was observed at 7WAP in some of the plots. The first *Striga* germination was observed in Omankwa intercropped with soybean plot but few, and in four days the other plots were observed with *Striga*. However, the highest *Striga* germination was observed in Omankwa intercropped with soybean, similar to Aburohemaa intercropped with soybean and Wang Data alone. It was also observed that the soybean (Afayak) actually fixed nitrogen in the soil because root nodules were active, as indicated pink colour when cut opened.

All the maize plants maintained its greenness even at 12 WAP, but Aburohemaa produced bigger cobs. Bihilifa recorded the tallest among the maize varieties, similar to Wang Data, and Omankwa which could be due to its genetic background and cropping system.

4.2 Gore rainfall in 2016 planting season

Total rainfall was 1112mm in 2016 growing season which started from March to October. The highest monthly rainfall was 279.2mm which occurred in August which was similar to that of September (271.8mm), thus supplying enough moisture to promote crop growth and development of the maize varieties (Figure 1).



The rains were well distributed throughout the growing season which might have resulted in good maize – soybean seedling emergence and growth. But in October rainfall recorded 25.4mm, yet no negative effect on the crops were observed as maize cobs were almost ready for harvesting.

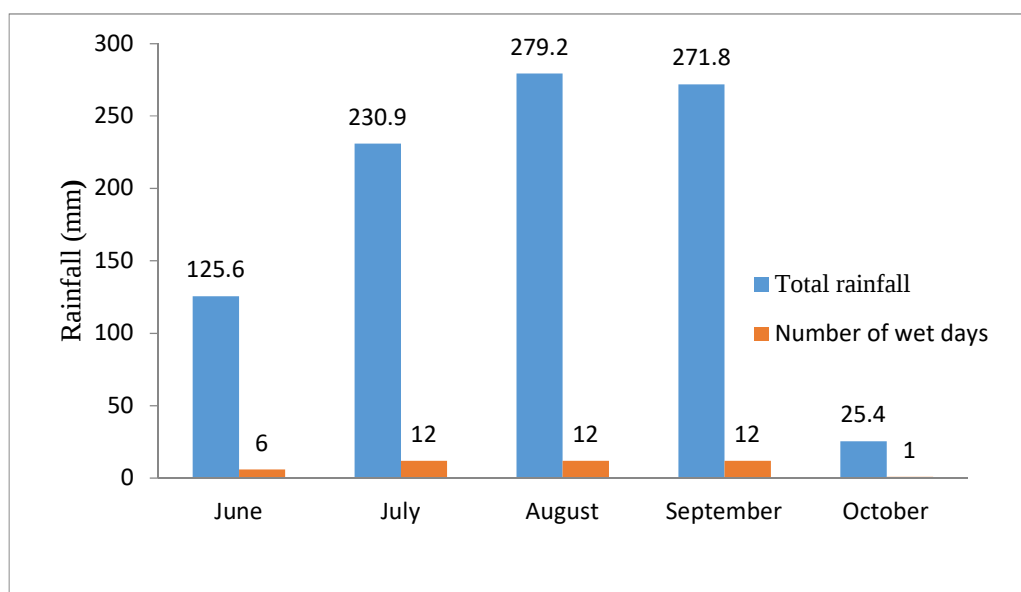


Figure 1: Rainfall variation at experimental location from June to October during the 2016 cropping season.

Source: Ministry of Food and Agriculture office, Zebilla

4.3 *Striga* emergence count

There was no significant difference ($P > 0.05$) for *Striga* emergence count at 7WAP, but significant differences ($P < 0.05$) were obtained at 9WAP and 12WAP. At 7WAP, the highest transformed *Striga* emergence count ($\sqrt{x+0.5}$) of 82 was recorded in Bihilifa



intercropped with soybean whilst sole Aburohemaa recorded the least (37) similar to sole Bihilifa (37). At 9WAP, Omankwa, Aburohemaa, Wang data, and Bihilifa intercrops with soybean were similar in *Striga* count whilst sole Aburohemaa had the least which was similar to sole Omankwa. At 12WAP, Omankwa, Aburohemaa, and Wang data intercrops with soybean had similar *Striga* count, followed by Bihilifa intercropped with soybean whilst sole Aburohemaa produced the least (Figure 2).

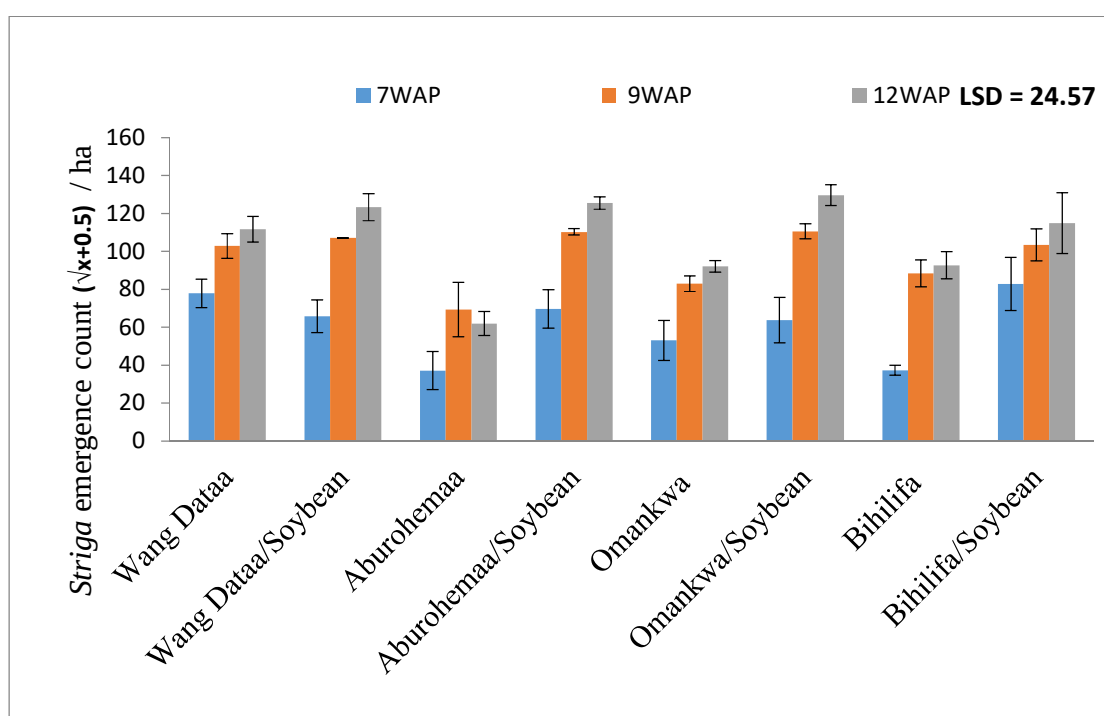


Figure 2: Effect of treatments on *Striga* emergence count at 7, 9, and 12WAP on maize. Bars represent SEM



4.4 Cumulative *Striga* emergence count

Significant difference was observed for cumulative *Striga* emergence count. At 12WAP, Omankwa and Wang data intercrops with soybean had similar results of 17.25 and 17.13 respectively. Wang data and Bihilifa intercrops with soybean produced 16.52 and 16.44 respectively, whilst the least was observed in sole Aburohemaa (9.78) (Figure 3).

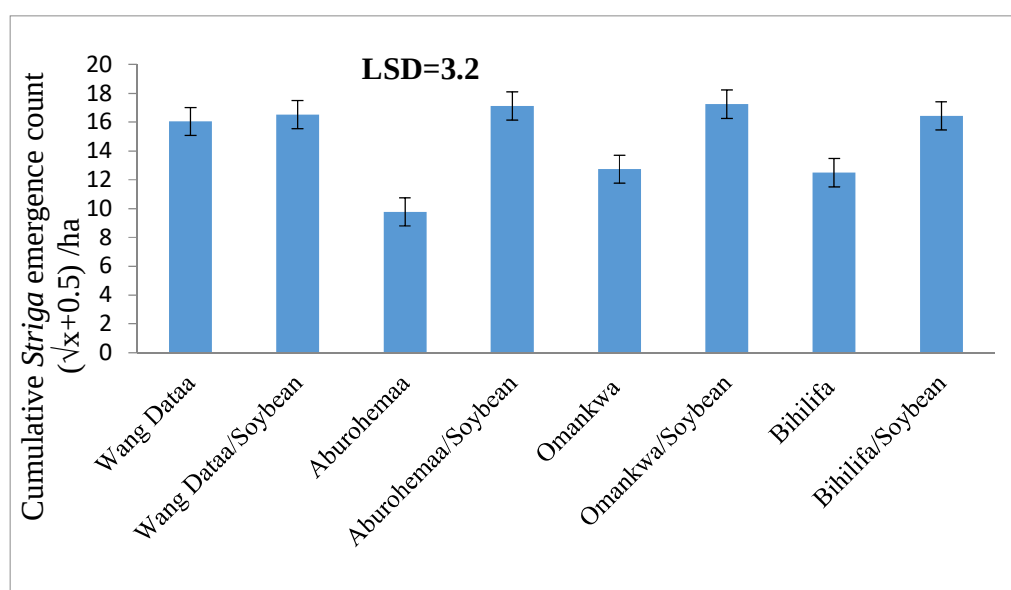


Figure 3: Effect of treatments on cumulative *Striga* emergence count at 12WAP. Bars represent SEM

4.5 *Striga* fresh weight and biomass

Significant differences were observed for fresh weight and biomass of *Striga* (Figure 4). At 12WAP, sole Wang data recorded the highest *Striga* fresh weight, followed by Omankwa intercropped with soybean, Aburohemaa intercropped with soybean, and then the least *Striga* fresh weight was recorded in sole Aburohemaa.



For the dry biomass of *Striga*, similar observations were observed as reported for fresh weight of *Striga* above with sole Wang data recording the maximum value of 46 g/ha and sole Aburohemaa being the minimum with 12g/ha.

