EFFECT OF SELECTED SOYBEAN ACCESSIONS ON GERMINATION AND ATTACHEMENT OF *Striga hermonthica* ON MAIZE

BY

JUDITH ACHIENG' ODHIAMBO

A thesis submitted to the graduate school in partial fulfillment for the requirements of the award of a Master of Science Degree in Agronomy (Crop Protection)

CROP, HORTICULTURE AND SOILS
EGERTON UNIVERSITY

JUNE 2009

DECLARATION AND APPROVAL

This thesis is my original work and has not been submitted for an award of degree or diploma in any University.

Judith Achieng' Odhiambo

Signature………………………Date…………………………..

This thesis has been submitted to the board of postgraduate studies for examination with our approval as University Supervisors.

DR. ISAIAH MASINDE TABU
Department of Crops, Horticulture and soils
P.O Box 536-20115
Egerton, Kenya
Signature: ________________________________Date: __________________

DR. BERNARD VANLAUWE
TSBF-CIAT,
P.O. Box 30677-00100,
Nairobi, Kenya

Signature: ________________________________Date: __________________

DR. FRED KANAMPIU
CIMMYT,
P.O. Box 1041-00621,
Nairobi, Village Market, Kenya

Signature: ________________________________Date: __________________

DEDICATION

I dedicate this work to my children Vincent, Sharon and Nancy who missed the motherly love when I was away undertaking the course.

COPYRIGHT

ACKNOWLEDGEMENTS

First I thank the almighty Lord God for the gift of life and the good health he granted to me and my family throughout the study period, which enabled me to carry out the research activities without gross disruptions. I also thank CIAT-TSBF who on behalf of AATF provided the funds for the study. Thanks also to my employer the Teachers Service Commission who granted me study leave to enable me undertake the course.

I sincerely acknowledge the efforts of my supervisors, Dr. Isaiah Tabu, Department of Crop, Horticulture and Soils, Egerton University; Dr. Bernard Vanlauwe, TSBF-CIAT and Dr. Fred Kanampiu, CIMMYT who guided me in this study; I am indebted for their selfless dedication during the weekdays and weekends. My gratitude also goes to Dr. Chris Ndirangu former chairman of Agronomy department for assisting me to acquire and use facilities within and beyond the department. Thanks also to the entire Crop, Horticulture and Soils Department staff for the cooperation and technical advice they provided.

I also thank the former station administrator (ICIPE-Mbita station), Dr. Charles Mwendwa for granting me permission to carry out laboratory and screen house research experiments at the Mbita research station centre and Dr. Zeyaur Khan of ICIPE-Mbita point for the technical advice, the workspace and equipment in the laboratory. Thanks also go to Mr. Charles Oyugi of ICIPE-Mbita for the assistance he offered me during the laboratory and greenhouse experiments and Mrs. Janet Otieno the farmer from Nyabeda Siaya District who provided me with the land for field experiments. My gratitudes also go to Mr. Laban Nyambega and Nelson Otieno of TSBF-CIAT Maseno for the assistance they offered me during my fieldwork at Nyabeda. The assistance from Mr. George Oriyo the field technician at CIMMYT-Kibos during the *Striga* germination and seed elutriation tests is gratefully acknowledged. Thanks also to my graduate student colleagues Chebet, Munyiri, Olwasi and Ndiso for their support and encouragement during the study.

Finally, I am indebted to my family for their financial support, encouragement and prayers during the study period. I thank my sister Esther for taking care of my children while I was away studying. All those who contributed to the success of this study in one-way or the other are all acknowledged. May God Bless you abundantly.

LIST OF ABBRAVIATIONS

AATF	- African Agricultural Technology Foundation
CIAT	- International Center for Tropical Agriculture
CIMMYT	- International Maize and Wheat Improvement Center
GOK	- Government of Kenya
ICIPE	- International Centre for Insect Physiology and Ecology
IITA	- International Institute of Tropical Agriculture
TSBF	- Tropical Soil Biology and Fertility

ABSTRACT

Production of maize in Western Kenya is adversely affected by *Striga hermonthica,* a hemiparastic weed that produces numerous seeds that remain dormant in the soil for even more than 20years. These characteristics coupled with continuous cereal cropping have contributed to the high level of *Striga* seeds in the soil and the accompanying maize yield losses. Integrating legumes as intercrops is one way of reducing density of *S. hermonthica* in the soil and improving the livelihood of subsistence farming communities. Legume species and varieties however vary in their ability to stimulate suicidal germination of *S. hermonthica* seeds. A study was conducted to select soybean (*Glycine max*) accessions with high ability to stimulate germination of *S. hermonthica* seeds (from Western Kenya) and to determine the effect of selected soybean accessions on the *Striga* attachment and emergence on associated maize. The cut-root technique was used *in-vitro* to screen 32 soybean accessions in the laboratory at icipe-Mbita. *Desmodium*, *Mucuna* and maize varieties: Nyamula, KSTP94 and WH502 were used as checks while strigol (Nijimegen 1®) and distilled water were used as positive and negative controls, respectively. Plants were grown in plastic pots containing sterilized sand for 21 days to provide roots for the experiments. The cut roots were arranged in a Completely Randomized Design (CRD) with three replications. Fourteen soybean accessions (selected from the cut-root experiment), *Desmodium* and *Mucuna* were then grown in association with maize variety WH502 in pots inoculated with *Striga* seeds in screen house in a CRD with three replications. Four soybean accessions (selected from the cut-root experiment) were grown in association with maize variety WH502 in a field at Nyabeda for two seasons in Randomly Complete Block Design (RCBD). Results showed a significant variation among soybean accessions in the ability to induce germination of *Striga*. The relative germination of *Striga* seed by soybean accessions ranged from 8% to 66% compared to 60%, 66% and 70% for *Desmodium, Mucuna* and synthetic germination stimulant Nijmegen 1®, respectively. Accessions TGX1448-2E, Tgm 1576, TGX1876-4E and Tgm1039 had the highest relative germination induction percentages. Most accessions that stimulated high germination of *Striga* seeds also increased the *Striga* attachment by 6% to 95%. *Desmodium* resulted in low *Striga* attachment on the associated maize. Accessions TGX 1831-32E, Tgm944, Tgm 1419 and Namsoy4m had high stimulation but low attachment hence making them potentially important trap crops. In the field experiment, maize grown in association with legumes had low *Striga* counts and high grain yield compared to maize grown in pure stand. This led to the conclusion that some soybean accessions could be used to control *Striga*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

Kenya's population of about 27 million people is expected to rise to 36 million by the year 2010 (Central Bureau of Statisctics, 2005). Increased productivity per unit area is essential if self-efficiency in food production is to be achieved for the fast expanding population. Per capita arable land that has declined from 0.23 ha in 1981 to 0.15 ha in 1996 (World Bank, 1998) implies that production of stable food crops has to be intensified. Maize, the main staple food crop in Kenya is predominantly grown in the high to medium potential agricultural areas, which are unfortunately also very highly populated. Nyanza and Western provinces, the major maize growing areas have population densities of between 350 and 406 persons/km^2, respectively (Central Bureau of Statisctics, 2005). While farmers in these areas grow hybrid maize varieties with a potential yield of up to 8 ton/ha, they realize less than 1 ton/ha because of low soil fertility (associated with continuous cropping), weeds, unreliable rainfall pests and diseases.

Striga hermonthica a root parasitic weed that inhibits host growth by competing for nutrients and impairing photosynthesis is one of the most important biological constraints to maize production in sub- Saharana Africa. Of the 23 *Striga* species prevalent in Africa, *S. hermonthica* infests about 40% of the arable land and causes between 30 and 100% loss of maize yield in East Africa (Khan *et al.,* 2001; Gressel et *al.,* 2004). In Kenya, *S. hermonthica,* a serious constraint to cereal production in the Lake Victoria Basin affects more than 200,000 ha of maize and results in crop losses worth about US$53 million per year (Hassan *et al*., 1995). *Striga* infection is increasing to new areas even as farmers abandon the heavily infested fields. The problem is more serious in highly populated areas where soil fertility is low because of continuous cropping.

Striga is pernicious because of the large number of seeds it produces. A single *Striga* plant can produce upto 200,000 small dust-like seeds that survive in the soil for up to 20 years (Ma *et al*., 2004). In western Kenya, there are about 61 to 158 million *S. hermonthica* seeds per hectare of land (Khan *et al*., 2006; Vanlauwe *et al.,* 2008). The large number of seeds, long period the seeds can stay in the soil and the practice of continuously growing cereals leads to a build up of a big bank of seed mass in the soil. Continuous cropping which is often associated with decline in soil fertility further increases the *Striga* problem (Oswald, 2005).

Management of *Striga* should therefore aim at tackling the twin problem of soil fertility and *Striga* control, through reduced *Striga* seed bank.

Striga hermonthica specifically parasitizes maize, sorghum, millet, rice and sugarcane. The host specificity is achieved by chemical cues from the host plant. On germination, *Striga* attaches to the host plant roots through the haustoria and continues to feed for several weeks while living underground hence by the time it emerges from the soil, substantial damage on the host has already been caused. Management of *Striga* should therefore aim at restraining development while below ground, seed productions and depletion of the *Striga* seed bank in the soil.

A number of strategies have been proposed to control the development of *Striga*. Each of the strategies in isolation are however not effective as the weed continue to persist and increase in area. Pre-emergence herbicide, such as dicamba has been used to control *Striga*, but the small spectrum of selectivity limits use in crop mixtures while the possible post-emergence herbicide 2,4-D is applied when substantial damage is already done. Currently, Imidazoline-Resistant (i.e IR) maize where herbicide imazapyr which inhibits acetolactate synthase is coated on herbicide resistant mutant maize is being promoted (Kanampiu *et al.*, 2003). Though the technology is inexpensive, environmentally safe and fits well within the existing cropping systems, it does not reduce the *Striga* seeds number in the soil and only delays the *Striga* germination to a later date when the effect of the chemical is reduced in the field. Mechanical weeding and hand pulling have traditionally been used, but are tedious and take a long time before the effect can be seen. Ransom and Odhiambo (1994) found that hand weeding of *Striga* before seed set resulted in an increase in maize yield only after four seasons of implementation. In sddition weeding is effected when a lot of damage has already been done. Application of supra-optimal nitrogen fertilizer (above 120kgN/ha) has also been suggested as a means of *Striga* control (Mumera and Bellow, 1993), but its expensive to the low resource farmers. In Kenya, maize cultivars (Nyamula, WH502 and KSTP92) have been identified as tolerating *Striga hermonthica* infestations but the large number of *Striga* seeds added to the soil each season increases the seed bank.

Depletion of the soil *Striga* seed bank remains one of the most important options for *Striga* management. Stimulation of *Striga* seed to germinate in the absence of a host plant (also referred to as suicidal germination) and trap cropping is one of the ways of depletion of the seed bank. The practice results in death of the *Striga* seedling and depletion of *Striga* seed bank in the soil. Chemical stimulants such as ethylene gas have been used successfully against *S. asiatica* in USA (Egly *et al.*, 1990; Botanga, *et al.,* 2003). Direct use of ethylene gas is also hazardous because it is pressurized, flammable and requires specialized storage and application equipment, hence not suitable for the resource-poor subsistence farmers. Synthetic strigol analogues such as GR24, GR7 and Nijmegen 1® have been developed but are expensive hence they are used only under research conditions or in developed countries.

In addition to the adaptive mechanisms, the genetic plasticity of *Striga* and the wide diversity of biophysical and socio-economic environments in which farmers operate imply that an integrated approach should be employed. Integrating trap crops whose exudates induce suicidal germination of *Striga* seeds but are not parasitized could go a long way to control *Striga*. Use of legume trap crops to reduce *Striga* seed bank could be even more important as this could also help improve soil fertility through biological nitrogen fixation and act as a cheap source of proteins for improving the livelihoods of farmers. In Kenya, forage legume *Desmodium unicinatun* has been found to reduce *S. hermonthica* infestation by producing allelopathic root exudates that stimulate germination of *S. hermonthica* and inhibits growth of the *Striga* radicle (Khan *et al.*, 2002; Tsanuo *et al*, 2003). The stimulants have been isolated and identified as Isoflavanones uncinanone B and uncinanone C and modelled into the ´push-and-pull` concept for control of *Striga* and stem borers (Khan et al., 2000). Though novel, adoption of this system is generally low probably because of the low viability or problems related with of *Desmodium* seeds production and their limited direct use as food.

Soybean is one of the important legumes being promoted in Kenya for utilization as an alternative source of proteins and cooking oils. It was introduced and has been promoted aggressively since the 1990s by FAO for improvement of proteins and soil fertility. Many soybean varieties have even been recommended for growing in diverse ecological zones of Kenya (Nassiuma *et al.*, 2002). Preliminary studies have shown that soybean has potential to induce *Striga* germination. Given the diversity of crop genotypes and *Striga* population, ability to stimulate germination is likely to vary. Preliminary work in the savannah zones of West Africa has shown accessions TGX1740-7F, TGX1448-2E and TGX 1864 to have potential of inducing germination of more than 50% of *S. hermonthica* (Carsky et al., 2000). The predominant variation within legumes and *Striga* populations implies that the ability for suicidal germination among soybeans has to be identified and quantified if a low cost *Striga* control option has to be developed. This was the basis under which this research was developed.

1.1 Statement of the Problem

The high population estimated at 36 million people by the year 2010 in Kenya implies that food production has to be increased. Western Kenya represents the largest fraction of medium to high potential agricultural land. The area receives adequate rainfall (1800-2000mm) for food production, but the area is food deficit because of sub-optimal production. Farmers grow improved maize varieties with potential yield of 10 ton/ha but realize less than 1.0 ton/ha. *S. hermonthica* is one of the major constraints to cereal production in Western Kenya. The problem is compounded by continuous cultivation that is predominant because of the high population density. The cropping system being principally cereal based results in large quantities of *Striga* seeds recharging the soil seed bank each season. Ransom and Odhiambo (1994) in Homabay found that cereal monocropping without weeding increased *Striga* seeds per kg of soil from 134 in 1991 to 404 in 1993. In badly infested fields, *Striga* causes up to 100% crop yield loss and is responsible for abandonment of large tracks of land. In addition to enhancing the *Striga* seed bank, continuous cereal cultivation also contributes to soil fertility depletion. A number of control strategies have been suggested for the management of *Striga*. Paradoxically farmers in *Striga*-infested areas have limited resources and cannot afford expensive control options. The *Striga* adaptive activities also imply that single strategies in isolation may be inadequate. An integrated approach that targetes the development stage and depletion of the seedbank is ideal. Intercropping maize with the leguminous non-host plants will help deplete the *Striga* seed bank in the soil, preventing parasitism at the early crop growth stages and improve soil fertility. Soybean has long been identified as potential trap crop for *Striga* control, as a source of proteins and important for soil fertility management. It is being promoted in Kenya and currently there are many varieties being grown. Limited information is however available about the relative efficacy of the accessions and varieties to cause germination of *S. hermonthica* seeds and prevent parasitism.

1.2 Objectives

Broad objective

To increase maize yield through control of *Striga hermonthica* using soybean accessions as trap crops.

Specific objectives

1. Identify and select *in-vitro*, soybean varieties/accessions with ability to stimulate *Striga* germination.
2. Determine the effect of selected soybean varieties as trap crops on *Striga* emergence in a maize-soybean intercrop.
3. Determine the effectiveness of selected soybean varieties as trap crops to reduce *Striga* infestation and parasitism in a maize- soybean intercrop.

1.3 Hypotheses

1. Soybean varieties/accession do not stimulate *Striga* seed germination.
2. Soybean varieties have no effect on *Striga* emergence in a maize-soybean inter-crop.
3. Soybean varieties do not reduce *Striga* infestation and parasitism in a maize-soybean inter-crop.

1.4 Justification

Kenya's population depends on maize as the main staple food for their livelihood. In Western Kenya, farmers realise maize yields of less than 1.0 ton/ha yet the potential of up to 10 ton/ha exists. The sub-optimal yields have been attributed to low soil fertility and weeds such as *Striga*, which sometimes cause maize yield losses of up to 100%. Reducing these losses could significantly increase the yield and improve the farmers' livelihood.

Striga have a variety of adaptive mechanisms that make its control difficult. A *Striga* plant can produce over 200,000 seeds that remain dormant in the soil for up to two decades or up to when stimulated to germinate. If *Striga* plants are allowed to flower and seed, a large number of seeds will be returned to the soil increasing the seed bank. The *Striga* problem is compounded by the cropping system (continuous cultivation of cereals), which contributes to decreasing soil fertility and increasing the *Striga* seed bank. The control strategy must therefore focus on reducing *Striga* seed numbers in the soil, their development as well as increasing soil fertility.

Legumes such as soybeans can induce suicidal *S. hermonthica* seed germination, and increase the vigour and uniformity of the associated cereal crop by increasing soil organic matter and nitrogen content. This is useful because most farming systems, which suffer from *Striga* infestation, also have low soil fertility due to continuous cereal cropping. Food legumes also improve the livelihood (nutrition) of subsistence farming communities by meeting their nutritional needs. In addition, the intercrop surplus can be sold to generate income for the farmer.

Soybean is one of the legume crops being promoted in Kenya for increased protein content, as source of cooking oil and for soil fertility enhancement. There is need however to fully understand its potential contribution to the farming system that includes *Striga* control. Since there is considerable variability among crop cultivars, there is need to screen for the ability to stimulate *Striga* germination and ultimate efficiency to reduce *Striga* parasitism, if ideal recommendation to farmers is to be reached.

CHAPTER TWO
LITERATURE REVIEW

The genus *Striga* is composed of about 50 species, which are all parasites of tropical cereals and legumes of which, *Striga hermonthica* (Del.) Benth, *S. asiatica* (L.) Kuntze and *S. gesnerioides* cause the most serious problems in Africa (Butler, 1995). *Striga hermonthica* infect crops like maize, sorghum, millet, sugarcane and upland rice and is one of the most important weeds limiting maize production in Kenya and the weed is most severe in areas where soil fertility (Oswald, 2005). In Nigeria, the farmers' common cereal based management systems such as cultivation of local maize as the main crop was found to lead to a *S. hermonthica* seed bank increase by 46% (Franke *et al*., 2005).

Striga.hermonthica reduces yields by competing for water, nutrients, space, light and photosynthates with the host plants (El-Halmouch *et al*., 2005). In Africa, crop yield losses associated with *Striga* related activities is about 40% and represents an annual loss of cereals worth US$7 to 13 billion (Khan *et al*., 2001). In East Africa, *S. hermonthica* is the most important species causing an estimated 20-100% total loss for maize, sorghum and millet (Emechebe and Ahonsi, 2003). In Kenya, *Striga* is most pronounced in Nyanza and some parts of Western provinces and the coastal strips, where it occurs in about 200,000 hectares resulting in crop losses accounting for about US$ 53 million per year (Hassan *et al*., 1995). In addition, to yield reduction, *Striga* also cause abandoning of arable fields, which results in food insecurity and malnutrition (Gressel *et al*., 2004; Gomba and Kachigunda, 2005).

2.1 Plant-Plant Communication and Implications for Control

2.1.1 Germination and stimulation

Seeds of most parasitic plants will readily germinate if appropriate environmental conditions, warmth, water, oxygen and temperature are met. Some parasite weeds such as those in the genera *Striga*, *Alectra* and *Orobanche* rely on host-derived germination factors. Identification of the germination stimulants and mechanisms involved is important for weed control. *Striga hermonthica* has ability to produce enormous number of seeds ranging from 50,00 - 200,000 that are minute (0.25mm long, weighing $5x10^{-5}$g each) and stay dormant for more than two decades years in the absence of a suitable host (Berner *et al*., 1997; Ma *et al*., 2004). The host- parasite interaction begins when germination of *Striga* seed is triggered by hosts' root exudates. The seeds require a dormant after- ripening period of several months and exposure to moist and warm (22ºC to 35° C) conditions for 1 to 3 weeks before responding to a germination stimulant (Parker and Riches, 1993; Aigbokhan *et al*., 1998). Even after conditioning only a few *Striga* seeds germinate. The survival mechanisms help build a seed bank of *Striga* seed in the soils (Ejeta *et al*., 1992).

