INTEGRATING LEGUME COVER CROPS AND STRIGA RESISTANT MAIZE VARIETIES IN THE CONTROL OF STRIGA ASIATICA IN COASTAL LOWLANDS OF KENYA

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A thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in Agronomy of Pwani University

AUGUST, 2014
DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or any other award

Signature: ................................................Date: ........................................

Bahati Abdallah

We confirm that the work reported in this thesis was carried out by the candidate under our supervision

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DEDICATION

This thesis is dedicated to my dear husband Bakari J.R. Tabwara and my lovely daughters Fatuma Bakari and Mwanahamisi Bakari.
ACKNOWLEDGEMENT

My sincere gratitude goes to my supervisors Dr. Mkuzi Saha and Prof. Muniru Tsanuo for their original contribution to the research topic and invaluable support throughout the research period. I would also wish to express my sincere appreciation to the striga management research team without whose support the research could not have been a success. I also thank the officer in-charge KARI Matuga, Mr. Finyange Pole for provision of land for my field research. I feel indebted to my daughters for their patience and understanding throughout my study. Lastly, I wish to recognize the moral support and encouragement offered by my husband throughout the research period.
Striga is a serious parasitic weed of cereals and legumes, negatively affecting farming in the developing world. In coastal Kenya, it is known as 'chitsai' (a little witch) because of its weakening effect on maize (*Zea mays* L.). The species that parasitizes maize, in coastal Kenya is *Striga asiatica*. Integrated management including growing resistant varieties is the most economic way to manage striga especially for resource constrained farmers. Technologies within the reach of the small scale farmers need to be developed. The objectives of this study were to:

i. Evaluate the effectiveness of striga-resistant maize varieties in the control of *S. asiatica*

ii. Evaluate the effectiveness of cowpea (*Vigna unguiculata*) and mucuna (*Mucuna pruriens*) in the control of *S. asiatica*

iii. Evaluate the effect of interaction between striga resistant maize variety and legume cover crop (cowpea or mucuna) in the control of *S. asiatica*

iv. Evaluate the effect of spatial arrangement of intercropped cowpea in the control of *S. asiatica*

The study was conducted at KARI Matuga to investigate the effect of integrating striga resistant maize varieties and legume cover crops (mucuna and cowpea) on the control of *S. asiatica* in coastal Kenya, in 2012 and 2013. The legumes were intercropped with maize at planting and plots of sole cropped maize were included as the control. A randomized complete block
design, with three replications, was used. Striga stand counts, striga seed density in soil, maize grain and stover yields were the parameters analyzed. Maize varieties differed significantly in their stover yield in 2012 and 2013 LR seasons. However, the results showed no significant effect of maize variety on striga stand counts at 7 and 9 WAP in 2012 and 2013 LR seasons. In 2013 legume intercropping significantly reduced maize grain yield by 17.25% and 18% under mucuna and cowpea, respectively. Spatial arrangement of intercropped cowpea significantly influenced maize grain and stover yields in 2013 LR season. Correlation analysis showed no meaningful correlation between striga stand counts and maize grain and stover yields since the coefficient of determination ($r^2$) was less than 0.5. The results of the study showed that cowpea significantly reduced the striga seed density in soil after the end of season one (2012 LR season). The reduction in striga seed density in soil was associated with suicidal germination of the weed seed after stimulation by cowpea. However, there is need for further research to evaluate the effectiveness of cowpea planted either as an intercrop or a rotation crop with maize in the control of *S. asiatica*. Maize varieties $V_2$ and $V_4$ showed some tolerance to striga weed. These varieties are therefore recommended for multi-locational evaluation under the National Performance Trials (NPTs) to ascertain their superiority to the current commercial maize varieties. Within row spatial arrangement of cowpea in a maize-cowpea intercrop gave higher maize yields than the between row arrangement. Farmers are therefore likely to realize improved maize yields by adopting the within row spatial arrangement of intercropped cowpea.
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
</tr>
<tr>
<td>CAN</td>
<td>Calcium ammonium nitrate</td>
</tr>
<tr>
<td>DAP</td>
<td>Di-ammonium phosphate</td>
</tr>
<tr>
<td>DM</td>
<td>Dry matter</td>
</tr>
<tr>
<td>GLM</td>
<td>General linear model</td>
</tr>
<tr>
<td>KARI</td>
<td>Kenya Agricultural Research Institute</td>
</tr>
<tr>
<td>LSD</td>
<td>Least significant difference</td>
</tr>
<tr>
<td>LR</td>
<td>Long rains</td>
</tr>
<tr>
<td>PH4</td>
<td>Pwani Hybrid 4 maize</td>
</tr>
<tr>
<td>PROCC CORR</td>
<td>The correlation procedure of SAS</td>
</tr>
<tr>
<td>RCBKD</td>
<td>Randomized complete block design</td>
</tr>
<tr>
<td>SAS</td>
<td>Statistical Analysis System</td>
</tr>
<tr>
<td>WAP</td>
<td>Weeks after planting</td>
</tr>
</tbody>
</table>
CHAPTER 1: INTRODUCTION

1.1 Background information

Striga is a serious parasitic weed to cereal and leguminous crops affecting subsistence farming in the developing world. It is commonly known as ‘chitsai’ (a little witch) in coastal Kenya because of its weakening effect on maize plants. According to Taylor (2009) and Atera et al. (2012) maize, sorghum, sweet potatoes, wheat, rice, beans, finger millet and cassava are some of the major food crops grown in Kenya. A large number of these crops are affected by striga species. Among all the crops grown in Kenya, maize is grown by almost every farmer. According to Gitau et al. (2009), small scale farmers account for about 70% of the total production in Kenya. With the increased striga infestation in the maize producing areas of coastal Kenya, there is likelihood of food insecurity if urgent measures are not taken to deal with the striga problem.

*Striga asiatica* is present in several parts of the coastal region of Kenya and seems to be spreading fast, presumably due to ignorance on its biology among the small scale farmers. Striga flourishes well in infertile soils and causes crop losses ranging from 70 to 100% (Ejeta, 2007). *Striga asiatica* was reported to occupy a large area in the coastal region of Kenya and attacked cereals and wild grasses (Gethi *et al.*, 2005).

Some of the control methods used in controlling striga weed as reviewed by Parker and Riches (1993), Kroschel (2001) and Omanya (2001) include
transplanting, crop rotation, trap and catch cropping, fallowing, hand pulling, nitrogen fertilization, time of planting, method of planting (intercropping and mixed cropping), solarization, use of herbicides, use of artificial seed germination stimulants, use of resistant crop varieties and biological method. The factors limiting adoption of striga control technologies as highlighted by Nambafu (2013) include: long term viability of striga seeds, uncontrolled sharing of farm implements, expensive technologies, lack of relevant information and labor requirements.

Striga control using resistant varieties will reduce the labor and time needed for physical control, help in environmental preservation and reduce production cost due to chemical control. Maize germplasm bred for resistance to *S. asiatica* was not completely resistant (Gethi, 2003) and therefore a combination of technologies is necessary to successfully control the weed.

*Mucuna pruriens* has been shown to control *S. hermonthica* by replenishing soil nitrogen. A study by Mureithi et al. (2003) conducted in Kendu Bay to evaluate the effectiveness of three green manure legumes (sunhemp, lablab and mucuna) in controlling *S. hermonthica* showed that the legumes had deterrent effect on striga. The plots with legumes had on average 10 striga plants per square meter while the control had 32 striga plants per square meter.

In an unpublished survey (H.S. Shauri, Personal communication), it was observed that some farmers in the striga prone areas of coastal Kenya plant maize and cowpea (*Vigna unguiculata*) in the same planting hole (Plate 1.1). It
was not quite clear why the farmers used such a cropping system, but probably
the earlier users had a good reason for using the system, such as minimizing
the striga menace. It was therefore necessary that a study be carried out to
establish whether spatial arrangement of intercropped cowpea has any effect in
the control of *S. asiatica*.

![Plate 1.1: Maize and cowpea planted in same hole on a farmer’s field](image)

It is generally accepted that no single striga control method can achieve a
100% results in an economically accepted way. As a result, an integrated
striga control approach is gaining prominence amongst researchers and
farmers in striga infested areas. Any integrated striga control should focus on containment and control of the weed and improvement of soil fertility.

From the literature reviewed a lot of striga research in Kenya was concentrated in the lake region in controlling *S. hermonthica*. Very little research has been undertaken on *S. asiatica* in coastal Kenya.

1.2 Statement of the problem

The striga problem in coastal Kenya is becoming worse due to soil fertility decline as a result of intensive land use for food production through continuous mono-cropping of cereals without adequate replenishment of nutrients in the soil. The continued cereal mono-cropping support striga and therefore increase its spread and area of coverage (Ejeta, 2007). This is because striga thrives well in poor, infertile, degraded land which is so in most areas in Africa because of poor soil management and farming practices (Ejeta, 2007). *Striga asiatica* infests maize, which is a staple food for the communities living in coastal Kenya. It devastates the crop and can lead to 100% loss depending on cultivar (Lagoke *et al*., 1991). This therefore reduces land productivity as it decreases food production, hence leading to food insecurity. This in turn affects livelihoods of the people of coastal Kenya due to lowered household food security.
1.3 Objectives

1.3.1 Broad objective

To enhance maize productivity in coastal Kenya by integrating the use of striga resistant maize varieties and legume cover crops to control *S. asiatica*

1.3.2 Specific objectives

i. To evaluate the effectiveness of striga-resistant maize varieties in the control of *S. asiatica*

ii. To evaluate the effectiveness of cowpea and mucuna in the control of *S. asiatica*

iii. To evaluate the effect of interaction between striga resistant maize variety and legume cover crop (cowpea or mucuna) in the control of *S. asiatica*

iv. To evaluate the effect of spatial arrangement of intercropped cowpea in the control of *S. asiatica*

1.4 Hypotheses

i. Striga-resistant maize varieties have no effect in controlling *S. asiatica*

ii. Legume cover crops have no effect in controlling *S. asiatica*

iii. There is no significant interaction effect between striga-resistant maize variety and legume cover crop in the control of *S. asiatica*

iv. Spatial arrangement of intercropped cowpea has no effect in the control of *S. asiatica*
1.5 Justification

The three important food crops grown in coastal Kenya include maize, cowpea and cassava (*Manihot esculenta* Crantz). Maize is grown on 99% of the smallholder farms (Saha *et al.*, 1993) and forms a major component of the diet of the coastal population (Wekesa *et al.*, 2003). However, its production is constrained by among other factors weed infestation, especially by *S. asiatica*. Striga is a major constrain in cereal production in sub-Saharan Africa (Atera *et al.*, 2012). It parasitizes cereals such as maize, sorghum, rice and wheat leading to crop losses ranging from 70 to 100% (Ejeta, 2007). The weed is reported to be infecting about 217,000 ha in Kenya causing annual crop loss of US$50 million (Woomer and Savala, 2009). With the increased striga infestation in the maize producing areas, there is a likelihood of food insecurity if urgent measures are not taken to deal with the problem. Although some progress has been made in the fight against striga, none of the available methods is appropriate to the resource poor farmers. However, intercropping maize with non-host plants is gaining prominence as a method that can offer a solution (Lagoke and M’Boob, 2002). This approach if integrated with the use of striga resistant maize varieties could offer a viable solution and more effective control to the striga problem than a single method. Work on *M. pruriens*, a non-host plant, has shown that it can reduce striga through enhancement of soil fertility thus making the soil unfavorable for the weed. Hardly any research has been carried out to evaluate the interaction effect of legume cover crops (cowpea and mucuna) and resistant maize varieties on *S.*
asiatica infestation in coastal Kenya. This research is aimed at using an integrated approach using striga resistant maize varieties and legume cover crops (M. pruriens and V. unguiculata) on the control of S. asiatica which is likely to reduce the seed load in soil. This will then enhance the productivity of maize in S. asiatica prone areas of the coastal lowland Kenya.
CHAPTER 2: LITERATURE REVIEW

2.1 Weeds

A weed may generally be defined as any plant that grows where it is not wanted (CABI, 2005). These are plants that are not sown but spontaneously grow on their own where the prerequisite conditions for their germination are favorable.