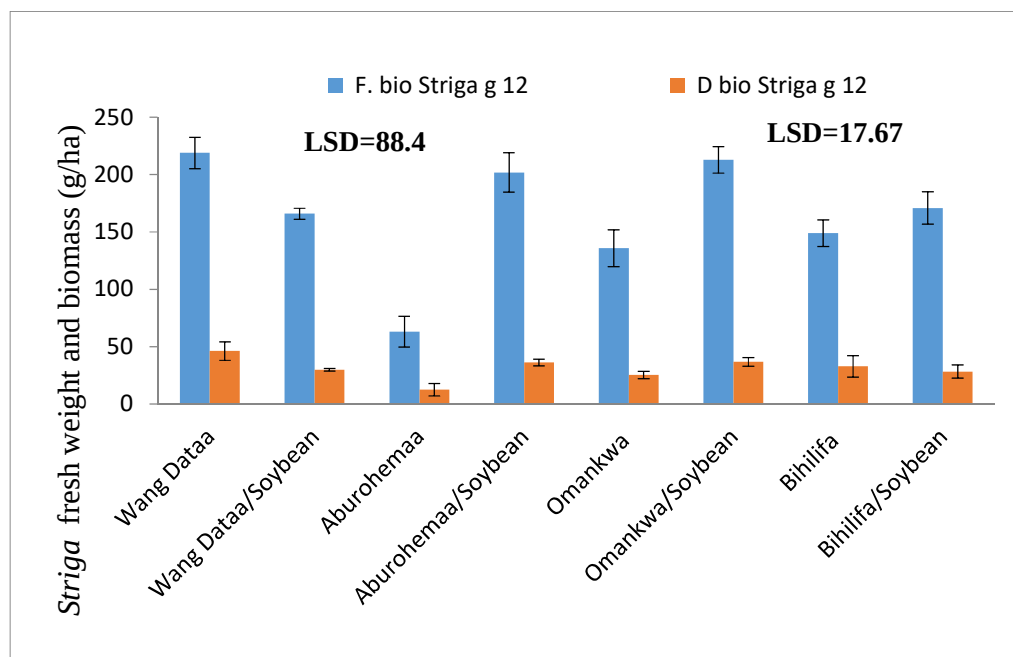


Figure 4: Effect of treatments on *Striga* fresh weight and biomass production at 12WAP. Bars represent SEM

4.6 Initial and postharvest *Striga hermonthica* seed bank

Initial *S. hermonthica* seed bank varied with plots and postharvest *S. hermonthica* seed bank was highly affected ($P < 0.001$) by the treatments (Figure 5). The initial *S. hermonthica* seed bank ranged from 133g - 187g for sole Omankwa and Bihilifa intercropped with soybean respectively.

The postharvest *S. hermonthica* seed bank revealed that minimum was 121g and maximum of 145g for sole Bihilifa and Bihilifa intercropped with soybean respectively (Figure 5).



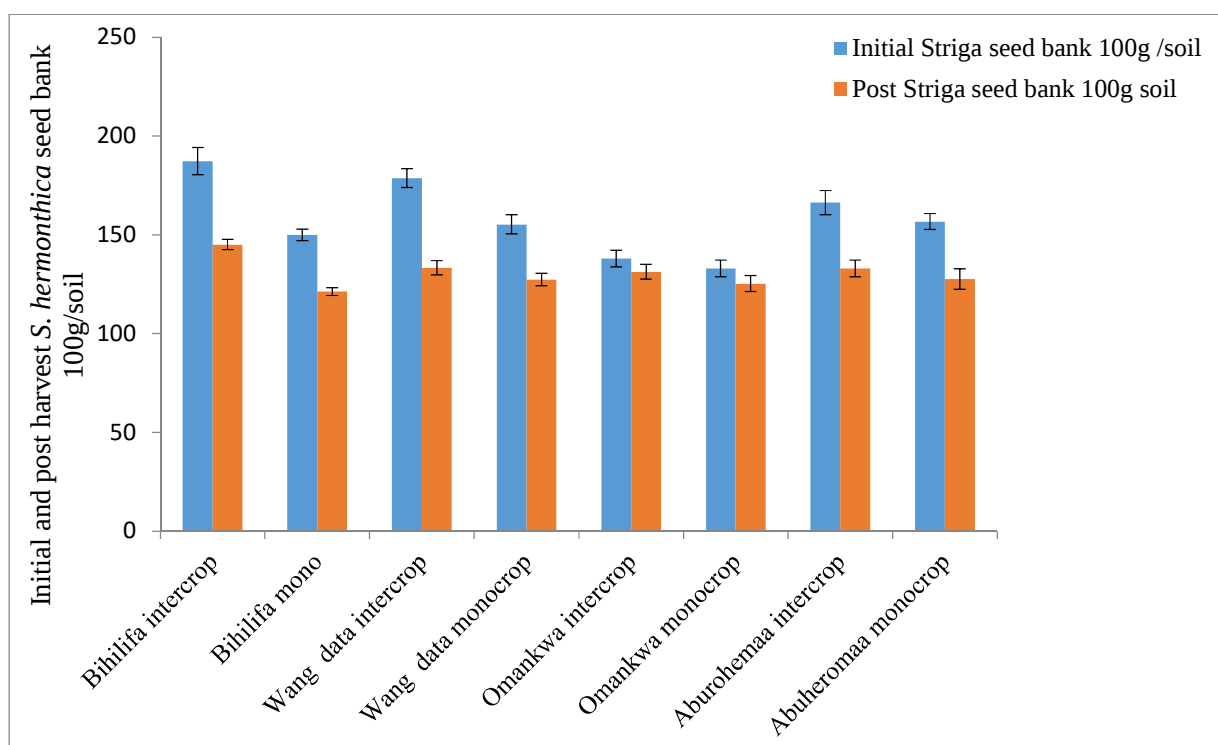


Figure 5: Effect of treatments on initial and postharvest *S. hermonthica* seed bank. Bars representing SEM

4.7 Percent reduction in *Striga hermonthica* seed bank

Maize with and without soybean (Afayak) varied in percent *S. hermonthica* seed bank reduction during the trial (Table 3). It was revealed that the percent reduction of *S. hermonthica* seed bank ranged from 5% - 26% of Omankwa without soybean and Wang data with soybean respectively.

Table 3: Percent reduction in *S. hermonthica* seed bank at Gore in 2016 trial

S/N	Treatments	Percent (%) reduction in <i>S. hermonthica</i> seed bank
1	Bihilifa without Afayak	19.0
2	Bihilifa with Afayak	22.5
3	Wang data without Afayak	18.1
4	Wang data with Afayak	25.7
5	Omankwa without Afayak	5.1
6	Omankwa with Afayak	6.0
7	Aburohemaa without Afayak	18.5
8	Aburohemaa with Afayak	19.9

4.8 Plant height of maize

Treatments exhibited significant effect ($P < 0.05$) at 7 and 9 WAP, but no significant effect ($P > 0.05$) at 3 and 5WAP on maize plant height. At 9WAP, the highest plant height was noted in sole Bihilifa (139.83 cm), followed by Wang data intercropped with soybean (135.83cm), Bihilifa intercropped with soybean (135.57cm), sole Aburohemaa (135cm), Aburohemaa intercropped with soybean (132.23cm), sole Wang data (132cm), Omankwa intercropped with soybean (130.27cm), and sole Omankwa (130.03 cm) (Figure 6).



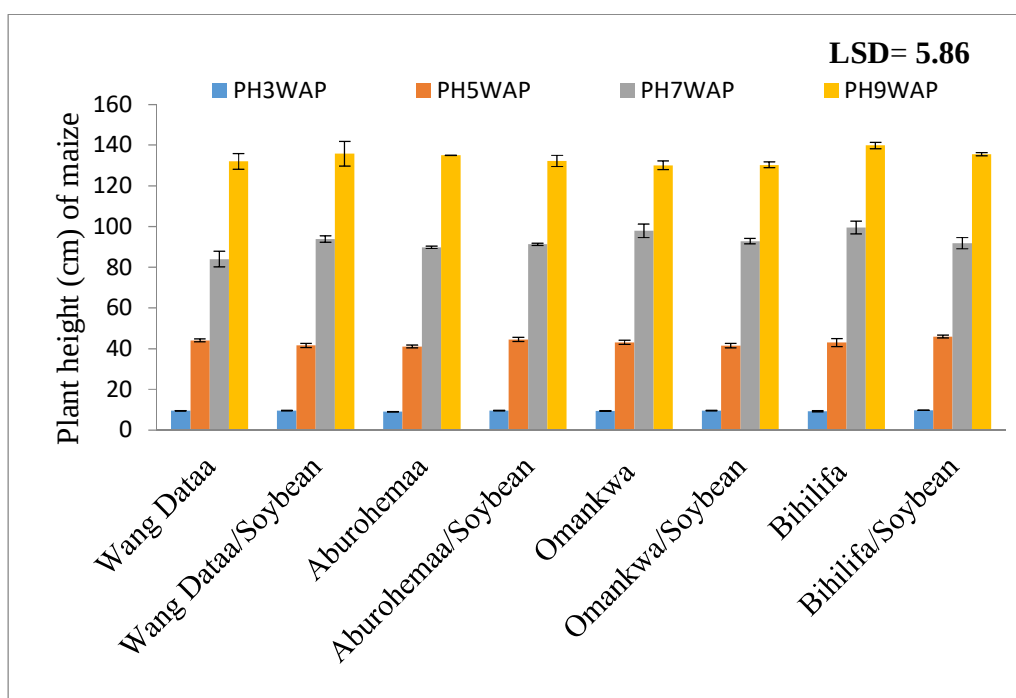


Figure 6: Effect of treatments on plant height of maize. Bars represent standard error of mean (SEM)

4.9 Maize plant stand at 3WAP and at harvest

The ANOVA showed that plant stand at 3 WAP and at harvest did not show significant difference ($P > 0.05$) among the treatments. At 3WAP, and at harvest, sole Aburohemaa recorded 21420 plants ha^{-1} whereas Bihilifa intercropped with soybean recorded 17106 plants ha^{-1} (Table 4).

4.10 Leaf count of maize

The analysis of variance indicated that there was a significant effect ($P < 0.05$) on number of leaves at 5 and 9WAP, but no significant effect ($P > 0.05$) at 3 and 7WAP.



At 9WAP, treatment means on number of leaves of maize were in the descending order: Bihilifa intercropped with soybean, followed by Omankwa intercropped with soybean and Wang data intercropped with soybean, sole Aburohemaa, Aburohemaa intercropped with soybean and sole Bihilifa, sole Wang data, and sole Omankwa (Figure 7).

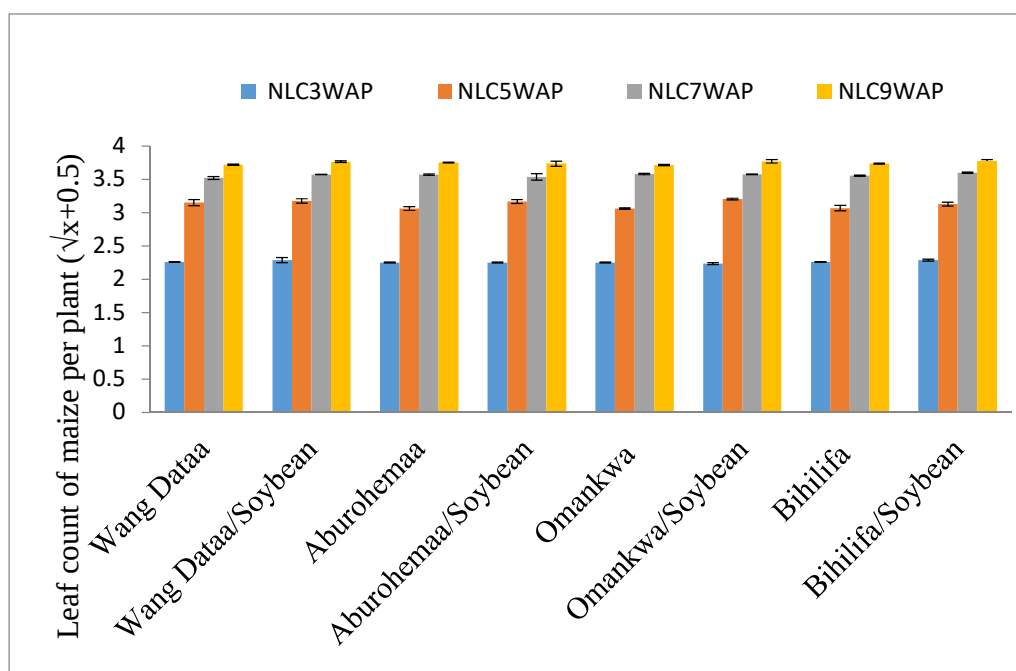


Figure 7: Effect of treatments on leaf count of maize/plant. Bars represent SEM

4.11 Leaf area (LAI) of maize

The ANOVA showed no significant difference on LA of maize plants at 7WAP. Maize leaf area index produced, ranged from 400cm² for sole Omankwa to 675cm² for sole Aburohemaa (Table 4).