After conditioning, *Striga* seeds respond to the germination stimulant exuded by roots of hosts and even some non-host within 3 to 24 hours (Ejeta and Butler, 1993). In the absence of a suitable germination stimulant, a pre- conditioned seed reverts back to "wet dormancy" in the soil. The adaptation is of evolutionary significance because the tiny seeds with limited food reserves cannot support the seedling for many days after germination unless the host root is invaded (Bouwmeester *et al.,* 2003). The stimulant dependent germination has a significant ecological impact as it ensures that *Striga* seed does not germinate unless a stimulus-exuding host is present and growing.

Three classes of compounds (dihydrosorgoleone, strigolactones and
Sesquiterpene lactones) with germination stimulating activity have been identified and described (Bouwmeester *et al*., 2003). Dihydrosorgoleones have been suggested to be the active germination stimulant in sorgoleone and was first isolated from the root exudates of sorghum and later on other monocotyledonous hosts (Chang *et al.,* 1986). Dihydrosorgoleone is however thought to be a germination stimulant in-vivo because it has low water solubility and no correlation between its production and the germination of *Striga* seeds has been observed (Wigchert and Zwanenburg, 1999). Some sesquiterpene lactones (germacranolide, eudesmanolide and pseudoguaianalide) have also been shown to induce germination of *Striga* seeds (Ruggut and Ruggut, 1997).Strigolactones (Strigol, Alectrol and Sorgolacton) have been identified in the root exudates of a variety of plant species. Cook *et al.* (1972) identified the first natural germination stimulant from cotton, a non-host and named it (+)-strigol. Hauck *et al*. (1992) then identified sorgolactone, a structural analogue of strigol as the major *Striga* germination stimulant produced by sorghum. Alectrol, a structurally related molecule has also been identified in cowpea, a host of *S. gesneriodes* (Muller *et al*., 1992). Strigol was later identified in the true *Striga* hosts (maize, sorghum and millet) and in exudates of the non-host leguminous medicinal plants like *Menispermum dauricium* and *Stephania cepharantha* (Siame *et al*., 1993; Yasuda *et al*., 2003). Inorganic synthetic analogues of the strigol such as GR7, GR24 and Nijmegen® 1 have been purified and are commercially sold.

Studies by Matusova *et al.* (2005) and Humphrey and Beale (2006) noted that *Strigol* is a product of carotenoid biosynthetic pathway, because germination of *S. hermonthica* induced by root exudates of maize and cowpea was strongly inhibited when host plant seedlings were grown in the presence of fluridone, a carotenoid biosynthesis inhibitor. Details of how *Strigol* and its analogues stimulate germination of *Striga* seeds have however not been elucidated. Wigchert and Zwanenburg (1999) suggested that strigolactones stimulate germination of parasitic weed seeds via a receptor-mediated mechanism. Other studies link the stimulation to initiation of biosynthesis of ethylene, which is required for germination of seeds (Babiker *et al.*, 1993; Koichi *et al.*, 1998; Zehhar *et al.*, 2002). Fungal metabolites, cotylenins and fusicoccins and ethylene producing bacteria *Pseudomonus syringae* pv.*glycinea* at low concentrations have also been found to induce *Striga* seed germination (Koichi *et al.*, 1998; Berner *et al.*, 1999). Recently Tsanuo *et al.* (2003), identified the compounds, 5,7,2′, 4′-Tetrahydroxy-6- (3-methylbut-2-enyl)-isoflavanone**1,**4″, 5″- dehydro -5,2′, 4′-trihydroxy-5″ isopropenylfurone2″, 3″, 7,6) isoflavanone **2** and 4″, 5″- dihydro-2′-methoxy-5, 4′-dehydroxy-5″-isopropenylfurano-(2″,3″,7,6) isoflavanone **3** which they named as unicinanone A, B and C in the root exudates of *Desmodium unicinatum,* a non host plant to be responsible for induction. Uncinanone B induced germination of *Striga hermonthica* while uncinanone C inhibied *S. hermonthica* radical growth (Tsanuo *et al.*, 2003).

2.1.2 Haustoria development and emergence of *Striga*

After germination endosperm reserves can only sustain the seedling for about four days in absence of the host after which the seedling dies (Berner and Williams, 1998).Generally a germinated *Striga* seedling radicle differentiates and elongates only after receiving another chemical signal derived from the host root (Ruggut *et al.,* 1996). Chemotrophic behaviour assists the parasite to make contact with the host roots. On contact, a second host-derived-chemical signal called haustorial initiation factor (HIF) induces the elongating radicle to differentiate into specialized structure haustorium by which the *Striga* seedling attaches to and penetrates the host roots (Ramaiah *et al.*, 1983). On contact, the *Striga* seedling produce hydrogen peroxide (H_2O_2), which binds to the peroxidase causing oxidation of the host root cell wall phenols to generate production of HIF. (Kujijit, 1991; Kim *et al.*, 1998; Palmer *et al.*, 2004). Unlike germination, attachment is not host specific (Yoder, 1998). The penetration continuous until xylem-xylem connection between parasite and the host root is established through which nutrients and water derived from the host moves to the parasite (Press *et al.*, 1990). The seedling also produces adventitious roots or secondary haustoria, which penetrate the host roots along with the primary haustorium (Ejeta *et al.*, 1992).

After successful attachment to the host, the young parasite becomes a metabolic sink for the carbohydrates produced in the host, thus depriving the host of some of its photosynthates, amino acids and sugar (Ramaiah *et al.*, 1983). Histochemical studies show that there is high enzymatic activity in the haustorial cells and high carbohydrates, amino acids and organic acids in the xylem sap of *S. hermonthica* compared to its host *S. bicolor* (Press, 1989). The results indicate that haustorial cells have specialized biochemical functions related to the regulation of solute transfer and that haustorium plays an active metabolic role in nutrition of parasitic plants (Stewart and Press, 1990). It has been suggested that *S. hermonthica* derive 100% of its carbon from maize before emergence and up to 59% after emergence (Aflakpui *et al.*, 2005). Lack of nitrate and nitrite reductase in *Striga* suggests that it completely depends on the host for organic nitrogen supply (Aflakpui *et al.*, 2005). To enhance water flow from host roots to *Striga*, the weed sustains a rate of transpiration far in excess of the sorghum host by keeping its stomata open at night while those of the host are closed (Press *et al.*, 1990).

The parasite seedling grows in a subterranean manner for 4 to 6 weeks before emergence (Pieterse and Pesch, 1983). During its subterranean stage of life, it induces considerable damage to the parasitized crop. When the *Striga* shoot emerges from the soil, it produces fleshy green stems, with narrow green leaves but still there is continued flow of carbohydrates, water and minerals from the host to the emerged parasite (Ramaiah *et al.*, 1983). The damaging effect of *Striga* on its host continues during the post emergence stage. *When it* grows to a height of 50-100 cm ,producing numerous small purple flowers that later form capsules containing many seeds.

2.1.3 Pathogenicity effects

In a typical *Striga* ecosystem, nutrition resources are rarely adequate hence, the competition between the host and the parasite. As a result of *Striga* infestation, growth inhibitors (abscisic acid and fernasol) in the host increase, and growth promoters (cytokinins and giberrallins) decrease due to host stress response, generally, impairing the host growth and reproduction (Frost, 1997).

When the *Striga* is still subterranean, symptoms include water soaked leaf lesions, chlorosis, eventual leaf and plant desiccation, necrosis and severe stunting and drought-like symptoms such as leaf margin curling (Berner *et al*, 1997). Symptom development in the host is intensified after emergence because of severe carbon and nitrogen deficit as a result of translocation of carbon and nitrogen from the host plant to the parasite (Aflakpui et al., 2005). This results in reduced growth of the host, which is eventually reflected in the host grain yield. According to Mumera (1992), competition for nitrogen can play a crucial role in the performance and survival of sinks in host-parasite associations. Host damage such as wilting, stunting, bleaching which are evident even before the emergence of the parasite suggest possible involvement of toxins produced by the parasite (Stewart and Press, 1990). Since *Striga* related yield losses on the host occur long before *Striga* emergence, a successful control option should have an inherent component of diminishing *S. hermonthica* seed bank in the soil and limiting further seed production.

2.2 Control strategies

Several methods have been suggested for the controls of *S. hermonthica*. The methods include those aimed at restraining *Striga* plant and seed development (herbicides, weeding, early sowing and breeding for resistant host varieties) and those targeting the seed bank reduction (suicidal germination).

2.2.1 Restraining *Striga hermonthica* development and seed production

Rouging

Removal of *Striga* plants through hand pulling, slashing or hoeing (weeding) is probably the oldest and most widely used method of *Striga* control by subsistence farmers. It is not widely practiced, probably because of the limited immediate returns from the practice and the tediousness of the task (Esilaba *et al*., 1997). In a long- study in Western Kenya, Ransom and Odhiambo (1994) found that hand weeding before *Striga* seed set increased yield only after four seasons of implementation. In addition uprooting at flowering and fruiting, still leads to broadcasting of viable seeds. The practice of uprooting *Striga* plants with already mature seed and placing them on the roads and footpaths instead of burning them, further help in increasing seed bank in the ecosystem.

Chemical control

Soil active herbicides have been identified which give partial control of *S. hermonthica* before it emerges from the soil. Dicamba® has been used to effectively control S. *asiatica* in the USA (Eplee and Norris, 1987). In Kenya, Odhiambo and Ransom (1993) found Dicamba® to be effective only when applied at the peak of *Striga* germination and attachment. Unfortunately, Dicamba® has small spectrum of selectivity. Post- emergence foliar applied herbicides such as 2, 4-D, bromoxymil® are however applied when substantial damage has already occurred. Other herbicides such as imidazolinone, imazapyr® that inhibit acetolactate synthase (ALS) has also been used especially on imidazoline-resistant (IR) maize (Kanampiu *et al*., 2001).

Host plant resistance

Host plant resistance is the plant's ability to prevent attachment of the parasite or to kill the attached parasite resulting in reduced emergence while tolerance is the ability of the plant to withstand the effects of the parasite already attached producing satisfactorily (Badu-Apraku *et al*., 2007). The selection and development of resistance is a major practical and reliable approach to the management of *Striga* especially in the context of peasant agriculture as it avoids reproduction of the parasite. Resistance to *Striga* has been shown in sorghum cultivars like SRN-39 (Hess and Ejeta, 1992). In maize, *Striga* tolerant varieties, which are either open pollinated, or hybrid varieties such as WS909, WH502 and KSTP94 and local variety Nyamula have been identified (Odongo *et al*., 1997). The major problem associated with the use of resistant/tolerant cultivars is the lack of universal resistance, because of the existence of different biotypes of *S. hermonthica* since it is cross-pollinated (Koyama, 2000). Such variation has been observed in variable response of S. *gesnerioides* to germination stimulation (Berner and Williams, 1998). As a result of variation, field screening for *Striga* resistance cultivars is often unreliable and slow because of the inconsistence nature of infestation within and between field, and across years (Vogler *et al*., 1995). Further-more the resistance genotype was found to lower the *Striga* seed bank only at very low infestation levels (Rodenburg et al., 2005). The production of tolerant and resistance varieties can be improved if they are used as major component of integrated *Striga* control packages.

Biological control

The larvae of the butterfly *Junonia orithya* feeds on the foliage while that of the fly *Ophiomia Strigalis* and the beetle *Smicronyx spp.* feed on gall seeds of the *Striga.* These predators have their natural enemies and appear to be polyphagous and consequently have limited potential as biological control agents (Greathead, 1984).

Mycoherbicidal organisms like *Fusarium oxysporum* (Marley *et al*., 1999; Ciotola *et al.,* 2000; Marley *et al*., 2004) and bacteria (Berner *et al*., 1999; Miche *et al*., 2000) have been cited as biocontrol agents. Jasmonates and fungal metabolites cotylenin and fusicoccins have also been found to induce germination of *S. hermonthica* and *Orobanche minor* seeds under experimental conditions but have not been packaged for use in field conditions (Yoneyame *et al*., 1998). Ethylene producing bacteria *Pseudomonous syringae* pv. *glycinea* have also been identified as possible for controlling *Striga* spp. (Berner *et al*., 1999). The pathogenity effect of these bacteria on the environment needs to be studied before they are recommended for use.

Extra fertilizer (Nitrogen nutrition)

In-vitro experiments have shown that nitrogen in form of ammonium or nitrate inhibits germination and radicle length of *Striga* as a result of inhibition of production of chemical stimulants by host plants (Raju *et al*., 1990). Studies have also shown a toxic effect of nitrogen on *Striga* development following attachment (Pieterse and Verkleij, 1991). Other studies show that the nitrogen effect is related to the host partitioning of resources between the root and the shoot (Parker 1984). Generally the root/shoot ratio of plants increases following *Striga* attack, but reduces in the presence of ammonium or nitrogen (Parker, 1984). Parker and Riches (1993) noted that nitrogen enhance shoot: root ratio resulting in less flow of photosynthate down to the root. According to Mumera and Bellow (1993) increased nitrogen availability alleviates *Striga* infection by enhancing the partitioning of dry matter to the ear over the maize vegetation. Supra-optimal levels of fertilizer (120 $kgha^{-1}$ inorganic nitrogen) that would be required for control of *Striga* are however too expensive for most small-scale farmers and could pollute the environment (Mumera and Below, 1993; Kim *et al*., 1996).

2.2.2 Soil *Striga* seed bank reduction

Striga species are very prolific producing a large number of seeds with prolonged viability. Ma *et al.* (2004) estimated that a well-grown *S. hermonthica* plant could produce about 200,000 seeds at a density of 20 plants m^{-2}. In addition, *Striga* exerts potential phytotoxic effects on the host and most of the *Striga*- induced losses on the host occur before it emerges from the soil (Ransom *et al*., 1996). Continuous cropping especially in cereal based systems increase the number of *Striga* seeds in soil. Depletion of the *Striga* seed bank in the soil is an important control strategy, because it is low cost, has long-term effects and fits within the dominantly cereal based cropping system in Kenya.

Suicidal germination using synthetic stimulants

Natural chemical compounds mainly phenolic metabolites exudated from the roots of hosts and non-host crops have been known to trigger germination of *Striga*. The first naturally occurring germination stimulant characterized was isolated from cotton, a non-host (Cook *et al.,* 1972) and later from maize, sorghum and millet (Hauck *et al*., 1992; Siame et al., 1993). Strigol belong to the strigolactone compounds, which are synthesized via carotenoid biosynthetic pathway. In the pathway, carotenoid cleavage dioxygenases such as 9-cis-epoxycarotenoid dioxygenase (NCED) cause oxidative cleavage of 9-cis-epoxycarotenoid to apocarotenoid (C25) and xanthoxin (C15) during the biosynthesis of abscisic acid (Matusova *et al*., 2005; Humphrey and Beale, 2006). The cleavage is followed by other enzymatic reactions that modify the apocarotenoid skeleton to form specific strigolactones (Matusova *et al*., 2005). The structure of strigol, a 15-carbon compound ($C_{15}H_{22}O_6$) was established in 1985 and consists of four rings. A six carbon ring (A), a five carbon ring (B) and a four-carbon lacton ring (C) coupled to another lacton ring (D) by a=c-o-(enol ether) connecting unit (Brooks *et al*., 1985). The connection between the tricylic lactones (C-ring) and butyrolactone (D-ring) via the enol ether bridge has been found to be crucial for the biological activity of strigolactone compounds (Humphrey and Beale, 2006).

Following the observation that natural exudates strigol from cotton induced *Striga* germination in the absence of a host and the identification of the active structures, commercial analogues (GR compounds) such as GR7, GR24 and Nijmegen® 1 that are cheaper and more efficient have been developed along the ABCD ring structure (Gerard *et al*., 1997). Strigol and its synthetic analogues stimulate germination of *Striga* seeds via ethylene biosynthesis (Humphrey and Beale, 2006). The high costs of production and instability of strigol and its synthetic analogues however hinder their use as practical control measures (Ejeta *et al*., 1993). Natural germination stimulant from *Desmodium* have also been isolated and characterised (Tsanuo *et al*., 2003)

Ethylene germination stimulant has been successfully used to control *Striga asiatica* in USA but it is not effective against *Striga hermonthica* in Eastern Africa (Egley et al., 1990; Ransom and Njoroge, 1991) whish could be attributed to different *Striga* species involved. Injection of ethylene gas is also potentially dangerous and requires specialized storage and application equipment, which make it costly and unsuitable for most small-scale farmers (Ma *et al*., 2004).

Intercropping with trap crops

Trap cropping to induce suicidal germination is one of the effective and low cost input options that farmers could use for *Striga* control. Trap crops offer the advantage of stimulating germination of *Striga* or other root parasites without themselves being parasitized. The principle of trap cropping applied mainly in pest and disease management also has potential in weed control (Hokkanen, 1991). Most of the *Striga* trap crops being legumes (cowpea, pigionpea, cotton and soybean) solve the twin problem of depleting of *Striga* seed bank and soil fertility (Parkinson *et al*., 1988). The grain and biomass obtained from legumes also offer additional benefits as sources of proteins, income, feeds for livestock and manure in the subsistence agriculture (Reda *et al*., 2005). Studies have found that nitrogen fixed and released by legume crops such as cowpea contributes to *Striga* suppression by enhancing soil fertility (Pieterse and Verkleij, 1991). Paradoxically, cowpea is susceptible to *Striga gesnerioides*, but is a trap crop of *Striga hermonthica* (Butler *et al*., 1995).

Short duration improved (or planted) fallows with leguminous trees and shrubs such as *Sesbania sesban*, *Markhamia lutea* and *Leucaena diversifolia* encourage suicidal germination of *Striga* seed during the fallow phase (Oswald et al., 1996, Rao and Gacheru, 1998). In addition to the increased amounts of mineral N in the topsoil and higher levels of N mineralisation in the subsequent cropping phase improves crop performance in this system. However the prevailing scarcity of land as a result of population increase has resulted in intensive land use and a shift away from this method (Berner *et al*., 1996, Kureh *et al*., 2000).

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

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

Intercropping has potential as a means of weed control because it offers the possibility of a mixture of crops capturing a greater share of available resources hence pre-empting their use by weeds. Allelopathic potential of some crops also offer an attractive alternative to chemical weed suppression. Such alternatives are increasingly important in the face of environmental pollution, ground water contamination and increased resistant of weeds to herbicide. *Striga* seeds in the soil have been shown to reduce with use of trap crops or catch crops in an intercropping system (Pieterse and Pesch, 1983). Carson (1989) observed reduced *S hermonthica* densities under sorghum/ groundnut intercrop (*Arachis hypogaea*). Intercropping sorghum with dolichos lablab (*Lablab purpureus*) resulted in suppressed *S. hermonthica* emergence and growth and increased yield of sorghum (Babiker *et al*., 1993). The spreading vegetation of trap crops such as *Mucuna* has also been shown to smoother emerging *Striga* plants before flowering (Kabambe, 1995). In Uganda, intercropping sorghum and *Celosia argentia* (Amaranthacae) has been shown to reduce *Striga* by 55 % (Olupot *et al*., 2003). In Kenya, silverleaf *Desmodium* has been found to suppress *Striga* by stimulating seed germination and inhibiting haustorium development and has been successfully modelled into ’push-pull’ control system (Khan *et al.,* 2001; Tsanuo *et al*., 2003). The ’push-pull’ system is however hampered by poor establishment of *Desmodium*. Its small size and slow growth during the early stages makes weeding with the farmers' traditional jembe difficult. Adoption of the system is also poor since most farmers are interested in food crops as opposed to fodder legume.

