GREEN GRAM POPULATION AND ARRANGEMENT EFFECT ON *Striga hermonthica* PARASITISM UNDER INTERCROPPING WITH *Zea mays*

BY

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Declaration

This thesis is my original work and has not been presented for the award of a degree in any other academic institution.

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Dedication

I dedicate this work to my family, my dad Kirirah, mum Liddah and my brothers for their love, support and encouragement during the course of my studies.

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Acronyms

CAN	**C**alcium **A**mmonium **N**itrate
CIMMYT	International Centre for the Improvement of Maize and Wheat
FAO	**F**ood and **A**griculture **O**rganization (of the United Nations)
ICIPE	**I**nternational **C**entre for **I**nsect **P**hysiology and **E**cology
ICRISAT	**I**nternational **C**rops **R**esearch **I**nstitute for the **S**emi-**A**rid **T**ropics
IRRI	**I**nternational **R**ice **R**esearch **I**nstitute
KARI	**K**enya **A**gricultural **R**esearch **I**nstitute
KMDP	**K**enya **M**aize **D**evelopment **P**rogramme
NCPB	**N**ational **C**ereals and **P**roduce **B**oard
NPK	**N**itrogen **P**hosphorous **P**otassium
USAID	**U**nited **S**tates **A**gency for **I**nternational **D**evelopment

Abstract

In Kenya maize is the staple food crop with 80% of the population using it as the main human food. Maize shortage in Kenya always causes food crisis threatening political and economic stability. Weeds are a major constraint to maize production due to associated losses and increased costs of their management. *Striga* is a major maize production hindrance with estimated losses ranging between 40-100 % in Africa. In Kenya *Striga* is mainly found in the Western part of the country. A trial was conducted at Kari Alupe in Busia County during the short rainy season in 2012 and the long rainy season in 2013.The aim of this study was to establish if intercropping maize with green grams has any effect on *Striga* reduction, and if so which is the best intercropping arrangement for the green grams. A maize variety susceptible to *Striga* Hybrid 403 and a green gram variety KS 20 were used. The treatments included, green grams planted in same hill with the maize, one row of green grams planted between two rows of maize, two rows of green grams planted between two rows of maize, broadcasting between two maize rows and thinned to the recommended population of 222,083 plants/ha and green grams planted in the same hill plus one line of green grams between two maize rows, maize alone with *Striga* incorporated, maize without *Striga* and green grams sole crop. The experiment was laid out in a randomized complete block design and replicated four times. Data collected included the number of *Striga* counts from eight weeks to fourteen weeks after planting at an interval of two weeks, wet grain weight of the naked cobs, dry grain yield, 1000 seed weight, the plant and ear height, number of cobs per plot, cob diameter per plant, cob length per plant and cob height per plant. Green grams parameters included; the number of branches per plant, number of pods per plant, plant population per plot and the grain weight of green gram per plot . Data collected was analyzed using GenStat software package version fourteen and ANOVA was used to assess the effects of different treatments. The treatment means were separated using Duncan's multiple range test at $P<0.05$ to recommend the most efficient and cost effective intercropping arrangement of green grams in *Striga* control. Results on *Striga* weed counts indicate that intercropping maize with green grams had significantly lower *Striga* counts when compared with maize that was artificially infested with *Striga*. Green grams plant arrangement had no significant differences in the *Striga* counts. Intercropping maize with green grams in the short rains had significantly higher dry grain weight when compared to the maize that was artificially infested with *Striga*. In the long rains intercropping had no significant difference between the dry grain weights when compared to the maize that was naturally infested with *Striga*. In the short rains uncontrolled *Striga* reduced dry grain weight by 67% while in the long rains it reduced the dry grain weight by83% when uninfested maize was compared to infested one. Intercropping reduced *Striga* incidence and increased the dry grain weight and since it is affordable to small scale farmers they should be encouraged to grow maize intercropped with green grams to manage *Striga* weeds, improve maize yield and achieve better utilization of land and labour.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Maize is a very important staple food in Kenya, grown in almost all agro ecological zones and in two out of every three farms (Odendo *et al* 2001). It accounts for about 40 percent of daily calories (www.fao.org) and has per capita consumption of 98 kilograms; this translates to between 30 and 34 million bags (2.7 to 3.1 million metric tons) of annual maize consumption in Kenya (Tegemeo, 2009). The country produces only 28 million bags and the deficit is bridged by imports from neighboring countries (Wambui, 2005). Over the last 10 years, domestic production has stagnated between 24 and 28 million bags (Wambui, 2005). The quantity of imported maize has increased from 2.9 percent between 1970 and 1991 to an average of 12 percent in the last 10 years (www.fao.org). However, the percentage of imports is highly underestimated because there is massive unreported cross border maize trade from Uganda, Tanzania, South Africa and Mozambique (Wambui, 2005).

Over 85 percent of the rural population derives its livelihood from agriculture, most of who engage in maize production. Maize is also important in Kenya’s crop production patterns, accounting for roughly 20 percent of gross farm output from the small-scale farming sector (Jayne, *et al.,* 2001).

The Kenyan government policy objective for the maize sub-sector is to encourage increased production so that self-sufficiency and food security can be achieved. However, the production of the crop has fluctuated over the years, partly due to climatic conditions and policy constraints. Some of the main reasons for the dwindling performance in maize production are associated with the following challenges: pest and diseases, poor access to credit, inadequate use of recommended technologies, high costs of inputs, poor agricultural extension services, and poor flow of information from the research stations to farmers. One of the limitation in the maize production in Kenya is *Striga hermonthica*, a parasitic weed that mostly thrives in the Western part of the country (Jenny et al 2011).

The purple witch weed *Striga hermonthica* threatens the lives of over 100 million people in Africa and infest about 40% of arable land in the savanna region, causing an estimated annual loss of $ 7 to 13 billion (www.icipe.org). It is almost certainly responsible for more crop loss in Africa than any other individual weed species. Over 5 million ha of crops - mainly sorghum, millets and maize - are affected in six countries of West Africa alone, possibly 10 million ha in Africa as a whole. One plant of *S. hermonthica* per host plant is estimated to cause approximately 5% loss of yield (Parker and Riches, 1993) and high infestations can cause total crop failure. The damaging effect of *S. hermonthica* on the host plant is not only from the direct loss of water, minerals, nitrogen and carbohydrate, but from a disturbance of the host photosynthetic efficiency and a profound change in the root/shoot balance of the host, leading to stimulation of the root system and stunting of the shoot (Mbwaga, 1996).

Young *Striga* seedlings are completely parasitic on the host while they are below the soil level and, at this stage, cause maximum damage to the host. *S. hermonthica* occurs mainly under conditions of low fertility (Mbwaga, 1996). It is also associated with farming systems in Africa in which farmers have few resources and very few options in terms of control measures. *Striga* has infested over 210,000 ha of otherwise high potential cropland in west Kenya, driving households into extreme poverty and placing the nation's food security at risk (AATF, 2006). Recommended control methods to reduce *Striga* infestation include intercropping with legume, heavy applications of nitrogen fertilizer, crop rotation, use of trap crops and chemicals to stimulate suicidal seed germination, hoeing and hand pulling, herbicide application and the use of resistant or tolerant crop varieties (ICIPE 2005). Effectiveness of all these methods, including the most widely practiced—hoe weeding—is seriously limited by the reluctance of farmers to accept them, for both biological and socioeconomic reasons (ICIPE 2005).

Intercropping maize with legumes such as green grams is a recommended practice since it's a farmer's practice thus no extra cost is imposed on the farmer. Green grams are a good source of protein and thus the farmers can use them to supplement their diets. The green gram provides a good ground cover to the soil thus reducing the emerging *Striga* and other weeds. This reduces the cost of production since the farmers do not carry out a lot of weeding for their maize.

1.2 Problem statement and justification

The amount of maize produced in Kenya today does not meet the consumption needs for the country's increasing population. A lot of work has been done to increase the production of maize but the demand has always outstripped the supply thus the government of Kenya imports the deficit in order to bridge the gap (Nyaga, 2012). The country's estimated consumption is between 30 and 34 million bags against 28 million bags per annum (Tegemeo, 2009). The above deficit is due to biotic and abiotic factors (Tegemeo, 2009). The abiotic factors include disruptions in input supply during planting, high prices of inputs like fertilizers and climate change (USAID 2012). Biotic factors include weeds, insect pest like the maize stalk borer and the larger grain borer, diseases like the highly contagious Maize Lethal Necrosis Disease (MLND) which has been reported in some districts of southern Rift Valley and Nyanza provinces where it has affected about 60 000 hectares and the production is projected to drop by 60-80 percent (FAO, 2012).

Weeds are the major constraint in maize production because they compete with maize plant for resources such as water, nutrients, light and space while other weeds act as alternate hosts to insect pests and disease causing organisms (IRRI and CIMMYT 2007). In Kenya maize yield losses up to 81% have been recorded (Elisaba, 2006). On average weeds account for 80% crop yield loss depending on weed species and density (Spitters *et al*, 1989). *Striga hermonthica* (Del.) Benth- (purple witch weed) *S. asiatica* (L.) sedges (*Cyperus rotundus* (L.) and *C. esculentus*) are among the most problematic weeds in Kenya (Christoffoleti *et al.*, 2007).