2.2 Striga

(Striga spp.) is characterized by bright-green stems and leaves and small, brightly colored flowers. Striga is thought to have originated from Africa. The weed is distributed mostly in almost all regions of sub-Saharan Africa. The genus striga has about 35 species of which about 11 species attack economically important crops (Raynal-Roques, 1991). In Kenya, there are nine known species of striga (Table 2.1). The most prevalent species of economic importance in agriculture are S. asiatica and S. hermonthica that parasitizes cereals and S. gesnerioides that attacks legumes.

Striga gesnerioides

Striga gesnerioides occurs in Africa, Arabian Peninsula, the Indian subcontinent, and the United States. This species causes its greatest economic damage on legume crops, especially cowpeas.
Table 2.1 *Striga* spp. distribution and occurrence in Kenya

<table>
<thead>
<tr>
<th>S/NO.</th>
<th>STRIGA SPECIES</th>
<th>HOST PLANT</th>
<th>OCCURRENCE AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><em>S. asiatica</em></td>
<td>Maize, rice, sugar cane sorghum, pearl millet, finger millet, wild grasses</td>
<td>Kwale, Kiungu, Kilifi, Alupe, Isiolo, Mathews range, Daka Chom</td>
</tr>
<tr>
<td>2.</td>
<td><em>S. hermonthica</em></td>
<td>Maize, pearl millet, finger millet, sorghum, rice, sugar cane, wild grasses</td>
<td>Churaiombo, Miwani, Kendu, Nyamira, Migori, Kuria, Siaya, Homabay, Bungoma, Alupe</td>
</tr>
<tr>
<td>3.</td>
<td><em>S. gesnerioides</em></td>
<td>Cowpea</td>
<td>Kilifi, Buna, Nairobi Homa hills, Rongo, Naivasha</td>
</tr>
<tr>
<td>4.</td>
<td><em>S. bilabiata</em></td>
<td>Wild grasses</td>
<td>Chyulu hills, Naivasha, Rumbia, Kahawa, Mathews range</td>
</tr>
<tr>
<td>5.</td>
<td><em>S. elegans</em></td>
<td>Wild grasses</td>
<td>Nairobi, Loitoktok, Laikipia, Rumuruti</td>
</tr>
<tr>
<td>7.</td>
<td><em>S. latericea</em></td>
<td>Sugar cane, wild grasses</td>
<td>Kilifi, Kwale, Mariakani, Samburu, Voi, Machakos, Sultan Hamud, Mwea</td>
</tr>
<tr>
<td>8.</td>
<td><em>S. lutea</em></td>
<td>Wild grasses</td>
<td>Kwale, Chyulu hills, Embu</td>
</tr>
<tr>
<td>9.</td>
<td><em>S. pubiflora</em></td>
<td>Sugar cane, wild grasses</td>
<td>Voi, Kwale</td>
</tr>
</tbody>
</table>

Source: Atera et al., 2013; De Groote et al., 2008; Gethi et al., 2005; Khan et al., 2007; Mohamed et al., 2001.

*Striga hermonthica*

*Striga hermonthica* is thought to have originated from the vast tropical savannah between the Semien Mountains of Ethiopia and the Nubian hills of Sudan (Gethi and Smith, 2004). It has the largest geographical distribution. In
Kenya, *S. hermonthica* is mostly found in western Kenya. It is the species that causes the greatest damage to crops (Gethi and Smith, 2004).

**Striga asiatica**

Like *S. hermonthica*, *S. asiatica* is also thought to have originated from the tropical savannah between the Semien Mountains of Ethiopia and the Nubian hills of Sudan (Gethi and Smith, 2004). *Striga asiatica* has its widest distribution in the eastern and southern Africa. It is also found in Asia, particularly in southern India, as well as the United States and Australia. In Kenya, *S. asiatica* is less widespread and only found in some parts along the Indian Ocean (Gethi and Smith, 2004). It has hairy, hard, quadrangle-shaped, and fibrous stems. The leaves are about 4 cm long and 1.5 - 3.5 mm wide. The flower color varies from bright red, pink, orange, yellow, white or purple (Gethi and Smith, 2004). The flowers are alternately arranged in the spike, much smaller than those of *S. hermonthica* but more prominent. The flowers are self-pollinated due to sticky pollen holding on the elongated style before the flower opens (Gethi and Smith, 2004).

2.2.1 Host range, biology, survival and dispersal

Different striga species attack different crops. Striga mostly attacks monocots, such as maize, millet, sorghum, rice, sugar cane and some grasses. It also affects dicots such as cowpea, peanut and some wild legumes. Sweet potato and tobacco are also affected by striga.
Striga is an obligate root parasite that requires a living host for survival. A mature striga plant is capable of producing numerous seeds (up to 500,000 per plant). Striga seeds are tiny (0.20-0.50 mm and 0.3-12.4 micrograms mass) and therefore very easy to disperse. The seeds can lie dormant in the soil for up to 20 years waiting for favorable conditions for them to germinate (Doggett, 1988). Striga seeds have been shown to survive in frozen soil at temperatures as low as -15°C (Sand et al., 1990).

Dormant striga seeds in the soil require a preconditioning period that involves exposure to a wet environment and a suitable temperature of about 30°C for a period of about 1-2 weeks for them to germinate. The seeds are then triggered
to germinate by a chemical stimulant from host roots (strigolactones) (Matusova et al., 2005). Pre-conditioned seeds that dry out before being stimulated to germinate revert back to the dormant state (secondary dormancy) (Matusova et al., 2005).

After germination, striga causes the release of chemicals by the host and these chemicals then induce haustorial formation. One such chemical is 2, 6-dimethoxybenzoquinone, a degradation product of host root lignin. The striga root tip then begins to produce structures that superficially resemble root hairs which attach the striga root to the host with a bell-like swelling that attaches to the host root (Johnson, 2005). When the host is suitable, the haustorium penetrates and forms a link with the host vascular system; this is the penetration stage.

The parasite then uses the haustoria to divert water and nutrients from the host plant. As the parasite becomes established and matures, a distinctive seedling of striga is formed. At this stage, the striga plant lacks chlorophyll, possesses scale leaves and produces abundant adventitious roots from which additional (lateral) haustoria can arise. The striga seedling takes control of the growth-regulatory systems of the host by altering hormone balances and stimulating root production. Significant host damage can occur at this stage. The parasite remains below ground for 4–7 weeks, depending entirely on host for nutrition.

The stage of emergence from the soil is critical for the parasite. It emerges above ground, produce chlorophyll and photosynthesizes but largely depends
on the host for water and mineral salts (Doggett, 1987). Flowering starts 10-12 days after emergence. Seeds are produced 90-120 days after planting the crop and the life cycle is completed. The stages of the biology or life cycle of striga may be summarized as diaspore, after ripening, preconditioning, germination, haustorial induction, attachment, penetration, development, emergence, flowering, fruiting and seeding (Sauerborn, 1991; Parker and Riches, 1993; Mohamed et al., 2001).

Striga seeds spread easily through wind, water, soil and animal vectors (Johnson, 2005; Nambafu, 2013). The major means of dispersal, however, is through human interaction, by means of machinery, hand tools, and clothing (Johnson, 2005). Farming practices as well as human and animal movement across geographic areas have been identified as the main factors responsible for the spread of parasitic weed seeds.

Crop seed is another major mode for striga seed dispersal, with up to 20-40% of seed-lots in the market contaminated by striga seeds (Berner et al., 1994). Majority of farmers in sub-Saharan Africa grow their own seed grain from a previous crop. Seed exchange among farmers within and among distant neighborhoods also contributes to the spread of striga. Grain consignments distributed as relief aid and seed aid often result in wide spread of striga (Gressel et al., 2004).
2.2.2 Environmental conditions preferred by striga

The ideal temperature for striga germination ranges from 30 to 35°C in a moist environment in absence of light. Striga has demonstrated a wide tolerance for soil type where soil temperatures are favorably high. Infertile agricultural land with light nutrient, depleted soils with low organic matter content and low nitrogen levels tend to favor the development of striga. However, high altitude areas with temperatures below 20°C and very high rainfall inhibit the development of the parasite.

2.2.3 Economic importance

Striga is one of the most destructive parasitic weed, parasitizing important economic plants such as maize, sorghum, millet, sugarcane and some legumes. The weed is capable of wiping out an entire crop (Johnson, 2005). In the United States, maize, sorghum, and sugarcane crops affected by striga had an estimated value of over $20 billion (Sand et al., 1990).

Striga affects 40% of Africa’s arable savanna region, resulting in up to $13 billion loss every year. Almost two thirds of the 73 million hectares under cereals is infested with striga, especially in the Sahel and Savanna zones of Africa where over 100 million people depend on cereals and cowpea for food (Lagoke et al., 1991).

In addition, the majority of crops in Africa are grown by subsistence farmers who cannot afford expensive striga control methods, and therefore are affected more. This therefore undermines the farmers struggle to attain food security.
In Kenya, striga is reported to be infesting approximately 217,000 ha, causing crop loss of about US$53 million (Woomer and Savala, 2009). A survey conducted in western Kenya by Woomer and Savala (2009) revealed that 73% of the farms are infested with *S. hermonthica*. It is estimated that the average yield loss due to striga is 0.99, 1.10 and 1.15 tons per hectare for millet, sorghum and maize respectively (MacOpiyo *et al.*, 2010). In areas with high striga infestation the damage can be as high as 2.8 tons per hectare of maize (Andersson and Halvarsson, 2011). The loss represents about 12.3% of the 2.4 million metric tons of maize that Kenya produces annually. Kenya is an agricultural based economy where agriculture accounts for approximately 26% of GDP (G.O.K, 2010). The huge losses due to striga infestation, presence of pests and diseases such as the lethal maize necrosis disease, unpredictable rainfall and small farm sizes makes Kenya a food insecure country where maize is the staple food.