4.12 Days to 50% flowering of maize.

Maize days to 50% flowering were influenced by treatment. Days to 50% flowering recorded on the different varieties varied from 53 - 56 days. The greatest number of days to 50% flowering was observed in Omankwa intercropped with soybean and sole Aburohemaa (56 days), whilst the lowest was recorded for Aburohemaa intercropped with soybean (53 days) (Figure 8).

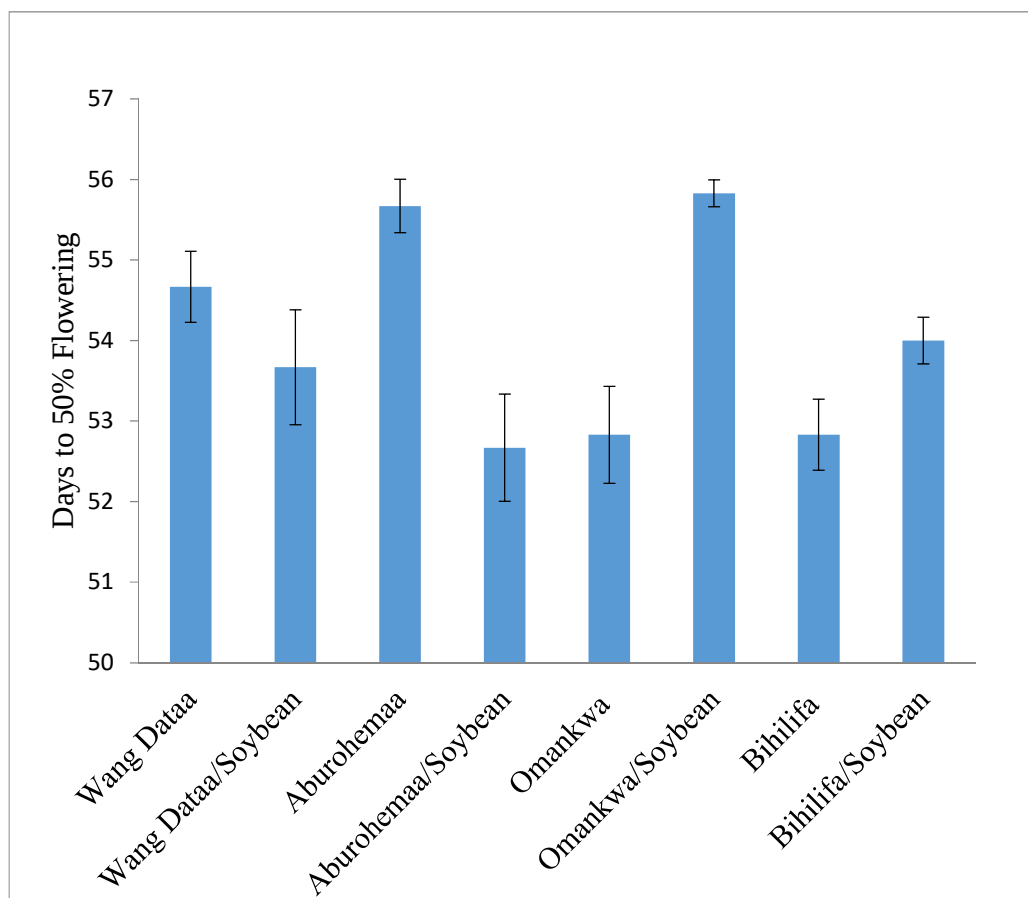


Figure 8: Effect of treatments on days to 50% flowering on maize. Bars represent SEM



4.13 Length of cob

The analysis indicated no significant difference ($P > 0.05$) on cob length among treatments. From Table 4, length of cob for the respective treatments ranged from 23.37 cm for sole Omankwa to 26.07 cm for Bihilifa intercropped with soybean.

4.14 Height of cob attachment

Height of cob attachment did not show significant difference. Treatment means ranged from 44.47cm for Wang data intercropped with soybean to 51.27 cm for Bihilifa intercropped with soybean (Table 4).

4.15 Number of cobs per plant.

The effect of treatments on the number of cobs per plant was not significant at 5% level of significance. Treatment means for all the treatments showed 1 cob per plant throughout (Table 4).



Table 4: Effect of treatments on length of cob, height of cob attachment, maize stand, number of cobs/plant, and leaf area index

Treatments	Length of Cob (cm)	Height of cob attachment (cm)	Maize Stand at 3WAP	Maize stand at harvest	No. of cobs/plant	LA of maize cm ²
Wang data	24.37	46.5	18633	18633	1	509
Wang data/soybean	23.87	44.47	19740	19740	1	590
Aburohemaa	23.93	48.1	21420	21420	1	675
Aburohemaa/soybean	25.37	49.73	20389	20389	1	506
Omankwaa	23.37	47.8	19740	19740	1	400
Omankwaa/soybean	24.93	49.5	21229	21229	1	419
Bihilifa	24.80	45.07	18709	18709	1	508
Bihilifa/soybean	26.07	51.27	17106	17106	1	506
Grand Mean	24.59	47.8	19621	19621	1	523
LSD (0.05)	2.35	7.57	4030.4	4030.4	*	157.5
P. Value	0.32	0.54	0.37	0.37	-	0.08
CV (%)	5.50	9.00	11.70	11.7	0	17.20

4.16 Straw weight of maize

The results indicated that treatments significantly ($P < 0.001$) affected straw weight of maize. The greatest straw weight was observed in Aburohemaa intercropped with soybean variety (Afayak) of 2088 kg/ha, followed by sole Aburohemaa of 1801 kg/ha,



whereas the rest of the six treatments showed similar weight, but sole Wang data recorded the lowest of 1391 kg/ha (Figure 9)

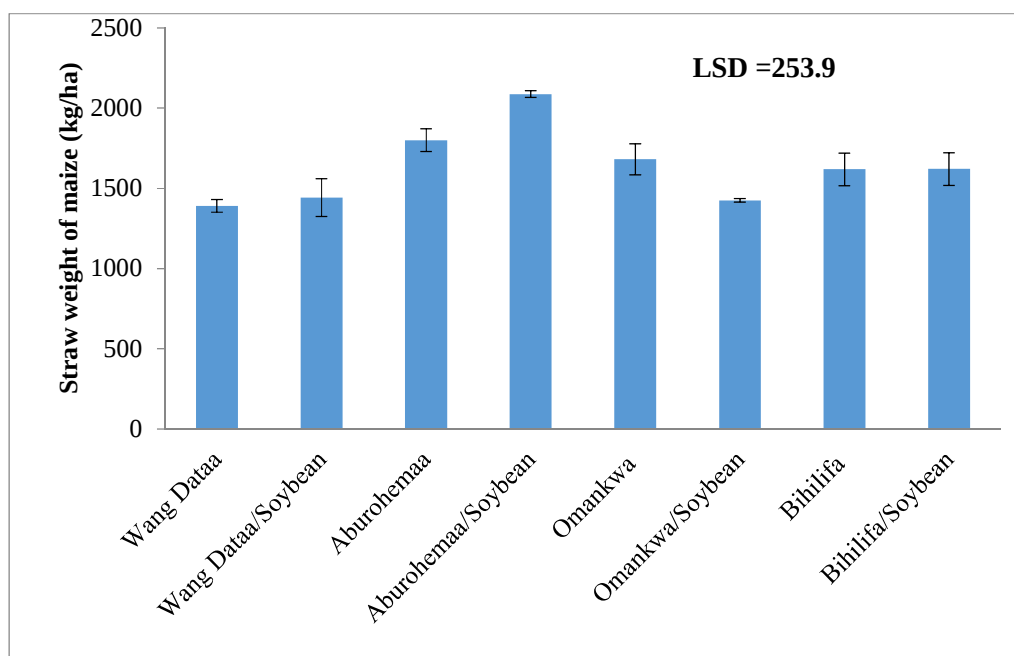


Figure 9: Effect of treatments on straw weight of maize. Bars represent SEM

4.17 Cob weight of maize

Maize cob weight showed significant difference ($P < 0.023$) among treatments. Bihilifa intercropped with soybean (1700kg/ha) supported the highest cob weight, followed by sole Omankwa and Wang data (1676 kg/ha), Wang data intercropped with soybean (1640 kg/ha), sole Aburohemaa (1580 kg/ha), Aburohemaa intercropped with soybean (1545 kg/ha), sole Bihilifa (1473kg/ha) which were similar to other treatments except Omankwa intercropped with soybean (1257 kg/ha) that had the least cob weight (Figure 10).



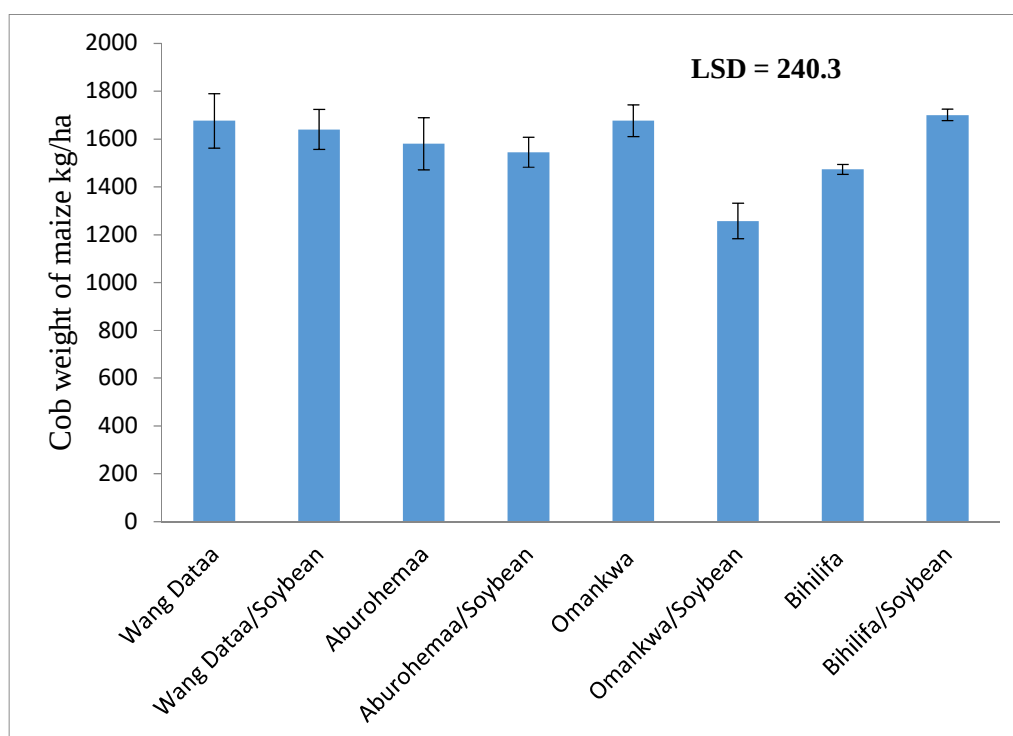


Figure 10: Effect of treatments on cob weight of maize. Bars represent SEM

4. 18 Grain yield of maize

The effect of treatments on grain yield of maize was significantly affected ($P < 0.027$) at 5% level of significance. It was observed that, Wang data intercropped with soybean recorded the greatest grain yield (1149kg/ha), followed by Omankwa intercropped with soybean (1137 kg/ha), Aburohemaa intercropped with soybean (1102 kg/ha), and then sole Omankwa (850kg/ha) produced the lowest grain yield (Figure 11).