Striga is one of the most noxious weed in Western Kenya. *Striga* is a parasitic weed that attaches its roots to the host plant and thus very difficult to control. Farmers have tried conventional tillage method in *Striga* control in maize fields like hand weeding which is tedious, drudgery and inefficient (Chui *et al,*.1996).

Each year, the average Kenyan consumes 98 kilograms of maize, the staple crop of the Kenyan diet (Jayne et al., 2001). Maize contributes to about 40% of daily calories according to KMDP, (2009) and the poorest population spending 28% of its income on maize. Maize prices in Kenya are among those listed highest in Sub-Saharan Africa. According to KMDP (2009) the poorest part of the population in Kenya today spends 28% of its income on the crop. Inefficient production and marketing in the maize subsector contribute to economic stagnation and poverty in Kenya.

Genus *Striga* has infested two thirds of the 73 million hectares under cereal in Africa causing an estimated loss of $7 to $13 billion annually (Jesse, 2005; ICIPE 2004-2005). This genus threatens the lives of 100 million people in Africa (ICIPE 2004-2005). An estimated 750000 ha of land (80% of the farm land) in Western Kenya is infested with *Striga* (Kanampiu and Friesen, 2004). Due to these infestation farmers are forced to abandon their arable lands. Subsistence farmers in these regions engage themselves in weeding out *Striga* which is a labor intensive activity and time consuming (ICIPE 2004-2005). Labor has become scarce and very expensive due to problems such as HIV/ AIDS in the society, rural-urban migration in search for white collar jobs thus maize production is limited (Nyaga, 2012).

There are several methods that are used or have been used or have been tried to control *Striga* infestation in maize. Crop rotation of maize with soybean can be an effective means of reducing the soil seed bank of *Striga* seeds in the soil but this practice is not viable in Western Kenya where land sizes are small and where the inhabitants' staple food is maize (Berner et al., 1997). Intercropping has been developed for integrated management of *Striga* weed. It's appropriate and economical to the resource-poor smallholder farmers in the region as it is based on locally available plants, not expensive external inputs, and fits well with traditional mixed cropping systems. Cereal–legume intercropping is a predominant cropping system in Kenya where it is used for maximizing use of limited farmlands, food security and improving soil fertility. Use of legume trap crops is an important low cost method for depletion of *Striga* seed bank in the soil and good intercropping of maize and green grams will ensure a more balanced diet for the farmers household considering green grams are a good source of proteins.

This study was therefore undertaken to achieve the following objectives;

1.3 Broad objective

To increase maize yield by reducing *Striga* parasitism on maize through intercropping with green grams

1.4 Specific objectives

1. To evaluate the effect of plant arrangement in an intercrop of green grams with maize in the reduction of *Striga* parasitism.
2. To evaluate the effect of plant population of green grams in an intercrop of green grams and maize in the reduction of *Striga.*
3. To evaluate the effect of intercropping maize with green grams on *Striga* parasitism and yields.

1.5 Hypothesis

1. Planting arrangement in a green gram- maize intercrop has an effect in reduction of *Striga* parasitism in maize.
2. Green grams plant population in an intercrop of maize and green grams has an effect on *Striga* population.
3. Intercropping maize and green grams reduce *Striga hermonthica* parasitism on maize thereby increasing yields and profitability.

2.0 CHAPTER TWO

LITERATURE REVIEW

2.1 Classification and origin of maize

Maize (*Zea mays L.)* is a coarse annual grass belonging to the large and important family graminaeae tribe maydeae, genus *Zea* and species *mays* (Lorroki, 2009*).* The crop is a native to the Americas (Gordon and Thottapilly, 2003) where nearly one-half of the total world production is done. It was produced by Indians as a priniciple food plant for many centuries before Europeans in America (Poehlman, 1987). It is believed to have originated in Southern Mexico and Central America because of the great diversity of the native forms found in cultivated fields in those regions (Lorroki, 2009). The cereal has two close wild relatives; *teosinte* and *tripsacum (*Lorroki, 2009).

Maize is a monoecious, annual grass which can grow to a height of about 1-4m depending on variety (Muiru, 2008). The root system mainly consists of adventitious roots that usually develops from the lower nodes of the stem below and often just above the soil surface, usually they are limited to the upper 75cm of the soil (Jugenheimer, 1985), maize stems are simple and solid with well defined nodes and internodes ranging from 8-21 (Hennery & Kettlewell,1996; George & Karin, 2004). The male and female inflorescence are separate but on the same plant (Sinclair et al., 2004). The female inflorescence usually referred to as the ear is a modified spikes usually it develops from the axil of one of the largest leaves about halfway the stem. It is enclosed by 8-13 modified leaves known as the husks (Henry & Kettlewell, 1996; Georg &

Karin, 2004). The male inflorescence is known as tassel consists of a terminal panicle up to 40cm long (Henry & Kettlewell, 1996; George & Karin, 2004).

Flower initiation is generally 20-30 days after germination. The period from planting to harvesting varies from 70-200 days (Muiru, 2008). Climatic conditions, latitude and altitude influence growth duration of the crop (Jugenheimer, 1985; Henry & Kettlewell, 1996; George & Karin, 2004).

2.3 The importance of maize as a staple food crop in Kenya

Transition of maize to a major crop occurred in Kenya during World War 1, when the colonial government encouraged farmers to plant maize for the war effort. At the same time, a serious disease epidemic in the traditional food crop, millet, led to famine and stocks of millet seed were consumed rather than saved for planting. By providing farmers with seed of a late-maturing white maize variety, the colonial government led the transition from millet to a maize-based food economy. After the war, the development of export markets encouraged maize production and by 1930s, maize was established as the dominant food crop in much of Kenya and Tanzania (Gerhart, 1975).

Maize accounts for about 40 percent of daily calories and per capita consumption is 98 kilograms (www.fao.org). The poorest households spend 28 percent of the annual household income on maize purchase (www.fao.org). Because of this importance, improvement in maize production will be crucial to solving Africa's food security problems and alleviating poverty. Maize is the main staple food for rural households in Kenya. It is associated with household food security such that a low-income household is considered food insecure if it has no maize stock in store, regardless of other foods the household has at its disposal (Tegemeo 2009).

Maize is important in Kenya's crop production patterns, accounting for roughly 20 percent of gross farm output for the small-scale farming sector (Jayne, *et al*., 2001). It is grown for commercial, subsistence or dual purposes. Maize yields during favorable condition ranges from 2.0 to 5.4 metric tons per hectare. The annual maize consumption is approximated at 30 to 34 million bags (2.7 to 3.1 million metric tons). This outweighs production and the deficit is imported mainly from Uganda, Tanzania, Brazil, South Africa and Mozambique at lower prices than that of domestic production. Over-dependence on imports is likely to displace the only livelihood of the local population (Tegemeo, 2009).

Though maize is grown in almost all Agro-ecological zones, the highest productivity is in the high potential and central highland zones while the lowest potential is in the lowland regions. An inter-zonal variation has been attributed to better soils, rainfall, access to agricultural extension services as well as adoption of technologies such as hybrid maize and fertilizers (Karanja, *et al*., 1998).

There was tremendous maize production potential exhibited around 1964-1975, fueled by the introduction of maize hybrids and related technologies often duped "Kenya's green revolution" (Karanja, 1996). However, there has been a marked decline in yield since 1997. Maize yield have declined from 1.85 metric tons per hectare in the period 1985-89 to the current yield of 1.57 tons per hectare.

2.4 Constraints to maize production

Maize yields of 5 tones/ha and 8-10 tones/ha in lowlands and highlands respectively are potentially attainable in subtropical and midland environments (Muiru, 2008). However, yields in most parts of Africa including Kenya fluctuates around 1.5 tones/ha (Mwangi, 1998). The low yields are as a result of many factors including biotic, abiotic, institutional and social economic constraints (Nyoro *et al.*, 2004).

The biotic factors that are dominant in limiting maize production are insect pests, weeds and diseases (Muiru, 2008). The insect pests include the field pests like stem borers, earworms of corn and armyworms among others; storage pests include the Angoumois grain moth, grain weevils, larger grain borer and rodents (Muiru, 2008). Some of the major diseases attacking maize are maize rust, smut, northern and southern leaf blight, downy mildew, ear rots, maize streak viruses among others (Agrios, 2005).

The most common weed of maize in Kenya is the witch weed though it's localized to the Western part of the county. Due to its mode of parasitism on the maize crop it leads to enormous yield loss of the maize crop in areas which it has infested.