Success of the intercropping system depends on the environment and crops used (Kabambe, 1995). Farmers' acceptance of any trap crop will depend on its economic value. One of the options would be to introduce a high nutritious and priced food legume. Currently many soybean accessions have been recommended for the diverse-ecological zones of Kenya and are being grown (Nassiuma *et al*., 2002). Expanding the horizontal use of soybean would increase potential for adoption and integration into existing cropping systems. This is because the acceptance of a technology by farmers depends on its suitability to the wide diversity of biophysical and socio-economic environments in which subsistence farmers' work (Oswald *et al.,* 2002; Marley *et al*., 2004; Franke *et al*., 2005). Kureh *et al.* (2000) found that sole hybrid maize supported significantly higher *Striga* incidence and infestation than when intercropped with selected soybean varieties TGX 1019-2E and TGX 1440-1E in Northern Guinea of Nigeria. Intercropping *Striga* tolerant maize and selected soybean varieties led to 46% reducetion in *Striga* seed bank and altimately 88% increase in maize production (Schulz *et al*., 2003; Franke *et al*., 2005). Studies have shown that there is variability among non-host crops and within crop cultivar in their ability to stimulate *Striga* seed germination and between *Striga hermonthica* populations to respond to germination stimulant (Kureh *et al*., 2000).

2.2.3 Integrated Pest Management (IPM)

Horticultural Crops Development Authority (2002) defined IPM as an ecologically based practice that promotes the health of crops and uses cultural control processes such as host resistance and biological control to confer pests while using pesticides only to improve the level of control if it is essential. It involves the use of different techniques in combination to control pests with an emphasis on methods that are least injurious to the environment and most effective to the particular pest. These, for example, involves combining use of pest resistant plant varieties, regular monitoring for pests, minimal pesticide use, and natural predators of the pest and good stand management practices**.** The genetic plasticity of *Striga* and the wide diversity of biophysical and socio-economic environments, in which farmers work, implies that, integrated approaches are necessary for *Striga* control (Franke *et al*., 2005). The integrated approach to be adapted should ensure satisfactory increase in grain yield but without substantial increase in investment. Integrating trap crops whose exudates induce suicidal germination of *Striga* seeds but are themselves not parasitized in intercropping system with tolerant cereal varieties could provide such affordable means of combating *Striga* menace.

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Site description

Laboratory screening and screen house pot experiments were carried out at the International Center for Insect Physiology and Ecology (icipe) Thomas Odhiambo Campus, Mbita Point, which lies at an altitude of 1240m above sea level, longitude between 34° 10`E and 34° 15`E and latitude 0°52`S and 0° 30`S; and within the agro-ecological zone LM V. The site has well-drained alluvial clay loam soil classified as *chromic Vertisols* and receives annual rainfall of between 700mm and 1200mm and temperature between 17.0°C - 34.8°C (Jaetzold and Schmidt, 1983).

The field trial was conducted at Nyabeda, Siaya District on a heavily *Striga* infested field during the long (March-August 2006) and the short (September- December of 2006) rainy seasons. The area lies at longitude between 34° 30`E and 35° 0`E, latitude between 0° 0`N and 0° 15`N and altitude 1300m above sea level within the agro ecological zone LM1 (Jaetzold and Schimdt, 1983). The area receives bimodal annual rainfall ranging from 1800-2000 mm per annum and temperatures range from 14-32°C. The soils are predominantly loamy sands classified as *humic Acrisols* and *rhodic Ferralsols* soils (Jaetzold and Schimdt, 1983). The farming system is mainly subsistence with maize as the major food crop.

3.2 Conditioning and surface sterilization of *Striga* seeds

Striga seeds that had undergone a dormant after- ripening period of four months obtained from Kibos, Kisumu CIMMYT project were surface disinfested as described by Berner *et al.* (1997), by soaking the *Striga* seeds in a 1% sodium hypochlorite solution ($NaOHCl_3$) and stirring for three minutes. The floating seeds and debris were discarded and the mixture poured into a funnel lined with filter paper. The seeds were then rinsed several times with sterile water and air-dried at room temperature. The surface sterilized *Striga* seeds were then conditioned as described by Berner *et al*. (1997), to induce physiological changes so that they could respond to the germination stimulant. Moistened 5mm discs of glass micro fibre filter paper (GR/A$^{®}$ Whatman) were arranged on a 9cm diameter sterilized petri-dishes lined with double layer moistened regular filter paper (No.1 Whatman). *Striga* seeds that had been surface sterilized were sprinkled on the moistened discs (about 50 seeds per disc). Petri-dishes were then covered with lids, edges sealed with parafilm and then wrapped in aluminium foil before placing them in an incubator at temperatures of 30°C for 14 days.

3.3 Tetrazolium (viability) and germination test

About 50 *Striga* seeds were placed in a petri-dish covered with aluminium foil. Four drops of 0.01% 2, 3-5 triphenyl tetrazolium chloride solutions were then added to barely cover the seeds before wrapping the petri-dish in the aluminium foil. Treated seeds were then incubated at 40ºC for 48 hours. Five drops of 1% sodium hypohlorite ($NaOHCl_3$) solution was added to the seeds after which the seeds were observed under a dissecting microscope for the red stained endosperm.

Germination test on *Striga* seeds was conducted using Nijmegen 1® as germination stimulant. Seeds used for germination test were conditioned before placing them on 5mm-diameter moist glass fiber discs. Twenty such discs were then placed on moist regular filter paper in a petri-dish and two drops of 10^{-4}M Nijmegen 1® solution added to each glass fiber discs. Seven trials on germination test were done each trial having three replications. The edges of petri-dishes were then sealed with parafilm and wrapped in aluminium foil. The petri-dishes were then placed in a dark incubator at 30ºC for 48 hours (Berner *et al.*, 1997). A dissecting microscope was then used to determine germinating seeds (those with emerging radicle).

3.4 Pot preparation

Filter papers were placed at the bottom of each pot to reduce loss of *Striga* seed through drainage. *Striga*-free soil from the icipe station field was mixed thoroughly with sand at the ratio of 4:1 and sterilized at 121ºC for 2 hours. Each pot was filled with 4kg of sterilized soil and then inoculated with 0.075g of *Striga* seeds whose viability and germination percent had earlier been determined. The pots were first filled three-quarter way with soil, *Striga* seeds sprinkled and the remaining soil added, i.e. *Striga* seed were placed at about 8 cm below the soil surface. The pots were watered carefully to avoid leakages from the pots on the first day of infestation and then later after 4 days in order to condition the *Striga* seeds. Maize and the legume (intercrops) were planted seven days after soil preparation as recommended by Berner *et al*. (1997). At planting, 0.25g of N and P fertilizers at equivalent rates of 60kg/ha of calcium ammonium nitrate (CAN) and triple super phosphate (TSP), respectively, was applied to each pot. Weeds were controlled by hand removal.

Hybrid maize (variety WH502) recommended for *Striga* prone areas was planted with the selected legumes in *Striga* inoculated pots at a depth of about 2-3 cm. The experiment was laid out as a CRD with three replications.

3.5 *Striga* seed extraction (elutriation)

Soil sub-sample weighing 250g from each plot was put on a sheet of coarse screen placed on top stacked series of sieves down from 250 and 90 microns. The stacked sieves and soil was put under flowing tap water, which washed the particles down through the sieves, until all the *Striga*-sized particles were collected on the 90-micron sieve. Potassium carbonate (K_2CO_3) separation method (Berner *et al.*, 1997) was used to extract *Striga* seeds from *Striga*-sized particles. A potassium carbonate solution heavier than water and *Striga* seeds (with specific gravity of 1.4) was prepared by adding 500g of $K_2 CO_3$ to 700ml of tap water. Five hundred ml (500ml) of the solution was then poured in a one litter separatory funnel mounted in a ring stand. The remaining solution was used to wash the contents of the 90-micron into the separatory funnel. Water was added to the K_2CO_3 solution in the separatory funnel up to 200ml mark and allowed to settle for 20 minutes to allow intact *Striga* seeds to settle at the water/K_2CO_3 interface. The K_2CO_3 was drained into a 500ml-beaker lined with a 60-micron nylon screen until 10cm potassium carbonate level remained. The beaker was then replaced with an empty one with clean nylon screen. Draining continued up to 10cm of water solution. At the same time the screens containing *Striga* seeds were saved and replaced as frequently as possible. The *Striga* seeds in each screen were counted under a dissecting microscope.

Striga count

Striga count was done in each experimental net plot every two weeks starting from the fourth week and ending at physiological maturity (14 weeks after planting). At 14 weeks after planting, all *Striga* plants within the net plot area were uprooted and fresh weight taken. They were then oven dried at 60°C for three days and the dry weight (*Striga* biomass) determined.

3.6 Parameters measured

Growth parameters

Height and leaf area index (LAI) were determined periodically at 4th, 6th, 8th, 10th and 12th. Plant height was measured from soil surface to the last fully formed leaf while LAI was determined by measuring length and maximum width of leaves from five plants per plot after every two weeks and leaf area calculated by multiplying the leaf length by leaf width and by

0.75 according to Norman and Campbell (1989) and leaf area index calculated by dividing leaf area by spacing.

Grain yield

Maize in the middle five rows was harvested by removing cobs, weighing them to obtain field yield and shelling to determine the grain weight and moisture content. Grain yield in kg/ha was standardized to 14% the storage moisture content.

Intercrop biomass

Soybean for biomass was harvested just before the first leaf from the bottom started drying. A 0.66m by 1m quadrant was placed in the plot and all the vegetation cover within it was harvested. A 0.33m by 1m quadrant was used for *Desmodium* and *Mucuna* just before the materials were incorporated into the soil. Fresh weight was taken immediately, after harvest, while dry weight was determined after drying the material in an oven at 60º C for 3 days.

3.7 Data analysis

Data was subjected to analysis of variance using SAS (version 8) statical computer package and means separated by Duncan Multiple Range Test at 5% level of significant

CHAPTER FOUR

IN-VITRO SELECTION OF SOYBEAN VARIETIES FOR CONTROL OF *Striga hermonthica* (Del.) Benth

4.1 Introduction

Striga hermonthica is a chlorophylous obligate root parasite, which can cause yield losses of up to 100% in major gramineae such as maize. The weed is endowed with high genetic diversity and fecundity, which together with high viability of seeds and continuous cultivation of cereals results in a large seed bank, which can survive in the soil for many years. Lately the longevity of *Striga* seed has been shown to vary with soil conditions (Gbehaunou *et al.*, 2003). *Striga* has infested over 210,000 ha of high potential agricultural land in Western Kenya where a severely infested field contains about 200,000 *Striga* plants and over 600 million dormant seeds per ha (AATF, 2006), Even at suitable temperatures and moisture, *Striga* seeds germinate only when exposed to a germination stimulant present in the root exudates of some host or non-host plant species (Parker and Riches, 1993). After germination the endosperm can sustain the seedling for only 3-7 days, after which it dies if the host is not present (Worsham, 1987). Trap cropping (suicidal germination) has generally been identified as a sustainable and economically viable *Striga* control option (Botanga *et al.*, 2003). Crops such as cowpea, pigeonpea, cotton and soybean when grown in rotation or as intercrop with cereal hosts have been reported to induce abortive germination of *Striga* seeds, with a consequent reduction in infestation (Parkinson *et al.*, 1988). Preliminary research has identified soybean as a potential trap crop because of its ability to induce suicidal germination and improve soil fertility (Kureh *et al.*, 2000). Soybean is one of the important legumes being promoted in Kenya for use as an alternative source of proteins and soil fertility improvement. Many soybean varieties have even been recommended for growing in diverse ecological zones of Kenya (Nassiuma *et al.*, 2002). The effectiveness of the cereal/legume intercropping in influencing *Striga* germination depends on the level of stimulant produced and its compatibility since the response of *Striga* to management options is specific (Parker and Riches, 1993). Studies by Botanga *et al.* (2003) found large variations in the stimulation of *S. hermonthica* by different accessions of cotton. The variation in trap crop genotypes and *Striga* populations implies that screening must be carried out if ideal crop cultivars are to be recommended for farmers. A relatively inexpensive cut- root laboratory assay, for testing of promising legume cultivars for inducing germination of *S. hermonthica* seeds, has been developed at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria (Berner *et al*., 1997). The in-vitro technique provides a fast means of identifying high stimulant producers which can be used effectively in *Striga* control.

An experiment was carried out to identify and select *in-vitro*, soybean accessions with ability to stimulate *S. hermonthica* germination and to determine the effect of selected soybean varieties on the attachment of *S. hermonthica* on associated maize.

4.2 Materials and methods

4.2.1 *In-vitro*-selection of potential soybean accessions for stimulation of germination of Striga seeds

Treatment combination

Treatments consisted of 32 soybean accessions, Velvet bean (*Mucuna pruriens*), Silver leaf desmodium (*Desmodium unicinatum*) and maize (varieties WH502, KSTP94 and Nyamula a local cultivar). A synthetic stimulant Nijmegen 1® and distilled water were used as positive and negative controls, respectively. The 32 soybean accessions included 10 (TGX1830-20E, TGX1831-32E, TGX1835-10E, TGX1871-12E, TGX1876-4E, TGX1895-4F, TGX1895-6F, TGX1895-33F, TGX1895-49F, TGX1740-2F) early maturing; eight (TGX1844-18E, TGX1869-31E, TGX1878-7E, TGX1889-12F, TGX1894-3F, TGX1893-10F, TGX1893-7F, TGX1448-2E) medium to late maturing; two (X-Baraton, J-499, Nyala) local varieties and 12 (Tgm1420, Tgm1511, Tgm1293, Tgm1360, Tgm944, Tgm1196, Tgm1419, Tgm1039, Tgm1576, Marksoy 1a, Namsoy 4m) varieties whose phenological information is least known. The soybean varieties were accessed from the CIAT-TSBF soybean project at Maseno, Kisumu.

Petri-dish screening technique

Petri-dish screening technique as described by Berner *et al.* (1997) was used to screen ability of test plant roots to stimulate *S. hermonthica* germination. Two pieces of regular filter papers were put at the bottom of 9cm-diameter petri-dish and then moistened with 5ml-distilled water. Aluminium foil ring of diameter 2cm and 1.5cm high was then placed at the center of petri-dish.

The test plants seeds were surface sterilized using 1% sodium hypochlorite then planted in the 625-ml plastic pots that had been filled with sterilized sand. Plants were grown in triplicate for 21 days to coincide with 14 days conditioning of *S. hermonthica* seeds (plate 2). At 21 days after sowing, roots were obtained from the test plants, washed free of soil, cut in 1cm long pieces. Then 1gm of 1cm long cut root pieces were placed in the aluminium foil ring at the center of the petri-dish lined with moisten double layer filter paper. Glass fiber discs with about 50-conditioned *Striga* seeds were then placed in four lines to form across radiating from the central aluminium foil root ring as shown in Figure 1 and plate 1. Each line had four discs with the first disc in each line touching the central aluminium ring and subsequent discs touching one another edge-to-edge i.e. 1, 2, 3 and 4, with the disc closest to the well taken as distance 1. Sterile distilled water (300µl) was then pipetted over the roots in the center of the well.

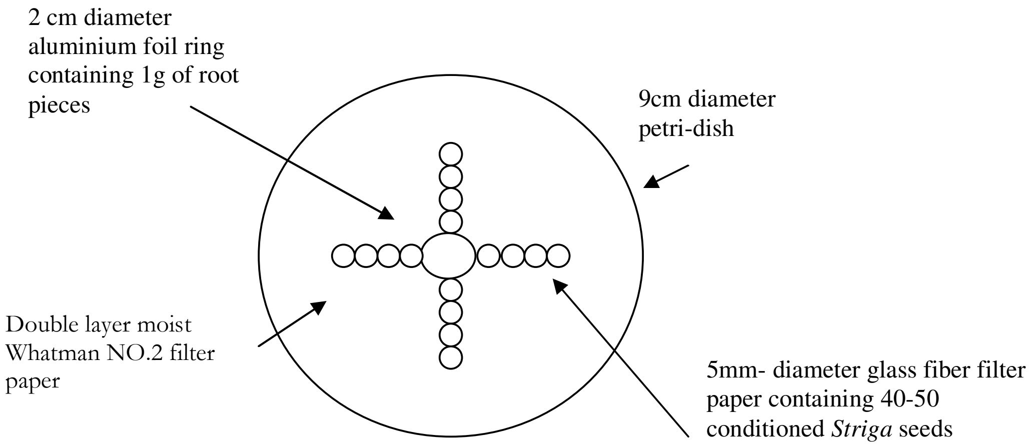


Figure 1: Set up of the test plants' roots in the petri-dish

As controls, 300µl of Nijmegen 1® (10^{-4}M) and 300µl of sterile water were substituted for the root pieces in the aluminium well as positive and negative controls respectively. Three petri-dishes were set up for each treatment acting as a replicate in the experiment. The experiment was arranged in a Completely Randomize Design (CRD).

The petri-dishes were covered with lids, sealed with para-film and wrapped in aluminium foil and incubated at 30ºC for 48 hours. The number of *Striga* seeds germinating on each glass fiber disc after 48 hours were counted using dissecting microscope. The mean germination percent and the Relative Germination Potential (RGP) (actual germination, adjusted for mean viability of *S. hermonthica* seeds used) per treatment were then calculated. Specific

Effectiveness Index, (SEI) (mean germination of *S. hermonthica* seeds when exposed to exudates of potential trap crop divided by the mean germination when exposed to Nijmegen 1®, for each potential trap crop was also calculated.

RGP= (Actual germination percentage/Striga seed viability)* 100

SEI= germination caused by root exudates/ germination caused by Nijmegen 1®

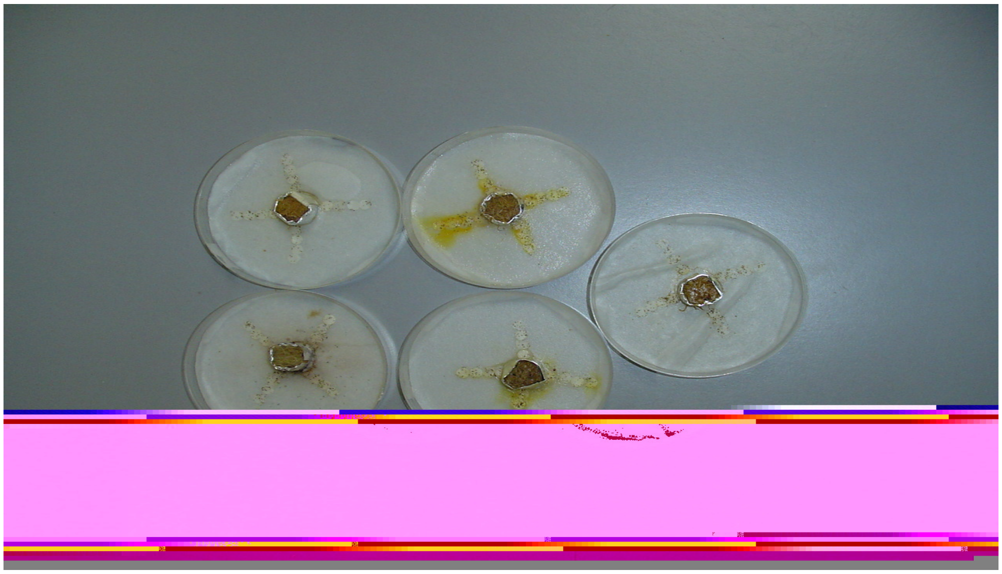


Plate 1: Petri-dish set up in the laboratory for in-vitro germination of Striga seeds

Plate 2: Twenty-one days old soybean seedlings

4.2.2 Striga emergence and attachment on maize intercropped with soybeans (pot experiment

Treatments combinations

Fourteen soybean varieties selected based on the screening results (section 3.2.2 iv) were used in the pot experiment. The accessions comprised the high stimulant producers (TGX 1448-2E, TGX 1740-2F, Tgm 1576, TGX 1876-4E, Tgm 1039, TGX 1831-32E, Namsoy 4m, TGX 1871-12E, Tgm 944 and Tgm 1419), two medium stimulant producers (Nyala and Tgm 1293) and two low stimulant producers (TGX 1869-31E and TGX 1895-6F). *Mucuna* and *Desmodium* were used as controls. The treatments were combined as:

1) WH502 maize mono crop in infested soil
2) WH502 maize intercropped with *Mucuna* in infested soil
3) WH502 maize intercropped with *Desmodium* in infested soil
4) WH502 maize intercropped with TGX1448-2E in infested soil
5) WH502 maize intercropped with TGX 1740-2F in-infested soil
6) WH502 maize intercropped with Tgm 1576 in infested soil
7) WH502 maize intercropped with TGX1876-4E in infested soil
8) WH502 maize intercropped with Tgm 1039 in infested soil

9) WH502 maize intercropped with TGX 1831-32E in infested soil
10) WH502 maize intercropped with Namsoy 4m in infested soil
11) WH502 maize intercropped with TGX 1871-12E in infested soil
12) WH502 maize intercropped with Tgm 944 in infested soil
13) WH502 maize intercropped with Nyala in infested soil
14) WH502 maize intercropped with Tgm 1293 in infested soil
15) WH502 maize intercropped with TGX 1869-31E in infested soil
16) WH502 maize intercropped with TGX 1895-6F in infested soil
17) WH502 maize mono crops in non-infested soil

Three maize seeds were planted in each pot and thinned to one plant per pot while soybeans were thinned to 8 plants per pot as recommended by Berner *et al*., 1997. Pots were watered with equal amounts of water every day and plants allowed to grow for 8 weeks after which the soil was washed off the roots of the plants for observation of *Striga* attachment on the roots of maize.