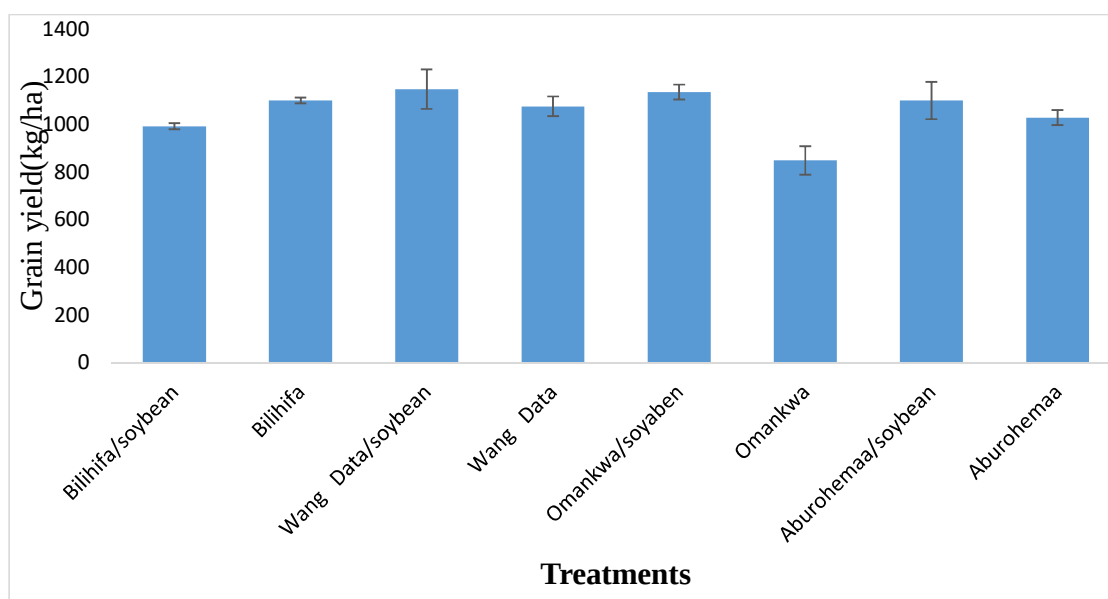


Figure 11: Effect of treatments on grain yield of maize. Bars represent SEM

4.19 Hundred seed weight of maize

There was no significant effect on hundred seed weight for both fresh and dry weight of maize among the treatments. On the fresh hundred seed weight, Wang data planted in sole recorded the highest of 23g, followed by Omarkwa planted in sole of 22g, sole Aburohemaa and intercrop, and Wang data intercropped had 19g each, and Omarkwa intercropped and Bihilifa intercropped had 17g each as the least (Figure 12).



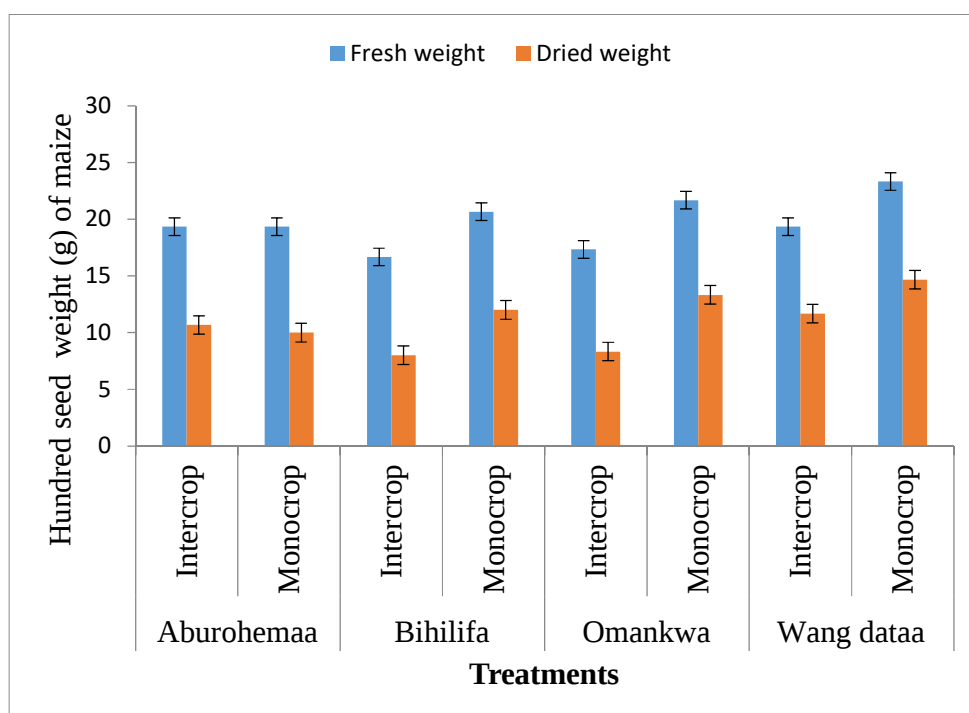


Figure 12: Effect of treatments on 100-seed weight of maize (fresh and dry). Bars represent SEM

4.20 Correlation analysis between *S. hermonthica*, growth and yield components of maize

The results for correlation analysis for plant height, cob weight, straw weight, *Striga* emergence count, and grain yield are shown in Table 5. Grain yield correlated positively with cob weight ($r = 0.966$) and straw weight of maize ($r = 0.102$). The *Striga* emergence count ($r = -0.235$) was negatively highly correlated with cob weight of maize.



Table 5: Spearman Correlation analysis among yield components and yield of maize

Parameter	Plant height 9WAP	<i>Striga</i> emergence count 12WAP	Straw weight kg/ha	Cob weight of maize kg/ha	Grain yield of maize kg/ha
Plant height 8WAP	1				
<i>Striga</i> emergence 12WAP	-0.2902ns	1			
Straw weight (kg/ha)	-0.0032ns	-0.2352ns	1		
Cob weight (kg/ha)	0.10296ns	-0.2351ns	0.08888ns	1	
Grain yield (kg/ha)	0.04523ns	-0.4087*	0.10242	0.96647***	1

4.21 Height of soybean

The results indicated that, there was no significant difference at 3 and 5WAP, but significant effect at 7WAP. At 3WAP, Bihilifa intercropped with soybean, Aburohemaa intercropped with soybean, and Wang data intercropped with soybean had almost the



same height and Omankwa intercropped with soybean produced the least height among the treatments. At 5WAP, Aburohemaa intercropped with soybean had the highest, followed by Wang data intercropped with soybean, and Omankwa intercropped with soybean both with similar height. The least was observed in Bihilifa intercropped with soybean. At 7WAP Bihilifa intercropped with soybean produced maximum height, followed by Omankwa intercropped with soybean, Aburohemaa intercropped with soybean and Wang data intercropped with soybean had similar results (Figure 13).

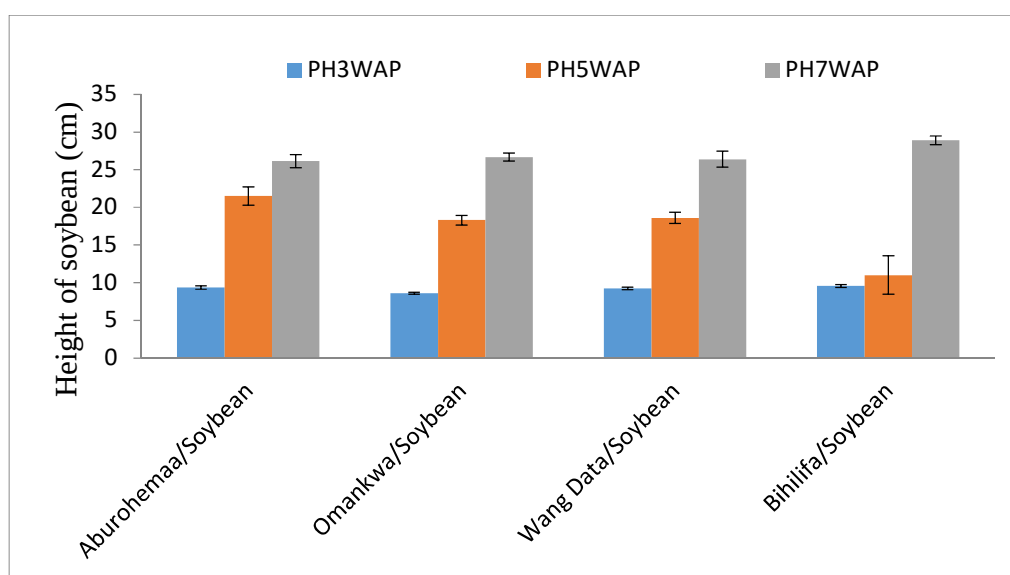


Figure 13: Effect of treatments on plant height of soybean. Bars represent SEM.

4.22 Leaf count of soybean

Leaf production had significant effect on soybean at 5 and 7WAP, but no significant effect at 3WAP. At 5WAP, Bihilifa intercropped with soybean produced numerically



greater number of leaves which was similar to Wang data intercropped with soybean, and Omankwa intercropped with soybean, whilst Aburohemaa intercropped with soybean produced the least number of leaves. Also, at 7WAP Bihilifa intercropped with soybean, Wang data intercropped with soybean, and Aburohemaa intercropped with soybean had similar maximum leaves count but Omankwa intercropped with soybean had the minimum count of leaves (Figure 14).