Striga is difficult to control once it is established on maize plants. This is because it gets its nutrients from maize, therefore contributing to the very low production of maize experienced in most countries in Africa. Striga has also led to indirect production losses such as farmers leaving crop areas fallow for long periods, some farmers even abandon their farms while others migrate to other areas due to striga infestation (Khan *et al.*, 2003). Due to the unavailability of an appropriate control method, striga infestation is increasing every year.
2.2.4 Symptoms of infestation

The symptoms of striga infestation resemble those of drought in plants. Host plant symptoms such as stunting, wilting, and chlorosis are similar to those seen from severe drought damage, nutrient deficiency, and vascular diseases (Sand et al., 1990). Affected plants remain stunted, they wilt and turn yellowish. Death of the host plants before setting seeds may follow if the plants are heavily parasitized. Striga attaches itself to the host plant using haustoria. It uses the haustoria to siphon nutrients and water from the host plant. One to several striga plants may be growing above ground next to the infected plants, although roots of many more striga plants, which do not survive to reach the surface, may parasitize the roots of the same host. Striga is capable of significantly reducing yields, in some cases wiping out the entire crop (Sand et al., 1990).

2.2.5 Current striga control methods

Management of striga is difficult because the major part of its life cycle takes place below ground and due to the large number of seeds it produces (Johnson, 2005). Successful restoration of infested fields requires the development of a sustainable long-term integrated control programme that is compatible with present farming systems and with farmer preference and income (Kroschel, 1999). For effective control of any parasitic weed, the understanding of its life cycle is very essential. However, several surveys have shown that most farmers and extension workers lack in depth knowledge on the biology of parasitic weeds in many countries such as Egypt, Malawi, Tanzania and
Kenya (Muller-Stover et al., 1999; Shaxson et al., 1993; Reichmann et al.,
1995; Frost, 1995) which has greatly contributed to the lack of success of the
available control methods.

A variety of control methods are used for the control of striga. These include
the following:

2.2.5.1 Physical methods

Hoe weeding

Hoe weeding is one of the widely used weed control method among the
resource poor subsistence farmers in Africa. However, since most of the striga
damage on the host occurs before striga emergence, this method fails to
effectively control the weed. Hoe weeding is mostly done two times and,
during the second time, soil is pulled-up the ridge (Mloza-banda and
Kabambe, 1996). Hoe weeding can only be applied to small scale farms.
Shallow weeding also encourages production of new tillers from cut stems
which increases the number of striga shoots.

Hand pulling of striga

Hand pulling before seed set is the most common method used by small scale
farmers. It is commonly done at two weeks interval up to harvest time (Terry,
1984; Mloza-banda and Kabambe, 1996). The effectiveness of this method is
only when the striga plants are removed before flowering and burnt (Ogborn,
1984). Hand pulling is laborious and time consuming. Significant reduction of
striga infestation occurs after about three consecutive cropping seasons and is
quite economical on fields least infested with S. hermonthica and not with S.
*asiatica* whose plants are quite small, mature more rapidly, and seeds become viable within 10 days after flowering (Odhiambo and Ransom, 1994; Stewart *et al.*, 1991; Sand, 1990; Parker and Riches, 1993; Ransom, 1996).

**Deep cultivation**

This is done during land preparation which aims at burying striga seeds. This method is quite tedious and expensive since it requires machinery that is not readily available to most farmers in striga prone areas. Subsequent cultivation may end up bringing buried dormant seeds to the surface leading to resurgence of infestation (Lagoke *et al.*, 1991; Terry, 1984).

**2.2.5.2 Cultural methods**

**Use of trap crops**

This involves planting a species in an infested field that will induce the striga seeds to germinate but will not support attachment of the parasite because is not among the host plants attacked by striga e.g. cotton and soybean (Kroschel, 2001). This is known as suicidal germination which involves the induction of germination in the absence of or away from the host root. This has been considered a great potential for striga control in Africa (Ma *et al.*, 1996). Trap crops are sometimes referred as false hosts and they are mainly used to reduce striga seed stock already in the soil. This method has been used in sorghum by planting Cockscomb (*Celosia argentea*) between the sorghum (Olupot *et al.*, 2003). Planting silver leaf (*Desmodium uncinatum*) has worked in maize crops. Cotton, sunflower, linseed, cowpea, sun-hemp, soybean and striga resistant maize have been reported as effective trap crops for *S.
hermonthica (Johnson, 2005). Trap crops produce exudates, which stimulate the germination of striga seeds without being parasitized. This lures striga into suicidal germination. Trap crops should be planted for at least three consecutive years in order to reduce parasitic seeds (Esilaba and Ransom, 1997). However, a study by Odhiambo and Ransom (1997) in western Kenya showed that even after four years of continuous cropping with cowpea or cotton, damaging levels of striga seed still remain in the soil. Bushmint (Hyptis specigera) has been used as a trap crop to control S. hermonthica in Southern Sudan (Kemey, 2007).

**Application of fertilizers**

Nitrogen fertilizers have been reported to reduce striga infestation in some cases (Mumera and Below, 1993). Heavy nitrogen fertilizer application reduces attack by increasing nitrogen levels in the soil. This increases soil fertility resulting in enhanced plant growth that leads to increased shading, creating high relative humidity and low temperature and causing reduced transpiration hence reducing flux from host to parasite (Parker and Riches, 1993). A study by Mumera and Below (1993) in Kenya, reported a 50% reduction of S. hermonthica emergence in maize when 39 kg N ha⁻¹ was applied as calcium ammonium nitrate. According to findings by Alabi (2007) potential of cotton used as a trap crop to control striga was improved at 90 kg N ha⁻¹ of urea fertilizer application than the lower levels evaluated. The treatment combination at 90 kg N ha⁻¹ with all the cotton varieties used delayed days to striga emergence, reduced damage score and increased total
maize dry weight. Some earlier reports have given no beneficial effects of nitrogen fertilizer in the suppression of striga (Pieterse and Verkleij, 1991). However, it has been suggested that nitrogen fertilizers reduce germination stimulants in the exudates from the host plant present (Sheriff and Parker, 1988), directly damage striga seeds and seedlings in the soil and reduce osmotic pressure on the parasite reducing the movement of water and nutrients from the host plant to the striga (Gworgwor and Webster, 1991). A study by Showemimo et al. (2002) demonstrated the effectiveness of nitrogenous fertilizer in minimizing striga infestation and increasing cereal crop yield.

**Crop rotation**

Crop rotation with other non-host food crops especially legumes for several years reduce the seed bank in the soil either through suicidal germination or through natural attrition. A study by Parkinson et al. (1988) showed reduced population of striga in subsequent maize crop following three years of continuous planting with soybean. However, this method may not be very effective as striga seeds can remain in the soil for many years waiting for favorable conditions. Rotation is needed for more than three years (Parker and Riches, 1993) and hence not favorable for the subsistence farmers as they lose the cereal crop which is their staple food during the rotation.

**Growing striga resistant or tolerant varieties**

Resistance is the ability of the crop to prevent attack by the parasite while a tolerant variety is one that is attacked by parasitic weed to the same extent but suffers less damage than a standard variety (Parker and Riches, 1993). Host
plant resistance is seen as the most promising method of striga control especially in subsistence agriculture (Elzein and Kroschel, 2003). Unlike in crop rotation, under this method the farmer is assured of harvesting his or her staple food. This method of control is also user friendly as it does not require any specialized skills. Few sources of resistance among the very large numbers of sorghum and maize genotypes screened to date have been identified (Malcolm and Gurney, 2000; Elzein and Kroschel, 2003). These include sorghum cultivars such as Dobb, Framida, and Serena in Kenya (Mumera, 1992).

Some crop varieties have been shown to resist striga infestation through reduced production of the required germination stimulant (Olupot, 2011). Some maize varieties in Kenya, such as Katumani Maize Composite, show partial resistance to striga. Maize hybrid Tzi-30 also has been reported to resist *S. hermonthica* infestation (Ransom *et al.*, 1990). The development of crop plants with resistance to striga has been limited because of the complexity of interactions between host, parasite, and the physical environment (Ejeta, 2007). Maize germplasm tested for resistance to *S. asiatica* was not completely resistant and a combination of technologies is necessary to control the menace (Gethi, 2003). Studies on genetic diversity of striga in coastal Kenya did not show any population structure, implying that strategies applied across board are likely to be successful (Gethi *et al.*, 2005).

Striga resistant cultivars of sorghum, maize and millet have been developed but none is yet available that can be applied in all the different ecological
zones due to poor adaptation to wide range of agro ecological zones (Parker and Riches, 1993). Another problem with resistant cultivars is that they are often not accepted by farmers because they give low grain yield, produce grain of poor quality, they are susceptible to pests and diseases, and over time their resistance is lost (Parker and Riches, 1993). Different mechanisms of resistance to striga have been suggested by various scientists.

According to Mohamed et al. (2003) and Rich (2004), some mechanisms of resistance to striga involved mutant host plants with low germination stimulation and low haustorial induction, formation of necrotic lesions (hypersensitive reaction) when striga first attaches, and incompatibility whereby early post-attachment growth of the parasite is stopped or slowed. In a study by Ejeta (2007), the natural resistance available in a primary sorghum gene pool was introduced into other agronomically important crop cultivars. Laboratory studies by Olupot (2011) showed that some of the new sorghum genotypes expressed both the low germination stimulant character and low haustoria initiation as mechanisms of resistance to *S. hermonthica* while others expressed either of the mechanisms.

**Use of catch crops**

Catch crops are susceptible to striga attack and therefore are also infected. They are used to stimulate germination of striga and once the striga attaches itself and develops haustoria, the host crop is then destroyed by uprooting, ploughing or use of chemicals before the striga flowers and set seeds (Lagoke *et al.*, 1991). Catch crop rotation is applicable in areas with bimodal rainfall
pattern where the catch crop is planted during one of the two seasons and ploughed or harvested before the main crop is planted in the following season (Tsanuo, 2001). An example of a catch crop is Sudan grass (*Sorghum sudanense* L.) which is normally used to control *S. hermonthica* (Oswald *et al.*, 1999). However, catch cropping has rarely been used by small scale farmers to control striga because the technique is not well understood and holds serious disadvantages if not adapted to a specific cropping system (Oswald *et al.*, 1999).

**Intercropping**

This involves intercropping of cereals with legumes such as in the push pull innovation. In the push pull innovation, germination stimulation of the striga seeds from the legume intercrop, increase in soil fertility, shading effect of the leafy legumes and allelopathic effects caused by the legume are reported to aid striga suppression (Hooper *et al.*, 2010; Tsanuo *et al.*, 2003; Khan *et al.*, 2002).

Intercropping cereals with legumes and other crops is a common practice in most parts of Africa and reports show that it influences striga infestation. A study by Oswald *et al.* (2002) showed that intercropping maize with cowpea and sweet potato significantly reduced the emergence of striga in Kenya. Studies conducted in Kenya showed that inhibition of *S. hermonthica* was significantly greater in maize-silver leaf desmodium intercrop than that observed with other legumes for example sunhemp, soybean or cowpea (Khan *et al.*, 2000). Intercropped *D. uncinatum* reduces striga infestation through
allellopathic effect, inhibiting the development of haustoria of striga (Khan et al., 2002; Tsanuo et al., 2003). It has also been suggested that the suppression due to intercropping may be the result of reduced temperature, whereby a temperature reduction of 2-3°C has been reported (Carson, 1989). However, this reduction is not adequate to significantly reduce the germination of striga in the tropical regions where temperatures are quite high. Studies carried out in western Kenya by Odhiambo and Ransom (1996) showed that even after four years of continuous cropping with cowpea or cotton, damaging levels of striga still remained in the soil.