4.3 Results and Discussions

4.3.1 *Striga* viability and germination

The *S. hermonthica* seeds used had a mean viability of 58.6 and an average absolute germination percent of 50.4 (Table 1). This indicates that 86% of the viable seeds were able to germinate. Gbehounou and Adango (2003) similarly found germination of *S. hermonthica* seeds to vary from 3% to 55% depending on source of seeds and time of testing.

Table 1: Viability and germination of *Striga hermonthica* seeds

Trial	Mean viability	Germination (%)	*Relative germination
1	55.9±2.0	49.1±4.3	87.9
2	58.4±1.7	43.9±4.5	75.1
3	66.2±8.8	56.6±5.4	85.5
4	63.6±3.7	54.9±4.1	86.3
5	53.6±3.7	47.4±3.7	88.4
6	53.9±4.3	43.9±3.3	81.4
7	58.5±1.9	56.7±5.3	96.9
Mean	**58.6**	**50.4**	**86.0**

*Relative germination percentage is the actual germination adjusted for percent viability of the *S. hermonthica* i.e. (Germination % / Viability %)* 100

4.3.2 The influence of soybean accessions on *Striga* germination

All the test plants had higher germination stimulation than the negative control, distilled water. The number of *S. hermonthica* seeds germinated, in response to different stimulants, however varied significantly (Fig 2). Distilled water did not elicit any stimulatory effect, while *Strigol* (Nijmegen 1®) at 10^{-4}M showed the highest (70.1%) relative germination potential.

Maize varieties (WH502, Nyamula and KSTP94) showed relative germination potentials of 61%, 56.5% and 54.9% and S.E.I of 0.87, 0.81 and 0.78 respectively (Figures 3 and 4). The germination potentials did not significantly differ from the stimulation caused by *Mucuna*, *Desmodium* and soybean varieties TGX 1831-32E, TGX1740-2F, TGX 1448-2E, Tgm1039 and Tgm1576. Tsanuo *et al*. (2003), Khan *et al*. (2002) and Ndungu (1999) observed similar stimulation potentials for *Desmodium* and *Mucuna*. The maize varieties used have been recommended for *Striga* prone areas in Kenya (Odongo *et al*., 1997). The high stimulation implies that they may be having *Striga* stress tolerating mechanism.

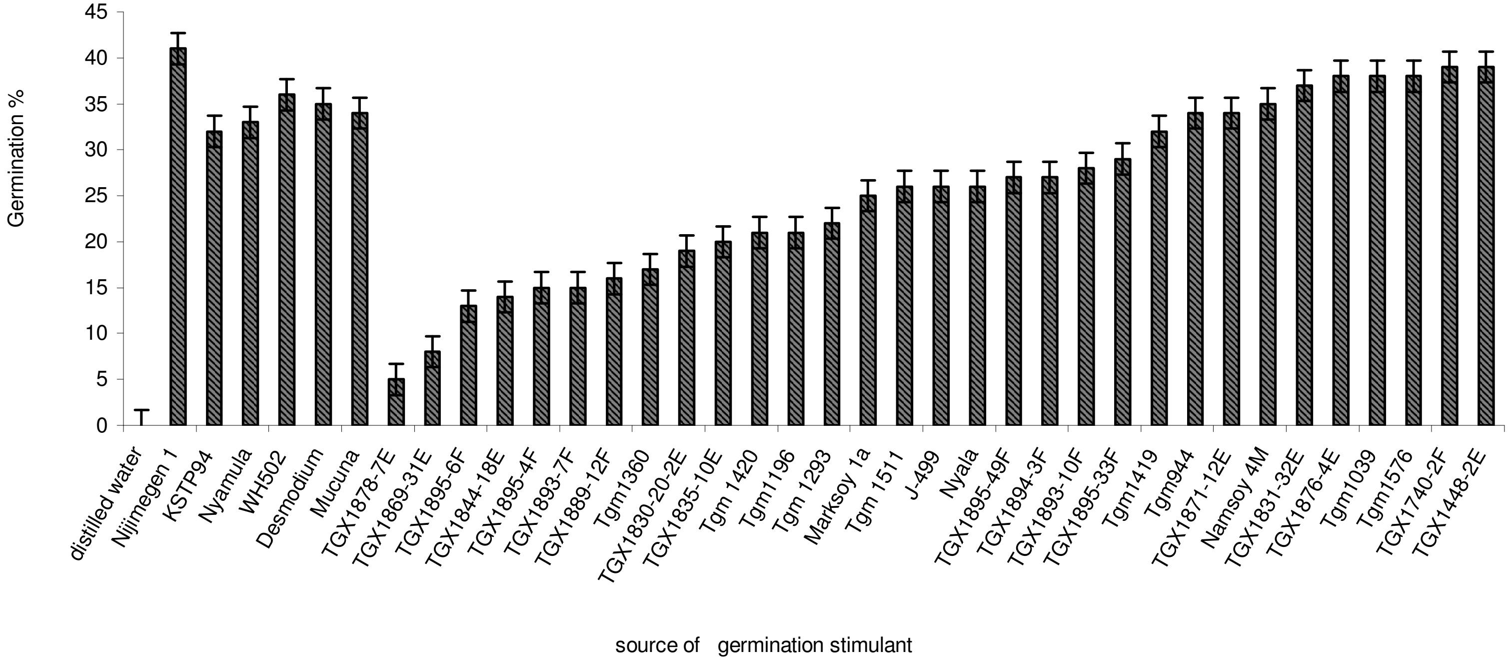


Figure 2: Actual germination percent of conditioned *Striga hermonthica* seeds caused by different stimulants

Error bars show standard error of between different treatments means at $p<0.05$

Soybean accessions varied significantly in the *Striga* stimulation potential. The relative induction ranged from 7.9% to 65.7% with a mean of 49%. Some accessions had high stimulation (relative germination of more than 50%), others had medium stimulation (relative germination stimulation between 30% and 49%) while others had low stimulation (relative germination less than 30%). Soybean accessions, TGX 1448-2E, TGX 1740-2F, Tgm 1576, TGX 1876-4E, Tgm 1039, TGX 1831-32E, Namsoy4m, TGX 1871-12E,Tgm 944 and Tgm 1419 caused relative germination of between 53.4% and 65.7% with SEI of between 0.76 to 0.94. The potential was comparable to the stimulation caused by *Desmodium, Mucuna*, maize varieties and the positive control, Nijmegen 1®. Soybean accessions TGX 1895-33F, TGX 1893-10F, TGX1894-3F, TGX1895-49F, Tgm 1511, J-499, Nyala Marksoy 1a, Tgm 1293, Tgm 1196, Tgm 1420,TGX 1835-10E and TGX 1830-20E caused medium stimulation of between 32.7% and 48.5% with a S.E.I of 0.47 and 0.69. Varieties Tgm 1360, TGX 1898-12F,TGX 1895-4F, TGX 1893-7F, TGX 1844-18E, TGX 1895-6F, TGX 1869-31E and TGX 1878-7E caused low stimulation of between 8% and 28% with a SEI of 0.11 to 0.40 (Figures 3 and 4). Thus, about 31% of soybean accessions were high germination stimulants while 41% were medium stimulants and 25% were low stimulants. Differences in percent relative germination of *S. hermonthica* seeds induced by different soybean accessions may probably be due to different levels of germination stimulants produced. Cotton and sorghum genotypes have similarly been found to vary widely in ability to stimulate *S. hermonthica* seed germination (Butler, 1995; Botanga *et al*., 2003). Emechebe and Ahonsi (2003) in comparing organ and age of plant (TGX 1448-2E) on stimulation found slightly lower stimulation than what was observed probably because of variations in *Striga* population.

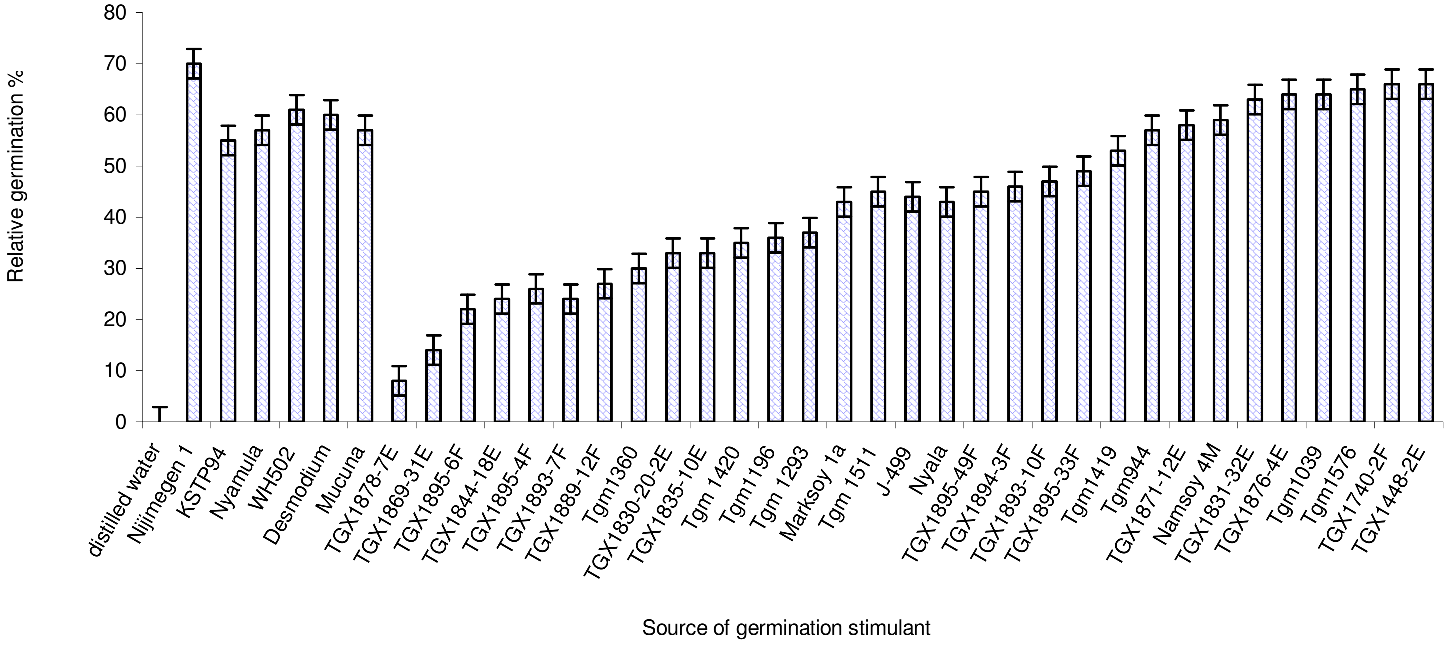


Figure 3: Percent relative germination adjusted for mean viability of *S. hermonthica* seeds used

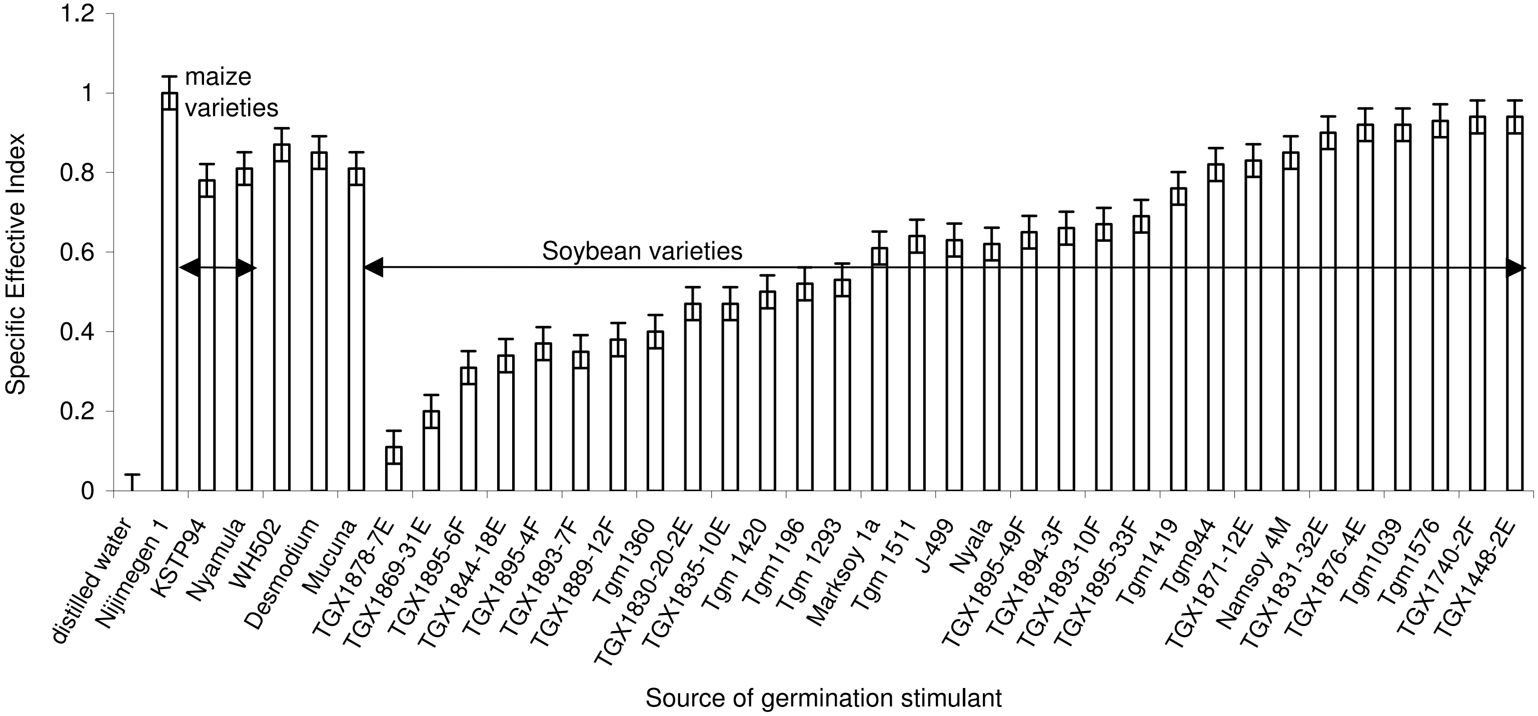


Figure 4: Effectiveness of test plant root exudates to cause germination of *S. hermonthica* seed relative to germination potential of Nijimegen 1®

4.3.3 *Striga* emergence and attachment on maize (pot experiment)

Sole maize grown on non-*Striga* infested soil seeds had no emerged *Striga* seedlings (Figure 5). Intercropping maize with legumes (that stimulated high *Striga* to germinate) resulted in 6% to 95% increase in *Striga* attachment to the associated maize. Total *S. hermonthica* seedlings emerged and attached were highest when maize was intercropped with *Mucuna*, and soybean accessions TGX 1448-2E, TGX 1740-2F, Tgm 1576, TGX 1876-4E, Tgm 1039,TGX 1871-12E and TGX 1895-6F. The screening experiment , (section 3.3.2 iv) found a similar trend in stimulation apart from variety TGX 1895-6F which was classified as low stimulating yet it achieved high attachment. Intercropping with *Desmodium* and soybean accessions TGX1831-32E, Namsoy 4m, Tgm 944, Tgm 1419, Nyala, Tgm 1293, and TGX 1869-31E did not however significantly increase the attachment. While the legumes had shown medium to low suicidal germination, during the laboratory screening, *Desmodium* and soybean varieties TGX 1831-32E and Namsoy 4m had shown high stimulation. This is in agreement with Tsanuo *et al*. (2003) who observed that in addition to the germination-stimulating chemical, *Desmodium* also produces a radicle growth inhibition chemical, which hinders the attachment of the parasite radicle onto the associated maize host plant. The mechanism behind the low attachment on maize intercropped with soybean varieties such as TGX 1831-32E and Namsoy 4m that are perceived to have high stimulation is however not clear .

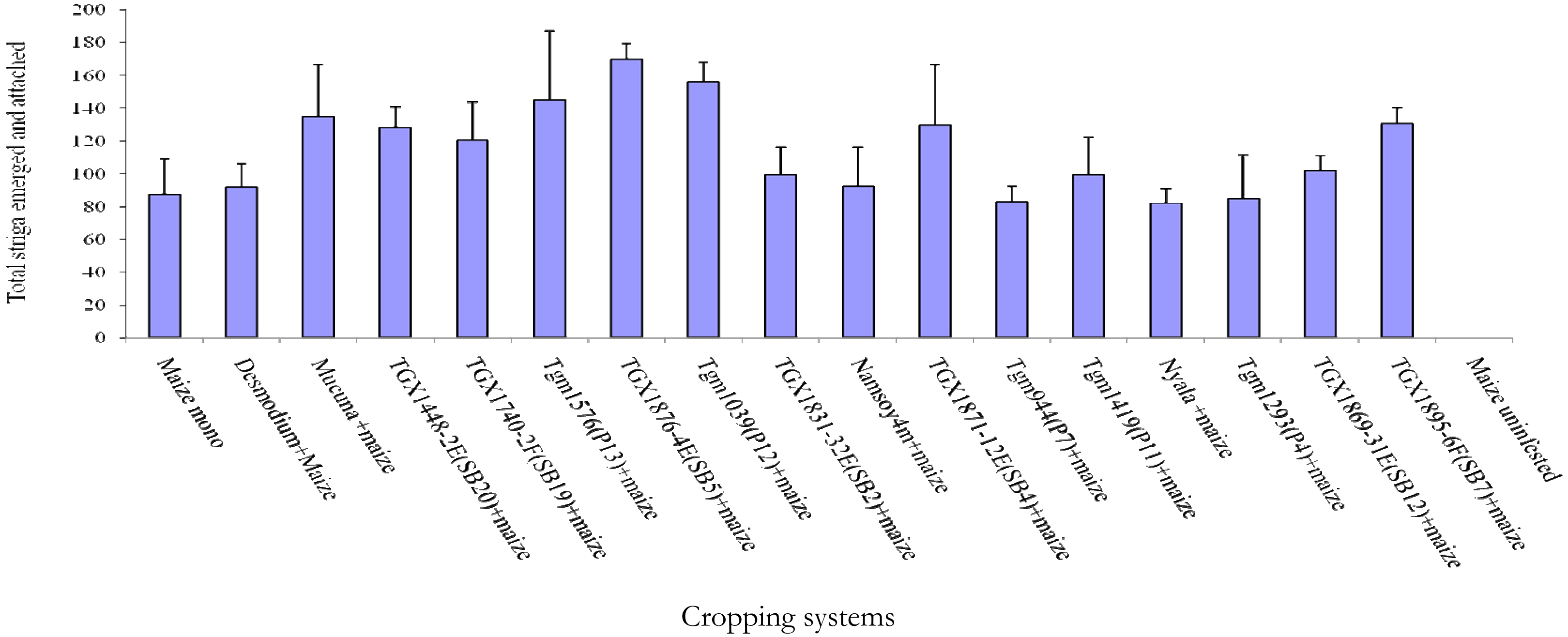


Figure 5: Effect of legumes on the total emerged and attached *Striga hermonthica* seedlings on maize plant root

4.3.4 Effect of intercropping of maize and soybeans on growth of maize in *Striga* infested soil

Presence of *Striga* reduced the height of maize by about 55% (Figure 6). This is probably because *Striga* affects cell elongation as it takes photosynthates a way from the maize crop leading to shorter maize internodes and stunted growth. In *Striga* infested soils, intercropping maize and legumes did not significantly reduce the height of maize except for TGX 1870-2F, TGX 1869-31E and TGX1895-6F. Since it is generally known that *Striga* is parasitic and affects maize growth, the contrary implies that legumes probably had a mechanism of suppressing the parasitic effects of *Striga*. Reduction of *Striga* emergence by inhibiting radicle growth hence attachment, increase in soil fertility and smothering effects have been suggested as mechanisms behind the legume reduction of *Striga* effect (Khan *et al*., 2001).