2.5 The genus *Striga*

Striga spp. is hemi-parasitic plants that parasitize the root systems of their hosts. The genus *Striga*, family Orobanchacecae, comprises about 41 species that are found in the African continent and parts of Asia; Africa is the presumed region of origin (Wolfe *et al.*, 2005). By parasitizing crop species, they can cause substantial yield losses and are therefore considered agricultural pests. The literature cites three species as having a significant impact on agriculture in tropical and subtropical areas. These are *S. hermonthica* (Del.) Benth. *S. asiatica* (L.) Kuntze and *S. gesneroide* (Willd.) Vatke. The first two species parasitize cereal crops and wild grasses while the third parasitizes broad leaved plants including the crop species cowpea (*Vigna unguiculata* (L.) Walp.) and tobacco (*Nicotiana tabacum* L.) (Mohamed *et al*., 2001). *S. hermonthica* is an obligate outcrosser, occurs only on the African continent, and has the greatest agricultural impact of all *Striga spp* (Mohamed *et al*., 2001).

Striga hermonthica (Del.) Benth is a green erect herb with bright pink flowers and a height of around 30–40 cm at flowering. *S. hermonthica* is suggested to have originated from the same area as sorghum (*Sorghum bicolor* [L.] Moench). It is thought to have co-evolved with wild relatives of sorghum during domestication in the Sudano-Ethiopian region of Africa (Mohamed *et al*., 1998). With the introduction of sorghum into new regions in Africa, it may have spread by crop seed contamination. It is thought that new areas and fields are still being colonized by contaminated crop seeds (Berner *et al*., 1994). *Striga hermonthica* parasitizes, not only, sorghum but also other cereals, e.g., maize (*Zea mays [L.])* and millet (*Pennisetum glaucum* [L.] R. Br.) (Parker & Riches, 1993). *Striga hermonthica* has been reported to parasitize rice (*Oryza glaberrima* [Steudel] and *O. sativa* [L.]), finger millet (*Eleusine coracana [L.] Gaertn*.) and sugarcane (*Saccharum officinarum [L.*]) (Gurney *et al*., 1995) and recently, tef and barley (*Hordeum vulgare* L.; Hussien, 2006). *Striga hermonthica* is one of the most important biological constraints to the production of millet, sorghum and maize in sub-Saharan Africa despite more than 50 years of research. Some fields have become so badly infested with *Striga* that farmers are forced to abandon the field or grow other crops (Hussien, 2006). *Striga* hermonthica occurs in sub-tropical areas with an annual rainfall ranging from 300– 1200 mm. However, it may be able to adapt to agro-climatic conditions outside its current distribution range and to other crop species (Mohamed *et al*., 2006).

2.5.1.1 The life cycle of *Striga hermonthica*

To understand the population dynamics of *Striga hermonthica* it is necessary to take a closer look at its most important life cycle stages and transitions.

2.5.1.1.1 Seeds

Striga hermonthica seeds are very small (0.2 × 0.3 mm), light weight (0.4–0.5 × 10–2 mg) and one plant can produce up to 200,000 seeds (Parker & Riches, 1993). Seeds have long life expectancies under both laboratory and field conditions (Samaké *et al*., 2006), and a persistent seed bank can build up within one or two years of flowering *Striga* plants occurring in a field (Webb & Smith, 1996). However, there is much controversy on the longevity of seeds in the soil and on the causes of seed mortality (Berner *et al*., 1997).

2.5.1.1.2 Germination

Seed exposure to moist conditions in combination with a temperature of between 25– 45 °C for a minimum of four days makes seeds responsive to germination stimulants (Muller *et al*., 1992). This period is referred to as (pre)conditioning. Germination of *Striga hermonthica* seeds is triggered by the presence of sesquiterpenes or strigolactones, which are exuded by host and non-host roots (Cook *et al.*, 1972). These sesquiterpenes are chemically similar to the signal that induces hyphal branching of mycorrhiza, the first step towards a mutualistic, symbiotic association between plants and mycorrhiza (Akiyama *et al*., 2005). When a host or a non-host root exudes trace amounts of germination stimulants, a chemical gradient is created (Bouwmeester *et al*., 2003; Fate & Lynn, 1996). The germinated seed needs to find, and attach itself, to the host root within three to five days, before seed reserves are depleted and host root penetration is no longer possible (Chang & Lynn, 1986). Furthermore, the radicle is only able to grow to a maximum of about 5 mm and so, optimally, the seed should only germinate if the root is less than 3–4 mm away (Ramaiah *et al.*, 1991).

2.5.1.1.3 Attachment and underground development

Contact between the tip of the radicle and the host root initiates 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 *Striga hermonthica* to withdraw water, nutrients and carbon assimilates from the host (Cechin & 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 suggests 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 host growth originates from simple competition for water, nutrients, assimilates and amino acids between the host (shoot) and the attached *Striga* seedling (Cechin & 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.*, 1999; Smith *et al*., 1995; Watling & 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 (Berner *et al*., 1997).

2.5.1.1.4 Emergence

The time between attachment and emergence can vary from three to six weeks (Olivier *et al*., 1991; Parker, 1965). Upon emergence, the 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 & Smith, 1996). Andrews (1945) and Doggett (1965) suggested that about 10–30% of the attached seedlings reach the soil surface.

2.5.1.1.5 Survival to maturity

Striga plants start flowering between one to two months after emergence (Parker & Riches, 1993). 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 (Thomas 2007).

2.5.1.1.6 Fecundity

Estimates of fecundity (number of seeds produced per mature *Striga* plant) vary widely and may depend on growing conditions, host species and host variety (Andrews, 1945; Parker & Riches, 1993; Rodenburg *et al*., 2006b). 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*., 2006b; Van Ast & Bastiaans, 2006).

2.5.1.1.7 Seed shed and dispersal

The time between capsule formation and its opening when ripe is about one week (Webb & Smith, 1996). Galling weevils (*Smicronyx spp*.) predate seed capsules (Pronier *et al*., 1998). No information is available on seed predation on the soil surface. Wind, run off water, cattle, harvested plant material, agricultural implements and infested crop seed lots may disseminate the *Striga hermonthica* seeds. Wind, (water and tillage) are probably responsible for short distance dispersal (<1 km within fields or between neighbouring fields), whereas harvested plant material, infested crop seeds and grazing cattle may facilitate long distance dispersal (>1 km, between villages and region (Berner *et al*., 1994).

2.6 Approaches to *Striga* control and their limitations

Controlling *Striga* and other root parasites is difficult because the weed can do much damage to the host crop before emerging above the ground. Cultural, mechanical, chemical and biological control measures are available to regulate the parasite population. However, few of these techniques can provide complete *Striga* eradication and it is usually necessary to use a combination of these methods (integrated control) most relevant to the farming system (Parker and Riches, 1993).

2.6.1 Cultural and mechanical control methods

2.6.1.1 Hand-weeding/hand-pulling

Hand-weeding is the most widely practiced control method for *Striga* in Kenya (Frost, 1994). Its labour intensive thus high labour costs in repeated hand-pulling of *Striga*. It is recommended that hand-pulling should not begin until 2-3 weeks after *S. hermonthica* begins to flower to prevent seeding (Parker and Riches, 1993). Hand pulling *Striga* plants before seed set in a maize crop is as effective as trap cropping in restoring the productivity of land infested with *Striga* in western Kenya (Odhiambo and Ransom, 1994).

2.6.1.2 Rotation: trap-crops and catch crops

Rotation with non-host crops interrupts further production of *Striga* seed and leads to decline in the seed population in the soil. The practical limitations of this technique are the more than 3 years required for rotation. The use of trap crops that induce the germination of *Striga* but are not themselves parasitized is currently one of the best methods to control agricultural root parasites.

Potential trap crops include sunflower, lablab, lupin, lucerne, phaseolus bean, pea and faba bean (Doggett, 1965). Catch crops are planted to stimulate a high percentage of the parasite seeds to germinate but are destroyed or harvested before the parasite can reproduce. The main crop could then be planted during the main rains (Parker and Riches, 1993).

2.6.1.3 Time and method of planting

The degree of infestation of the host plant by *Striga* can be affected by the sowing date (Ransom and Osoro, 1991). The selection of the genotype was more important than date of planting in minimising *Striga* related yield losses (Ransom and Osoro, 1991). In a bimodal rainfall pattern, *Striga* is normally worst in the crops sown in the early rains. Under suitable soil and climate conditions, high planting density in rows should be the goal (Ransom and Osoro, 1991).

2.6.1.4 Application of nitrogen fertilizer

The use of nitrogen to suppress *Striga* has been demonstrated in the East and Central African highlands (Esilaba and Ransom, 1997; Esilaba *et al*., 2000; Gacheru and Rao (2001). Mumera (1993) recorded a 64% reduction in *S. hermonthica* emergence in maize using 39 kg N ha as calcium ammonium nitrate (CAN). Farmyard manure trials indicated that 100 t ha reduced *Striga* counts and increased maize yield. However, Ransom and Odhiambo (1994) showed that there was N by organic matter interaction in field. From the many studies conducted on the effect of fertilizer on *Striga*, it may be concluded that under certain conditions, N may reduce infestation. However, under nutrient depleted soil conditions, fertilizer may stimulate infestation. This increase could be due to an increase in the biomass of host roots enabling more parasite seeds to germinate. The difference in results from various N fertilizer studies may be due to differences among host plants, chemical interactions, micro-organisms, soil texture and moisture (Esilaba 2006).