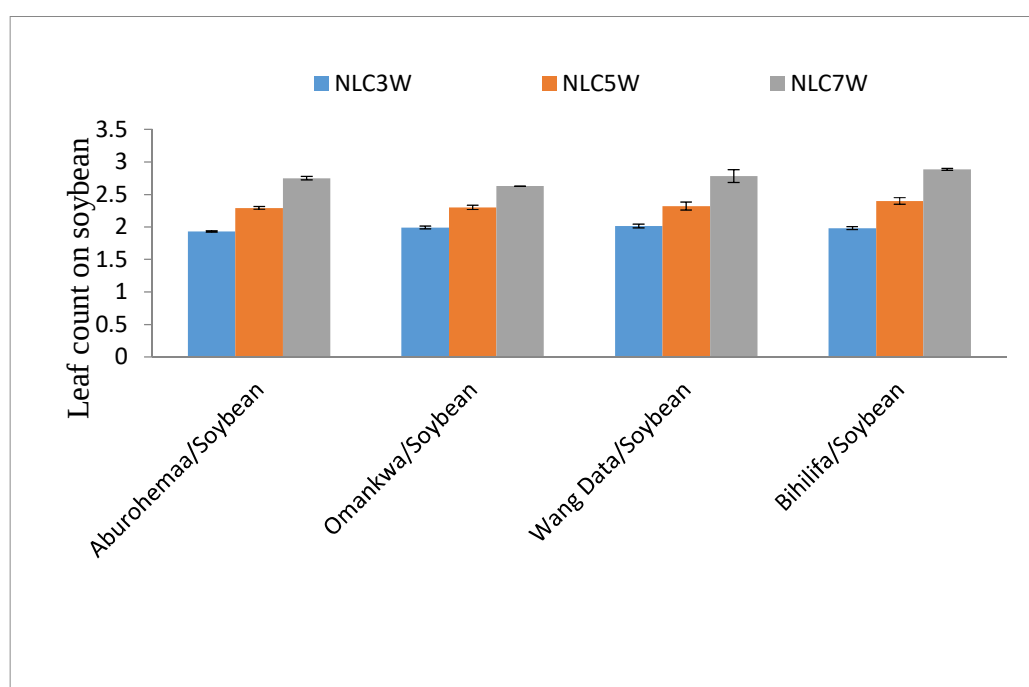


Figure14: Effect of treatments on leaf count of soybean. Bars represent SEM



4.23 Plant stand of soybean

The number of soybean plants stand per hectare was not significantly affected by the treatments. Plant stand per hectare ranged from 40053 (Aburohemaa intercropped with soybean) to 44903 (Omankwa intercropped with soybean) (Table 6).

4.24 Leaf area (LA) of soybean.

Treatments did not show significant effect on LA of soybean from the results. Result of leaf area of soybean plant at 9WAP is presented in Table 6. At 9WAP, Aburohemaa intercropped with soybean produced the greatest LA of 166 cm² whilst Wang data intercropped with soybean produced the lowest value of LA of 37cm².

4.25 Number of nodules per plant (NNP)

Treatments indicated no significant difference for number of nodule per plant of soybean. Root nodule number of the soybean variety (Afayak) that was counted and transformed ranged from 23 - 24 for Omankwa intercropped with soybean and Bihilifa intercropped with soybean respectively (Table 6).

4.26 Number of pods per plant (NPP)

The results of the number of pods per plant for the treatments are presented in Table 6. It was observed that Bihilifa intercropped with soybean had the highest number of pods per plant transformed (8.20), whilst the least (7.34) was Wang data intercropped with soybean which was similar to the other treatments.



4.27 Haulm weight of soybean

Soybean haulm weight was not significant at 5% level of significance (Table 6). Haulm weight from soybean of Omankwa intercropped treatment was 2191 kg/ha as the greatest among the treatments, followed by Wang data intercropped with soybean (1892kg/ha), Bihilifa intercropped with soybean (1832kg/ha), and Aburohemaa intercropped with soybean (1820 kg/ha).



Table 6: Effect of treatments on plant stand, number of nodules per plant (NNP), Haulm weight, number of pods per plant (NPP), and leaf area of Soybean.

Treatment	Soybean	SQRT	Haulm	SQRT	
	Stand at	Nodule	weight	Pods/ha	LA(cm ²)
	3WAP	Count/ha	kg/ha		
		10WAP			
Aburohemaa/soybean	40053.00	23.78	1820.0	7.46	166.0
Omankwa/soybean	44903.00	23.14	2191.0	7.34	44.0
Wang data/soybean	42058.00	23.83	1892.0	7.67	37.0
Bihilifa/soybean	42574.00	24.17	1832.0	8.20	51.0
Grand Mean	42397.00	23.73	1934.0	7.67	74.0
LSD (0.05)	7246.20	4.6.00	313.0	1.07	137.2
P. Value	0.49	0.95	0.08	0.30	0.17
CV (%)	8.60	9.70	8.1	7.00	92.2

4.28 Grain yield of soybean

Grain yield of soybean varied statistically (Figure 15). Bihilifa intercropped with soybean supported the greatest grain yield of 1173kg/ha, followed by Wang data intercropped with soybean of 970kg/ha, Aburohemaa intercropped with soybean produced 898kg/ha,



which was similar to Omankwa intercropped with soybean with the lowest yield of 862kg/ha.

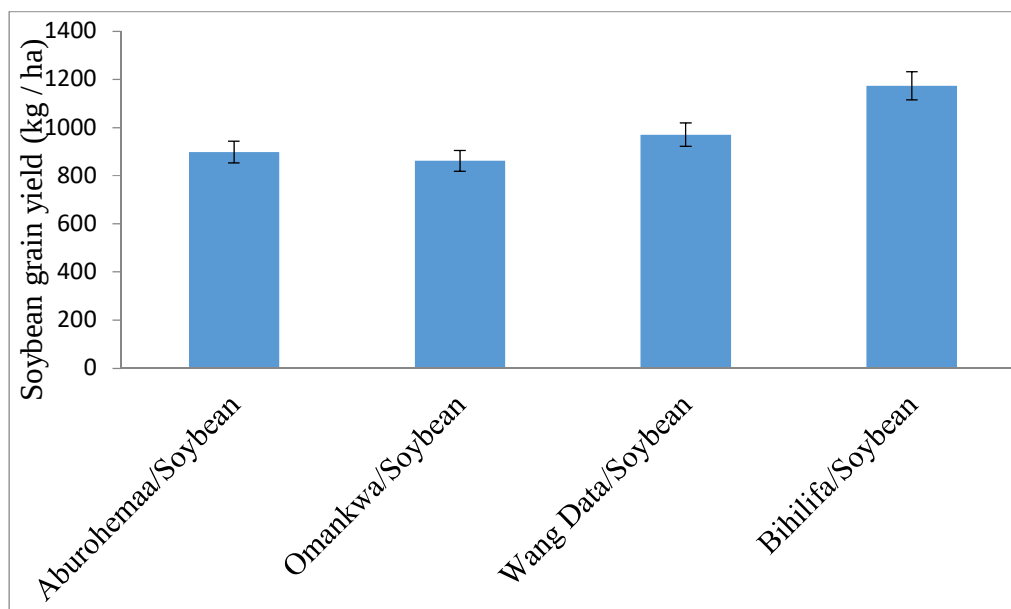


Figure 15: Effect of treatments on soybean grain yield. Bars represent SEM



CHAPTER FIVE

5.0 DISCUSSION

5.1 *Striga* emergence count

Significant difference for *Striga* emergence count at 12WAP might be due to the influence of the resistant/tolerant maize varieties and the soybean variety (Afayak) used. The high *Striga* numbers in some of the treatments might be attributed to high initial *Striga* seed bank at the site. This high *Striga* seed bank might lead to more *Striga* emergence as compared to low *Striga* seed bank in the soil. The higher number of *Striga* in some of the plots might also be due to variation in soil fertility where some plots might have low soil fertility. *Striga* thrives well in less fertile soils as supported by Cardoso *et al.*, (2010) who reported that one of the witch weed most contributing factors for development is low soil fertility and cropping systems in SSA with no external inputs.

Reduced emergence of *Striga* in some of the treatments in the current study implies that, reduced germination of *Striga* or reduced attachment of germinated *Striga* to roots of the host plant, or both. Because *Striga* is an obligate parasite, interactions between *Striga* and its host plays a crucial role in survival of the parasite, if this interaction was disrupted, it might be a beneficial approach for integrated management of this parasite. Differences in production of *Striga* stimulants are known to occur between crop cultivars (Hesse *et al.*, 1992), and that may be the cause for reduced *Striga* emergence in some of the treatments in the current study. The low number of *Striga* plants in some of the treatments could be due to their ability to show some levels of resistance to the parasitic weed, which reduced the extent of severity of *Striga* infestation. This is supported by a baseline study carried



out by Ndwiga *et al.*, (2013) looking at the extent of *Striga* infestation on maize grown in Western and Nyanza provinces. It was also observed that, some maize plots intercropped with soybean resulted in high numbers of *Striga* emergence count than some of the maize plots that were sole cropped (Figure 2). This was probably because of the soybean variety (Afayak) which has the ability to cause germination of *Striga* seeds but do not support it subsequent growth and development. This present study is not in line with Mashark *et al.*, (2006) who reported that the maize varieties grown in Ghana under intercropping supported fewer *Striga* infestation compared to those grown in sole cropping.

It was interesting to note that, the *Striga* higher numbers in germination or emergence did not show any negative effect on the crops which might be due to maize resistance/tolerance level to the witch weed. According to Ejeta and Butler (1993) who observed that crops such as cowpea and soybean lured *Striga* seed germination but did not support its subsequent growth and development. Nevertheless, this is in contrast with research by Carson (1989) who reported that intra row intercropping of sorghum with crops reduced the density of *Striga hermonthica*. Comparing to maize plots with sorghum plots, sorghum plots were observed to have the lowest *Striga* emergence. This could be as a result of low amount of exudates (*Strigolatum*) released by the crop to stimulate *Striga* seeds to germinate.

On the other side, some plots with sole maize exhibited resistance to *S. hermonthica* by supporting the lowest number of *Striga* plants germination unlike some of the maize-soybean intercropped with greatest number of *Striga* emergence. Possible reason for this could be due to *Striga* seeds which did not germinate because of absence of chemical



stimulant. Also, the *Striga* seeds will not germinate unless they have been conditioned, that is., are no longer dormant and are exposed to the right environmental conditions for germination. This result agrees to that of Lagoke and Isah (2010) who reported that nitrogen reduced the severity of *S. hermonthica*. It also agrees with the findings of Ejeta *et al.* (1997) who reported that maize resistance to the *Striga* is the eventual expression of a series of interactive events between the parasite and its hosts. Similarly, Ejeta *et al.* (1992) and Doggtt (1988) reported that resistant crop genotypes supports significantly fewer emerged *S. hermonthica* plants. Besides, this study confirmed with the findings of Ejeta *et al.* (1992) who reported that resistant varieties effectively reduced the *Striga* with and without other options, indicating that host plant resistance alone could be used in situations where integration of all options is impossible.

5.2 Cumulative *Striga* emergence count

The highest cumulative *Striga* count was recorded in Omankwa intercropped with soybean, followed by Aburohemaa intercropped with soybean, and Wang data intercropped with soybean as compared to sole maize treatments (Figure 4). Differences observed in cumulative *Striga* emergence count might be due to initial *Striga hermonthica* seed bank load which will lead to more *Striga* germination with a suitable host translating in higher cumulative emergence *Striga* count.