Maize intercropped with trap crops increases the efficiency of land use through improved soil productivity and reduction of the witch weed (Kureh et al., 2000). Intercropping of cereals with *Hyptis specigera* (Labiateae) was reported to greatly reduce striga infestation in Sudan (Kemey, 2007). Investigation of the root exudates of *H. specigera* found out that it has high germination stimulation activity on *S. hermonthica* comparable to that of GR-24, a known natural germination stimulant (Tsanuo et al., 2007). Silver leaf desmodium or green leaf desmodium when planted as an intercrop with maize covers the surface in between the rows of the main crop. Desmodium emits a chemical into the soil that is unfavorable to striga growth (Khan et al., 2003). Mucuna is a tropical or subtropical, self-pollinating short-day annual climbing legume (Duke, 1981). The crop grows well in areas receiving an annual rainfall of 650-3000 mm and prefers soils with sandy or sandy clay texture (Carsky et al., 1998). A study conducted in coastal lowland Kenya identified
mucuna (M. pruriens) as a green manure legume (GML) with great potential for solving soil fertility and weed problems. The legume establishes quickly and produces a large proportion (over 90%) of active nodules (Saha et al., 2000).

Intercropping with non-host plants is gaining prominence as a method that can offer a solution to the resource poor farmers (Lagoke and M’Boob, 2002). This intercropping approach combined with striga resistant maize varieties could offer a viable solution to the striga problem. No research has been carried out to evaluate the interaction effect of legume cover crops (cowpea and mucuna) and resistant maize varieties on S. asiatica infestation in coastal Kenya.

**Proper seed selection**

This is by using crop seed that is free from striga seeds, avoiding using seed from the previous harvest if the crop was infested with striga and buying the seeds for the next cropping from an agricultural seed store in the locality. However, most farmers cannot afford to buy certified seeds.

**Transplanting**

This method has been traditionally practiced in millet and sorghum cultivation in some parts of Asia and Africa. This is normally done to fill the gaps after emergence of the crop. According to Gbèhounou et al. (2004) transplanting maize after cultivating it in a striga free nursery combines the benefits of early planting and the effect of less infestation due to delayed planting. However, transplanting of maize has not been practiced in sub-Saharan Africa under rain
fed conditions due to lack of specialized techniques to control moisture especially at the time of transplanting. Oswald et al. (2001) assessed the effect of transplanting maize and sorghum on grain yield and striga parasitism under rain fed field conditions in western Kenya and found a significant increase in maize grain yield, less striga attachment and emergence compared with direct seeding. Cechin and Press (1993) found that less striga plants attached and less damage was afflicted on host with increasing age of sorghum.

In vitro experiments, germination and underground development of *S. hermonthica* was reported to be low in transplanted sorghum compared with sorghum which was sown directly (Dawoud et al., 1996). However, transplanted sorghum failed to reduce striga emergence or to improve grain yield. Considerable low striga weed densities were observed at 17 day old at transplanting. It could be concluded that transplanting of sorghum and maize seems to be a potential method that might lead to increased crop tolerance to striga infestation. Transplanting as a method of striga management has some advantage because it is simple and does not require specialized skills. Therefore, it can be practiced by subsistence farmers. However, due to its high labor requirements, transplanting maize under rain fed conditions is probably only suitable for small areas. In addition nursery establishment, management and the timing of transplanting require a certain level of farm management that can restrict the adoption of this technique.
Fallowing

This method can be introduced where soils are poor and severely depleted. Under this method of striga management leguminous shrubs or trees are planted so as to enhance nitrogen addition into the soil (Rao and Gacheru, 1998). According to Oswald et al. (1996) and Rao and Gacheru (1998), trees grown on farms can increase soil fertility and or cause suicidal germination which in turn reduces the amount of striga seed bank. The major advantage of this method of striga management is that once the trees and shrubs are established, they need little management and can produce a lot of fuel wood and fodder. Promising tree species include *Senna spp.*, *Crotalaria agatiflora*, *Calliandra calothyrsus*, *C. grahamiana*, *Leucaena leucocephala*, and *Desmondium distortum* (Rao and Gacheru, 1998).

In an experiment carried out in eastern Zambia, maize fields did not show any infestation of *S. asiatica* following three years of *Sesbania sesban*, *Leucaena Leucocephala* and *Senna siamea* fallows (ICRAF, 1996). According to Rao and Gacheru (1998) agro forestry reduces striga by the trees in the fallow acting as false hosts hence causing suicidal germination, increase mineral nitrogen to the top soil at the end of the fallow and nitrogen mineralization in subsequent cropping phase. The leaves that fall off the trees decompose thereby increasing microbial activity following the incorporation of organic residues in the soil hence affecting striga seed conditioning and seed viability. The improved soil fertility due the organic residues enables maize plant to grow better with striga and reduce the damaging potential of striga.
2.2.5.3 Chemical methods

Use of chemicals

Striga management using chemicals can be divided into two categories i.e. killing the seeds before they germinate and vegetation control (Eplee, 1984). Chemicals such as germination stimulants, fumigants, and anti-transpirants are some of the various chemical methods employed to control striga (Mloza-banda and Kabambe, 1996). Germination stimulants have been used to stimulate suicidal germination of striga seeds in fields not yet planted with crops. This method involves the application of germination stimulants such as Nijmegen 1 and ethylene gas to induce suicidal striga seed germination. Some of the germination stimulants have been identified and isolated (Matusova et al., 2005). Ethylene, ethephon strigol, and stigol analogues can induce germination of striga seeds in the absence of a suitable host and therefore reduce seed reserves in the soil (Esilaba and Ransom, 1997). Application of germination stimulants such as ethylene to induce suicidal seeds germination of striga weed appears attractive because of their safety, decomposition in the soil within a short period of time and their high biological activity at very low rate. In some parts of Africa ethylene was found to be more effective than trap crops in reducing the striga seed bank (Odhiambo and Ransom, 1997). The use of ethylene gas to control *S. asiatica* was very successful in the USA, but in Kenya it achieved 50 - 60% reduction in the seed bank (Egley *et al.*, 1990). Ethylene gas and its application require expensive equipment which is not readily available to the resource-poor farmers in Africa. The chemical 2-chloroethane phosphoric acid, an ethylene releasing agent also has similar
effect (Terry, 1984). Synthetic strigol analogues, e.g., GR-7 and GR-24 can also induce suicidal germination of striga seeds in the absence of host plants (Johnson et al., 1987). These analogues however, are extremely unstable in soil and as a result there has been a limited application under practical field conditions. Other known compounds that can induce germination include cytokinins, L-methionine, sulphuric acid, coumarine derivatives, thiourea and ally thiourea, sodium hypochlorite and scopoletine (Parker and Riches, 1993). Anti-transpirants, such as di-1-p-methene, when applied to *S. hermonthica* severely damages it (Parker and Riches, 1993).

Fumigants, for example methyl bromide and vapam are also used (Eplee et al., 1991). Vapam can be drenched or incorporated into the soil. Methyl bromide is effective in killing seeds in the soil but is very expensive and environmental hazardous.

Unfortunately, each striga plant can produce tens of thousands of tiny seeds and these can remain dormant in the soil for up to twenty years (Mourik, 2007). Thus, chemical treatments do not remove all seeds from the soil. It has also been observed that some germination stimulants such as strigolactone are likely to be unstable (Babiker et al., 1993; Siame et al., 1993). Therefore, there is need to probe non-host plants for potent, more stable stimulants (Ma et al., 1996). The naturally produced stimulants like strigolactones also cannot be isolated for commercial application due to their extremely low concentration in the roots of host plants (Wigchert and Zwanenburg, 1999).
**Herbicide application**

Eplee and Noris (1995) reported that though herbicides may be used in the management of striga, there is no effective treatment to control all species. According to Odhiambo and Ransom (1997) and Odhiambo and Ransom (1993) dicamba as a post emergence herbicide, has been shown to control striga when applied soon after attachment but timing is very critical to maximize its effectiveness, both in terms of striga control and safety of the crop and also has not proven to be consistently cost–effective. 2,4-dichlorophenoxyacetic acid (2,4-D) can be used to prevent further striga seed production. However due to its low selectivity, the herbicide cannot be used in intercropping (Pare et al., 1996).

Herbicides such as oxyfluorfen, pendeimenthalin, trifluralin and metachlor have been used in the control against striga with limited success (Mumera, 1992). Seed coating of non-transgenic maize with low dose of herbicides was recently developed and released in Kenya (Parker and Riches, 1993; Elzein and Kroschel, 2003).

Herbicide seed coating is also very key to root parasitic weed control e.g. acetolactate synthesis (ALS) inhibiting herbicide as seed dressing on maize genotypes posses target site resistance. The advantage of this maize genotype is that it allows the use of an extensive family of effective herbicides against striga. Imazapyr and pyrithiobac were safe to ASL-resistant maize seed drenches, priming and coating which were found to provide excellent and effective striga control and increased maize yields (Kanampiu et al.,
In further laboratory investigations, almost complete destruction of viable striga seeds in the upper 10cm and 80% suppression of the seed germination at 30cm depth was reported when imazapyr and pyrithiobac was dressed to the seed of imidazolinone resistant (IR) maize. Maize variety WS303 which was treated with imazapyr, a systemic imidazolinone herbicide, had the lowest striga weed population (Nambafu, 2013).

The technology is easy to adopt and does not require any specialized skills. However, it is not an option for resource poor farmer, and should be hoped that herbicide resistance will not be developed by the new races of striga and care should be taken when using susceptible intercrops. Some of the limitations in the use of herbicides for striga control include lack of application technology, marginal crop selectivity, low persistence and availability of the herbicides and also most farmers can’t afford.

2.2.5.4 Biological methods

Biological weeds control refers to the use of living organisms such as insects and microbial agents to suppress, reduce, or eradicate weed densities. The use of Bio-control of striga has recently emerged as one of the potential control measure. Natural enemies of striga weed have been found among insects, fungi and bacteria. However, current bio-control agents are probably not effective enough in the control of striga. Bio-control has also been done using fungi that infect striga. The use of microbial agents has some limitations in controlling striga such as high cost making it not suitable for commercial use,
viability of field performance and biological, environmental and technological limitation as it can also affect other crops (Auld and Morin, 1995). In some instances, cowpea does cause suicidal germination of striga or the resulting weed will not produce viable seeds. This helps in reducing existing seed banks and new addition of viable seeds to the soil.

2.2.5.5 Integrated control approaches

Considering the many constraints to a successful control of parasitic weeds, so far it’s recognized that no single method of control can provide an effective and economically acceptable solution. There is no standard integrated control package for parasitic weeds which can be put forward; therefore control needs to be adjusted to individual cropping systems, local needs and performance.

With regard to striga weed any ideal integrated control strategy should consider containment and control as well as the need to improve soil fertility in order to be successful in achieving sustainable crop production.
CHAPTER 3: MATERIALS AND METHODS

3.1 Site description

The study was conducted on-station at the Kenya Agricultural Research Institute (KARI) Matuga in Kwale county, coastal Kenya, during the long rain seasons of 2012 and 2013 cropping season. This on-station site was chosen for the study because it was already infested with S. asiatica. Care was taken to ensure that the plots laid out in 2012 were maintained such that a given treatment was reapplied to the same plot in 2013.