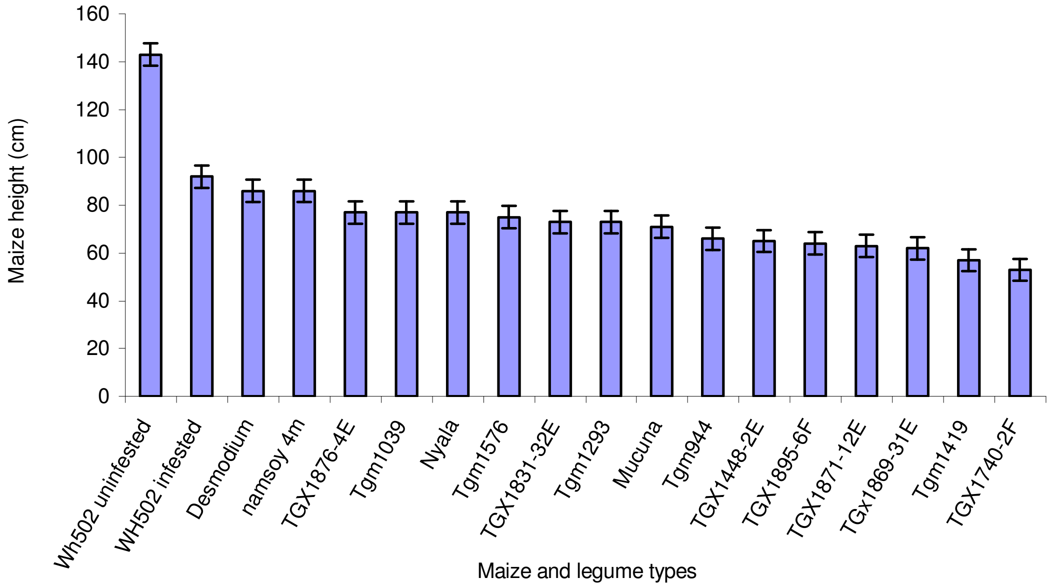
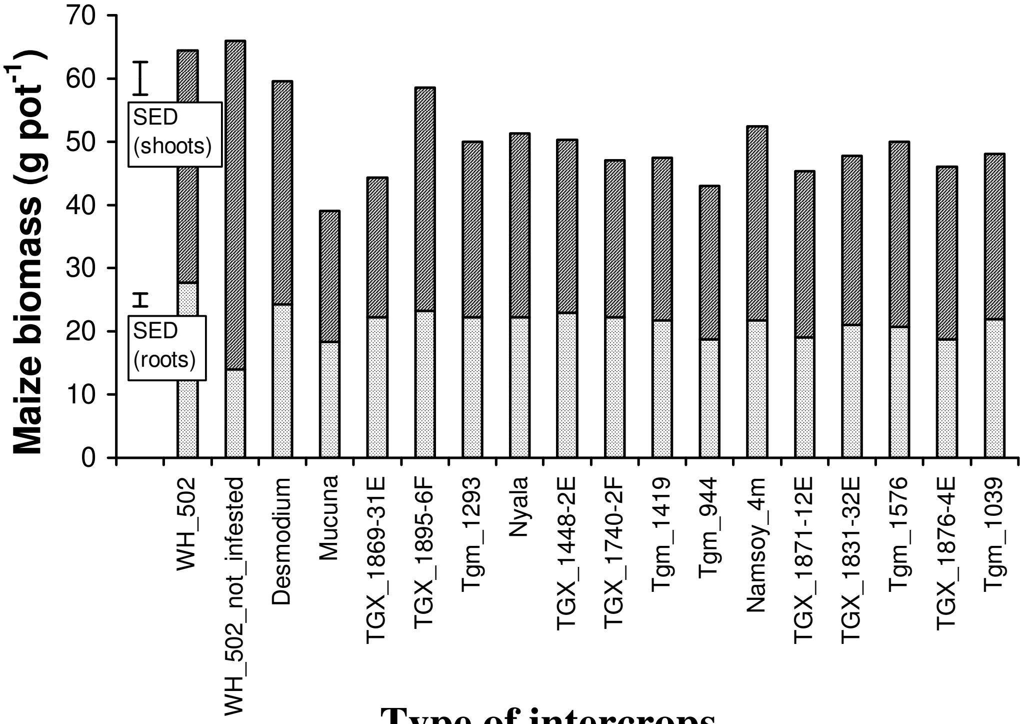


Figure 6: Effect of intercropping maize and selected legumes on maize height 8 weeks after planting

Striga infestation reduced maize shoot weight by 30% (Figure 7). Comparable levels of reduction in shoot weight have also been observed by Mumera and Bellow (1993), Aflakpui *et al*. (2002) and Aflakpui *et al*. (2005). Intercropping maize with *Mucuna* and soybean accessions TGX 1740-2F, Tgm944, Tgm 1419 and TGX 1869-31E led to significantly low maize shoot dry weight. The intercrops also had high legume shoot dry weight (Figure.8). There was a negative correlation (R^2=0.44) between maize height and the number of total *Striga* plants emerged and attached (Table 2). This is an indication that the effect of *Striga* increases with increase in the number of parasitic *Striga* attached to a host plant. The intercrops may have had high competition with the associated maize as seen by the negative correlation (R^2 =0.62) between the maize shoot dry weight and the legume shoot dry weights. The intercrops also had low stimulation of *Striga hermonthica* seed germination in the laboratory with the exception of *Mucuna* and TGX 1740-2F.

The legumes did not significantly affect maize root dry weight. There was also no correlation between maize/ legume root weight and the number of *Striga* emerged and attached. Aflakpui *et al*. (2002) also found no correlation between maize/ legume root weight and number of *Striga* attached. *Striga* infestation of maize increase the root: shoot ratio. Intercropping maize with legumes reduced the root: shoot ratio in *Striga* infested soil probably because of reduced *Striga* influence (partitioning) (Aflakpui *et al*., 2005); *Striga* attachment may trigger root growth to compensate for surface area for nutrient/water uptake. There could be a mechanism taking place (probably hormonal imbalance) which makes the plant relocates its energy to root formation under *Striga* infestation.

In the intercropping pot experiment, most of the accessions with high triggering ability also resulted in high *Striga* seedling attachment on the associated maize plant while a few of them including Tgx 1831-32E and Namsoy 4M resulted in low attachment. On the other hand, some accessions with low *Striga* germination triggering potential like TgX 1895-6F caused high attachment. Thus there was low correlation between lab petri-dish experiment and intercropping experiment and hence the laboratory petri-dish experimental approach was not very definite in determining the effectiveness of different soybean accessions in triggering *Striga* seed germination. This could be attributed to artificial conditions in the laboratoty as compared to the natural condition in the field which could have offered optimam germination conditions compared to pot conditions.



Type of intercrops

Figure 7: Effect of *Striga* on maize shoot and root dry weight when maize was intercropped with legumes.

SED means standard error of the difference for root and shoot.

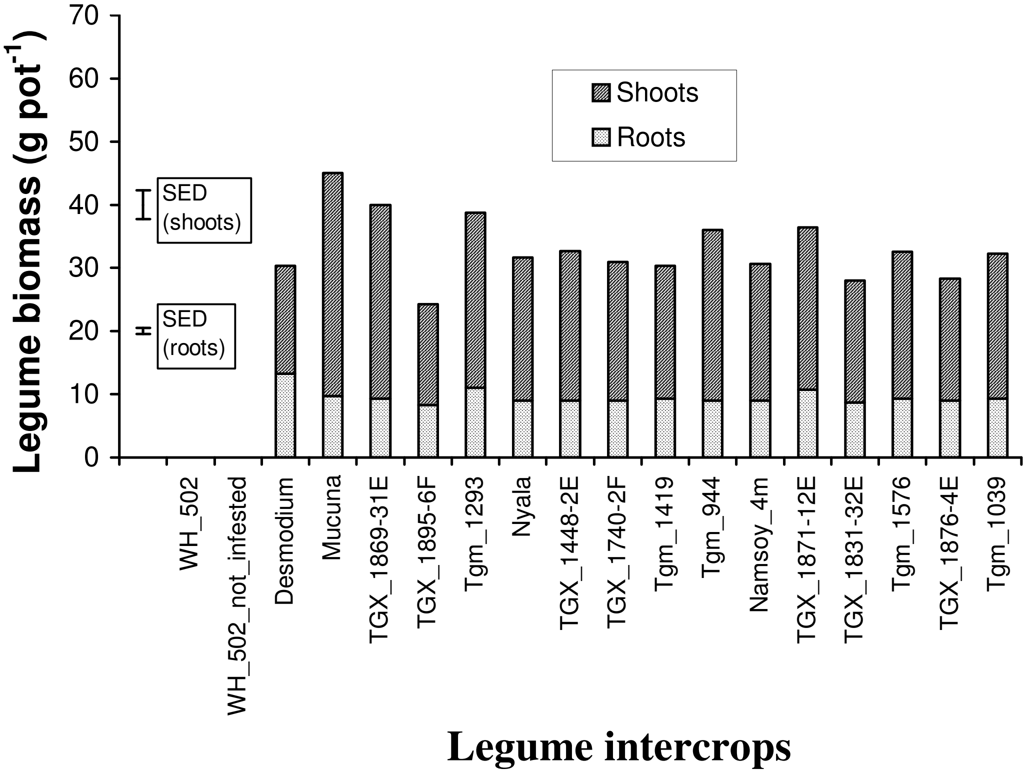


Figure 8: Effect of *Striga* on the legume shoot and root dry weight

Table 2: Correlation coefficient (R^2) between maize (WH502) and soybean growth parameters and *Striga* emerge and attachment (pot experiment)

	WH502 maaize height (cm)	WH502 maize shoot dry weight (g)	WH502 maize root dry weight (g)	Soybean shoot dry weight (g)	Soybean shoot dry weight (g)	Total *Striga* counts
Maize height	1.0					
Maize shoot dry weight	0.75***	1.0				
Maize root dry weight	-0.02	-0.02	1.0			
Legume shoot dry weight	-0.04	-0.62***	-0.25	1.0		
Legume root dry weight	0.12	0.104	0.08	-0.01	1.0	
Total *Striga* counts	-0.44**	-0.42**	0.05	-0.01	0.07	1.0

** Significant at p ≤ 0.05, *** Significant at p ≤ 0.01

4.4 Conclusion

The laboratory germination experiment results showed that some soybean accessions grown in Kenya have high potential of producing *S. hermonthica* seed germination stimulants. Based on the specific effectiveness index (SEI), values observed *in-vitro,* soybean accessions, TGX 1448-2E, TGX1740-2F, Tgm 1576, TGX 1876-4E, Tgm 1039 and TGX 1831-32E showed higher germination potential than even the host plant maize varieties. The soybean varieties have much potential to be used as *Striga* trap crops and could probably be used in intercropping with susceptible species or in crop rotations to reduce the amount of *S. hermonthica* in the soil.

From the pot experiment soybean varieties which stimulated high *Striga* germination also caused high *Striga* attachment and emergence but did not affect the growth of the intercropped maize The varieties included TGX 1448-2E, Tgm 1576, TGX 1876-4E and Tgm 1039.

CHAPTER FIVE

EFFECT OF SELECTED SOYBEAN ACCESSIONS ON *Striga* PARASITISM AND YIELD OF ASSOCIATED MAIZE

5.1 Introduction

The parasitic weed *Striga hermonthica* is a major yield-limiting factor of maize in Western and coastal regions where the soils are infertile and populations are high. Trap cropping which can be implemented via intercropping has been identified as solution to the twin problem of *Striga* and soil fertility. Intercropping is an age-old practice that has survived for along time because of its multiple uses of insect pest control, soil fertility improvement and for socio-economic purposes. Cereal/legume intercropping is predominant in Western Kenya where it is used as a means of maximizing the use of limited farmlands and for food security of the subsistence farmers.

Preliminary work in Nigeria has shown that intercropping maize with some soybean varieties reduced *Striga* incidence (Kuchinda *et al.,* 2003). In Kenya, Khan *et al.* (2006) found a high reduction (98% to 100%) in *S. hermonthica* emergence when sorghum was intercropped with *Desmodium intortum*. The response of *S. hermonthica* however varies with the genetic makeup of the weeds and legumes (Berner *et al.*, 1996). Methodologies have even been developed for screening large population of legumes for response to *Striga* (Berner *et al.*, 1997). A high correlation has been found between cowpea cultivars selected from laboratory screening and their effectiveness in reducing parasitism of *S. hermonthica* on susceptible sorghum in field (Berner *et al.,* 1995). *Desmodium* is one of the legumes that have been recommended for controlling *Striga* through intercropping (Khan *et al.*, 2001). Adoption is however limited because it is used more as fodder and not directly as food crop. Promotional work has been carried out in Kenya since 1990s to encourage use and production of soybeans. Many soybean varieties have been introduced to increase crop yield. Diversifying the possible uses of soybeans is likely to increase production. Many soybean varieties exist but limited work has been done to quantify the effect of maize/soybean cropping system on *Striga* management. An experiment was therefore carried out in the field to determine the effect of some selected soybean species on *Striga* emergence and attachment to associated maize.

5.2 Materials and Methods

5.2.1 Treatment combination and experimental design

The four soybean varieties (TGX 1448-2E, Tgm 1576, TGX 1876-4E and Tgm 1039) that had been selected for high stimulant production from laboratory experiment alongside *Desmodium* and *Mucuna* were planted in companion with maize (variety WH502) in (4×3) m^2 plots; giving six rows of maize and six rows of legume. The experiment was laid out as a Randomised Complete Block Design (RCBD) with four replications. The treatment combination included:

(1) Sole maize (2) Maize intercropped with *Mucuna* (3) Maize intercropped with *Desmodium* (4) Maize intercropped with TGX 1448-2E, (5) Maize intercropped with Tgm 1576, (6) Maize intercropped with TGX 1876-4E (7) Maize intercropped with Tgm 1039.

Crops were planted in ‘mbilli’ arrangement where two maize rows were alternated with two legume rows. The inter-row spacing between the two adjacent maize rows was 50cm, while that between maize and legume row or two legume rows was 30cm. The inter-row spacing of maize was 25cm giving a plant population of 68,572 plants/ha. *Desmodium* was drilled while *Mucuna* and soybeans were planted (2 seeds per hill) at an intra-row spacing of 30cm and 5cm respectively. Maize, soybeans and *Desmodium* were planted on the same day while *Mucuna* was planted four weeks after maize so as to reduce interference with maize growth.

The initial seedbed preparation was done using the traditional oxen-drawn plough. Subsequent subplots preparations were however done using human labour. At planting phosphorus fertilizer in form of TSP (equivalent rate of 30kg P/ha) was applied. Nitrogen fertilizer in form of CAN (equivalent rate of 40kg N/ha) was applied as top dress, six weeks after planting. Hoe weeding was done three weeks after sowing followed by hand pulling of other weeds carefully not to interfere with the *Striga* plants. At the beginning of each season soil samples at a depth of 15cm at eight points within each plot area were taken using soil auger randomly, bulked and mixed thoroughly in redness for elutriation (*Striga* extraction). At the end of the first season maize, soybeans and *Mucuna* were harvested while *Desmodium* was cut back to 5cm above ground level and allowed to re-grow.

5.3 Results and Discussions

5.3.1 Effect of intercropping maize and soybean varieties on *Striga* count and biomass

The *Striga* counts were higher during the first season than in the second season probably because of depletion of the viable *Striga* seeds in the soil and limited water available during the latter. The *Striga* counts increased significantly with time from 8 weeks after planting through 10 to 12 weeks after planting irrespective of season. *Striga* counts were however lower in the plots where maize was intercropped with legumes. The exception was however in season 1 when *Desmodium* did not significantly affect the *Striga* counts. The unexpected result was probably because of the poor establishment of *Desmodium* and hence low root development in the first season (Table 3).The poor establishment can be attributed to the small seeds of Desmodium hence low food reseve. The pot experiment results were more consistence in the field experiment. The relatively lower *Striga* counts under intercropping implies a reduced potential for flowering and capsule production and consequently a reduced capacity of increasing the *Striga* soil seed bank in the soil. Sprich (1994) similarly reported an annual reduction of *Striga* seed bank by about 30% through induction of suicidal germination by soybean intercropping. Massawe *et al*. (2001) and Aliyu and Emechebe (2006) also found lower *Striga* counts when maize was intercropped with cowpea. The reduced *Striga* counts during intercropping could be attributed to smothering of emerging *Striga* by the spreading vegetation of the non-host crops, low Soil temperatures (Kabambe, 1995; Kureh *et al*., 2000) and the exudates could be inhibiting attachment. The increased reduction in *Striga* count in *Desmodium* plots in the second season may be due to residual effect from the previous season. Intercropping maize with *Mucuna* and soybean led to lower *Striga* counts in both seasons.

The soybean varieties did not vary in their influence on *Striga* counts. This confirms the earlier results (Section 3.2) that the soybean varieties were comparable in their ability to stimulate *Striga* seed germination. Kureh *et al*. (2000) also found no difference in the ability of soybean varieties TGX 1019-2EB and TGX 1440-1E to stimulate *Striga* seed germination and infestation on maize. Intercropping reduced the *Striga* biomass by 25-65% and 10-80% during the first and second season respectively (Figure 9).

The *Striga* biomass was generally lower during the short rains than in long rains save for plots where soybean TGX 1876-4E was used (Figure 9). *Desmodium* and *Mucuna* drastically reduced *Striga* biomass in the second season in relation to their effect on the biomass in the first season. Among the soybean intercrops Tgm 1576 and Tgm 1039 also resulted in a drastic reduction in *Striga* biomass in the second season in relation to the first season.