Also, it might be that the treatments (the four maize varieties and soybean) had caused more *Striga* emergence in some of the plots which led to more cumulative *Striga* count in some treatments. Some legumes have the ability to trigger *Striga* seed to germinate but do not support its growth and development just like the Afayak (soybean), which has



been developed for the purpose of stimulating suicidal germination of *Striga* (CSIR-Savanna Agricultural Research Institute, 2012). Ejeta and Butler (1993) also observed that crops such as cowpea and soybean induced *Striga* seed germination but did not support its subsequent growth and development.

The shading effect from the plants might also cause some less cumulative *Striga* count in some treatments than others. This is in line with previous report that smothering effects of soybean plants, might have created a microclimate that could have affected the emergence of *Striga* plants (Oswald *et al.*, 2002; Emechebe and Ahonsi, 2003; Gbèhounou and Adango, 2003; Kuchinda *et al.*, 2003; Olupot *et al.*, 2003). Carson (1988) also reported that the spreading vegetation of non-host crops (trap crops) smothers emerging *Striga* plants thereby reducing its vigour. These two factors are detrimental to the growth and development of *S. hermonthica* plants. *Striga hermonthica* transpires less when shaded, thereby reducing the amount of nutrients and water drawn from the maize (Stewart and Press, 1990). In the current study, Aburohemaa intercropped with soybean produced the highest *Striga* cumulative count followed by Wang Data intercropped with soybean, and sole Aburohemaa produced the lowest. So the Afayak (soybean variety) intercropped with any of the four maize varieties gave strong evidence of the synergy between the *Striga* tolerant maize varieties and the soybean in promoting *Striga* emergence for accelerated *Striga* seed bank depletion

The number of *S. hermonthica* plants that emerged in some of the intercrops and in the mono crops at the site during the season indicated a reduced potential for overall flower and capsule production and consequently, a reduced capacity of increasing the *S.*



hermonthica seed bank in the soil. The current study indicated that, mono cropping of cereal hosts of *S. hermonthica* with little or no specific measures against this witch weed would lead to accumulation of huge seed banks in the soil. Among the suggested methods in combination with others, to reduce *Striga* seed banks, is the use of trap crops such as cotton, soybean (Sauerborn *et al.*, 2000) and cowpea (Gbehounou and Adango 2003) in association with cereals. An efficient trap crop stimulates the germination of many *Striga hermonthica* seeds as possible in the soil.

5.3 *Striga* fresh weight and biomass

From figure 3, the analysis indicated significant differences on *Striga* fresh weight and *Striga* dry weight among all the treatments. Greater number of *Striga* biomass was observed in Wang data planted sole, Wang data intercropped with soybean, sole Bihilifa, and sole Omankwa. The greater *Striga* biomass might be due to initial *Striga* seed bank variations at the site and the more the seed bank the more seeds will germinate with suitable hosts, hence, translating to greater *Striga* biomass. The greater *Striga* biomass might also be due to high crop density with high host and soybean root surface area might lead to high number of *Striga* seed germination and later greater biomass. According to Gurney *et al.*, (1999), the level of *Striga* biomass on a host influences host productivity, but added that the relationship is non-linear; that is a point is reached where host grain production is independent of parasite biomass. The greater *Striga* biomass in some of the plots could also be due to variation in soil fertility status of the site as *Striga* thrives well in soils with poor fertility. So plots disadvantage with good soil fertility will have more *Striga* germinating resulting in greater *Striga* biomass



The reduction in *Striga* biomass in some of the treatments could be due to reduction in number of *Striga* plants emerged which might also be due to the differences in the initial *Striga* seed bank, and soil fertility.

Though *Striga* emerged in all the plots, but treatments did not have any *Striga* symptoms. It implied that these treatments had more tolerance level to *S. hermonthica* infestation. This result agrees with Gurney *et al.*, (1999) who observed that highest *Striga* infestation did not necessarily translate into the least yield with resistant varieties.

Generally, the results indicated reduction of *Striga* biomass in intercrop maize and increase for the sole maize which might be due to the shading effects. This observation is in line with Kureh *et al.*, (2006) who reported that reduction may be due to shading effects from the maize – soybean intercropped plots. Intercropping reduced the *Striga* biomass by 25-65% and 10-80% during the first and second season respectively (Odhambo, 2009).

In fresh weight of *Striga*, sole Wang Data had 46g/ha, followed by Omankwa/soybean (36g/ha) similar to Aburohemaa/soybean (36g/ha) whilst sole Aburohemaa had the least (12g/ha). The dry weight of *Striga* followed a similar trend in the treatments in fresh weight of *Striga*. It still means that those treatments were highly tolerant to *Striga* negative effects because crop growth was not affected.

5.4 Initial, postharvest, and percent reduction in *Striga hermonthica* seed bank

Striga hermonthica seed bank rapidly increases in subsequent cropping seasons when suitable host plants (crops or weeds) grow in the field (Lopez-Granados and Garcia-



Torres, 1999). It was observed that *S. hermonthica* seed bank before planting varied across all the experimental plots, but postharvest *S. hermonthica* seed bank indicated highly significant difference. The high seed bank load at before planting or harvest might be due to the level of *S. hermonthica* plants that flowered and produced seeds previously. This is in line with Ejeta and Gressel, (2007) who reported that *Striga* seed bank is determined by the level of *Striga* plants that flower and produce seeds, coupled with lack of suicidal germination. The high seed bank load may also be favoured by mono cropping because mono cropping of cereal hosts with little or no specific measures against *Striga* would lead to huge amounts of seeds accumulating in the seed bank.

Though, *S. hermonthica* seed bank was high at the initial stage but at the postharvest and percent reduction in *S. hermonthica* seed bank had reduced between 5% - 26% across all the treatments (Figure 5 and Table 2). The decreased number of *S. hermonthica* seed bank in the maize/soybean intercrop may be attributed to the suicidal germination caused by the germination stimulant produced by the soybean (Afayak) roots. This is in line with De Groote *et al.*, (2010) observation that the use of trap crop such as soybean triggers suicidal germination of *Striga* and therefore reduces the *Striga hermonthica* seed bank in the soil when intercropped with maize. In addition to being a trap crop, soybean provides shade which smothers the *Striga* thereby reducing its vigour.

In the current study, germination stimulants differences within the four maize cultivars might also be the cause of the *Striga* seed bank load differences which is being supported by Hesse *et al.*, (1992) observation that differences in production of *Striga* germination stimulants are known to occur between crop cultivars. This result indicated that these



Striga tolerant maize varieties when planted sole can help reduce *Striga* seed bank in *Striga* endemic areas in the near future, as more will germinate but its growth and development is not supported. The reduced *S. hermonthica* seed bank in the soil in both cropping systems during the 2016 cropping season at Gore in the field means a reduced potential for overall flower and capsule production and, consequently, a reduced capacity of increasing the *S. hermonthica* seed bank in the soil. An effective management approach for *Striga* should aim, among other things, to reduce and eventually deplete the soil seed bank.

5.5 Plant height and stand of maize

The results revealed that maize plant height differences were not significant at 7 and 9 WAP. The differences in plant height as demonstrated by the four maize varieties at 7 and 9WAP might be as a result of the environmental conditions that favoured the performance of some treatments. As indicated by Eugen Ulmer, and Stuttgart (2006), it is important to choose the best adapted resistant cultivar for every location as resistance is often regional and also performance depends on environmental conditions. It could also be the genetic makeup (that is gene for height) of the varieties that led to their outstanding performance in height.

The present study suggested that there is indeed the existence of genetic differences among the maize varieties because the genetic materials belong to different pool. Similar results had been reported by Raouf *et al* (2009), where significant plant height differences among maize cultivars. In conformity with this result, Konuskan (2000), and Gozubenli *et al.*, (2001) reported a considerable varietal variation for plant height of maize cultivars.



Presence of *Striga* in the experimental plots did not reduce the height of maize. Although, *Striga* reduces cell elongation as it takes photosynthesis away from the maize leading to shorter maize internodes and stunted growth, but these symptoms were not observed on the plants proven. Plots that were intercropped most had similar plant height which might be due to environmental factors and also *Striga* did not have negative effect on the crops as the roots of *Striga* were attached to the roots of soybean. This agrees with Khan *et al.*, (2001, 2002, and 2006), who reported that intercropping sorghum and maize with legume crop especially *Desmodium spp*, significantly enhanced both plant height and grain yield in maize.

The plant population per unit area at harvest is one of the most important yield contributing factors to maize. The results showed that plant stand count of maize was not significantly affected by treatments. It was observed that in plant stand of maize all the maize varieties used germinated well. Also, it means birds and rodents did not remove the seeds/seedlings at the initial stages. This result was not in agreement with the findings of Ahmad *et al.*, (2012) who reported that both plant population density and variety showed significant difference in final plant population of maize. The differences in the two studies might be as a result of genetic materials used or might also be that, some of the seeds used in the study of Ahmad *et al*, (2009) were not viable.

5.6 Leaf count of maize

The number of maize leaves indicated significant effect among the treatments. It was observed at 9WAP that the maize intercrop indicated slight differences of leaf count to the sole maize at all the sampling occasions. Experimental plots in which there was *Striga*



emergence, the leaves of the maize did not show any symptom as a result of *Striga* infestation. This did not correspond with the findings of Parker and Riches (1993) who reported that infestation by *S. hermonthica* resembled those of drought stress, chlorotic symptoms or yellow blotches and wilting of the maize plant even when the soil is still wet. In other words, it might be so as a result of genetic difference of the various maize varieties and Afayak that gave these varieties advantage to performed better under the stressed condition of *Striga*.

Also, initial competition that might have caused the production of taller plants also led to increased leaf production as the two processes go together as observed in Bihilifa intercropped with soybean. Minimum leaf production was observed in sole Omankwa and the maximum was in Bihilifa/Afayak intercrop which might be due to more nutrients from the soybean plants.

5.7 Leaf area (LA) of maize

The leaf area (LA) describes the size of the assimilatory apparatus of a plant stand and is the main factor that determines the rate of dry matter production in a closed stand. It also reflects differences in productive efficiency between crop varieties (Kvet *et al.*, 1971).

The non-significant difference of leaf area observed in the present study conducted could be due to the genetic makeup of the varieties, environmental conditions, and cropping systems used. Twala and Ossom (2004) also did not find any significant differences in LA between maize mono cropped and maize intercropped with legume crops such as sugar beans, soybean or groundnuts. The variable differences in LA exhibited between treatments at 9WAP might have been due to genotypic characteristics and also



environmental factors. *Striga* did not have any effect on LA because *Striga* signs were not observed on the leaves. This is in line with Adu *et al* (2014) that these four maize varieties are resistant/ tolerant to *S. hermonthica* infestation.

5.8 Days to 50% flowering of maize

High significant difference recorded among the treatments on days to 50 percent flowering might be due to the varieties used with different genetic make-up, or due to environmental conditions within treatments, and /or inter-specific competition within intercropped maize and sole cropped maize at the site. There was no reduction or addition of days to flowering which could have been due to higher level of *Striga* on physiology of maize plants during susceptible vegetative stage up to flowering initiation. The number of days to 50% flowering on maize – soybean intercrop and sole maize ranged from 53 - 56. The higher value recorded in this study might be due to difference in genotypes used and variation in the levels of *Striga* infestation.