The site (KARI Matuga) lies within coastal lowland agro-ecological zone three (CL3), at an altitude of 132 meters above sea level. It lies between latitude 4°9’52’’ South and longitude 39°34’23’’ East. The rainfall pattern is bimodal: with the long rains (LR) season (from March/April to June/July) and short rains (SR) season (from September/October to December) (Appendix 1.1). The amount of rain ranges from 760 mm to 1200 mm per year. The annual mean maximum temperature range is between 26°C and 30°C while the mean annual minimum temperature is 22°C. The relative humidity varies between 60% and 95%.

The soils at KARI Matuga are sandy, with a substantial amount of clay. This site is characterized by dry spells during the cropping season (Figures 3.1 and 3.2). A drip irrigation kit was therefore installed so as to provide supplemental water to the experiments.
Figure 3.1: Rainfall distribution in the 2010 LR season

Figure 3.2: Rainfall distribution in the 2011 LR season
3.2 Experimental design

The randomized complete block design was used. Treatments were replicated three times. The plot size was 5 m x 2.7 m.

Treatments:

Two experiments were conducted: one on maize-legume intercropping system and the other on spatial arrangement of intercropped cowpea. The following treatments were evaluated in the two experiments:

**Experiment 1:**

Factor A: Maize variety

1. Commercial variety-PH4 (V₁)
2. Striga resistant variety MS 2011-10 CML 312/T2Mi/TzL2/MUG 1-2-4 (V₂)
3. Striga resistant variety MS 2011-08 TzL1/CML 312//TzL2/MUG 1-2- 4 (V₃)
4. Striga resistant variety MS 2011-10 CML 312/CML373/KEN 3/TzL2- 2-6 (V₄)
5. Striga resistant variety MS 2011-08 TzL3/DIPLO1-5-7/TzL2/MUG 1- 2-4 (V₅)
6. Striga resistant variety MS 2011-10 CML 384/KEN 3/TzL 2-2-6 (V₆)

Factor B: Legume species

1. *No legume* (L₀)
2. *Vigna unguiculata* var. K80 (L₁)
3. *Mucuna pruriens* var. utilis (L₂)
This gave 18 factorial combinations of factors A and B, as shown below:

**Table 3.1 Treatment combinations for experiment 1**

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<th>Combination</th>
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</table>

**Experiment 2:**

**Factor A: Maize variety**

1. Commercial variety-PH4 (V₁)
2. Striga resistant variety MS 2011-10 CML 312/T2Mi/TzL2/MUG 1-2-4 (V₂)

**Factor B: Spatial arrangement of intercropped cowpea**

1. Between maize rows (S₀)
2. Within maize row (S₁)
3. Same hill with maize (S₂)
**Treatment combinations:**

This gave six factorial combinations of factors A and B, as shown below:

**Table 3.2 Treatment combinations for experiment 2**

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<td>V₂S₁</td>
</tr>
<tr>
<td>6</td>
<td>V₂S₂</td>
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</table>

**3.3 Crop establishment**

Each plot in experiment 1 consisted of three maize rows (5m long) and two legume rows (each planted between two maize rows). Maize was sown at three seeds per hill at a spacing of 90 cm x 50 cm giving a seed rate of 99 seeds per plot. The legumes were planted at three seeds per hill between two maize rows and spaced at 30 cm within row giving a seed rate of 102 seeds per plot.

The following cowpea spatial arrangements were evaluated in experiment 2: (i) between maize rows (S₀), (ii) within maize row (S₁), and (iii) same hill with maize (S₂). In the first spatial arrangement (S₀), each plot consisted of three maize rows (5 m long) and two cowpea rows (each planted between two maize rows). The cowpea was planted at three seeds per hill and spaced at 30 cm
within row, giving a seed rate of 102 seeds per plot. In the second spatial arrangement \((S_1)\), maize and cowpea was planted in alternating hills. Each plot consisted of three rows (5 m long). Maize was sown as in the first spatial arrangement \((S_0)\). The cowpea was planted at three seeds per hill between two maize hills, giving a seed rate of 90 seeds per plot. In the third spatial arrangement \((S_2)\), maize and cowpea was planted in the same hill. Both maize and cowpea were sown at three seeds per hill at a spacing of 90 cm x 50 cm, giving a seed rate of 99 seeds per plot for each crop. To ensure uniform striga infestation in the plots, a mixture of striga seeds and sand (a 1:2 ratio) was used to inoculate the plots. The mixture was placed beside the maize hills. The plot size for maize grain yield was 2.7 m by 5 m while for maize stover yield was 0.9 m by 5 m.

3.4 Crop management practices

The following management practices were carried out in both experiments: The maize and cowpea were thinned at two weeks after planting (WAP) to two plants per hill. All crops were weeded twice, at four and seven WAP. Regrowth of weeds other than striga was controlled by hand-pulling. Fertilizer was applied to maize at the recommended rates of 60 kg N ha\(^{-1}\) and 20 kg P ha\(^{-1}\). The nitrogen fertilizer was applied four WAS. Bulldock (0.05GR 0.5g/kg Beta cyfluthrin) was applied around the time of first weeding to control maize stem borer and cowpea pests.
3.5 Data collected

The following data were collected from the experimental plots:

(a) **Grain yield**

All the three rows of maize in each plot were harvested for the determination of maize grain yields. After harvesting plot weight was measured after dehusking the cobs. Two cobs were taken at random from each plot, shelled and the grains weighed to get grain yield after harvesting. Shelling percentage was calculated as the grain yield over the cob weight for each plot.

Grain moisture content was recorded (Plate 3.1). Maize grain yield was then calculated based on a storage moisture content of 13% using the following formula:

\[
Y = \frac{FW_{ear} \ (kg)}{Area \ (m^2)} \times \frac{10,000 \ (m^2 \ ha^{-1})}{1,000 \ kg \ t^{-1}} \times \frac{100 - MC_{grain}}{100 - MC_{store}} \times SF
\]

where \( Y \) = grain yield (t ha\(^{-1}\)); \( FW_{ear} \) = Field weight of maize ears; Area = Net plot area; \( MC_{grain} \) = Percent grain moisture content; \( MC_{store} \) = Percent storage moisture (13%); \( SF \) = Shelling fraction.
(b) Stover yield

Field stover weight (Plate 3.2) and stover dry matter (DM %) were recorded. The middle row of maize was used to determine stover yield. Six samples, each consisting of two maize plants were taken at random per variety and weighed fresh. The samples were then oven-dried at 105°C for 48 hours for DM determination. DM was calculated using the following formula:

$$DM \ (kg\ ha^{-1}) = \frac{S_{\text{oven}} \ (g)}{S_{\text{fresh}} \ (g)} \times \frac{PW \ (kg)}{A \ (m^2)} \times 1,000 \ m^2 ha^{-1}$$

where $S_{\text{oven}} = $ sample oven weight; $S_{\text{fresh}} = $ sample fresh weight; $PW = $ plot weight; $A = $ net plot area
Maize stover yield was then derived using the following formula:

\[
Y = \frac{SW (kg)}{A (m^2)} \times \frac{10,000 \, m^2 \, ha^{-1}}{1,000 \, kg \, t^{-1}} \times DM
\]

where \( Y \) = stover yield (t DM ha\(^{-1}\)); \( SW \) = field stover weight; \( A \) = net plot area; \( DM \) = proportion of DM in fresh stover.

(c) Striga weed data

The number of striga plants that had emerged in each plot was taken as the striga emergence counts at 7 and 9 weeks after planting during the 2012 and 2013 cropping seasons (Plate 3.3). The striga stand counts were used as a measure of striga infestation on the maize plants. Maize yield was used as a parameter to gauge the effectiveness of striga control method.
(d) Striga seed density

Soil samples were collected from all the plots in experiments 1 and 2 at the end of the 2012 LR and 2013 LR seasons. A small subsample of the mixed soil (15-20g) was weighed and placed to dry in an oven at 70°C for 48 h. After drying, the soil was reweighed and moisture content of the sample calculated as:

$$\text{Moisture} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Wet weight}}$$

The remaining sample was weighed and dry matter calculated as:

$$\text{Dry matter} = \text{Sample weight} \times (1 - \text{Moisture content})$$

The seed was then separated from the soil. This was done sequentially, by first sieving the striga-size particles from both larger and smaller particles. A series of sieves was stack down from 250, 212, and 90 microns. Over the 250
micron sieve, a small sheet of coarse screen was placed to remove the largest particles. The sample was poured onto the coarse screen. The stacked sieves and soil were placed under flowing tap water, and the particles washed sequentially through the sieves. After washing the soil on the coarse screen, the washing was continued to wash the particles on the 250 micron screen. Five minutes washing was done per sieve after which all of the striga-size particles collected on the 90 micron sieve. The striga-size particles were separated by weight to further reduce the amount of trash in the sample and facilitate subsequent counting by employing specific gravity in a separatory funnel. A solution heavier than both water and striga seed was prepared (a potassium carbonate solution of specific gravity 1.4 is ideal which was achieved by adding 500g K₂CO₃ to 700 ml of tap water. This was mixed and the specific gravity checked with a hydrometer. A 1 liter separatory funnel was mounted in a ring stand and 400-500 ml of solution poured in. The remaining solution was poured into a wash bottle to wash the contents of the 90 micron sieve into the separatory funnel. A layer of water was added over the K₂CO₃ solution by squirting a stream of water down the inside of the separatory funnel and washing any adhering soil particles into the solution. This was done slowly so that water and the solution do not mix but rather formed two layers. The water layer was 200=300 ml thick. The soil/striga was allowed to settle for 20 min, after which the heavier particles had precipitated to the bottom of the funnel, while the lighter particles were floating on the surface of the water. Empty striga seed coats were found in this upper layer, while the intact striga seeds were at the water/K₂CO₃ interface. A nylon screen
of 60 micron opening was placed over 500 ml beaker to conserve the potassium carbonate solution and recycle it for future use. This was placed under the separatory funnel and the stopcock opened, draining off the lower potassium carbonate layer and recollecting it in the beaker. Draining was stopped when there was 5 cm of solution left below the water layer. The trash was washed off of the nylon screen and replaced it over the beaker. Draining was continued until 1 cm of K₂CO₃ remained. The contents of the screens contained striga seed. The screens were saved and replaced as frequently as necessary. When there was only 1 cm of the K₂CO₃ layer left, the beaker was removed and replaced with an empty one. Only the solution collected up to this point was saved and the water contaminated solution discarded. Collecting of striga seed continued for the next 5-10 cm of water/solution. The rest of the water was discarded. The material in the upper 1-2 cm of water was collected separately. After collection, the striga seed on each screen was counted under a dissecting microscope at 20-30X magnification. To make the counting process easier, a grid was made on a large index card with two different colored markers, one color vertical and the other horizontal. The number of striga seeds in 100 g of soil was determined to reflect the striga seed density in soil.

3.6 Data analysis
Striga stand counts and maize grain and stover yields data collected in section 3.5 above were subjected to the analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of the Statistical Analysis System
(SAS). Because of the high variability observed for the actual striga stand counts, the log10 \[ n+1 \] transformations of the original data (n) were performed before analysis so as to improve the normality of the data. Where the F values were significant, treatment means were separated using the Least Significant Difference (LSD) at the 5% level of significance.