2.6.1.5 Intercropping

The roots of several legumes are known to induce suicidal germination of *Striga* seed, this feature has led to the incorporation of cereal-legume intercropping in *Striga* suppression strategies Worsham (1987). *Silverleaf desmodium* is particularly effective in suppressing *Striga* and has been incorporated into a biological control system known as push and pull. In pushpull, desmodium neutralizes *Striga* (Woomer, 2004). Intercropping cereal with cowpea in the same row gave the highest yield in Cameroon and in Ethiopia (Mbwaga *et al*., 2001). Intercropping with legumes also improves soil fertility through fixation of atmospheric nitrogen (Ariga, 1995). Addition of nitrogen to the soil is generally considered to alleviate the effects of *Striga* and to lower the amount of *Striga* supported by the host. The effectiveness of cereal/legume intercropping to influence *Striga* germination depends on the effectiveness of the produced stimulants/inhibitors, root development, fertility improvement, shading effect and its compatibility to *Striga* species (Mbwaga *et al*., 2001). Mixed cropping of cereals and cowpea has been observed to reduce *Striga* infestation significantly (Khan *et al.*, 2002). This is thought to be due to the soil cover of cowpea creating unfavorable conditions for *Striga* germination (Mbwaga *et al*., 2001; Musambasi *et al*., 2002). Intercropping maize and beans in the same hole had the highest grain yield, which was 78.6 % above the yield of pure maize stands due to the fact that beans is able to fix nitrogen which will improve maize yield (Odhiambo and Ariga, 2001).

2.6.2 Development of *Striga* resistant/tolerant varieties

The development of resistant and tolerant lines of susceptible crops constitutes an important, practical and reliable approach to controlling *Striga*. Host plant resistance is an effective means to reduce the reproduction of the parasite (Esilaba, 2006).

Sorghum variety Serena, a cross between Dobbs and Swaziland variety P127, has a satisfactory level of *Striga* resistance. Further crossing of Serena produced Seredo which had some resistance during screening trials in western Kenya (Kiriro, 1991). Mumera (1983) found Serena and Serenex to have high resistance while MY146 and ZKX were susceptible and MY146 tolerant. Several Machakos/Yatta landraces (MY134, MY183 and MY95-Z) performed well under *Striga* infestation (Kiriro, 1991). Field screening of sorghum cultivars conducted in Kenya identified stable resistance for ICSV 1112 BF, Namonimbri and IS 9830. High *Striga* susceptibility was observed for 88MW 5200, MY 134, SAR 24, Andiwo II, Esuti, Neburomoyi and Othuwa I (Ayiecho and Nyabundi, 2000).

2.6.3 Chemical control methods

2.6.3.1 Germination stimulants

Certain chemicals such as ethylene, ethephon, strigol and strigol analogues can induce germination of *Striga* seeds in the absence of a suitable host and therefore deplete seed reserves in the soil (Esilaba and Ransom, 1997). Ethylene can reduce *S. asiatica*, however, *S. hermonthica* may not be well controlled by ethylene under field conditions in eastern Africa (Ransom and Njoroge, 1991).

2.6.3.2The use of herbicides

Among the chemicals investigated for efficacy in controlling *Striga* is Dicamba which can provide early season control but has not proven to be consistently cost-effective (Odhiambo and Ransom, 1993). However, Imazapyr gives early season *Striga* control in specific varieties with increased yields and may offer complete control at an affordable cost for subsistence farmers (Abayo *et al.*, 1996 and 1998). Recent on-farm trials in Kenya and Tanzania indicate that seed dressing with Imazapyr and Pyrithiobac offers good *Striga* control and increased yields (Kanampiu *et al*., 2004). Many herbicides are useful in preventing the build-up of *Striga* seeds in the soil but may not prevent the damage done by *Striga* plants before emergence (Esilaba, 2006).

2.6.4 Biological control methods

Few systematic studies of individual natural enemies of *Striga* and their influence on the population of host plants have been conducted (Abayo *et al.*, 1996 and 1998). The genus of greatest interest for biological control is Smicronyx, an insect, of which several species are highly specific to *Striga*. Some fungal pathogens have been isolated from emerged *Striga* plants of which *Fusarium nygamai* and *F. semitectum var. majus* reduce germination and/or kill *S. hermonthica*. However, further studies under field conditions need to be conducted (Esilaba, 2006).

2.7 Green grams

Grams are annual legume crops grown for their seed. Grams could be green, black or yellow in color. Grams are native crops of India (www.infonet-biovision.org). Often called green gram or golden, it is cultivated in several countries of Asia, Africa, and the Americas. The dried beans are prepared by cooking or milling. They are eaten whole or split. The seeds or the flour may be used in a variety of dishes like soups, porridge, snacks, bread, noodles and even ice cream. Green gram also produces great sprouts, which can be sold in health food shops or eaten at home. Crop residues of *Vigna radiata* are a useful fodder. Green gram is sometimes specifically grown for hay, green manure or as a cover crop (AATF, 2006).

Green grammes grow best at an altitude of 0-1600 m above sea level and under warm climatic conditions (28 to 30°C). They are well adapted to red sandy loam soils, but also do reasonably well on not too exhausted sandy soils. Green grams are not tolerant to wet, poorly drained soils. They are drought tolerant and will give reasonable yields with as little as 650 mm of yearly rainfall. Heavy rainfall results in increased vegetative growth with reduced pod setting and development (Maiti *et al*., 2012).

Intercropping maize with legumes strategy was developed in western Kenya. It's based upon staggering maize rows and growing legumes in intercrops thus allowing the legume to suppress *Striga* through suicidal germination while still producing higher value pulse intercrops (AATF. 2006). Intercropping sorghum with cowpea [*Vigna unguiculata* (L.) Walp.], greengram [*Vigna radiata* (L.) Wilczek], and crotalaria (*Crotalaria ochroleuca* G. Don), and maize with crotalaria significantly reduced *Striga* populations (Zeyaur *et al.*,2007). The results also indicates that intercropping sorghum with cowpea, green gram, or crotalaria and maize with crotalaria could be combined with other cultural methods for a sustainable control of *S. hermonthica* (Zeyaur *et al.*, 2007) . If green grams intercrop with sorghum could significantly reduce *Striga* the same may be achieved by intercropping maize with green grams and more effectively in different green gram plant arrangement (Zeyaur *et al.*, 2007).

3.0 CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site

The field experiment was laid out at KARI station in Alupe Busia. Busia is a county in the Western Province of Kenya. It borders Kakamega county to the east, Bungoma county and Teso county to the north, Busia District, Uganda to the west, and Lake Victoria to the south. It covers an area of 1,695 Sq Km with average temperature of 22°C and between an annual rainfall of about 750mm to 1,800mm. Alupe altitude is 1189m above sea level with a bimodal rainfall classified as short and long rains from October to December and March to June respectively. The experimental site was traversed by longitude 34’ 07’E and latitude 0’28’N. The soils are well drained to moderately drained, moderately deep, dark reddish brown to dark brown, friable, gravely sandy clay loam to clay. The soil pH –water was 4.5 and a CEC of 14% (Njoroge et *al*, 2010*)*.

3.2 Experimental design and layout

The experiment was laid out in a Randomized Complete Block Design (RCBD) with four replications. The experimental land size was 53.5m by 24m, the field plots measured 6m by 4m. Block to block spacing was 1m while treatment to treatment spacing was 0.5m.

3.3 Methodology

3.3.1 Treatments

The experiment was carried out in two seasons; during the short rains (October 2012 to February 2013) and the long rains (March to July 2013). A commercial maize Hybrid variety 403 recommended for the region was used for the experiment. Also a farmer's most commonly grown variety of green grams KS 20 was used for the intercropping. During land preparation**,** a perceived *Striga* free field was ploughed using a tractor, harrowed using jembes till a fine tilth was obtained. The land was then demarcated into four blocks each measuring 53.5 m in length and 4m wide. The blocks were then divided into plots measuring 6m by 4m. Planting was done using marked field strings where maize holes were dug at a spacing of 75cm by 25cm, while the green grams were drilled at a spacing of 45cm by 10cm. Six rows of maize per plot were planted while in green grams pure stand 10 rows were planted. *Striga* seeds were incorporated into the field during planting where ten grams of harvested and cleared *Striga* seed was mixed with five kilograms of sand to enhance uniformity. *Striga* seeds were applied at one corner of the planting hole in all the treatments except in treatments with maize without *Striga* and green gram pure stand plots. Plant inoculation was done using one tablespoonful which is approximately 10gm. The 10gm of the mixture carries about 2000 viable *Striga* seeds. Twenty (200kg/ha) of NPK (23:23:0) per planting hole was placed in the opposite corner of the planting hole (opposite to *Striga* seeds). Also during planting termites were prevented by using reagent which was applied in the planting hole.