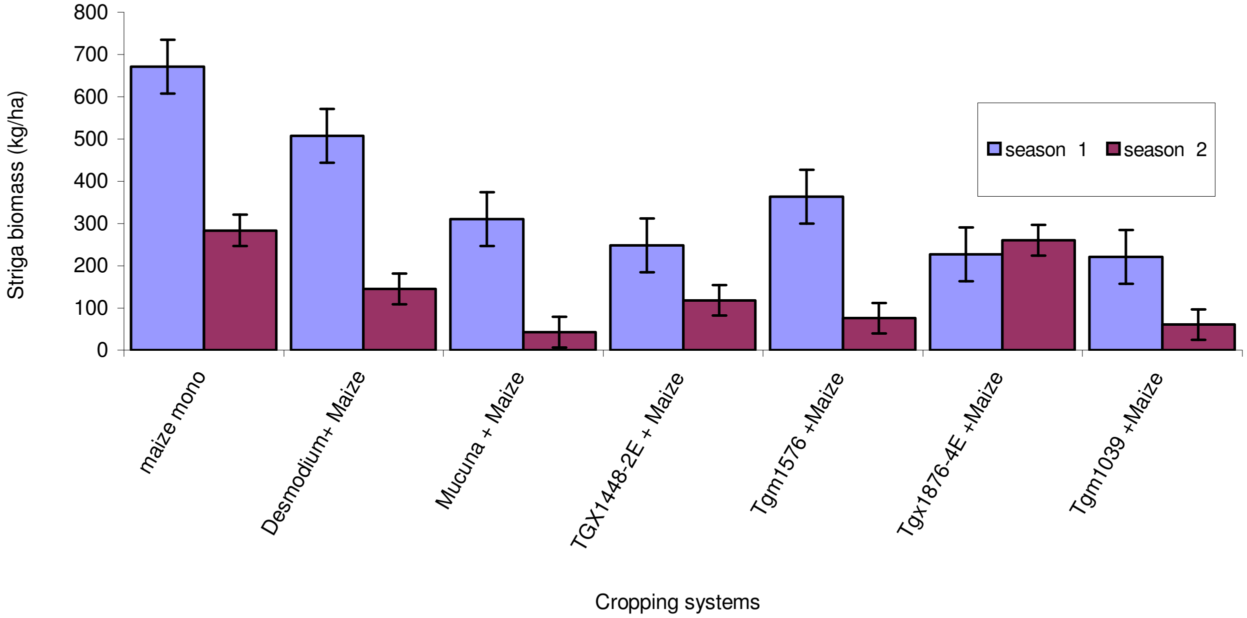


Figure 9: Effect of intercropping maize and legumes on *Striga* biomass

There was a high correlation between *Striga* count and *Striga* biomass in the first season, but not in the second season (Tables 7 and 8). During the second season, other factors like rainfall may have affected the growth of crops and hence the parasitism biomass of *Striga*. Parker and Riches (1993) found that increased humidity and low temperatures common under intercrops reduced the growth of emerging *Striga*. Kureh *et al*. (2000) also noted that emerged *Striga* plants in a maize/ soybean intercrop were etiolated and died earlier than those in sole maize crop because of the smothering.

Table 3: Effect of intercropping maize (WH 502 variwety) and soybean on Strigacount at Nyabeda, Siaya, Kenya in 2006

Striga count per plot

	6WAP		8WAP		10WAP		12WAP	
	Long Rains	Short Rains	Long Rains	Short Rains	Long Rains	Short Rains	Long Rains	Short Rains
Maize monocrop	59^{a*}	0.0	239^{a}	14^{a}	263^{ab}	78.0^{a}	514.0^{ab}	255^{a}
Maize+*Desmodium*	67^{a}	0.0	293^{a}	4^{bc}	396^{a}	41^{bc}	608.0^{a}	96^{c}
Maize+*Mucuna*	25^{a}	0.0	109^{c}	2^{c}	191^{b}	19^{c}	294.0^{b}	34^{c}
Maize+TGX1448-2E	29^{a}	0.0	164.3^{bc}	8^{ab}	200^{b}	44^{b}	297.0^{b}	163^{b}
Maize+TGX1448-2E	33^{a}	0.0	178^{abc}	8^{ab}	242^{b}	43^{b}	408.3^{ab}	102^{bc}
Maize+Tgm1576	46^{a}	0.0	211^{abc}	7^{ab}	250^{b}	40^{bc}	388.5^{ab}	115^{bc}
Maize+TGX1876-4E	45^{a}	0.0	163^{bc}	9^{ab}	242^{b}	46^{b}	393.3^{ab}	138^{b}
Maize+Tgm1039	30^{a}	0.0	134^{b}	10^{ab}	192^{b}	45^{b}	404.3^{ab}	138^{b}

WAP refers to weeks after planting, * Means followed by similar letters within a column are not significantly different ($p \leq 0.05$)

5.3.2 Effect of intercropping on maize height and leaf area index

Maize was generally shorter in the short rains than in the long rains probably because of the moisture stress during the former (Table 4). The treatments did not significantly affect the height of maize during the long rains however during the short rains the treatments significantly affected the height of maize. Maize was significantly taller, when intercropped with *Mucuna* which could have changed the soil micro-climate making it unsuitable for Striga growth. This may be attributed to high *Mucuna* biomass in the first season. Time to flowering and plant height of sorghum has also been found to increase with increase in the *Celosia argentia* (*Striga* chaser) intercrop ground cover (Olupot *et al*., 2003).

The leaf area index (LAI) was high in the intercropped plots than in sole maize plot with *Mucuna* plots having the highest LAI of 1.7 and 0.08 at 12 weeks after planting in the long and short rains respectively indicating an increased photosynthetic area of maize intercropped. Aflakpui *et al*. (2002) also observed lower leaf area in maize infested with *Striga*. There was negative correlation between *Striga* count and *Striga* biomass with maize height and LAI during the LR (Table 7 and 8). During the SR, only *Striga* biomass was negatively correlated with maize height and LAI indicating that *Striga* biomass was a better indicator of the weed effects on maize growth.

Table 4: Effect of intercropping on height and leaf area index of maize (WH 502) at Nyabeda, Siaya Kenya

	Maize height (cm)								Leaf area index					
	6WAP		8WAP		10WAP		12WAP		6WAP		8WAP		12WAP	
	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR
Maize mono crop[4]	66^{a}	96^{b}	92^{a}	89^{b}	129^{a}	114^{b}	149^{a}	123^{bc}	0.9^{b}	0.03^{a}	1.0^{a}	0.04^{a}	0.9^{b}	0.06^{a}
Maize+*Desmodium*	63^{a}	100^{ab}	85^{a}	98^{ab}	111^{a}	102^{b}	131^{a}	108^{c}	1.1^{ab}	0.03^{a}	1.3^{a}	0.04^{a}	1.3^{ab}	0.07^{a}
Maize+*Mucuna*	69^{a}	102^{a}	91^{a}	113^{a}	148^{a}	179^{a}	169^{a}	200^{a}	1.4^{a}	0.04^{a}	1.5^{a}	0.05^{a}	1.7^{a}	0.08^{a}
Maize+TGX1448-2E	72^{a}	98^{ab}	92^{a}	98^{ab}	137^{a}	116^{b}	160^{a}	127^{c}	1.2^{ab}	0.03^{a}	1.4^{a}	0.05^{a}	1.4^{ab}	0.07^{a}
Maize+TGX1448-2E	70^{a}	100^{ab}	87^{a}	97^{ab}	121^{a}	121^{b}	134^{a}	134^{c}	1.2^{ab}	0.03^{a}	1.4^{a}	0.05^{a}	1.3^{ab}	0.07^{a}
Maize+Tgm1576	65^{a}	99^{ab}	85^{a}	107^{ab}	112^{a}	132^{b}	126^{a}	154^{b}	1.0^{ab}	0.04^{a}	1.1^{a}	0.05^{a}	1.2^{ab}	0.07^{a}
Maize+TGX1876-4E	66^{a}	100^{ab}	89^{a}	101^{ab}	124^{a}	116^{b}	146^{a}	126^{c}	1.2^{ab}	0.03^{a}	1.4^{a}	0.05^{a}	1.4^{ab}	0.07^{a}
Maize+Tgm1039	65^{a}	100^{ab}	89^{a}	98^{ab}	131^{a}	114^{b}	153^{a}	138^{c}	1.1^{ab}	0.03^{a}	1.3^{a}	0.04^{a}	1.2^{ab}	0.06^{a}

WAP = weeks after planting, LR = long rains, SR= short rains; Means followed by same letters within the column are not significantly different ($p \leq 0.05$)

5.3.3 Effect of intercropping maize and soybean varieties on yield and yield components of maize

Maize yield was generally lower during the short rains than during the long rains, probably because of low amount rainfall. During the long rains, intercropping maize with legumes increased maize yield save for *Desmodium*. Intercropping maize with *Mucuna* increased maize grain yield by 47% while intercropping with other legume varieties increased maize yield by between 39% and 107% and intercropping with *Desmodium* reduced maize yield by 6% (Table 5). During the short rains, intercropping resulted in significantly higher maize yield, which ranged between 28% and 244% (Table 6). Similarly Oswald *et al.* (2002) observed that intercropping maize with cowpea, soybean, yellow gram, bambara, bean, groundnut and green gram increased maize yield in Alupe, Western Kenya. Carruthers *et al.* (2000) also found no negative effect of intercropping on the yield of maize. The high *Striga* biomass in the sole maize treatment might have been responsible for the low maize yield. Gurney *et al.* (1999) found that the level of *Striga* biomass on the host influences host productivity though the relationship is not linear. The higher maize yield in the intercrop could be attributed to the effectiveness of the system in reducing the *Striga* effect. Earlier work showed the high yields in he intercropped maize could be due to stimulating the suicidal germination of the *Striga* seeds, nitrogen supply and reduction in leaching of soil nutrients by the legume intercrop cover. Gbehounou and Adango (2003) similarly observed high yield of maize in the maize / cowpea intercrop.

Among the intercrops, maize yield was lowest when it was intercropped with *Desmodium* in both seasons. The highest yield was observed when it was intercropped with soybean variety Tgm 1039 and *Mucuna* in the long and short rains respectively. The low yield in maize intercropped with *Desmodium* could be attributed to the low establishment of *Desmodium* and altimately lower effect on *Striga*. Further, the effectiveness of a trap crop to influence *Striga* seed germination and ultimately improve performance of the host crop depends on the agronomic characteristics of the environment and the genotype of the trap crop used hence the high maize yield when it was intercropped with *Desmodium* compared to when maize is intercropped with other legumes (Khan *et al.*, 2001). Growing maize together with the four soybean accessions did not significantly affect the maize yield in both seasons. This shows that the soybean accessions had similar potential for use to control *Striga hermonthica* genotype. Kureh *et al.* (2000) also found no significant difference in yield when maize was intercropped with two soybean varieties though maize yields was significantly higher in the intercropped plots than the sole maize plot. Stover yield was significantly low in maize sole crop in both seasons. Intercropping increased the maize Stover yield by between 31% and 150% and 6% and 100% in the long and short rains respectively. Like grain yield, stover yield was highest under soybean accession Tgm 1039 and *Mucuna* association in long rains and short rains seasons respectively.

Intercropping resulted in higher hundred seed weight and harvest index. This implies that maize intercroped with legumes partitions more photosynthates to the reproductive growth and grain filling.

5.3.4 Effect of intercropping on yield and biomass of intercropped legumes

The yield of the four soybean varieties was generally lower in the short rains compared to the long rains (Table 5 and 6). Soybean variety TGX 1448-2E gave the highest yield in both seasons which was not significantly different from the yields of varieties Tgm 1576 and Tgm 1039. In the second season the low and erratic rainfall could have interfered with grain filling. Earlier work observed that the substantial grain yields and biomass produced by the intercrop legumes could further intensify the productivity per unit area of land in addition to reducing the soil *Striga* seed bank (Ariga *et al*., 1997).

The mean biomass yields in descending order was *Mucuna*, *Desmodium*, Tgm 1039, Tgm 1576, TGX 1448-2E and finaly TGX 1876-4E in both seasons.The soybean varieties with high biomass also produced the highest yields. The high biomass produced by *Mucuna* and *Desmodium* intercrops without compromising maize grain yield could serve as source of fodder and manure.

Table 5: Effect of intercropping maize and legumes on yield and yield components of maize and legumes during the 2006 long rain season in Nyabeda

	WH502 maize				Legume intercrop		
Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	100- seed weight (g)	Harvest index	Grain yield (kg ha^{-1})	100 seed weight (g)	Biomass (kg ha^{-1})
Sole maize	1149^{c}	4113^{c}	21.8^{a}	0.07^{b}	-	-	-
Maize +*Desmodium*	1076^{c}	5398^{bc}	21.0^{a}	0.17^{ab}	-	-	4096^{b}
Maize +*Mucuna*	1687^{b}	7026^{abc}	24.8^{a}	0.25^{a}	-	-	7518^{a}
Maize +TGX 1448-2E	2361^{a}	9823^{a}	22.8^{a}	0.32^{a}	681.9^{a}	11.4^{d}	1829^{c}
Maize +Tgm 1576	1596^{bc}	4948^{bc}	24.4^{a}	0.27^{a}	537.1^{ab}	12.8^{b}	2115^{c}
Maize +TGX1876-4E	2160^{ab}	8246^{abc}	23.0^{a}	0.22^{ab}	405.5^{b}	12.2^{c}	1221^{c}
Maize+Tgm 1039	2389^{a}	10302^{a}	23.1^{a}	0.2^{ab}	504.0^{ab}	15.4^{a}	2164^{c}

*Means followed by the same letter(s) within the column are not significantly different ($P \leq 0.05$)

Table 6: Effect of intercropping maize and legumes on yield and yield components of maize and legumes, during the 2006 short rain season at Nyabeda

	WH502 maize				Legume intercrop		
Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	100 seed weight (g)	Harvest index	Grain yield (kg ha^{-1})	100 seed weight (g)	Biomass (kg ha^{-1})
Sole maize	665^{bc}	3333^{b}	14.4^{a}	0.13^{b}	-	-	-
Maize +*Desmodium*	854^{bc}	3542^{b}	13.8^{a}	0.2^{ab}	-	-	3558^{b}
Maize +*Mucuna*	2287^{a}	6667^{a}	14.3^{a}	0.25^{a}	-	-	7273^{a}
Maize +TGX 1448-2E	975^{bc}	3858^{b}	14.3^{a}	0.2^{ab}	380^{a}	9.6^{a}	903^{c}
Maize +Tgm 1576	1384^{b}	4583^{b}	14.3^{a}	0.23^{a}	251^{ab}	9.5^{a}	1033^{bc}
Maize +TGX1876-4E	958^{bc}	4167^{b}	13.6^{a}	0.2^{ab}	207^{b}	9.0^{a}	902^{c}
Maize +Tgm 1039	1411^{b}	4375^{b}	14.5^{a}	0.25^{a}	319^{ab}	9.5^{a}	1073^{bc}

*Means followed by the same letter(s) within the column are not significantly different ($p \leq .0.05$)

5.3.5 Relationship between *Striga* and maize intercropped with legumes

The correlation analysis (Table 7 and 8) shows that stover weight, grain yield and 100-seed weight of maize were negatively correlated with both *Striga* count and biomass in long rains and with *Striga* biomass in short rains. This showed that the *Striga* biomass has more influence on the host productivity than the *Striga* count, as it is a positive indicator of the amount of photosynthate channelled from the host to the parasite. Harvesting index was negatively correlated with *Striga* biomass in the short rains. This shows that a yield component such as 100-seed weight is a good indicator of maize yield losses due to *Striga*. This is in agreement with earlier findings that the cob weight is a better indicator of the effect of *Striga* on maize yield (Kuchinda *et al*., 2003). There was a positive correlation between maize height and maize grain yield. This showed that the reproductive stage of the crop is highly influenced by the vegetative growth and that interference with the early growth of the crop would be automatically reflected on the final performance of the crop in terms of quantity. There was a negative correlation between the legume biomass produced during the first planting season and the *Striga* biomass in the second planting season (Figure 10). The high legume biomass must have changed the microclimate of the soil making it unsuitable for the development of the parasitic *Striga*. On the other hand there was a high positive correlation between the legume biomass produced in the first season and the maize yield in the second season (Figure 11). This shows that the legume biomass in one season changes the soil conditions making it suitable for development of the subsequent maize crop but unsuitable for *Striga* growth.

Table 7: Peason correlation coefficient (R^2) between *Striga* parameters and maize growth and yield components at Nyabeda-(Long rains, 2006)

	Maize height	LAI	*Striga*seed bank	*Striga* count	*Striga* biomass	Stover yield	Maize grain yield	100seed weight	Harvest index
Maize height	1.0								
Leaf area index	0.84***	1.0							
Striga seed bank	-0.70***	-0.50***	1.0						
Striga count	-0.80***	-0.80***	0.40**	1.0					
Striga biomass	-0.50***	-0.70***	0.31*	0.71***	1.0				
Stover yield	0.71***	0.67***	-0.50***	-0.72***	-0.67***	1.0			
Maize grain	0.49***	0.50***	-0.31*	-0.63***	-0.80***	0.789***	1.0		
100 seed weight	0.58***	0.62***	-0.53***	-0.48***	-0.47***	0.54***	0.4015**	1.0	
Harvest index	-0.44***	-0.30*	0.33*	0.25	0.11	-0.389**	0.10	-0.23	1.0

* Significant at $p \leq 0.1$, ** Significant at $p \leq 0.05$, *** Significant at $p \leq 0.01$

Table: 8: Pearson correlation coefficient (R^2) between *Striga* parameters and maize growth and yield components for the second season intercropping at Nyabeda (Short rains 2006).