Model for RCBD in factorial arrangement:

\[ Y = block + m_v + l_s + m_v l_s + e \]

where:

- Y - any observation as listed in section 3.5 above for which
- \( m_v \) = maize varieties
- \( L_s \) = legume species
- \( m_v \times l_s \) = interaction of maize varieties and legume species
- \( e \) = random error

The PROC CORR procedure of SAS was used to correlate maize grain and stover yields and striga stand counts. Since treatments were applied to the same plots in both seasons one (2012 LR season) and two (2013 LR season), a paired t-test was performed on the striga seed counts in soil to determine whether there was a significant change in striga seed density in the soil.
CHAPTER 4: RESULTS AND DISCUSSION

4.1 Effect of maize variety and legume intercropping system in the control of Striga asiatica

In the 2012 LR season, maize variety had no significant effect on striga stand counts \( (F = 0.57, P = 0.72) \) \( (F = 1.72, P = 0.16) \) and maize grain yield \( (F = 2.03, P = 0.10) \). The fact that striga stand counts did not differ significantly between maize varieties shows that the varieties got similar exposure to the weed. Therefore, any difference in yield may be associated with tolerance to \( S. \) asiatica. Maize variety \( V_4 \) produced significantly higher stover yield than the rest of the varieties \( (F = 2.72, P = 0.04) \) (Table 4.1; Appendix 2.1). Although this variety had been bred for resistance to \( S. \) asiatica, in this study it displayed tolerance to the weed and gave the highest stover yield.

**Table 4.1  Effect of maize variety on striga stand counts and maize grain and stover yields in the 2012 LR season**

<table>
<thead>
<tr>
<th>Maize variety</th>
<th>Striga stand counts</th>
<th>Maize grain yield (t ha(^{-1}))</th>
<th>Maize stover yield (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count 1 ( (7 \text{ WAP}) )</td>
<td>Count 2 ( (9 \text{ WAP}) )</td>
<td></td>
</tr>
<tr>
<td>( V_1 )</td>
<td>0.29</td>
<td>1.58</td>
<td>3.31</td>
</tr>
<tr>
<td>( V_2 )</td>
<td>0.00</td>
<td>0.17</td>
<td>3.78</td>
</tr>
<tr>
<td>( V_3 )</td>
<td>0.36</td>
<td>4.22</td>
<td>3.31</td>
</tr>
<tr>
<td>( V_4 )</td>
<td>0.37</td>
<td>0.93</td>
<td>4.46</td>
</tr>
<tr>
<td>( V_5 )</td>
<td>0.17</td>
<td>1.30</td>
<td>3.64</td>
</tr>
<tr>
<td>( V_6 )</td>
<td>0.00</td>
<td>0.42</td>
<td>3.45</td>
</tr>
<tr>
<td>LSD</td>
<td>0.730</td>
<td>4.208</td>
<td>0.880</td>
</tr>
<tr>
<td>Pr &gt; F</td>
<td>0.72</td>
<td>0.16</td>
<td>0.10</td>
</tr>
<tr>
<td>CV</td>
<td>334.4</td>
<td>157.2</td>
<td>25.0</td>
</tr>
</tbody>
</table>

\( V_1 \) = PH4 maize variety; \( V_2, V_3, V_4, V_5 \) and \( V_6 \) = striga resistant maize varieties

Column means followed by same superscript are not significantly different at \( P<0.05 \)
Varieties V₂, V₃, V₅ and V₆ did not differ significantly with the commercial variety (V₁) in their stover yield. This is an indication that the four maize varieties (V₂, V₃, V₅ and V₆), which had been bred for resistance to *S. asiatica*, are not superior to the susceptible commercial variety (V₁). This confirms the findings by Gethi (2003) that maize germplasm bred for resistance to *S. asiatica* was not completely resistant.

The results for the 2013 LR season showed that maize variety had significant effect on stover yield (F = 3.38, P = 0.01) (Table 4.2; Appendix 2.2) but had no effect on grain yield (F = 0.86, P = 0.52) and striga stand counts (F = 2.05, P = 0.10) (F = 2.20, P = 0.08). Maize varieties V₆, V₄, V₃ and V₂ did not differ significantly in their stover yield. Varieties V₆, V₄, and V₃ gave higher stover yield than V₅. Maize varieties V₃, V₁, and V₂ did not differ significantly in their stover yield. Varieties V₅, V₁, and V₂ did not show significant differences in their stover yield.

These results show that maize varieties V₆, V₄, and V₃ are likely to be tolerant to striga infestation, since they were able to produce significantly high stover yields under similar exposure to the weed as variety V₅. It is expected that stover yield would be high where striga counts are low, i.e. the two parameters are expected to be negatively correlated. However, correlation analysis of the 2013 LR season data showed no significant correlation between striga stand counts and maize stover yield (r² = 0.01, P=0.40 for stand count at 7 WAP and r² = 0.02, P=0.26 for stand count at 9 WAP). Correlation analysis of the 2012 LR season data showed no significant correlation between striga stand count 1
and maize stover yield ($r^2 = -0.05$, $P=0.12$) but a very weak negative correlation between striga stand count 2 and maize stover yield ($r^2 = -0.09$, $P=0.03$). According to Taylor (1990) a statistically significant correlation coefficient does not show evidence of relationship between variables – it only signifies a nonzero population correlation coefficient. Taylor (1990) also suggests that the coefficient of determination ($r^2$) is a more meaningful determinant of relationship between variables than the correlation coefficient. The fact that correlation analysis of the 2012 LR season data gave absolute coefficient of determination ($r^2$) values of less than 0.10 shows that less than 10% of the variations in the yield parameter can be explained by the relationship between striga stand counts and stover yield. This is an indication that there was no meaningful correlation between striga stand count and maize stover yield.

**Table 4.2  Effect of maize variety on striga stand counts and maize grain and stover yields in the 2013 LR season**

<table>
<thead>
<tr>
<th>Maize variety</th>
<th>Striga stand counts</th>
<th>Maize grain yield (t ha$^{-1}$)</th>
<th>Maize stover yield (t ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count 1 (7 WAP)</td>
<td>Count 2 (9 WAP)</td>
<td></td>
</tr>
<tr>
<td>$V_3$</td>
<td>4.74</td>
<td>6.08</td>
<td>3.73</td>
</tr>
<tr>
<td>$V_5$</td>
<td>1.89</td>
<td>1.42</td>
<td>3.55</td>
</tr>
<tr>
<td>$V_1$</td>
<td>1.54</td>
<td>2.25</td>
<td>3.41</td>
</tr>
<tr>
<td>$V_4$</td>
<td>0.39</td>
<td>0.66</td>
<td>3.54</td>
</tr>
<tr>
<td>$V_2$</td>
<td>0.52</td>
<td>1.29</td>
<td>3.22</td>
</tr>
<tr>
<td>$V_6$</td>
<td>0.47</td>
<td>0.38</td>
<td>3.72</td>
</tr>
<tr>
<td>LSD</td>
<td>5.301</td>
<td>5.740</td>
<td>0.600</td>
</tr>
<tr>
<td>Pr &gt; F</td>
<td>0.10</td>
<td>0.08</td>
<td>0.52</td>
</tr>
<tr>
<td>CV</td>
<td>151.5</td>
<td>123.7</td>
<td>17.8</td>
</tr>
</tbody>
</table>

$V_1$ = PH4 maize variety; $V_2$, $V_3$, $V_4$, $V_5$ and $V_6$ = striga resistant maize varieties  
Column means followed by same superscript are not significantly different at $P<0.05$
The results of the 2012 LR season showed that legume intercropping had no significant effect on striga stand counts ($F = 1.94$, $P = 0.16$) ($F = 0.90$, $P = 0.42$) and maize grain ($F = 3.05$, $P = 0.06$) and stover yields ($F = 0.32$, $P = 0.73$) (Table 4.3).

The results showed that intercropped legume significantly influenced maize grain yield in the 2013 LR season ($F = 7.48$, $P = 0.00$). Sole cropped maize gave significantly higher grain yield (4.00 t ha$^{-1}$) than intercropped maize (3.28 and 3.31 t ha$^{-1}$ for maize-cowpea and maize-mucuna intercrops, respectively) (Table 4.4; Appendix 2.3). Intercropping maize and legume reduced maize grain yield by 17-18%. This is probably due to competition between maize and the legumes for growth factors such as soil moisture and nutrients. A study by Saha (2007) showed that mucuna reduced the uptake of N and K by the cereal by 26-36% and 42-47% when it was intercropped at the same time with maize. The low maize grain yield observed in the maize-legume intercropping system in this study probably resulted from reduced uptake of nutrients.

### Table 4.3  Effect of legume on striga stand counts and maize grain and stover yields in the 2012 LR season

<table>
<thead>
<tr>
<th>Legume</th>
<th>Striga stand counts</th>
<th>Maize grain yield t ha$^{-1}$</th>
<th>Maize stover yield t ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count 1 (7 WAP)</td>
<td>Count 2 (9 WAP)</td>
<td></td>
</tr>
<tr>
<td>Cowpea</td>
<td>0.47</td>
<td>1.62</td>
<td>3.38</td>
</tr>
<tr>
<td>Mucuna</td>
<td>0.04</td>
<td>0.58</td>
<td>3.51</td>
</tr>
<tr>
<td>Control (No legume)</td>
<td>0.09</td>
<td>1.40</td>
<td>4.08</td>
</tr>
<tr>
<td>LSD</td>
<td>0.454</td>
<td>1.261</td>
<td>0.619</td>
</tr>
<tr>
<td>Pr &gt; F</td>
<td>0.16</td>
<td>0.42</td>
<td>0.06</td>
</tr>
<tr>
<td>CV</td>
<td>334.4</td>
<td>157.2</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Column means followed by same superscript are not significantly different at $P<0.05$
Table 4.4  Effect of legume on striga stand counts and maize grain and stover yields in the 2013 LR season

<table>
<thead>
<tr>
<th>Legume</th>
<th>Striga stand counts</th>
<th>Maize grain yield (t ha(^{-1}))</th>
<th>Maize stover yield (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count 1 (7 WAP)</td>
<td>Count 2 (9 WAP)</td>
<td></td>
</tr>
<tr>
<td>Cowpea</td>
<td>3.12</td>
<td>2.92</td>
<td>3.28(^b)</td>
</tr>
<tr>
<td>Mucuna</td>
<td>1.43</td>
<td>1.56</td>
<td>3.31(^b)</td>
</tr>
<tr>
<td>Control (No legume)</td>
<td>0.64</td>
<td>0.70</td>
<td>4.00(^a)</td>
</tr>
<tr>
<td>LSD</td>
<td>2.530</td>
<td>2.805</td>
<td>0.430</td>
</tr>
<tr>
<td>Pr &gt; F</td>
<td>0.32</td>
<td>0.12</td>
<td>0.00</td>
</tr>
<tr>
<td>CV</td>
<td>151.5</td>
<td>123.7</td>
<td>17.8</td>
</tr>
</tbody>
</table>

Column means followed by same superscript are not significantly different at P<0.05

Although intercropping maize with legume reduced the grain yield of the cereal, it had no significant effect on stover yield. This is probably an indication that the effect of intercropping is felt more on maize grain yield than on stover yield. Probably the legume intercrop affected the partitioning of photosynthates to the sink (maize grain). Correlation analysis of the 2013 LR season data showed no meaningful correlation between striga stand count and maize grain yield (\(r^2 = -0.08\), P=0.04).