Topdressing was done with CAN 26% (200kg/ha) when maize was at knee height stage (after second weeding). The experiment was carried out under rain fed conditions during both seasons.

To control other weeds hand weeding was carried out, hand weeding was the preferred method of weed control in order to prevent uprooting of *Striga*. A pinch of bulldock was applied per plant in the maize funnel two weeks after planting to control maize stalk borer. To control insect pests such as thrips, African boll worm, white flies and aphids on green grams an insecticide duduthrin was sprayed, using the recommended manufacturer's rate, at an interval of two weeks. Harvesting of green grams and maize was undertaken 3 and 4 months after planting respectively.

There were eight treatments replicated four times; Green grams planted in same hill with the maize, one row of green grams planted between two rows of maize, two rows of green grams planted between two rows of maize, broadcasting of green grams in the maize field. Broadcasting was done by one of the local women who did it for the two seasons for uniformity. Thinning was done two weeks, green grams (two seeds per hill) planted in the same hill with maize plus one line of green grams planted between the two maize rows, maize with *Striga* incorporated, maize without *Striga* and green grams pure stand (Table 1).

Table 1 list of treatments

Treatments
Maize + *Striga*
Maize no *Striga*
Maize +Green gram (same hill)
Maize +Green gram(same hill + one row)
Maize +Green gram (one row)
Maize +Green gram (two rows)
Maize +Green gram (Broadcasting)
Green grams

3.4 Data collection

3.4.1 Maize

The percent maize seed germination was observed two weeks after planting. Scouting of the fields was done in order to capture the 50 percent days to tasselling and silking, the total maize stand was captured by counting the total maize plants that were in each plot. Plant girth diameter was captured using a labeled string where five plants per plot were captured and the average diameter was recorded. Plant height and ear height were measured at the 16 week when the plants had achieved full maturity the plant height and ear height was measured. The number of lodging maize both at the stem and the root was observed and noted at the 16 week after planting. During harvest the number of cob per plant, the cob diameter and the cob length was measured using a ruler. During harvesting the numbers of lodged plants were counted per plot, this was done by counting the number of plants that had lodged at the stem; this was scored as stem lodge while those that had lodged at the root were scored as root lodge. Also during harvesting the number or rotten ears were counted and recorded, the maize yield parameters taken included: unshelled weight of the naked cobs, dry grain yield and 1000 seed weight. These yield parameters were recorded using a weighing balance while the grain moisture content was recorded using a moisture gauge.

3.4.2 *Striga*

The soil *Striga* seed count at the beginning and the end of the season was established using the elutriation procedure (Berner *et al*.,1997). Emerged *Striga* was counted from 6th week after planting to 16th week after planting at an interval of two weeks. *Striga* syndrome (on the 12th

week after planting) on a scale of 1-9. The *Striga* syndrome is a visual rating of the damage caused to the maize plant by the *Striga*. The rating is as follows; 1= Normal maize growth, no visible symptoms, 2= scattered small and vague whitish leaf blotches visible, 3= blotching and streaking easily noticeable, 4= extensive blotching and streaking and mild wilting, 5= like four above but wilting rather than mild wilting, 6= leaf scorching covering about a third of the leaf, about a third reduction in height, reduction in stem diameter, ear and tassel size, 7= leaves turning gray and necrotic some stalks breaking, 50% reduction in height, 8= scorching on most part of the leaf area, husks leaves are noticeably short and open, 9= virtually all leaf area scorched, two thirds or more reduction in height, most stems collapsing, no useful ear formed, plant dead or nearly dead (Berner *et al* 1997) .

3.4.3 Green grams

The green grams germination percent was taken two weeks after planting, five plants were picked at random; their branches and pods per plant were counted and recorded. Shelling of the green grams was done per plot and the seed weight measured.

3.5 Data analysis

Data collected was analyzed using GenStat computer software package (Pyne *et al.*, 2009). Analysis of variance (ANOVA) was conducted to determine significant differences between treatments on the *Striga* population, maize yields and green grams yield by comparing their respective means. Different treatment means were separated using Duncan's multiple range tests and the level of significance between the means was determined at ($P<0.05$).

4.0 CHAPTER FOUR

RESULTS

4.1 Effect of green gram arrangement in an intercrop of green grams and maize on *Striga*

This study sought to find out if the different green gram planting arrangement had any influence on the number of emerging *Striga* in the maize field. Due to the difference in the green gram planting arrangements they gave rise to different green gram densities. Intercropping is known to reduce the number of emerging *Striga* plants due to the effectiveness of the intercrop to increase the humidity and to lower the temperatures (Parker and riches 1993). The higher the plant densities the more the ground cover thus more humidity is increased and the temperatures lowered.

4.1.1 Influence of treatments on *Striga* count

For both seasons across time there was a significant difference between the treatment where the maize was artificially infested with *Striga* and that of the intercrops and the control (Table 2).
At eight weeks after planting for both seasons, there was significantly higher number of emerged *Striga* in maize artificially infested with *Striga* compared with the entire green gram intercrops. During the long rains there was no significant difference among the intercrops. However results from the short rains shows that intercropping had significant different number of emerged *Striga* weeds. This was in exception with the maize intercropped with green grams two rows, maize intercropped with green grams (broadcasting) and maize intercropped with green grams (same hill) which had no significantly different numbers of emerged *Striga* plants. Maize intercropped

with green grams (same hill plus one row) had the least emerged *Striga* while maize intercropped with green grams (same hill) had the highest number of emerged *Striga*.

At 10 WAP numbers of emerged *Striga* increased from the 8WAP across all treatments . During the short rains there was no significant difference between the emerged *Striga* in the intercrops and in the maize artificially infested with *Striga*. Results for the long rains shows that, among the intercrops there was no significant difference between the emerged *Striga* among the intercrops. Number of emerged *Striga* weeds in maize intercropped with green grams (broadcasting) was the lowest but not significantly different with maize with naturally infested *Striga* and maize intercropped with green grams (same hill plus one row).

At the 12th WAP the *Striga* counts were high across all treatments while in the 14 WAP the number of emerged *Striga* reduced.

It was observed that during the long rains broadcasting of green grams intercropped with maize had the least number of emerged *Striga* among all the intercrops. However during the short rains green grams planted in the same hill with maize plus one row between two rows of maize had the least emerged *Striga* (Table2).

Table 2: Means of *Striga* count from 8 WAP to 14 WAP/ plot by treatments

Treatments	8WAP[1]		10WAP		12WAP		14WAP		Average	
	LR[2]	SR[3]	LR	SR	LR	SR	LR	SR	LR	SR
Maize + *Striga*	2.320_{c}	2.505_{e}	3.141_{d}	3.228_{b}	3.447_{c}	3.333_{c}	3.451_{d}	3.207_{c}	3.019_{c}	2.931_{e}
Maize no *Striga*	1.167_{a}	0.000_{a}	2.230_{a}	0.195_{a}	2.652_{a}	0.957_{a}	2.696_{a}	0.569_{a}	2.388_{a}	0.489_{a}
Maize +Green gram (same hill)	2.113_{bc}	2.292_{d}	2.969_{cd}	2.921_{b}	3.289_{bc}	3.092_{bc}	3.332_{cd}	2.915_{bc}	2.908_{bc}	2.740_{d}
Maize +Green gram(same hill + one row)	1.921_{b}	2.082_{b}	2.682_{bc}	2.784_{b}	2.986_{ab}	2.847_{b}	2.906_{ab}	2.828_{b}	2.678_{b}	2.602_{b}
Maize +Green gram (one row)	2.003_{bc}	2.227_{c}	2.830_{cd}	2.823_{b}	3.043_{b}	2.943_{b}	3.103_{bcd}	2.841_{b}	2.661_{b}	2.675_{c}
Maize +Green gram (two rows)	2.271_{bc}	2.305_{d}	2.895_{cd}	2.828_{b}	3.076_{b}	2.954_{b}	2.990_{abc}	2.848_{b}	2.808_{bc}	2.711_{cd}
Maize +Green gram (Broadcasting)	1.908_{b}	2.251_{cd}	2.426_{ab}	2.957_{b}	2.690_{a}	3.165_{bc}	2.674_{a}	3.083_{bc}	2.343_{a}	2.716_{cd}
Green grams	-	-	-	-	-	-	-	-	-	-
cv(%)	11.9	2.0	8.1	6.7	7.4	8.2	7.8	8.5	6.8	1.3

[1]WAP refers to weeks after planting, [2]LR refers to Long Rains, and [3]SR refers to Short Rains.

-No emerged *Striga* was recorded.

Means followed by similar letters within a column are not significantly different

The best overall treatment which consistently and significantly reduced the number of emerged *Striga* from 12 to 14 WAP was planting green grams in the same hill with maize plus one row between two rows of maize. The number of *Striga* that emerged in maize plots not artificially infested was low.