Franke *et al.*, (2006) did a similar experiment and recorded days to 50% anthesis ranging from 58 to 94 and the mean was 70. The higher mean value recorded in this study might be due to difference in genotypes used and the variation in levels of *Striga* infestation.

5.9 Number of cobs per plant

There was no significant difference observed in the number of cobs per plant. This result was in line with that of Raouf *et al.*, (2009) who reported that plant population and maize varieties had no significant variation with respect to number of ears per plant. However, the number of cobs per plant is a genetically controlled factor but environmental and



nutritional level may also influence the number of cobs per plant. The more number of cobs per plant lead to more grain yield.

5.10 Length and height of cob per plant

There was no significant difference on the length and height of cob per plant among the maize varieties. This might probably be because of nutritional level in the soil and genetic make-up of the maize varieties used. Bihilifa intercropped with soybean gave the highest ear length (26.07cm), while sole Omankwa cropped gave the lowest (23.37cm) ear length. This could be because of genetic variation among the four maize varieties and/or environmental conditions or nutritional level in the soil at the location. This result is not in line with the findings of Abuzar *et al.*, (2011), where they reported significant differences among the maize varieties for ear length.

5.11 Straw weight of maize

The study indicated that there was significant difference in straw weight of maize. The highest straw weight was observed in Aburohemaa intercropped with soybean, followed by sole Aburohemaa, but sole Wang data gave the lowest straw weight. This could be as a result of the highest inherent tolerance of Aburohemaa to *Striga* infestation. This is in line with Kling *et al* (2000), who reported that inbred lines and hybrids that have host plant resistance are able to reduce parasite emergence and effects under artificial infestation with *Striga hermonthica*.

In this present study, the marginal difference recorded by the treatments could be due to the ability of varieties (host plant) to prevent attachment of the parasite. This is supported



by Badu-Apraku *et al* (2007) who stated that host plant resistance is the plant's ability to prevent attachment of the parasite or to kill the attached parasite resulting in reduced emergence. However, some of the maize intercropped and monocropped, showed similar straw weight and this could be the tolerance nature of the four maize varieties and Afayak that reduced the ability of the *Striga* attaching the plants and using its nutrients. The result is in contrast with the findings of Gurney *et al* (1996) who said that, *Striga* infestation resulted in a large reduction in host straw biomass and eventually grain yield loss.

5.12 Grain yield of maize

Grain yield of maize was significant among the treatments (Appendix 18). The high grain yield displayed by sole Wang data than the other treatments suggest that, there was less competition for nutrients for sole Wang data. Also, this might be because of varietal difference among the varieties, plant density, number of cobs per plant, straw weight, and other yield components. Grain yield of maize difference is in line with McCutcheon *et al.* (2001), who reported significant differences among maize cultivars. For example, the variety Wang data gave the lowest straw weight but with reference to the grain yield, it gave the highest grain yield. This might be that less photosynthetic products were directed to the production of vegetative parts than to the maize seed. Generally, the yields of maize in the intercrops were similar to those in the sole crops. This attested to the fact that maize components that positively correlate to maize grain yield were not affected by *Striga*, as *Striga* appeared in both cropping patterns and no symptoms of the witch weed were observed. The maize varieties were really tolerant to *Striga* which is in line with



Adu *et al.*, (2014) that the newly developed maize genotypes by CSIR – SARI and CSIR –CRI are resistant / tolerant to *Striga* infestation and these varieties include Wang–Data, Bihilifa, Omankwa, Abontem, and Aburohemaa.

Mutungamiri, (1999), also concluded that intercropping has no negative effect if maize population is not reduced below 37 000 plant/ha. In intercrops usually the cereal has a competitive advantage since they are tall and benefits from maximum photosynthetic active radiation (PAR) reaching the foliage and hence they may not experience yield declines. In other studies, yield declines of 11% by Ofori and Stern (1987), 15% decline by Silwana and Lucas (2002) 12 – 22% declines by Mashingaidze (2004). Maize in the pure stands and in intercrop yielded similarly the same. The fact that there was no increase in maize yields as a result of intercropping with soybean indicated that it was unlikely that soybean could provide a nitrogen advantage to associated crops within an intercropping pattern in the same season. But Giller (2001) also reported that there was little evidence for direct transfer of significant amounts of nitrogen between roots of legumes and cereals in mixture. The nitrogen advantage would benefit the proceeding crop after harvesting the legume (Mpeperekki and Giller, 1998). There was no reduction in maize yield due to intercropping which was probably because of lack of competition between the maize and soybean. The two crops extracted nutrients from different zones in the soil profile since they have different rooting depths so competition for nutrients could have been minimal or non- existent.



5.13 Relationship between *S. hermonthica*, growth, and yield components of maize

The results of correlation analysis revealed that grain yield positively and highly correlated with dry cob weight of maize, and straw weight of maize. The positive and highly significant correlation exhibited with some characters of maize varieties might be due to the influence of treatments and fertilizer application. This result is in line with the finding of Pearl (2012) who reported in his study a significant correlation between grain yield and 1000 seed weight, days to mid anthesis, days to mid silking, cob aspects and cob length, ears per plant, grain length, grain width, plant height and shelling percentage. Positive ($P < 0.05$) correlation and highly significant ($P < 0.01$) correlation between grain yield and yield components and harvest index of maize were also reported by Inamulah *et al.* (2011). However, *Striga* emergence count showed negative, not significant and negative correlation with cob weight of maize. The observed correlation results obtained with *Striga* parameters probably could be attributed to the genetic characteristic of maize varieties.

This result is in consonant with the finding of Kim and Adetimirin (1997), who reported significant and negative correlation between grain yield of maize and *Striga* damage rating. Similar observation was made by Haron *et al.*, (2012), who cited highly negative correlation between grain yields of maize and *Striga* damage rating. From this study, susceptible maize variety created an enabling environment for *Striga hermonthica* to compete favourably with the crop which depresses the crop growth and subsequent poor yield at harvest, but in contrast, the *Striga* resistant/tolerant maize varieties supported lower *Striga* incidence which lead to greater yield.



5.14 Soybean plant height

In cereal-legume intercropping systems, the subordinate legume crops are typically suppressed in their growth and grain yield due to resource competition or the shading effect of dominant cereal crop (Keating and Carberry, 1993). The current study revealed the growth suppression of the intercropped soybean. Plant height was affected by the treatments at all growth stages. It was observed that, Bihilifa intercropped with soybean produced the tallest at 7WAP though it was the shortest at 5WAP and the rest of the soybean intercropped had similar heights at all sampling stages. However, soybean intercropped might have effective utilization of available environmental resources like light, water, and nutrients as a result of less plants competitive effect. This might have accounted for the greater plant height for the growth periods.

5.15 Leaf area (LA) of soybean

Soybean intercropped with Aburohemaa recorded higher LA whilst the lowest value was in soybean intercropped with Wang data. The variable differences in LA exhibited by the treatments at 9WAP might have been due to genotypic characteristics and also environmental factors. Like the soybean /Aburohemaa, the highest LA might be that the soybean was not disadvantage by the maize crops in the field. However, the soybean intercropped with maize exceeded the minimum recommended LA value of 3.5 - 4.0 by 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 corroborate with the statement by Malone *et al.*, (2002) that early maturing soybean



genotypes achieve minimum LA values required for maximum potential yield by the early reproductive stage of growth.

5.16 Soybean nodule count/plant

It was observed that Afayak intercropped with all the four maize varieties had similar values of nodules produced (Table 5). The similar means obtained could be due to the capacity of the Afayak to compete with the respective treatments for nutrients and also the application of the inoculant. The results of this study was similar to those reported by Okogun *et al.*, (2005) and Chemining'wa *et al.*, (2007) who reported no significant increase in nodulation following *rhizobia* inoculation. The slight increase in nodule number/plant and active nodules after the application of inoculant may be due to its ability to supply some plant nutrients; P, K, Ca, Mg and S. This accounts for the improvement in nodulation since soybean plant requires an adequate supply of major elements for effective nodulation (Musandu and Ogendero, 2001).

Adequate moisture in the soil enabled rhizobial activities below the roots of plants and later led to the number of nodules produced by Afayak. Soybean plant may divert 20 – 30% of its photosynthates to production of nodules instead of other parts functions when nodules are actively fixing nitrogen (Mir, 2012). It might also be that nitrogen in the soil 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.

5.17 Number of pods per plant

The number of pods per plant of soybean (Afayak) did not show significant difference. Pod number per plant is one of the most important yield components of soybean. But



experimental plots of Bihilifa intercropped with soybean, Wang data intercropped with soybean, Aburohemaa intercropped with soybean, and Omankwa intercropped with soybean had 8.20, 7.67, 7.46, and 7.34 pods per plant respectively as the transformed means. The result might be due to genetic factors of the soybean variety (Afayak) that had contributed to no significant effect in pods and might be due to the response of the inoculation and environmental conditions at the site. This agrees with Sable *et al.*, (1998) and Hernandez and Cuevas (2003) who also reported that increased numbers of pods per plant is response to inoculation. Also, the Bihilifa intercropped with soybean that had the highest number of pods per plant might be that there was less inter-specific competition for (light, water, and nutrients) and shading effect imposed by tall maize plants than the other treatments. 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. The reason being, that the amount and quality of solar radiation intercepted by the canopy is important determinant of yield components.

5.18 Haulm weight of soybean

Haulm weight of soybean did not vary significantly among the plots of soybean-maize varieties intercropped. This could be due to variation in leaf positioning on the plant which reduced suppression of soybean in some plots of the maize. Omankwa intercrop was 2191 kg/ha whilst Wang data intercropped, Bihilifa intercropped, and Aburohemaa intercropped with soybean gave 1892, 1832, and 1820 kg/ha of soybean haulm weight respectively.



5.19 Grain yield of soybean

Appendix 32 revealed that soybean yield was significantly influenced by the treatments. Soybean grain yield was in the order Bihilifa/soybean > Wang data/soybean > Aburohemaa/soybean > Omankwa/soybean. This observation followed a similar trend observed in the number of pods per plant (Table 5). The result indicated that, number of pods per plant is an index of grain yield and this is in line with the work of Osafo (1977). The significant grain yield differences might be due to the influenced by treatments. Also, soybean responses to the inoculation might have led to the differences in grain yield for soybean. This is in line with Seneviratne *et al.*, (2000), Albareda *et al.*, (2009) and Katulande (2011) who reported substantial responses in grain yield to inoculation confirming the results of the present study. Even though the same treatments were applied to all experimental units but grain yield of soybean recorded was not the same which might be due to the effect of the intercropping system with soybean. Reduced yield in intercropping maize or sorghum with soybean has been reported by several researchers (Neupane, 1983; Olufajo, 1992; Palet *et al.*, 1992; Heibsch *et al.*, 1995; Muneer *et al.*, 2004; Muoneke *et al.*, 2007; Egbe *et al.*, 2010; Ijoyah and Fanen, 2012;). This reduction in soybean yields under intercropping could be due to inter-specific competition between the intercrop components for water, light, air, and nutrients, and also the aggressive effects of maize (C₄ species) on soybean, a C₃ species (Egbe, *et al.*, 2010; Muoneke *et al.*, 2007). According to Heibsch *et al.*, (1995), crops with C₄ photosynthetic pathways have been known to be dominant when intercropped with C₃ species like soybean. The shading of soybean by the maize plants (taller) may also have contributed to the reduction of the



yields of intercropped soybean and interception of solar radiation might have been affected. Olufajo (1992) also reported that shading by the taller plants could reduce the photosynthetic rate of the lower growing plants and thereby reduce their yields was a positive correlation with the amount of radiation intercepted by crops in intercropping systems.



CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study revealed that, Wang data intercropped with soybean, Omankwa intercropped with soybean, and Aburohemaa intercropped with soybean produced the best results with reference to plant height, number of leaf count, leaf area, days to 50% flowering of maize, height and length of cob attachment, straw weight, cob weight, number of nodules and pods per plant, and grain yield of maize and soybean.

Treatments depleted seed bank of *Striga hermonthica* to some levels base on the percent reduction in seed bank table which indicated that, Bihilifa intercropped with soybean reduced more of the seed bank similar to Wang data intercropped with soybean and Aburohemaa intercrops. The reason is that the Afayak used could cause suicidal germination of *Striga* seeds and could probably be used in intercropping with any of these maize varieties (Bihilifa, Aburohemaa, and Wang data) to deplete the seed bank of *Striga hermonthica*.

6.2 Recommendations

- Intercropping Wang data or Aburohemaa with Afayak in *Striga* endemic area could reduce *Striga* infestation and improve maize grain yield.
- Intercropping Wang data or Aburohemaa with Afayak can help to deplete the *Striga* seed bank in the long term. But farmers should integrate the intercropping with cultural



practices such as uprooting of emerged *Striga* before flowering and seed production to avoid replenishment of *Striga* seed bank in the soil.

- The use of Wang data or Aburohemaa will reduce labor and time needed for physical control in environmental preservation and reduces production cost.
- Further investigation can be done to evaluate across a wider combination of maize and soybean varieties across different locations within Guinea/ Sudan savannah zone of Ghana.



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APPENDICES

Appendix 1: Analysis of variance for transformed *Striga* emergence count at 7WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	1748.2	874.1	2.41	
Treatment	7	6193.7	884.8	2.44	0.073**
Residual	14	5067.4	362.0		
Total	23	13009.4			

**=Not Significant

Appendix 2: Analysis of variance for transformed *Striga* emergence count at 9WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	394.7	197.3	1.36	
Treatment	7	4733.3	676.2	4.66	0.007*
Residual	14	2030.3	145.0		
total	23	7158.3			

*=Significant

Appendix 3: Analysis of variance for transformed *Striga* emergence count at 12WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	207.1	103.6	0.53	
Treatment	7	10977.6	1568.2	7.97	0.001***
Residual	14	2755.7	196.8		
Total	23	13940.4			

***=Highly Significant



Appendix 4: Analysis of variance for transformed *Striga* emergence cumulative count at 12WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	14.339	7.169	2.04	
Treatment	7	160.301	22.900	6.51	0.002 ***
Residual	14	49.260	3.519		
Total	23	223.900			

***= Highly Significant

Appendix 5: Analysis of variance for *Striga* fresh weight at 12WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	3930.	1965.	0.77	
Treatment	7	54522.	7789.	3.05	0.034*
Residual	14	35708.	2551.		
Total	23	94160.			

*= Significant

Appendix 6: Analysis of variance for *Striga* dry weight at 12WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	94.2	47.1	0.46	
Treatment	8	2018.1	288.3	2.84	0.030*
Residual	14	1422.1	101.6		
Total	23	3534.4			

*= Significant



Appendix 7: Analysis of variance for initial *Striga hermonthica* seed bank

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	90.33	45.17	0.55	
Treatment	7	7364.00	1052.00	12.71	0.001***
Residual	14	1159.00	82.79		
Total	23	8613.33			

***=Highly Significant

Appendix 8: Analysis of variance for post *Striga hermonthica* seed bank

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	43.58	21.79	1.22	
Treatment	7	1061.96	151.71	8.48	0.001***
Residual	14	250.42	17.89		
Total	23	1355.96			

***=Highly Significant

Appendix 9: Analysis of variance for plant height of maize at 3WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	0.32250	0.16125	3.37	
Treatment	7	0.89292	0.12756	2.66	0.056**
Residual	14	0.67083	0.04792		
Total	23	1.88625			

**= Not Significant



Appendix 10: Analysis of variance for plant height of maize at 5WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	3.276	1.638	0.41	
Treatments	7	62.032	8.862	2.24	0.095**
Residual	14	55.451	3.961		
Total	23	120.758			

**=Not Significant

Appendix 11: Analysis of variance for plant height of maize at 7WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	24.09	12.05	0.63	
Treatments	7	484.25	69.18	3.64	0.019*
Residual	14	265.98	19.00		
Total	23	774.32			

*= Significant

Appendix 12: Analysis of variance for plant height of maize at 9WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	254.62	127.31	11.36	
Treatments	7	232.34	33.19	2.96	0.03*
Residual	14	156.86	11.20		
Total	23	643.82			

*= Significant



Appendix 13: Analyses f Variance for maize plant stand at 3WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	3250762.	1625381.	0.48	
Treatment	7	46352061.	6621723.	1.97	0.133**
Residual	14	47029440.	3359246.		
Total	23	96632263.			

**=Not Significant

Appendix 14: Analysis of variance for leaf count of maize at 3WAP

Source of variation	D.f.	S.s.	M.s.	V.r.	F pr.
Rep	2	0.0007548	0.0003774	0.46	
Treatment	3	0.0040548	0.0013516	1.65	0.223
Residual	14	0.0114663	0.0008190		
Total	23	0.0190545			

Appendix 15: Analysis of variance for leaf count of maize at 5WAP

Source of variation	D.f.	S.s.	M.s.	V.r.	F pr.
Rep	2	0.005531	0.002766	0.96	
Treatment	3	0.013481	0.004494	1.56	0.244
Residual	14	0.040410	0.002886		
Total	23	0.109905			



Appendix 16: Analysis of variance for leaf count of maize at 7WAP

Source of variation	D.f.	S.s.	M.s.	V.r.	F pr.
Rep	2	0.005756	0.002878	2.69	
Treatment	3	0.004717	0.001572	1.47	0.265
Residual	14	0.014957	0.001068		
Total	23	0.034497			

Appendix 17: Analysis of variance for leaf count of maize at 9WAP

Source of variation	D.f.	S.s.	M.s.	V.r.	F pr.
Rep	2	0.0091547	0.0045773	7.71	
Treatment	3	0.0010232	0.0003411	0.57	0.641
Residual	14	0.0083126	0.0005938		
Total	23	0.0305253			

Appendix 18: Analysis of variance for LA of maize

Source of variation	D.f	S.s	M.s	Vr	Fpr
Rep	2	30	15	0.00	
Treatment	7	134053	19150.	2.37	0.081**
Residual	14	113259.	8090.		
Total	23	247342.			

** =Not Significant



Appendix 19: Analysis of variance on days to 50% on maize

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	10.583	5.292	2.91	
Treatment	7	20.958	2.994	1.65	0.020*
Residual	14	25.417	1.815		
Total	23	56.958			

*= Significant

Appendix 20: Analysis of variance for length of cob on maize at 10WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	57.123	28.561	15.81	
Treatment	7	16.340	2.334	1.29	0.322**
Residual	14	25.284	1.806		
Total	23	98.746			

**=Not Significant

Appendix 21: Analysis of variance for height of cob attachment on maize at 10WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	134.44	67.22	3.60	
Treatment	7	117.02	16.72	0.90	0.536**
Residual	14	261.45	18.67		
Total	23	512.91			

**=Not Significant



Appendix 22: Analysis of variance for straw weight of maize

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	10567.	5283.	0.25	
Treatment	7	1129038	161291.	7.67	0.001***
Residual	14	294371.	21026.		
Total	23	1433975.			

***=Highly Significant

Appendix 23: Analysis of variance for cob weight of maize

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	18493.	9247	0.49	
Treatment	7	457596	65371.	3.47	0.023*
Residual	14	263634.	18831.		
Total	23	739722.			

*= Significant

Appendix 24: Analysis of variance for grain yield weight of maize

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	2258.	1129.	0.13	
Treatment	7	200789.	28684.	3.30	0.027*
Residual	14	121603.	8686.		
Total	23	324650.			

*=Significant



Appendix 25: Analysis of variance for soybean plant height at 3WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	1.8067	0.9033	2.18	
Treatment	3	1.8233	0.6078	1.47	0.045*
Residual	6	2.4867	0.4144		
Total	11	6.1167			

**= Not Significant

Appendix 26: Analysis of variance for soybean plant height at 5WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	67.13	33.56	1.01	
Treatment	3	68.44	22.81	0.68	0.064**
Residual	6	199.91	33.32		
Total	11	335.48			

**= Not Significant

Appendix 27: Analysis of variance for soybean plant height at 7WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	0.527	0.263	0.04	
Treatment	3	12.307	4.102	0.66	0.026*
Residual	6	37.073	6.179		
Total	11	49.907			

*= Significant



Appendix 28: Analysis of variance for transformed leaf count on soybean plant at 3WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	0.01050	0.00520	1.88	0.059**
Treatment	3	0.01097	0.00366	1.29	
Residual	6	0.01689	0.00280		
Total	11	0.03836			

**= Not Significant

Appendix 29: Analysis of variance for leaf count on soybean plant at 5WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	0.03502	0.01751	1.70	0.034*
Treatment	3	0.04244	0.01415	1.38	
Residual	6	0.06167	0.01028		
Total	11	0.13913			

*= Significant

Appendix 30: Analysis of variance for leaf count of soybean plant at 7WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	0.04317	0.02158	1.52	0.023*
Treatment	3	0.08899	0.02966	2.09	
Residual	6	0.08513	0.01419		
Total	11	0.21729			

*= Significant



Appendix 31: Analysis of variance for soybean plant count at 3WAP

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	316614	1583077	5.36	
Treatment	3	630426	2101422	0.71	0.580**
Residual	6	177217	2953538		
Total	11	556866			

**= Not Significant

Appendix 32: Analysis of variance for transformed number of nodules/soybean plant

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	34.960	17.480	2.36	
Treatment	3	1.992	0.664	0.09	0.963**
Residual	6	44.463	7.411		
Total	11	81.414			

**= Not Significant

Analysis 33: Analysis of variance for transformed number of pods/ soybean plant

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	0.7595	0.3797	0.46	
Treatment	3	3.8090	1.2697	1.54	0.299**
Residual	11	9.5211			
Total	8				

**= Not Significant



Appendix 34: Analysis of variance for haulm weight of soybean

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	115170	575865	9.28	0.146**
Treatment	3	486841	162280	2.61	
Residual	6	372442	62074		
Total	11	201103			

**=Not Significant

Appendix 35: Analysis of variance for grain yield of soybean

Source of variation	D.f.	S.s	M.s	V.r	Fpr
Rep	2	157406	78703	4.39	0.031*
Treatment	3	199553	66518	3.71	
Residual	6	107518	17920		
Total	11	464477			

*= Significant