Results of this study showed that there was no significant interaction effect of striga resistant maize variety and legume cover crop (cowpea or mucuna) on maize grain yield. This is an indication that maize had the same response to legume intercropping regardless of the maize variety.

The results of the study showed that cowpea reduced the striga seed density in soil at the end of season one (2012 LR season) (\(F = 7.57\), P = 0.00) (Table 4.5; Appendix 2.4). However, at the end of season two (2013 LR season) legume treatment had no effect on striga seed density in soil (\(F = 1.37\), P = 0.27).  At
the end of season one (2012 LR season), plots where maize was intercropped with mucuna and those with no legume had higher striga seed densities than those intercropped with cowpea. The significant reduction of striga seed density in soil in the maize-cowpea intercrop is probably the result of suicidal germination of striga seed caused by the legume. This is contrary to the findings by Odhiambo and Ransom (1997) who observed no significant reduction of striga seed in soil even after four years of continuous intercropping with cowpea or cotton.

Table 4.5  Effect of legume on striga seed density in soil

<table>
<thead>
<tr>
<th>Legume</th>
<th>Striga seed density</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>End of season 1</td>
<td>End of season 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Cowpea</td>
<td>7.85&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.00</td>
<td></td>
</tr>
<tr>
<td>Mucuna</td>
<td>12.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.53</td>
<td></td>
</tr>
<tr>
<td>Control (No legume)</td>
<td>10.63&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.46</td>
<td></td>
</tr>
<tr>
<td>LSD</td>
<td>2.216</td>
<td>2.117</td>
<td></td>
</tr>
<tr>
<td>Pr &gt; F</td>
<td>0.002</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>32.2</td>
<td>52.1</td>
<td></td>
</tr>
</tbody>
</table>

Column means followed by same superscript are not significantly different at P<0.05

The fact that intercropped cowpea reduced striga seed density in soil by end of season one demonstrates the potential of the legume in controlling striga. However, this potential would be utilized better in a cereal-cowpea rotation system than in an intercropping system. This is because, in a rotation system, the striga seeds stimulated to germinate by the legume will have no host plant to attach to. Under cereal-cowpea intercropping, roots of the companion crops are in close proximity and therefore some striga seeds stimulated by the legume may attach to roots of the cereal and grow to maturity. Thus the striga
seed bank in soil may not be reduced as much as it would under a cereal-legume rotation system.

The results of the 2012 LR season also showed no significant differences in striga seed density between plots with mucuna and those without legume. This implies that mucuna was not effective in reducing striga seed density in soil. Probably, this legume does not have as much suicidal germination effect on striga seed as compared with cowpea, indicating that the two legumes have different mechanisms of controlling striga. In a study by Mureithi et al. (2003), mucuna was shown to control *S. hermonthica* by replenishing soil nitrogen.

Results of the paired t-test conducted on the striga seed density in soil showed that there was significant difference between striga seed density in soil at the end of seasons one (2012 LR season) and two (2013 LR season) (Table 4.6). The test statistic (T) (7.5763) was greater than the t-critical (2.0057) and the probability $T \leq t$ (5.3373E-10) was less than the 5% level of significance. This shows that the striga seed density in soil at the end of season two (2013 LR season) was significantly lower than that observed at the end of season one (2012 LR season). The planting of maize or maize-legume intercrop might have stimulated striga seed germination, leading to reduction in striga seed density in soil by the end of season two.
Table 4.6  Results of the paired t-test

<table>
<thead>
<tr>
<th></th>
<th>End of 2012 LR</th>
<th>End of 2013 LR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.032407407</td>
<td>1.19907407</td>
</tr>
<tr>
<td>Variance</td>
<td>0.561429944</td>
<td>0.4136312</td>
</tr>
<tr>
<td>Observations</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>0.333846345</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>7.57632642</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>2.66863E-10</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.674116237</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>5.33725E-10</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.005745949</td>
<td></td>
</tr>
</tbody>
</table>

4.2  Effect of maize variety and spatial arrangement of intercropped cowpea in the control of *Striga asiatica*

The results of the 2012 LR season showed that maize variety had no significant effect on striga stand counts (F = 0.00, P = 0.95) (Table 4.7). The maize varieties also did not differ significantly in their grain and stover yields (F = 2.53, P = 0.14) (F = 1.34, P = 0.27). However, in the 2013 LR season, maize varieties differed significantly in their stover yield. Variety V₂ produced higher stover yield than V₁ (F = 7.71, P = 0.02) (Table 4.8; Appendix 2.5). The two varieties got similar exposure to the weed thus did not differ significantly in their striga stand counts. This therefore, shows that maize variety V₂ had some tolerance to *S. asiatica* and gave higher stover yield than commercial maize variety (V₁).

Correlation analysis of the 2013 LR season data showed moderate negative correlation between striga stand counts and maize stover yield  \((r^2 = -0.46, P=0.002\) for stand count at 7 WAP and \(r^2 = -0.41, P=0.004\) for stand count at 9
WAP). This is an indication that less than 50% of the variations in the yield parameter can be explained by the relationship between striga stand counts and stover yield, implying that there was no meaningful correlation between striga stand count and maize stover yield.

**Table 4.7** Effect of maize variety on striga stand counts and maize grain and stover yields in the 2012 LR season

<table>
<thead>
<tr>
<th>Maize variety</th>
<th>Striga stand counts</th>
<th>Maize grain yield (t ha(^{-1}))</th>
<th>Maize stover yield (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count 1 (7 WAP)</td>
<td>Count 2 (9 WAP)</td>
<td></td>
</tr>
<tr>
<td>(V_1)</td>
<td>1.51</td>
<td>11.40</td>
<td>3.26</td>
</tr>
<tr>
<td>(V_2)</td>
<td>1.97</td>
<td>22.17</td>
<td>4.15</td>
</tr>
<tr>
<td>LSD</td>
<td>1.551</td>
<td>12.863</td>
<td>1.241</td>
</tr>
<tr>
<td>Pr &gt; F</td>
<td>0.95</td>
<td>0.74</td>
<td>0.14</td>
</tr>
<tr>
<td>CV</td>
<td>152.1</td>
<td>59.5</td>
<td>31.9</td>
</tr>
</tbody>
</table>

\(V_1 = \) PH4 maize variety; \(V_2 = \) striga resistant maize variety  
Column means followed by same superscript are not significantly different at P<0.05

**Table 4.8** Effect of maize variety on striga stand counts and maize grain and stover yields in the 2013 LR season

<table>
<thead>
<tr>
<th>Maize variety</th>
<th>Striga stand counts</th>
<th>Maize grain yield (t ha(^{-1}))</th>
<th>Maize stover yield (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count 1 (7 WAP)</td>
<td>Count 2 (9 WAP)</td>
<td></td>
</tr>
<tr>
<td>(V_1)</td>
<td>14.97</td>
<td>39.11</td>
<td>1.67</td>
</tr>
<tr>
<td>(V_2)</td>
<td>9.29</td>
<td>25.71</td>
<td>2.07</td>
</tr>
<tr>
<td>LSD</td>
<td>7.993</td>
<td>15.591</td>
<td>0.530</td>
</tr>
<tr>
<td>Pr &gt; F</td>
<td>0.47</td>
<td>0.48</td>
<td>0.12</td>
</tr>
<tr>
<td>CV</td>
<td>66.7</td>
<td>34.9</td>
<td>27.0</td>
</tr>
</tbody>
</table>

\(V_1 = \) PH4 maize variety; \(V_2 = \) striga resistant maize variety  
Column means followed by same superscript are not significantly different at P<0.05

Spatial arrangement of intercropped cowpea had no significant effect on striga stand counts (\(F = 0.45, P = 0.72\)) (\(F = 0.38, P = 0.77\)), maize grain yields (\(F = 0.21, P = 0.81\)) and maize stover yields (\(F = 0.25, P = 0.79\)) in the 2012 LR season (Table 4.9).
Table 4.9 Effect of spatial arrangement of intercropped cowpea on striga stand counts and maize grain and stover yields in the 2012 LR season

<table>
<thead>
<tr>
<th>Spatial arrangement</th>
<th>Striga stand counts</th>
<th>Maize grain yield (t ha(^{-1}))</th>
<th>Maize stover yield (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count 1 (7 WAP)</td>
<td>Count 2 (9 WAP)</td>
<td></td>
</tr>
<tr>
<td>Between row</td>
<td>3.61</td>
<td>20.22</td>
<td>3.95</td>
</tr>
<tr>
<td>Within row</td>
<td>1.95</td>
<td>22.02</td>
<td>3.64</td>
</tr>
<tr>
<td>Same hill</td>
<td>0.86</td>
<td>11.18</td>
<td>3.53</td>
</tr>
<tr>
<td>LSD</td>
<td>3.226</td>
<td>11.059</td>
<td>1.520</td>
</tr>
<tr>
<td>Pr &gt; F</td>
<td>0.65</td>
<td>0.69</td>
<td>0.81</td>
</tr>
<tr>
<td>CV</td>
<td>152.1</td>
<td>59.5</td>
<td>31.9</td>
</tr>
</tbody>
</table>

Column means followed by same superscript are not significantly different at P<0.05

The results of the 2013 LR season also showed that spatial arrangement of intercropped cowpea had no significant effect on striga stand counts (F = 3.23, P = 0.08) (F = 1.84, P = 0.21). These results are contrary to the findings by Tenebe and Petu-Ibikunle (2012), who reported low striga populations on plots of sorghum and cowpea sown on the same hill and attributed this to confusion of the parasite on recognition of the appropriate host. Unlike in the 2012 LR season, spatial arrangement of intercropped cowpea significantly influenced maize grain (F = 4.35, P = 0.04) and stover yields (F = 5.99, P = 0.02) in the 2013 LR season (Table 4.10; Appendices 2.5 and 2.6).

Plots in which cowpea was planted within the maize row had significantly higher maize grain and stover yields than those in which the legume was planted between maize rows. The results of this study are in line with those of Carsky et al. (1994) who reported highest yield of sorghum in alternating stands of sorghum and cowpea within the same row. The observed high maize yields where cowpea was planted within the maize row is probably due to
nitrogen transfer between the cowpea and maize root systems, as well as the improved ground cover within the maize rows effected by the legume. The relatively high ground cover within the maize row probably led to moisture conservation for longer periods than in plots in which cowpea was planted between maize rows.