	Maize height	*Striga* count	*Striga* biomass	Stover yield	Maize grain yield	100seed weight	Harvest index	LAI
Maize height	1.0							
Striga count	0.12	1.0						
Striga biomass	-0.62***	0.03	1.0					
Stover yield	0.18	0.03	0.00	1.0				
Maize grain yield	0.80***	-0.11	-0.73***	0.20	1.0			
100seed weight	-0.50***	-0.14	-0.58***	0.03	0.77***	1.0		
Harvest index	-0.43**	-0.22	-0.60***	0.15	0.80***	0.79***	1.0	
The leaf area index	0.87***	0.81***	0.55***	0.94***	0.94***	0.12	0.4**	1.0

** Significant at $p \leq 0.05$, *** Significant at $p \leq 0.01$

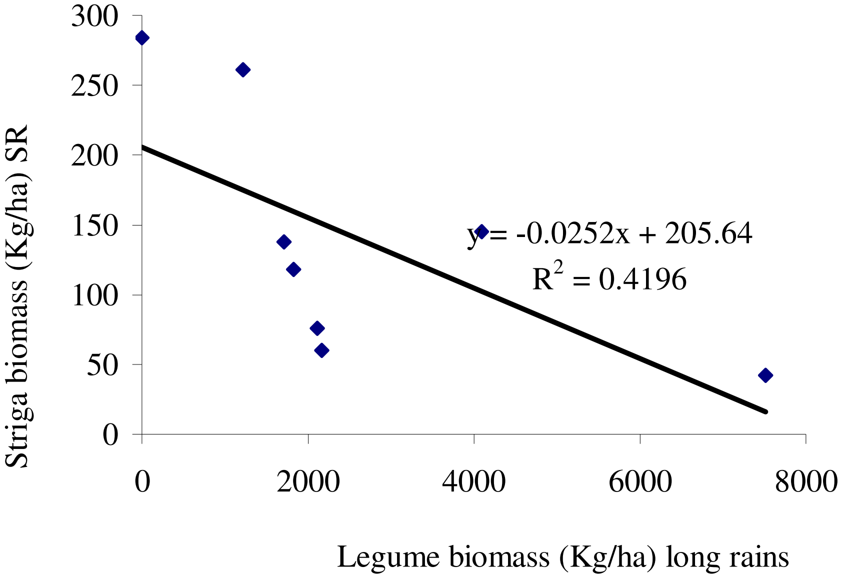


Figure 10: Relationship between the legume biomass in the first planting season and the *Striga* biomass produced in the second planting season

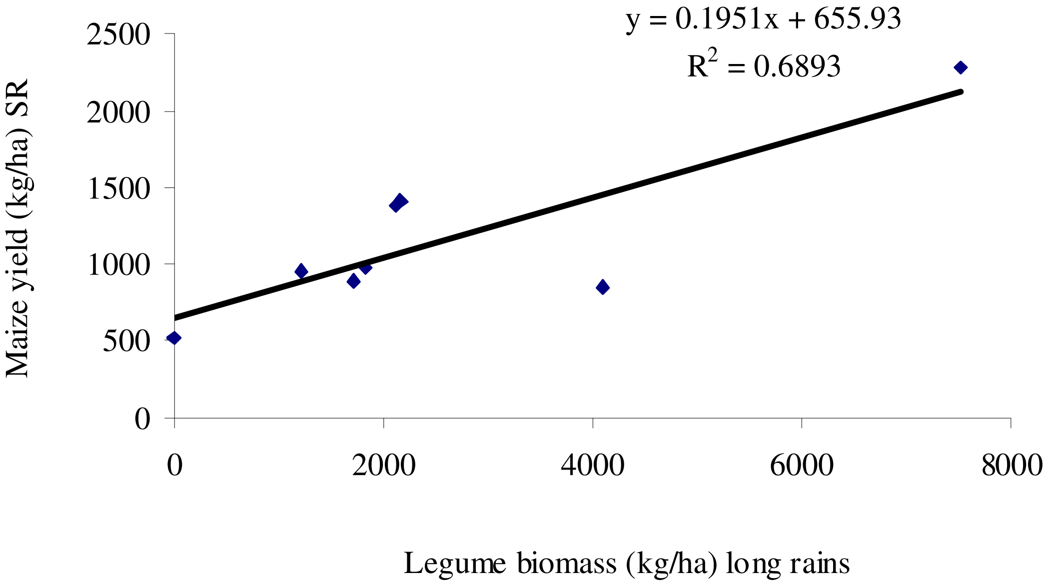


Figure 11: Relationship between legume biomass produced during the short rains and the maize yield produced during the long rains

5.4 Conclusion

Results obtained from field experiments showed that growing maize in association with legume non-host plants resulted in lower *Striga* incident as seen from the *Striga* count and *Striga* biomass, and better growth and yield of the associated maize. The low *Striga* count coupled with the high maize yield in the intercrops can be attributed to the effectiveness of the intercrops in controlling *S. hermonthica* and the effectiveness of the system. The high yield of both maize and the intercrops shows that it was possible to realise higher overall yields per unit area through intercropping by optimising benefits from the system. The grain yield and biomass yield obtained from the intecrops can serve as a source of food, fodder and manure, commodities that are limited in subsistence farming communities. There was high yield when maize was associated with *Mucuna* probably because the high biomass of *Mucuna* may have improved soil fertility and smothering of the emerging *Striga* plants. *Desmodium* needs time to establish it self before its effect on *Striga* could be seen. This is exhibited by the sharp changes in *Striga* parameters and maize yields in the second season in plots in which maize was associated with *Desmodium* when compared with the season one. Soybean accessions used exhibited similar potential for use to control *Striga* under intercropping system as there were no significant different in *Striga* parameters and maize growth and yields and yield components among the soybean accessions. The relative low number of *Striga* counts in intercropping indicates a reduced potential for flowering and hence capsule production consequently resulting in a reduced capacity of increasing the *Striga* seed bank in the soil.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclutions

1 *Striga hermonthica* is one of the most important constraints to maize production. There was a wide variation within soybean varieties on the ability to stimulate *Striga hermonthica* seed germination. Some accessions had higher stimulating ability than the host plant maize and *Desmodium unicinatum* and are to be producing more germination stimulant.

2 Among the high stimulation varieties, TGX 1448-2E, TGX 1740-2F, Tgm1576, TGX 1876-4E and Tgm 1039 resulted in high attachment of *Striga* seedlings onto maize plant roots in pot trial. There was however poor correlation between maize and legume root weight and the number of attached *Striga* under intercropping. There is need to investigate the effect of intercropping on the rate at which stimulant is exuded from the roots of maize and the legume intercrop and amount of root spread.

3 From the pot experiment most of the soybean varieties which stimulated high *Striga* germination also caused high *Striga* attachment and emergence on the associated maize crop. The soybean varieties (TGX 1448-2E, Tgm 1576, TGX 1876-4E and Tgm 1039) did not negatively affect growth of the associated maize. The varieties are therefore recommended for verification under field conditions.

4 In the field trials soybean varieties, TGX 1448-2E, TGN 1740-2F, Tgm 1576, TGX 1876-4E and Tgm 1039 resulted in lower *Striga* counts and reduced *Striga* biomass on maize by 66% on average and increased the maize yield by 70%. The relatively low number of *Striga* counts in intercropped system indicates a reduced potential for flowering and capsule production and consequently a reduced capacity of increasing the *Striga* seed bank in the soil. The field results show that intensifying cropping by integrating soybean varieties and maize could provide a sustainable system than the sole maize cultivation.

5 Intercropping and other improved cropping system approaches could result into multiple benefits by increasing the farm income from the sale of the legume grains in addition to

increasing maize yield per unit area and minimizing risks in unfavorable seasons and hence intercropping is encouraged in *Striga* stressed areas.

6.2 Recomandations

1 There is a need to investigate other agronomic traits of the soybean varieties used in this study such as tolerant to both the abiotic and biotic factors common in the production lands.

2 There is also a need to determine the potential of the recommended soybean varieties in symbiotic nitrogen fixation for fertility improvement.

3 Further research is required to determine the mechanism of *Striga hermonthica* suppression under field conditions by the soybean varieties. This would affect their acceptability by the farmers for inclusion into the existing cropping systems.

4 Research is also required to determine the planting pattern that reduce labour requirement and maize/soybean competition and at the same time being effective in *Striga* trapping.

5 It is recommended that screening of the potential soybean varieties be done for different *Striga hermonthica* populations from different locations representing variable *Striga* genotypes in order to determine their ability across the board.

6 Further work is needed to determine the specific chemical factors in soybeans that are involved in the stimulation of *Striga* seeds to germinate and how they function.

7 There is also a need to determine the inherent genetic differences among the soybean varieties used in this study so that breeding could be done for increased stimulant production.

8 The reduction of *S. hermonthica* count and biomass in maize in the field trial indicate that there is need to investigate the mechanisms by which soybeans inhibit the parasite by evaluating the role of shedding, nitrogen (N) and allelopathy in *Striga* suppression by soybean.

REFERENCES

AATF, 2006. Empowering Africa farmers to eradicate *Striga* from maize crop lands. The African Agricultural Technology Foundation, Nairobi, Kenya. 17pp.

Aflakpui, G., K., S., Gregory, P. J. and Froud-Williams, R., J., 2002. Growth and biomass partitioning of maize during vegetative growth in pesponse to *Striga hermonthica* infection and nitrogen supply. *Exp. Agric*.38: 265-276.

Aflakpui, G., K., S., Gregory, P., J. and Froud-Williams, R., J., 2005. Carbon (^{13}C) and nitrogen translocation in a maize-*Striga hermonthica* association. *Exp. Agrc. 41: 321-339*.

Aigbokhan, E., Berner, D.K., and Musselman, L.J., 1998. Reproductive ability of hybrids of *Striga aspera* and *Striga hermonthica*. *Ecology and Population Biology*. 88 (6) :563-567.

Aliyu, B. S. and Emechebe, A.M., 2006. Effect of intra-row and inter-row mixing of sorghum with two varieties of cowpea on host crop yield in a *Striga hermonthica* infested field. *African Journal of Agricultural Research* 1 (2):024-026.

Ariga, E.S., Ransomm, J.K., Odhiambo, G. D., Abayo, G.O. and Ndungu, D.K., 1997. Potential of using cotton and other trap crops for *Striga hermonthica* management in cereals in Kenya. In: Adipala, E., Tusiime, G. and Okori, P. (Eds.). Proccedings of the 16th Biennial Weed Science Conference for Eastern Africa, Kampala 15th-18th September 1997. 247-253.

Babiker, A.G.,Ejeta, G.,Butler, L.G.and Woodson,W.R.,1993. Ethylene Biosynthes and Strigol-induced germination of *Striga asiatica*. *Plant Physiology*. 88: 359-365.

Badu-Abraku, B., Fakorede, M.A. and Feontemlum, A., 2007. Evaluation of experimental varieties from recurrent selection for *Striga* resistance in two extra-early maize populations in the savannas of West and Central Africa. *Expl Agric*. 43:18-200.

Berner, D.K., Kling, J.G., and Singh, B.B., 1995. *Striga* research and control: A perspective from Africa. *Plant Disease*. 79:652-660.

Berner, D.K., Carsky, R, Dashiel,l, K., Kling, J. and Manyong, V., 1996.A land management based approach to integrated *Striga hermonthica* control in sub-sahara Africa. *Outlook on Agricultue* 25: 157-164

Berner, D.K., Winslow, W.D., Awad, A.E., Cardwek, K.F., Mohanraj, D.R., and Kim, S.K., 1997. *Striga* Research Methods, 2nd Edition. International Institute for Tropical Agriculture, Ibadan, Nigeria.

Berner, D.K., and Williams, O.A., 1998. Germination stimulation of *Striga gesnerioides* seeds by hosts and nonhosts. *Plant Disease*. 82:1242-1247.

Berner, D.K., Schad, N.W., and Volkson, B., 1999. Use of ethylene –producing bacteria for stimulation of *Striga hermonthica* spp. seed germination. *Biological Control* 15:274-282.

Botanga, C.J., Alabi, S.O., Echekwu, C.A., and Lagoke, S.T.O., 2003. Genetics of suicidal germination of *Striga hermonthica* (Del.) Benth by cotton. *Crop Science* 43:483-488.

Bouwmeester, H.J., Matusova, R., Zhongkui, S. and Beale, M., 2003. Secondary metabolite signalling in host-parasite plant interactions.*Current Opinion in Plant Biology* 6:358-364.

Brian, R. T. 1986. Resourse use by intercrops. In: Charles, A.F. (ed). Multiple cropping systems. Colliar Macmillan, New York, London. p57-62.

Brooks, D. W., Bevinakatti, H.S. and Powell, D.R., 1985. The absolute structure of (+)- strigol *J. Org. Chem*. 50, 3779-3781.

Butler, L.G., 1995. Chemical communication between parasitic weed *Striga* and its crop host. Anew dimension in allelochemistry. Agricultural Experimentation Station. Purdue University. West Lafayette, International 156-166.

Carruthers, K.B., Printhiviraj, Q. F., Cloutier, D., Martin, R.C. and Smith, D.L., 2000. Intercropping corn with soybean, lupin, and forages: yield component responses. *Eur. J. of Agronomy* 12:103-115.

Carsky R.J., Berner, D.K., Oyewole, B.D., Dashell, K. and Schulz, S., 2000. Reduction of *Striga hermonthica* parasitism on maize using soybean rotation. *Intern.l J. of Pest Management* 46 (2):115-120.

Carson, A.G., 1989. Effect of intercropping sorghum and groundnut on density of *Striga hermonthica* in the Gambia. *Tropical Pest Management 35: 130-132*.

Charles, A.F., 1986. Distribution and importance of multiple cropping. In: Charles, A. F., (ed). Multiple cropping systems. Colliar Macmillian, New York, London. P 1-16

Central Bureau of Statistics (C. B.S.) Statistical Abstract 2005. Ministry of Planning and National Development. Government Printers, Nairobi.

Chang, M., Netzly, D.H., Butler, L.G., and Lynn, D.G., 1986. Chemical regulation of distance: characterization of the first natural germination stimulant for *Striga asiatica*. *J. of Am. Chemical Society 108:7858-7860.*

Ciotola, M., DiTommaso, A., and Watson, A.K., 2000. Chlamydospore reproduction, inoculation methods and pathogenicity of *Fusarium oxysporum* M12-4A, a biocontrol for *Striga hermonthic*a. *Biocontrol Science Technology 10: 129–145*

Cook, C.E., Whichard, L.P. Wall, M.E., Egly, G.H., Coggan, P., Luhan, P.H., and McPhall, A.T., 1972. Germination stimulants ll. The structure of Strigol- a potent germination stimulant for witch weed (*Striga lutea*). *American Chemistry Society 94:6198-6199.*

Egley, G.H., Eplee, R.E., and Norris, R.S., 1990. Discovery and development of ethylene as a witch weed seed germination stimulant. In: P.F. Sand, R.E Eplee, R.G. Westbrooks (eds.), Witch weed research and control in the United States. *Weed Science Society of America. Champaign, IL, P46-55.*

Ejeta, G. and Butler J.G., 1993. Host-parasite interactions throughout the *Striga* life cycle and their contribution to *Striga* resistance. *Afr. Crop Science Journal, 1:75-80.*

Ejeta, G., Butler, L.G., and Babiker, A.G.T., 1992. New approaches to control of *Striga*: *Striga* research at Purdue University; Agricultural Experimental Station, Purdue University. West Lafayette, IN 47907.

El-Halmouch, Y., Benharrat, H. and Thalouarn, P., 2005. Effect of root exudates from different Tomato genotypes on Broomrape (*O. aegyptiaca*) seed germination and turbacle development. *Crop Protection* 1:1-7

Emechebe, A.M., Ahonosi, M. O., 2003. Ability of excised roots and stem pieces of maize, cowpea and soybean to course germination of *Striga hermonthica* seeds. *Crop Protection 22: 347-353.*

Eplee, R.E. and Norris, R.S., 1987. Chemical Control in Musselman, L.J., (ed) *Striga* in parasitic weeds in Agriculture.Vol. 1 pp 173-182. CRC Press Boca Ratoon, Florida.

Esilaba, A.O., Mulatu, T., Reda, F., Ransom, J.K., Woldwahid, G., Tesfaye, A., Fitwy, I., and Abate, G., 1997. Factors affecting the incidence of *Striga* and its control in Northern Ethiopia. 16th East African Biennial Weed Science Conference Proceedings, p. 221-259.

Franke, A.C., Ellis-Jones, J., Tarawali, G., Schulz, S., Hussaini, M.A., Kureh, I., White, R., Chikoye, D., Douthweite, B., Oyewole, B.D. and Olanrewaju, A.S., 2005. Evaluating and

Scaling-up integrated *Striga hermonthica* control technologies among farmers in Northern Nigeria. *Crop Protection* 1:8-18.

Frost, H., 1997. *Striga hermonthica* Surveys in Western Kenya. In proceedings. Brighton Crop Protection Conference- Weeds. Farnham, Great Britain: BCPC. 145-150.

Gbehounou, G., Pieterse, A.H. and Vekleiji, J.A.C., 2003. Longevity of *Striga* seeds reconsidered: Results of a field study on purple witch weed (*Striga hermonthica*) in Benin. *Weed Sci*. 51:940-946.

Gbehounou, G., and Adango, E., 2003. Trap Crops of *Striga hermonthica*: In-vitro identification and effectiveness in situ. *Crop Protection 22: 395-404.*

Gerard, H.L.N., Jan Willem, J.F.T., Marco, F.M.B., and Zwanenburg, B., 1997. Synthesis of a phthaloylglycine-derived strigol analogue and its germination stimulatory activity toward seeds of the parasitic weeds *Striga hermonthica* and *Orobanche crenata*. *Journal of Agricultural Food Chemistry 45: 2273-2277.*

Gomba, A. and Kachigunda, B., 2005. Effect of Leaf Extracts of multipurpose trees on the life cycle of *Striga asiatica* (L.) Kuntze. *Journal of Agronomy 4 (4): 161-164.*

Greathead, D.J., 1984. The Natural Enemies of *Striga spp*. and the prospects for their utilization as biological control agents. In: E.S. Ayensu, H. Dogget, R.D. Heynes, J. Marton-Lefevre, L.J. Musselman, C. Parker and A. Pickering (eds.) *Striga* Biology and Control. ICSU/IDRC. Paris, France. p. 133-160.

Gressel, J., Hanafi,A., Head, G., Marasa, W., Obilana, A.B., Ochanda, J., Souissi, T. and Tzotzos, G., 2004. Major heretofore-intractable biotic constraints to African food security that may be amenable to novel biotechnogical solutions. *Crop Protection 2:,661-689.*

Gurney, A. l., Pressa M. C.and Scholes, J. D., 1999. Infection time and density influence the response of sorghum to the parasitic angiosperm *Striga hermonthica*. *New Phytologist 143: 573-580.*

Hassan R., Ransom, J.K., Ojiem, J., 1995. The spartial distribution and farmers strategies to control *Striga* in maize: Survay results from Kenya. In: Jewell, D., Waddington, S., Ransom, J.K., Pixley, K.(Eds.), Proceedings of the Forth Eastern and Sourthen Africa Regional Maize Conference .CIMMYT, Harare pp 250-254.

Hassan, R.M., 1998. Maize technology and transfer. Application for research planning in Kenya. Wallingford (United Kingdom), CAB International.

Hauck, C., Muller, S., and Schildknecht, H., 1992. A germination stimulant for parasitic flowering plants from *Sorghum bicolor* a genuine host plant. *Journal of Plant Physiology 139:474-478.*

Hess, D.E., Ejeta, G., and Butler, L.G., 1992. Selecting sorghum genotypes expressing a quantitative biosynthetic trait that confers resistance to *Striga. Phytochemistry 31:493-497.*

Horticultural Crops Development Authority (2002). Horticultural produce handling facilities.No. 26 Jan/Feb. issue.

Humphrey, A.,J. and Baele, M.H. 2006. Strigol: biogenesis and physiological Activity. *Phytochemistry 67: 632-640.*

Hokkanen H.M.T., 1991. Trap cropping in pest management. *Ann. Rev, Entomol.*36:119-138

Jaetzold, R. and Schimdt, H. 1983. *Farm Management Handbook of Kenya: Natural and Farm Management Information Vol.II/B.* Nairobi: Ministry of Agriculture, Livestock Development and Marketing.

Kabambe V. H., 1995. Trap-cropping, intercropping and manual removal show promise on *Striga asiatica* control in maize in Malawi. The 3rd Regional *Striga* Working group meeting, Mombasa, (Kenya) Tanga (Tanzania). June 12th-14th, 1995. 12-15.

Kanampiu F.K., Kabambe, V., Massawe, C., Jasi, L., Friesen, D., Ransome, J.K., Gressel, J., 2003. Multisite, multiseason field tests demonstrate that herbicide seed- coating herbicide- resistance maize controls *Striga spp*. and increases yields in several African countries. *Crop Protection 22: 697-706.*

Kanampiu, F. K., Ransom J. K., and Gressel, J., 2001. Imazapyr seed dressing for *Striga* control on acetolactate synthase target site resistant maize. *Crop Protection 20:885-895.*

Khan, Z.R., Midega, C.A.O., Hassanali, A., Pickett, J. A., Wadhams, L.J. and Wanyonya, A., 2006. Management of witch weed, *Striga hermonthica*, and stermborers in sorghum,*sorghum bicolor*, through intercropping with green leaf desmodium, *Desmodium intortum*. *International J. Pest management* 52 (4): 297-302.

Khan, Z, R., Hassanali, A., Overhot, W., Khamia, T., M., Hooper, A.,M., Pickett, J,A., Wadhams, L.,J., Wood-cock, C., 2002. Control of the witch weed *Striga hermonthica* by intercropping with *Desmodium* spp. and the mechanism defined as allelopathic. *Journal of Chemical Ecology 28*: *1871-1885.*

Khan, Z.R., Picket, J.A., Wadhams, L., and Muyekho, F., 2001. Habitat management strategies for the control of cereal stem borers and *Striga* in maize in Kenya. *Insect Science and its Application 21 (4): 375-380.*

Khan, Z.R., Picket, J.A., Van den Berg, J., Wadhams, L. J., and Woodcock, C. M., 2000. Exploiting chemical ecology and species diversity: Stemborers and *Striga* control for maize and sorghum in Africa. *Pest Management Science 56:957-962.*

Kim, D.K., Boone, L., Keyes, W.J. and Lynn, D.G., 1998.On becoming a parasite: Evaluating the role of wall oxidases in parasitic plant development. *Chem. Biol.* 5: 10-107.