4.1.2 Effects of the various treatments on maize *Striga* syndrome

The *Striga* syndrome rating was scored at the 12 WAP for both seasons. A one (no damage) to nine (maize plants dead or dying) scale was used as described in Chapter 3. During the short rains 2012 there was a significant difference in the *Striga* syndrome between the control (maize planted alone without *Striga* inoculation) and the treatment where maize was planted and *Striga* inoculated. The intercrops significantly reduced the syndrome compared to the infested maize but there was no significant difference between the intercrops where there was broadcasting, two rows of green gram planted between the two rows of maize and the one row of green grams planted between the maize rows (Figure 1).

It was observed that during the long rains 2013 maize without *Striga* infestation had the lowest *Striga* syndrome score and was not significantly different from the intercrop treatments. All the intercrops showed a lower *Striga* syndrome compared to the maize that was artificially infested with *Striga* (Figure 2).

For both the seasons maize that was artificially infested with *Striga* had the highest syndrome score followed by the maize/ green gram (same hill) intercrop. In both treatments the intercrop that had the least syndrome was the planting green grams in the same hill with maize plus one row between two rows of maize while the highest syndrome score among the intercrop was the intercrop maize /green grams in the same hill.

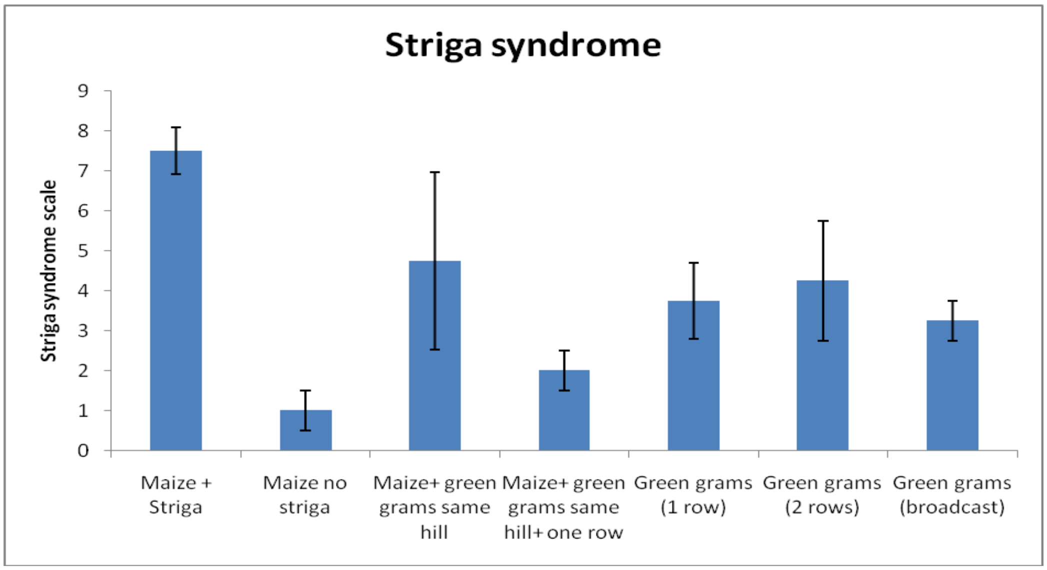

Figure 1. Means of *Striga* syndrome score as at the 12 WAP during the short rains 2012. The bars represent the standard errors.

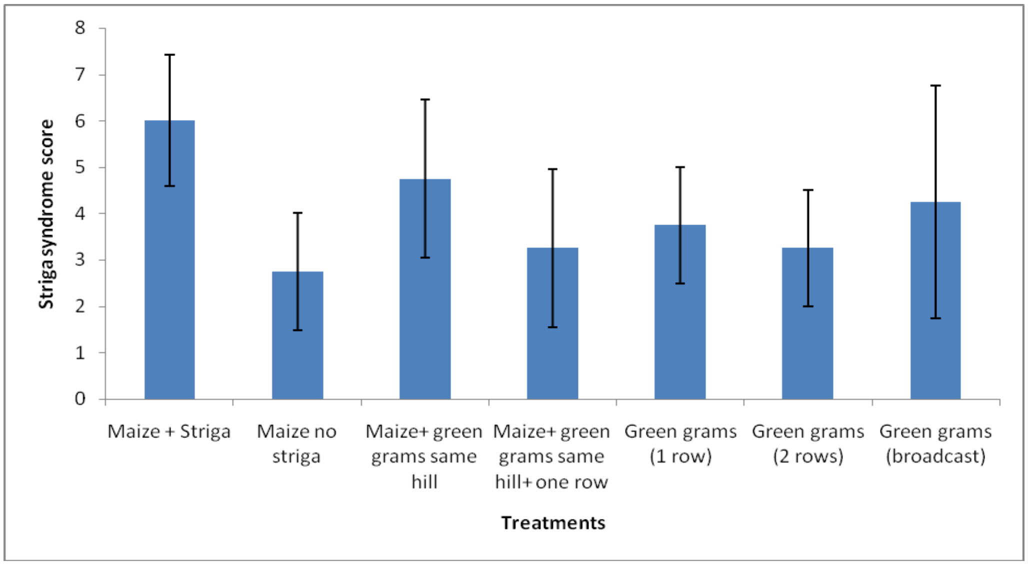

Figure 2. Means of *Striga* syndrome score as at the 12 WAP during the long rains 2013. The bars represent the standard errors

4.2 Effects of inter cropping maize with green grams on *Striga* parasitism and yields

The study sought to find out if the *Striga* count and the *Striga* syndrome ameliorated by different treatments affected the maize yield parameters. Intercropping is known to increase crop yield. The relatively higher yield can be attributed to the effectiveness of the intercrop system in reducing the *Striga* effect on the maize.

4.2.1 Effect of treatments on grain yield parameters

The results shows that in the short rains there was a significant difference between the dry grain weight for all the intercrop treatments with that of the control (maize without *Striga*) and that of the treatment where maize was planted with *Striga* incoproprated. During the short rains all the intercrops had no significant difference in their grain yield except for the same hill plus one row which was significantly superior. In the short rains uncontrolled *Striga* reduced dry grain weight by a factor of 67% while in the long rains it reduced the dry grain weight by 83% when uninfested maize was compared to infested one (Table 3). In the long rains there was no significant difference between the dry grain weight in the uninoculated with the intercrops except the treatment where green grams were planted in the same hill with maize. Among the intercrops in both seasons planting green grams in the same hill with maize plus one row between two rows of maize had the highest dry grain weight among the intercrops though not significant in the long rains while the green grams were planted in the same hill with maize had the least dry grain weight (Table 3).

All the intercrop irrespective of arrangement significantly improved the one thousand seed weight compared to infested maize without intercrop. During both seasons *Striga* reduced the weight of the seeds leading to poor quality light seeds. It was observed that during the short rains broadcasting green grams between maize rows, one row of green grams between two rows of maize and two rows of green grams planted between two rows of maize, green grams planted in the same hill plus one row significantly increased the quality of maize, as measured by the 1000 seed weight as compared to the treatment where pure maize was planted and *Striga* inoculated. Green gram in the same hill with maize did not significantly improve the grain quality over the infested maize alone. During the long rains the quality of maize was not significantly different between the intercrops and the maize that was naturally infested with *Striga*. The quality of maize in the maize artificially infested with *Striga* , two rows of green grams planted between two rows of maize and broadcasting green grams between maize rows was not significantly different (Table 3).

Results shows that all the intercrops during the short rains had low maize grain moisture content which were not significantly different from maize with *Striga* alone. It was observed that in both seasons, *Striga* significantly reduced maize grain moisture content at harvest when inoculated and non inoculated maize were compared. The percentage moisture content where maize was not artificially infested, was the highest in both seasons compared with all the other treatments. The percentage moisture content in uninfested maize in the short rains was significantly different with the other treatment while in the long rains it was the highest although non significant. The presence of *Striga* reduced the moisture content at harvest (hastened the maturity of the maize).

The results shows that during the long rains the dry grain weight, wet grain weight , 1000 seed weight and grain moisture content was higher than in the short rains.

Table 3: Means of grain yield parameters during short and long rains.

Treatment	Dry Grain Weight(g)		Wet grain Weight(g)		1000seed weight(g)(dry grain)		Moisture content(%	
	LR[1]	SR[2]	LR	SR	LR	SR	LR	SR
Maize + *Striga*	2168_{a}	680_{d}	3192_{a}	1045_{d}	183.2_{a}	121.3_{c}	19.55_{a}	18.45_{b}
Maize no *Striga*	6570_{c}	4015_{a}	8365_{c}	5555_{a}	253.5_{b}	229.0_{a}	21.93_{b}	22.25_{a}
Maize +Green gram (same hill)	3100_{ab}	1000_{cd}	4160_{ab}	1600_{cd}	241.6_{b}	163.5_{bc}	20.25_{ab}	16.38_{b}
Maize +Green gram(same hill + one row)	5815_{bc}	2325_{b}	7428_{bc}	3028_{b}	250.8_{b}	180.1_{b}	20.13_{ab}	17.80_{b}
Maize +Green gram (one row)	4270_{abc}	1580_{c}	5572_{abc}	1980_{c}	236.4_{b}	188.1_{ab}	20.30_{ab}	17.93_{b}
Maize +Green gram (two rows)	4855_{abc}	1560_{c}	6265_{abc}	2265_{bc}	225.9_{ab}	178.0_{b}	19.43_{a}	18.55_{b}
Maize +Green gram (Broadcasting)	4850_{abc}	1485_{c}	6125_{abc}	1870_{c}	227.6_{ab}	173.7_{b}	20.88_{ab}	17.58_{b}
Green grams	-	-	-	-	-	-	-	-
cv(%)	44.5	21.6	42.5	21.1	13.0	16.4	7.0	8.3

[1]LR refers to Long Rains 2013, and [2]SR refers to Short Rains 2012.