Table 4.10 Effect of spatial arrangement of intercropped cowpea on striga stand counts and maize grain and stover yields in the 2013 LR season

<table>
<thead>
<tr>
<th>Spatial arrangement</th>
<th>Striga stand counts</th>
<th>Maize grain yield (t ha(^{-1}))</th>
<th>Maize stover yield (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count 1 (7 WAP)</td>
<td>Count 2 (9 WAP)</td>
<td></td>
</tr>
<tr>
<td>Between row</td>
<td>35.87</td>
<td>63.70</td>
<td>1.42(^{a}) 3.98(^{b})</td>
</tr>
<tr>
<td>Within row</td>
<td>16.14</td>
<td>28.63</td>
<td>2.27(^{a}) 5.67(^{a})</td>
</tr>
<tr>
<td>Same hill</td>
<td>8.45</td>
<td>18.50</td>
<td>1.92(^{ab}) 4.94(^{ab})</td>
</tr>
<tr>
<td>LSD</td>
<td>28.137</td>
<td>47.025</td>
<td>0.650 1.090</td>
</tr>
<tr>
<td>Pr &gt; F</td>
<td>0.08</td>
<td>0.21</td>
<td>0.04 0.02</td>
</tr>
<tr>
<td>CV</td>
<td>66.7</td>
<td>34.9</td>
<td>27.0 17.5</td>
</tr>
</tbody>
</table>

Column means followed by same superscript are not significantly different at P<0.05

A spatial arrangement where cowpea is planted between rows of a cereal crop is known to have a larger area of soil surface exposed than an arrangement where the legume is planted within the cereal row, leading to higher soil temperature which encourages greater moisture loss from the soil through evaporation (Tenebe and Petu-Ibikunle, 2012). The observed high maize yields where cowpea was planted within the maize row was probably the result of reduced temperature and moisture conservation effected by the overlapping maize and cowpea canopies. Nutrient uptake is known to increase with improved soil moisture. Maize that had been intercropped with cowpea
within the row probably responded to soil moisture conservation by increasing its nutrient uptake, leading to increased yields.

Plots in which cowpea was planted within the maize row probably had the highest volume of active maize root hairs in close proximity with cowpea roots where biological N fixation was taking place. A study by Fujita et al. (1992) showed that the distance between the intercrop root systems is important because N is transferred through the intermingling of the root systems of the companion crops. Hanegraaf (1987) reported the following three important routes for the transfer of nitrogen from legumes to soil; release of nitrogen from droppings of animals that fed on legumes, decomposition of aerial parts of leguminous plants, and decay of legume root tissues and nodules. The maize that had been intercropped with cowpea within the row most likely benefited from the cowpea root system turnover. Frankow-Lindberg and Dahlin (2013) have suggested that a major part of the legume root system turnover occurs in the uppermost part of the soil profile. In a study in coastal lowland Kenya, Saha (2007) observed the highest maize root length density in the top 30 cm of the soil profile.

The results of the experiment on maize variety and spatial arrangement of intercropped cowpea also showed that maize variety and legume spatial arrangement had no effect on striga seed density in soil at the end of both seasons one (2012 LR season) and two (2013 LR season). This shows that striga-resistant maize variety $V_2$ and the commercial variety PH4 ($V_1$) had similar effect on striga seed density in soil. Since suicidal germination plays a
key role in the reduction of striga seed load in soil, the results of this study show that suicidal germination of striga seed by cowpea is not affected by the spatial arrangement of the legume.

The results of the 2013 LR season showed a significant interaction effect of maize variety and spatial arrangement of intercropped cowpea on striga stand count at 7 WAP ($F = 4.35$, $P = 0.04$) and at 9 WAP ($F = 5.99$, $P = 0.02$) (Figures 4.1 and 4.2; Appendices 2.7 and 2.8). This shows that the effect of spatial arrangement of intercropped cowpea on striga stand count will most likely be influenced by maize variety.

Figure 4.1: Effect of maize variety and spatial arrangement on striga stand count at 7 WAP in the 2013 LR season.
Overall, PH4 had relatively higher mean grain yields in the research plots as shown in sections 4.1 and 4.2 (average yield of 2.8 t ha$^{-1}$) than the PH4 mean grain yields realized by farmers (1.62 t ha$^{-1}$) (SDA, 2013). The striga resistant maize varieties, which outperformed PH4 in research plots, are therefore likely to perform better than PH4 when planted by farmers in coastal Kenya.
CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

The results of this study showed a reduction in striga seed density in soil at the end of season one (2012 LR season) under maize-cowpea intercropping system, probably as a result of suicidal germination stimulation of striga seed by the legume. It is therefore likely that continued maize-cowpea intercrop may reduce striga seed bank in soil. To fully benefit from suicidal germination of striga seed by cowpea, it might be necessary to plant the legume in rotation with cereals. This is likely to eliminate the possibility of striga seeds stimulated to germinate by the legume attaching to maize roots as was probably the case under the cereal-cowpea intercrop system. However, there is need for further research to evaluate the effectiveness of cowpea planted either as an intercrop or a rotation crop with maize in the control of *S. asiatica*. There is need to compare the loss in maize grain yield resulting from interspecies competition in a maize-cowpea intercrop and that caused by forgoing one maize crop in a rotation system with the yield gain resulting from reduced striga infestation.

The study showed that maize varieties V₂ and V₄ had some tolerance to striga weed. These varieties therefore could be recommended for multi-locational evaluation under the National Performance Trials (NPTs) to ascertain their superiority to the current commercial maize varieties. If proved superior, the two maize varieties may then be multiplied for use by farmers in the *S. asiatica* prone areas of coastal lowland Kenya.
Results of the correlation analysis showed no evidence of meaningful correlation between striga stand counts and maize grain and stover yields since the coefficient of determination ($r^2$) was less than 0.5, implying that less than 50% of the variations in the yield parameters can be explained by the relationship between striga stand counts and maize grain and stover yields.

Spatial arrangement of intercropped cowpea was found to influence maize yield under maize-cowpea intercropping. The within row legume spatial arrangement of intercropped cowpea gave higher maize yields than the between row arrangement. It is therefore recommended that farmers adopt the within row spatial arrangement of intercropped cowpea for improved maize yields.
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striga (*Striga hermonthica* (Del.) Benth.) in two recombinant inbred


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Division) CL5 (Kaloleni Division) of Kilifi District, Coast Province. 

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APPENDICES

Appendix 1: Rainfall distribution at the study site


Appendix 2: Analysis of Variance Tables

Appendix 2.1: Effect of maize variety on maize stover yield - Experiment 1 (2012 LR season)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>REP</td>
<td>2</td>
<td>25.93284444</td>
<td>12.96642222</td>
<td>15.45</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>MVAR</td>
<td>5</td>
<td>11.41515556</td>
<td>2.28303111</td>
<td>2.72</td>
<td>0.0358</td>
</tr>
<tr>
<td>LEG</td>
<td>2</td>
<td>0.53367778</td>
<td>0.26683889</td>
<td>0.32</td>
<td>0.7297</td>
</tr>
<tr>
<td>MVAR*LEG</td>
<td>10</td>
<td>7.61356667</td>
<td>0.76135667</td>
<td>0.91</td>
<td>0.5372</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>28.52648889</td>
<td>0.83901438</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>53</td>
<td>74.02173333</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix 2.2: Effect of maize variety on maize stover yield - Experiment 1 (2013 LR season)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>REP</td>
<td>2</td>
<td>58.28107778</td>
<td>29.14053889</td>
<td>22.65</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>MVAR</td>
<td>5</td>
<td><strong>21.71183889</strong></td>
<td><strong>4.34236778</strong></td>
<td><strong>3.38</strong></td>
<td><strong>0.0139</strong></td>
</tr>
<tr>
<td>LEG</td>
<td>2</td>
<td>2.61601111</td>
<td>1.30800556</td>
<td>1.02</td>
<td>0.3725</td>
</tr>
<tr>
<td>MVAR*LEG</td>
<td>10</td>
<td>10.00570000</td>
<td>1.00057000</td>
<td>0.78</td>
<td>0.6491</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>3.73472222</td>
<td>1.2863154</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>53</td>
<td>136.3493500</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix 2.3: Effect of legume on maize grain yield - Experiment 1 (2013 LR season)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>REP</td>
<td>2</td>
<td>8.84263333</td>
<td>4.42131667</td>
<td>11.17</td>
<td>0.0002</td>
</tr>
<tr>
<td>MVAR</td>
<td>5</td>
<td>1.70330556</td>
<td>0.34066111</td>
<td>0.86</td>
<td>0.5172</td>
</tr>
<tr>
<td>LEG</td>
<td>2</td>
<td><strong>5.91803333</strong></td>
<td><strong>2.95901667</strong></td>
<td><strong>7.48</strong></td>
<td><strong>0.0020</strong></td>
</tr>
<tr>
<td>MVAR*LEG</td>
<td>10</td>
<td>5.11727778</td>
<td>0.51172778</td>
<td>1.29</td>
<td>0.2732</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>13.45403333</td>
<td>0.39570686</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>53</td>
<td>35.03528333</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix 2.4: Effect of legume on striga seed density in soil - Experiment 1 (End of season 1)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>REP</td>
<td>2</td>
<td>1.28009259</td>
<td>0.64004630</td>
<td>1.50</td>
<td>0.2386</td>
</tr>
<tr>
<td>MVAR</td>
<td>5</td>
<td>3.40856481</td>
<td>0.68171296</td>
<td>1.59</td>
<td>0.1886</td>
</tr>
<tr>
<td>LEG</td>
<td>2</td>
<td><strong>6.48148148</strong></td>
<td><strong>3.24074074</strong></td>
<td><strong>7.57</strong></td>
<td><strong>0.0019</strong></td>
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<tr>
<td>MVAR*LEG</td>
<td>10</td>
<td>4.03240741</td>
<td>0.40324074</td>
<td>0.94</td>
<td>0.5087</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>14.55324074</td>
<td>0.42803649</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>53</td>
<td>29.75578704</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix 2.5: Effect of maize variety and spatial arrangement of intercropped cowpea on maize stover yield - Experiment 2 (2013 LR season)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Mean square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>REP</td>
<td>2</td>
<td>43.57321111</td>
<td>21.78660556</td>
<td>30.10</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>MVAR</td>
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<td>5.57780000</td>
<td>5.57780000</td>
<td>7.71</td>
<td>0.0196</td>
</tr>
<tr>
<td>SARRANG</td>
<td>2</td>
<td>8.66821111</td>
<td>4.33410556</td>
<td>5.99</td>
<td>0.0195</td>
</tr>
<tr>
<td>MVAR*SARRANG</td>
<td>2</td>
<td>5.11143333</td>
<td>2.55571667</td>
<td>3.53</td>
<td>0.0691</td>
</tr>
<tr>
<td>Error</td>
<td>10</td>
<td>7.23692222</td>
<td>0.72369222</td>
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<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>17</td>
<td>70.16757778</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix 2.6: Effect of spatial arrangement of intercropped cowpea on maize grain yield - Experiment 2 (2013 LR season)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Mean square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>REP</td>
<td>2</td>
<td>3.70163333</td>
<td>1.85081667</td>
<td>7.27</td>
<td>0.0112</td>
</tr>
<tr>
<td>MVAR</td>
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<td>0.75235556</td>
<td>0.75235556</td>
<td>2.95</td>
<td>0.116</td>
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Appendix 2.7: Interaction effect of maize variety and spatial arrangement of intercropped cowpea on striga stand count 1 - Experiment 2 (2013 LR season)

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Appendix 2.8: Interaction effect of maize variety and spatial arrangement of intercropped cowpea on striga stand count 2 - Experiment 2 (2013 LR season)

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