- No maize yield parameter was observed.

Means followed by similar letters within a column are not significantly different.

4.2.2 Impact of treatments on maize cob parameters

During the short rains uncontrolled *Striga* in artificially infested maize significantly reduced the number of cobs per plot, cob length and cob diameter compared to all other treatments. In both seasons it was observed that there were no significant differences in the number of cobs per plot among all the maize/ green grams intercrops. They were significantly higher than sole *Striga* incorporated maize. This was with the exception during the long rains where there was no significant difference in the number of cobs between intercrops with green grams planted in the same hill with maize and solo *Striga* incorporated maize. Number of cobs in maize without *Striga* incorporation was highest. They were significantly different from those in the maize/green grams planted in the same hill plus one row of green grams between two rows of maize, during the short rains but were not significantly different from other intercrops in the long rains (Table 4).

During the short rains the cob diameter in artificially infested maize was significantly lower than all other treatments. Also the uncontrolled *Striga* in artificially infested maize reduced the cob diameter by thirty three percent when compared to the cob diameter in the maize without *Striga* incorporation. In both seasons it was observed that the cob diameter in the maize without *Striga* incorporation was the highest. During the short rains the cob diameter in uninfested maize was significantly longer from all the other treatments except the maize and green grams planted in the same hill plus one row of green grams between two rows of maize rows while in the long rains it was not significantly longer from the intercrops. Results for the two seasons showed that the cob diameter was not significantly different in all the intercrops. This was with the exception of the maize and green grams planted in the same hill plus one row of green grams between two rows of maize rows which had the highest cob diameter among all the intercrops, during the short rains (Table 4).

Tble 4 shows that during the short rains uncontrolled *Striga* in artificially infested maize significantly reduced the cob length per plant compared to other treatments. In the same season, in all the intercrops the cob length per plant was significantly higher than the cob length per plant in the artificially infested maize. The cob length per plant was highest in the maize without *Striga* infestation for both seasons. Results for the long rains showed that the cob length was not significantly different from the all the intercrops. This was different during the short rains where the the cob length was not significantly different with the artificially infested maize and the maize/ two rows of green grams between two rows of maize (Table 4).

The cob height was not significantly different between the treatments during the short rains. During both seasons the results showed that the cob height in maize with naturally infested *Striga* was the highest. During the long rain there was no significant difference between the maize with naturally infested *Striga* and the intercrops except in the green grams planted in the same hill with maize (Table 4).

Table 4: Means of cob parameters by treatments during the short rains and long rains

	Cob parameters							
	Number of cobs/plot		Cob diameter(cm)/ plant		Cob Length(cm)/plant		Cob height(cm)/plant	
Treatments	LR[1]	SR[2]	LR	SR	LR	SR	LR	SR
Maize + *Striga*	52.75_{a}	30.00_{a}	3.28_{a}	3.15_{a}	10.70_{a}	10.95_{a}	58.75_{a}	66.69_{a}
Maize no *Striga*	80.25_{b}	67.00_{c}	3.83_{b}	4.075_{c}	13.53_{b}	16.42_{c}	83.75_{b}	81.12_{a}
Maize +Green gram (same hill)	53.75_{a}	46.50_{b}	3.55_{ab}	3.675_{b}	12.93_{ab}	12.57_{b}	68.75_{ab}	60.94_{a}
Maize +Green gram(same hill + one row)	79.50_{b}	58.50_{bc}	3.88_{b}	4.025_{c}	13.60_{b}	15.95_{c}	77.50_{ab}	71.50_{a}
Maize +Green gram (one row)	74.00_{b}	48.75_{b}	3.75_{b}	3.725_{b}	12.80_{ab}	12.77_{b}	68.75_{ab}	78.12_{a}
Maize +Green gram (two rows)	77.00_{b}	50.25_{b}	3.63_{ab}	3.825_{b}	12.08_{ab}	13.02_{b}	77.50_{ab}	59.06_{a}
Maize +Green gram (Broadcasting)	71.75_{b}	47.00_{b}	3.68_{b}	3.600_{b}	12.75_{ab}	12.47_{b}	62.50_{a}	65.31_{a}
Green grams	-	-	-	-	-	-	-	-
cv(%)	13.8	15.7	6.2	4.5	12.5	6.8	17.6	19.8

[1]LR refers to Long Rains 2013, and [2]SR refers to Short Rains 2012.

- Means no cob parameter data was recorded.

Means followed by similar letters within a column are not significantly different.

4.2.3 Effect of treatment on plant parameters

The plant girth diameter was taken at the first node above the ground. Results for the two seasons showed that it was significantly reduced by the emerged *Striga*. This is seen in the uncontrolled *Striga* in maize infested artificially with *Striga* which had the least significant plant girth diameter in both seasons compared to other treatments. The intercrop where the maize was planted in the same hill plus one row of green grams between two rows of maize had the highest plant girth diameter and was not significantly different with the treatment maize without *Striga* incorporation for both seasons and it was not also significantly different with the other intercrops except the treatment where maize was planted in the same hill with the green grams (Table 5 and 6). There was no significant difference in the fifty percent days to flowering in all the treatments (Table 5).

In both seasons there was no significant difference in the number of lodged plants both at the stem and at the root among the intercrops (Table 5 and 6). Maize infested with *Striga* had the highest although non-significant stem lodging and least number of root lodged plants (Table 6).

Table 5: Means of plant parameters by treatments during the short rains 2012

Treatment	Height/plant(cm)	lodging/plot		Days to 50% flowering/plot		Girth diameter/ plant(cm)
		Root	Stem	Tasselling	silking	
Maize + *Striga*	123.8_a	2.250_a	4.500_a	71.25_a	77.25_a	4.400_a
Maize no *Striga*	186.9_b	6.500_b	9.500_b	72.25_a	74.75_a	6.935_d
Maize + *Striga* (same hill)	127.9_a	3.000_a	4.500_a	72.50_a	82.25_a	5.565_b
Maize + Green grams (same Hill + one row)	135.3_a	2.750_a	4.500_a	70.50_a	77.25_a	6.630_{cd}
Maize + Green grams (one row)	145.9_a	1.500_a	2.750_a	71.00_a	76.00_a	6.100_{bcd}
Maize + Green grams (two rows)	131.3_a	0.750_a	3.000_a	71.50_a	77.50_a	5.795_{bc}
Maize + green grams(Broadcasting)	127.8_a	1.750_a	4.000_a	70.25_a	78.75_a	5.785_{bc}
Green grams	-	-	-	-	-	-
cv(%)	14.1	57.8	40.9	2.3	7.5	10.9

-No plant parameter was recorded.
Means followed by similar letters within a column are not significantly different.

Table 6: Means of plant parameters by treatments during the long rains 2013

Treatment	Height/plant(cm)	lodging/plot		Days to 50% flowering/plot		Girth diameter/plant(cm)
		Stem	Root	Tasselling	silking	
Maize + *Striga*	133.8_{a}	3.250_{a}	2.750_{a}	59.75_{a}	63.75_{a}	3.392_{a}
Maize no *Striga*	193.8_{b}	2.250_{a}	4.000_{ab}	61.25_{a}	64.75_{a}	5.750_{c}
Maize + *Striga* (same hill)	166.2_{ab}	1.250_{a}	4.250_{abc}	61.75_{a}	68.00_{a}	4.260_{b}
Maize + Green grams (same Hill + one row)	171.2_{ab}	1.000_{a}	5.000_{abc}	60.75_{a}	64.00_{a}	5.440_{c}
Maize + Green grams (one row)	143.8_{a}	1.750_{a}	4.250_{abc}	61.50_{a}	65.00_{a}	4.885_{bc}
Maize + Green grams (two rows)	160.0_{ab}	1.250_{a}	6.500_{bc}	60.75_{a}	64.75_{a}	4.945_{bc}
Maize + green grams(Broadcasting)	152.5_{ab}	1.500_{a}	7.000_{c}	61.75_{a}	66.75_{a}	4.352_{b}
Green grams	-	-	-	-	-	-
cv(%)	17.0	116.1	42.8	3.9	4.8	11.5

- No plant parameter was recorded.
Means followed by similar letters within a column are not significantly different.

4.2.3 Effects of treatments on mean green grams parameters

Table 7 displays that in both seasons there was no significance difference in the number of branches per plant and the number of pods per plant. Similarly there was no significance difference in the weight of green grams among the intercrops. The long rains results showed that broadcasting had the highest grain weight though not significantly different, while two rows of green grams planted between two rows of maize had the least grain weight. The plant population/ plot in both seasons were least in the green grams planted in the same hill with maize (Table 7).

Table 7: Means of green grams parameters of various treatments during the 2012 short rains and 2013 long rains.

Treatment	Number of branches/plant		Number of pods/plant		Plant population/ plot		Dry grain weight/plot	
	LR[1]	SR[2]	LR	SR	LR	SR	LR	*SR
Maize + Green grams (same hill)	3.008_{ab}	0.910_{a}	7.650_{a}	1.837_{a}	289.5_{a}	84.5_{a}	226.3_{a}	
Maize + Green grams (same Hill + one row)	3.150_{a}	1.025_{a}	4.750_{a}	1.917_{a}	615.2_{bcd}	202.0_{b}	215.7_{a}	
Maize + Green grams (one row)	3.550_{ab}	1.31_{a}	4.950_{a}	2.088_{a}	375.2_{ab}	167.2_{ab}	166.2_{a}	
Maize + Green grams (two rows)	3.550_{ab}	1.276_{a}	6.600_{a}	1.145_{a}	512.8_{abc}	230.2_{b}	164.4_{a}	
Maize + Green grams(Broadcasting)	3.650_{ab}	1.152_{a}	7.050_{a}	1.471_{a}	820.5_{d}	196.8_{b}	290.5_{a}	
Green grams pure stand	5.050_{b}	2.229_{b}	9.150_{a}	3.486_{b}	741.5_{cd}	401.5_{c}	289.8_{a}	
CV(%)	25.0	67.5	54.0	83.5	30.5	27.9	71.00	

[1]LR refers to Long Rains 2013, and [2]SR refers to Short Rains 2012. * There was a crop failure in SR 2012 and dry grain weight/ plot was not recorded.
Means followed by similar letters within a column are not significantly different.

CHAPTER FIVE

DISCUSSION

5.1 Effect of green gram arrangement in an intercrop of green grams with maize on *Striga* populations.

Results gotten from this study shows that intercropping maize and green grams significantly reduced the number of *Striga* incidence. The roots of several legumes are known to induce suicidal germination of *Striga* seeds, this feature has become incorporated into *Striga* suppression strategies involving cereal-legume rotation or intercropping. This is consistent with the reports of Khan *et al*., (2002) who found out that mixed cropping of cereals and cowpea reduce *Striga* infestation significantly. Zeyaur *et al* 2007 observed that in pooled analysis across seasons that intercropping sorghum with green gram, cowpea and crotalaria, and maize with crotalaria significantly reduced *Striga* populations. Musambasi *et al*. (2002) reported that maize/cowpea intercrop supported less *Striga* plant/m^2 than sole maize. Also he found out that *Striga* infestation and incidence were lower when maize was intercropped with cowpea than when planted sole. Mbwaga *et al*. (2001) also observed that intercropping cereals and cowpea has been observed to reduce *Striga* infestation significantly.

Increased humidity and lowered temperatures under the intercrops reduced the growth of emerging *Striga* (Parker and Riches, 1993). Emerged *Striga* plants in a maize soy bean intercrop were etiolated and dried earlier than those in sole maize crop because of the smothering (Kurech *et al.*, 2000). The *Striga* counts were relatively high during the long rains season than the short rains. This is in consistence with the finding of Odhiambo *et al*. (2011) who reported that maize intercropped with soy bean had lower *Striga* incidence during the short rains than in the long rains.

Irrespective of the season, the *Striga* counts increased significantly from 8 to 12 WAP. This was in agreement with the findings of Odhiambo *et al*. (2011) who reported that in a maize soy bean intercrop there was a significant increase in the *Striga* count from the 8 week to the 12 week after planting. Kurech *et al.* (2000) noted that emerged *Striga* plants in a maize soybean intercrop were etiolated and dried earlier than those in sole maize crop because of the smothering. At the 12th WAP *Striga* counts were high across all the treatments. This is could be attributed to the fact that it's the most productive stage of the maize crop. In the 14 WAP the number of emerged *Striga* reduced. At this stage the maize has reduced physiological activity.

5.2 Effect of green gram arrangement in an intercrop of green grams with maize on *Striga* syndrome.

In this study intercropping reduced *Striga* incidence in the intercrops compared to the inoculated maize with *Striga*. *Striga* populations were positively correlated to the *Striga* syndrome which was highest in the maize without *Striga*. This is in agreement with Kureh *et al*., 2000 who reported that intercropping maize with soy beans supported lower incidence and infestation of *Striga* and exhibited lower crop syndrome reaction score than sole maize. Likewise Carl and Niguise (2011) reported that highest crop *Striga* syndrome level were recorded where desmodium was absent in the intercrop. Kuchinda *et al* (2003) reported that intercropping of maize with soy bean and groundnut significantly reduced *Striga* incidence and the maize syndrome score.

The entire green gram stands completely suppressed *Striga* emergence showing that green grams are non hosts. These might have caused suicidal germination where *Striga* seeds are induced to germinate because of the germination stimulant they produce but they cannot be parasitized because they are non host crops and maize roots are far away. Worsham (1987) suggested that suicidal germination of the *Striga* seeds in the absence of the roots of a host cereal crops leads to death of the *Striga* seedlings within 3-5 days, thus the *Striga* seedling has to be close to the host crop roots.

5.3 Effects of intercropping maize and green grams on the yields and yield parameters

Intercropping increases crop yield depending on the crop species and environment. During the long rains of the this study, intercropping maize with green grams led to a yield increase of 67% while in the short rains a yield increase of 55.6% was recorded. Similar observations have been made by Odhiambo (2011) who reported that soybean led to a yield increase of 39% to 107% when maize was intercropped with soybean. Oswald *et al*. (2002) and Gbehounou and Adango (2003) also observed a higher yield when maize was intercropped with cowpea, soybean, yellow gram, bambara, bean, groundnut and green gram in Western Kenya. Chivinge *et al*. (2001) reported that intercropping cowpea cultivars with maize resulted in maize yield increases of 650-860% during the 1996/97 season with yields of 3.8-4.8 tha-1. Musambasi *et al* (2002) supported that intercropping maize with legumes results in higher yield. In contrast, Wandahwa *et al*. (2006) found that intercropping maize and soybean (Nyala and Gazelle variety) reduced the yield of maize probably because of competition for resources. The relatively high maize yield in the intercrop could be attributed to the effectiveness of the systems in reducing the *Striga* effect. The high *Striga* biomass in the inoculated sole maize might have been responsible for the low maize yield. Nitrogen supply and reduction in leaching of soil nutrients by the intercrop cover may be responsible for the higher maize yield. Gurney *et al*. (1999) and Aliyu and Emechebe (2006) found the level of *Striga* biomass to negatively influence the host productivity.

In this study the planting pattern of green grams had no significant influence on *Striga* infestation on maize and ultimate grain yield during both the long and short rains. However maize intercropped with green grams planted in the same hill with maize plus one row of green grams between two rows of maize had low *Striga* emergence compared to the rest of the intercrop, which was reflected in high, though non-significant maize grain yield. This is in line with the reports of Odhiambo and Ariga (2001) who observed that the planting pattern of beans in a maize bean intercrop had no significant influence in the *Striga* infestation and the maize grain yield in Nyadwera during their two seasons. The results of this study shows that, among the intercrops green grams planted in the same hill showed the highest number of emerged and the lowest yield. This is in contrast with Odhiambo and Ariga (2001) who reported that Intercropping maize and beans in the same hole had the highest grain yield, which was 78.6 % above the yield of pure maize stands.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study established that intercropping maize with green grams reduced *Striga* incidence in the maize.

Planting arrangement of green grams in the intercrop has no significant difference in reducing the *Striga* incidence.

Intercropping maize and green grams had a significantly higher difference in the maize dry grain weight in when compared to the maize with uninfested *Striga*.

Uncontrolled *Striga* reduced dry grain weight 67% during the short rains and 83% during the long rains when uninfested maize was compared to infested one.

The study results gotten shows that, there were no significant differences in the number of lodged plants both at the stem and at the root among the intercrops. Maize infested with *Striga* had the highest although non-significant stem lodging and least number of root lodged plants.

The study results indicates that one row of green grams planted between two rows of maize had the least number of rotten ears although not significant.

6.2 Recommendations

Small scale farmers should be encouraged to grow maize intercropped with green grams to assist in *Striga* weed management, improve maize yield and better the utilization of land and labor.

Extension officers can advise small scale farmers to practice intercropping of maize and green grams irrespective of the planting arrangement in the intercrop, since it increased the plant populations thus reducing the number of *Striga* without affecting the maize yield

Future studies on the cost benefit of intercropping maize and green grams to reduce the effect of *Striga* parasitism on maize should on maize.

Pre screening of available green grams varieties for *Striga* germination stimulation and testing further intercropping and rotation.

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