Kim, S., Adetimirin, V.O., Akitunde, A.Y., 1996. Nitrogen effects on *Striga hermonthica* infestations, grain yields and agronomic traits of tolerant and susceptible maize hybrids. *Crop Science 37: 711-716.*

Koichi, Y., Yasutomo, T., Masaru, O., Makoto, K., Yukihiri, S. and Takeshi, S. 1998. Cotylenins and Fusucoccins stimulate seed germination of *Striga hermonthica* (Del.) Benth and *Orobanche Minor* (Smith). *Journal of Agricultural Food Chemistry 46:1583-1586.*

Koyama, M.L., 2000. Molecular markers for studying pathogen variability: Implications for breeding for resistance to *Striga hermonthica.* In: B.I.G. Haussman (ed.), Breeding for *Striga* resistance in cereals. Proceedings of a workshop held at IITA, Ibadan, Nigeria. 18-20 August 1999. Margraf. Verlag, Weirkersheim, Germany. p 227-245.

Kuchinda, N.C., Kureh, I., Tarfa, B.D., Shiggu, C., and Omollehin, R., 2003. On-farm evaluation of improved maize varieties intercropped with some legumes in the control of *Striga* in the Northern Guinea savannah of Nigeria. *Crop Protection 22: 533-538.*

Kujijit, J., 1991. The haustorial interface: what does it tell us? In: Ransom, J.K.Musselman, L.J., Worsham, A.D. and Parker, C., (eds). Proceedings of the 5th International symposium of Parasitic Weeds.Nairobi CIMMYT: 1-5

Kureh, I., Chiezey, U.F. and Tarfa, B.D.,2000. On-station verification of the use of soybean trap crop for the control of *Striga* in maize. *Afr. Crop Science Journal* 8 (3): 295-300.

Ma, Y.Q., Cheng, J.M., Inanaga, S., and Shui, J.F., 2004. Induction and inhibition of *Striga hermothica* (Del.) Benth. germination by extracts of traditional Chinese medicinal herbs. *Agronomy Journal 96:1349-1356.*

Maguel, A.A. and Matt, L., 1986. Insect weed and plant diseases management in multiple cropping systems. In: Charles A.F., (ed.) Multiple cropping systems. COLLIAR Macmillan, New York, London p 183.

Marley, P. S., Aba, D. A., Shebayan, J. A. Y., Musa, R. and Sannis, A., 2004. Integrated management of *Striga hermonthica* in sorghum using a mycoherbicide and host plant resistance in the Nigerian Sudano-sahelian savanna. *European Weed Research Society Weed Research* 44:157-162.

Marley P.S, Ahmed, S.M., Shebayan J.A.Y., & Lagoke S.T.O., 1999. Isolation of *Fusarium oxysporum* with potential for biocontrol of the witchweed *(Striga hermonthic*a) in the Nigerian savanna. *Biocontrol Science Technology 9: 159–163.*

Massawe, C. R., Kaswande, J. S., Mbwaga, A. M. and Hella, J. P., 2001. On-farm verification of maize/ cowpea intercropping on the control of *Striga* under subsistence farming. Seventh eastern and sourthern Africa regional maize confrence 11th- 15th February 2001. 165-167.

Matusova, R., Rani, K., Verstappe, F.W.A., Franssen, M.C.R., Beale, M.H., Bouwmester, H.J., 2005. The strigolactone germination stimulants of the plant parasitic *Striga* and *Orobanche* spp. are derived from the Caratenoid Pathway. *Plant Physiology 139:920-934.*

Miche L, Bouillant ML, Rohr R, Salle G., & Bally R., 2000. Physiological and cytological studies on the inhibition of *Striga* seed germination by the plant growth-promoting bacterium *Azospirillum brasilens*e. *European Journal of Plant Pathology 106: 347–351*

Muller, S., Hauck, C. and Schildknecht, H., 1992. Germination stimulants produced by *Vignia unguiculata* Walp cv. Saunders Upright. *Journal of Plant Growth Regulators, 1992, 11:77-84.*

Mumera, L.M., 1992. Nitrogen and genotype effects on assimilate partitioning and resistance to *Striga* in maize. Ph.D Thesis. University of Illinois, Urbana, USA.

Mumera, L.M., and Bellow, F. E., 1993. Role of nitrogen in resistance to *Striga* parasitism of maize. *Crop Science 33 (4): 758-763.*

Nassiuma, D., Wafula, W., 2002. Stability assessment of soybean varieties in Kenya. *Afr. Crop Science*, 2: 139-144.

Odhiambo, G., D. and Ransom, J., K., 1993.The effect of nitrogen and cowpea intercropping on development of *Striga* in maize. Proceedings of the 13th Biennial weed science conference of the weedscience society for Eastern Africa, p 30-32.

Norman, J., M. and Campbell, G., S,. 1989. Canopy structures. In: Pearcy, R,. W., (ed). Plant physiological ecology.Chapman and Hall. London P301-325

Odongo, O.M., Abayo, G.O., Ojiem, J.O., Ransom, J.K., 1997. *Striga hermonthica* control strategy through maize variety resistance/tolerance in Western Kenya. In: Devries, J.D. and Ochieng, J.A.W. (eds.). Advances in *Striga* research in Kenya. Proceedings of a workshop sponsored by the Kenya Agricultural Research Institute (KARI) and the Rockerfeller Foundation, held in Kisumu, Kenya.p 56-65.

Olupot, J.R., Osiru, D.S.O., Oryokot, J. and Gebrekidan, B., 2003. The effectiveness of *Celosia argentia* (*Striga* "chaser") to Control *Striga* on Sorghum in Uganda. *Crop Production, 22 : 463-468.*

Oswald, A., Frost, H., Ransom, J. K., Kroschel, J., Shepherd, K. And Sauerborn, J. 1996. Studies on the potential for improved fallow using trees and shrubs to reduce *Striga* infestations in Kenya. :In Monero, M. T., Cubero, J. i., Berner, D., Joel, D., Muselman, L. J. And Parker, C.(eds.). Advances in parasitic plant research: proceedings of the 6th Parasitic weeds Symposium, 16-18 April 1996.

Oswald A., Agunda J. and Ransom, J., 1999. On-farm research and training of farmers groups on *Striga* control using aparticipatory approach. Abstracts of the XIVth International plant protection congress, plant protection towards the third millennium- where chemistry meets Ecology, IPPC, Jerusalem Israel p.74

Oswald, A., Ransom, J.K., Kroschel, J. and Sauerborn, J., 2002. Intercropping controls *Striga* in maize based farming systems. *Crop Protection*, 21:367-74.

Oswald, A., 2005. Technologies and their Dissemination. *Crop Protection 24:333-342.*

Palmer ,G.A., Maresh, R.G.J., Erbil, W.K. and Lynn, D.G., 2004. Chemical biology of multi-host/pathogen interactions:chemical perception and metabolic complementation. *Ann. Rev. phytopath*, 42: 439-464.

Parker, C., 1984. The influence of *Striga* species on sorghum under varying nitrogen fertilization. In Parker C., Musselman I.,J., Polhill, R. M. and Wilson, A. K.(eds) proceedings of the 3rd international symposium on parasitic weeds, allelopathy. International Centre for Research in the Dry Areas: 90-98.

Parker, C. and Riches, C.R., 1993. Parasitic weeds of the world: Biology and control. CAB International Wallingford, UK:.332.

Parkinson, V., Kim, S.K., Efron, Y., Bello, L., and Dashiel, K., 1988. Potential of Trap crops as a Cultural Measure of *Striga* Control in Africa. FAO Bulletin Number 96.

Perrin, R.M., 1980. The role of environmental diversity in crop protection. *Pro Ecol*. 2:77-114.

Pieterse, A.H. and Pesch, C.J., 1983. The Witchweed (*Striga* spp.).A Review. *Abstracts of Tropical Agriculture* 9:9-35.

Pieterse, A. H. and Verkleij, J. A. AC., 1991. Effect of soil conditions on *Striga* development- A Review. In: Ransom J. K. Musselman, L. J., Worsham, A.D. and Parker, C. (eds) Proceedings of the 5th International Symposium on Parasitic Weeds. CIMMYT, Nairobi. PP 329-339.

Press, M.C., Gravis, J.D., and Stewart, G.R., 1990. Physiology of interaction of angiosperm Parasites and their plant hosts: A review. *Plant Cell and Environment 13:91-104.*

Press, M. C., 1989. Autotrophy and Heterotrophy in root hemiparasite. Trends in ecology Evolution 4: 258-263

Raju P.S., Osman, M. A., Soman, J.P and Peackock, J. M., 1990. Effect of N. P. and K on *Striga asiatica* (L) Kintze; seed germination and infestation of sorghum. *Weed Reseach 30: 139-144.*

Ramaiah, K.V., Parker, C., Vasudeva Rao, M. J. and Musselman, I. J., 1983. *Striga* Identification and Control Handbook Information. Bulletin No-15 Patancheru, A.P., India: International Crops Research Institute for the Semi- Arid Tropics.

Ransom, J.K., and Njoroge, J., 1991. Seasonal variation in ethylene-induced germination of *Striga hermonthica* in Western Kenya. In: J.K. Ransom, L.J. Musselman, A.D. Worsham and C. Parker (eds.) proceedings of the fifth International Symposium of Parasitic Weeds. CIMMYT, Nairobi, Kenya, p 391-396.

Ransom, J.K., and Odhiambo, G.D., 1994. Long-term effects of soil fertility and hand weeding on *Striga* in Maize. In: A.H. Piertese, J.A.C. Verkleij (eds.), Biology and management of Orobanche. Proceedings of the 3rd International Symposium on Orobanche and related *Striga* Research. Royal Tropical Institute, Armsterdam, p. 513-519.

Ransom, J.K., Odhiambo, G.D., Eplee, R. E. and Diallo, A.O., 1996. Estimates from field studies of the phytotamic effects of *Striga* species on maize. In: Maseno M. T., Cobero J. I., Berner, D., Joel, L., Musselman, L. T. and Parker, C. (eds.). Advance in parasitic plant research. Sixth Edition International Parasitic Weed Symposium in Cordoba, Spain April 16-18 1996 pp 327-334.

Rao,M. R. And Gacheru, E., 1998. Prospects of agroforestry for *Striga* management. *Agroforestry Forum* 9 (2): 22-27.

Reda, F., Verkleij, J.A.C., and Ernst, W.H.O., 2005. Intercropping for the improvement of sorghum yields in the subsistence agriculture region of Tigray (Northern Ethiopia). *Journal of Agronomy and Crop Science 191:10-19.*

Rodenburg,J., bastian, L., Kropff, M.J. and Vanast, A., 2005. Effect of host plant genotype and seedbank density on *Striga* reproduction. *Weed Research*, 46: 251-26.

Ruggut, J. K., Ruggut, J.K., Rostem, K., Irani, N., Fischer, H., Berner, D. K. and McCarley, T.D. 1996. GC/MC evaluation of compounds in dry and conditioned *Striga* species Seeds. *Journal of Agricultural Food Chemistry, 44:3977-3982*

Ruggut, J. K. and Ruggut, K. 1997. Stimulation of *Striga hermonthica* seed germination by 11β, 13-Dehydroparthenoide. *Journal of Agricultural Food Chemistry 45: 4845-4849.*

Schulz, S., Hussaini, M.A., Kling, J.G., Berner, D.K. and Ikie, F.O., 2003. Evaluation of integrated *Striga hermonthica* control technologies under farmer's management. *Exp.. Agric. 39:99-108.*

Siame, B.A., Weerasuriya, Y., Wood, K., Ejeta, G. and Butler, L. G., 1993. Isolation of strigol, a germination stimulant for *Striga asiatica*, from host plants. *Journal of Agriculture and Food Chemistry 41:1486-1491.*

Sprich, H., 1994. The impact of farming practices on *Striga* control. In Report on the ICRISAT Sector Review for *Striga* control in Sorghum and Millet. ICRISAT-Bamako, Mali. 27th-28th May 1996.

Stewart, G.R., and Press, M.C., 1990. The physiology and biochemistry of parasitic angiosperms. *Annual Review of Plant Physiology 41:127-151.*

Tsanuo, K. M., Hassanali, A., Hooper, A. M., Khan, Z., Kaberia, F., Pickett, J. and Wadhams, L., 2003. Isoflavanones from allelopathic aqueous root exudates of *Desmodium unicinatum. Phytochemistry 64: 265-273.*

Vanlauwe, B., Kanampiu, F., Odhiambo, G.O., De Groote, H., Washams, L.J. and Khan, Z.R., 2008. Integrated management of *Striga hermonthica*, stemborers and declining soil fertility in Western Kenya. *Field Crops Research 107: 102-115.*

Vogler, R.K., Ejeta, G., and Butler, L.G., 1995. Integrating biotechnological approaches for the control of *Striga*. African. *Crop Science Journal 3 (2): 217-222.*

Wigchert, S.C.M. and Zwanenburg, B., 1999.A critical account on the inception of *Striga* germination. *Journal of Agriculture and Food Chemistry 47:1320-1325*.

World Bank. 1998. World development indicators. Warshington D. C., USA.

Worshman, A.D., 1987. Germination of witchweed. In: L.J. Musselman (ed.). Parasitic weeds in Agriculture. Vol.1:60 CRC Press, Boca Raton, FL. Weeds,

Yasuda, N., Sugimoto, Y., Kato, M., Inanaga, S. and Yoneyama, K., 2003. (+)-Strigol, a witchweed seed germination stimulant, from *Menispermum dauricum* root culture. *Phytochemistry 62:1115-1119.*

Yoder, J.I., 1998. Parasitic plant responses to host plant signals: A model for subterranean plant-plant interactions *Current Opinion in plant biology* 2: 65-70.

Yoneyama, K.Y., Ogasawara, M., Takeuchi, Y., Konnai, M., Sugimoto, Y., Seto, H., and Yoshida. M., 1998. Effects of Jasmonates and related compounds on seed germination of Orobanche minor Smith. and *Striga hermonthica* (Del.) Benth. *Biosci. Biotechnol. Biochem. 62(7): 1448-1450.*

Zehhar, N., Ingouff, M., Bouya, D.and Fer, A., 2002. Possible involvement of gibberellins and ethylene in *Orobanche ramosa* germination. *Weed Research 42: 464-469*.

APPENDICES

Appendix 1: Analysis of variance on *Striga hermonthica* germination percentages caused by root exudates from various test plants

Source	**DF**	**ANOVA SS**	**MST**	**MSE**	**F**	**C.V**	**LSD**	**Pr≤F**
Treatment	36	10045.5	279.0	267	11.03	19	4.3	**0.0001**[*]
Distance	3	891.8	297.3	149	1.99	54	1.4	0.114
Radius	3	19.5	6.5	185	0.04	60	3.6	0.9912

[*] Values in bold face show significant difference at p≤0.05.

Appendix 2: Analysis of variance on the effect of intercropping of maize and soybean on *Striga hermonthica* attachment and growth on associated maize

Source	**DF**	**ANOVA SS**	**MST**	**MSE**	**F**	**C.V**	**LSD**	**Pr≤F**
Emerged striga	15	2054	137	142	0.96	83	7.2	0.6031
Attached Striga	15	24701	1646	432	3.81	21	35	**0.0009**
Total *Striga*	15	34335	2289	497	4.6	19	37	**0.0002**

[*] Values in bold face show significance difference at p≤0.05.

Appendix 3: Analysis of variance on effect of intercropping maize with legumes on maize growth parameters in *Striga* infested pots

Source	**DF**	**ANOVA SS**	**MST**	**MSE**	**F**	**C.V**	**LSD**	**Pr≤F**
Maize height	15	19844	1167	226	5.16	19.8	24.9	**0.0001**
Maize shoot dry weight	15	2606	153	40	3.8	21.7	10.5	**0.0005**
Maize roo dry weight	15	1257	74	83	0.89	27.2	15.7	0.5886

[*] Values in bold face show significance difference at p≤0.05.

Appendix 4: Analysis of variance on the effect of intercropping on the biomass of the legumes in Striga infested pots

Source	**DF**	**ANOVA SS**	**MST**	**MSE**	**F**	**C.V**	**LSD**	**Pr≤F**
Legume shoot weight	15	1115	74.3	37.9	1.96	26	10.2	0.0568
Legume root weight	15	63.61	4.2	1.8	2.32	14	2.35	**0.0245**

*Values in bold face show significant different at p≤0.05.

Appendix 5: Analysis of variance on the effect of growing maize together with soybeans on the height of maize on Striga infested soil

Maize height	**DF**	**ANOVA SS**	**MST**	**MSE**	**F**	**C.V**	**LSD**	**Pr≤F**
Long Rains								
6weeks	7	255.4	36.4	50.5	0.72	10.6	10.4	0.0654
8weeks	7	255.9	36.5	126.7	0.29	12.7	16.5	0.9540
10weeks	7	4230	604	698.3	0.87	20.8	38.8	0.5489
12weeks	7	6206	886	1180	0.75	23.5	50.5	0.6331
Short Rains								
6weeks	7	73	10.4	9.8	1.06	3.1	4.6	0.4199
8weeks	7	1404	200.5	147	1.37	12	17.6	0.2695
10weeks	7	15483	2211	597	3.7	19.6	35.9	**0.0092**
12weeks	7	21908	3124	742	4.22	19.6	40.05	**0.0048**

*Values in bold face show significant different at p≤0.05.

Appendix 6: Analysis of variance on the effect of growing maize together with soybean on maize stover and grain yields in *Striga* infested soil

Parameters	DF	ANOVA SS	MST	MSE	F	C.V	LSD	Pr≤F
Long Rains								
Maize stover yield	7	152418954	21774136	8937464	2.4	40	4396	0.0539
Maize grain yield	7	15345242	2192177	171921	12.7	23	609	0.0001
Harvest index	7	0.16	0.02	0.01263	1.8	52	0.16	0.1353
100 seed weight	7	39.9	5.7	7.34207	0.78	12	2.8	0.6127
Short Rains								
Maize stover yield		27774318	4253474	1979991	2.2	32	2069	0.0830
Maize grain yield	7	8151239	1164462	211138	5.5	39	675	**0.0010**
Harvest index	7	0.0470	0.006	0.00329	2.0	27	0.08	0.0972
100 seed weight	7	2.88	0.4	0.65831	0.63	5.7	1.2	0.7293

*Values in bold face show significant different at p≤0.05.

Appendix 7: Analysis of variance on the effect of growing maize together with soybeans on the Striga parameters in the field

Parameters	DF	ANOVA SS	MST	MSE	F	C.V	LSD	Pr≤F
Long Rains								
Striga Counts:								
6 Weeks	7	6705	957	875	1.09	71	43.5	0.4020
8 Weeks	7	95800	13685	16937	1.97	44	122.4	0.1040
10 Weeks	7	120505	172.5	8598	2.0	37	136.3	0.1032
12 Weeks	7	308113	44016	23055	1.97	36	223.2	0.1189
Striga Biomass	7	745906	106558	21078	5.06	42	53.4	**0.0018**
Short Rains								
Striga Counts:								
6 Weeks	7	0	0	0	0	0	0	0
8 Weeks	7	325.5	46.5	14.4	3.23	49.7	5.58	**0.0175**
10 Weeks	7	7186.6	1026.6	254	4.04	35.8	23.4	**0.0060**
12 Weeks	7	113304	16186	3816	4.24	47.5	90.8	**0.0046**
Striga Biomass	7	224702	32100	11327	2.83	75	110.6	**0.0303**

*Values in bold face show significant different at p≤0.05

Appendix 8: Rainfall records

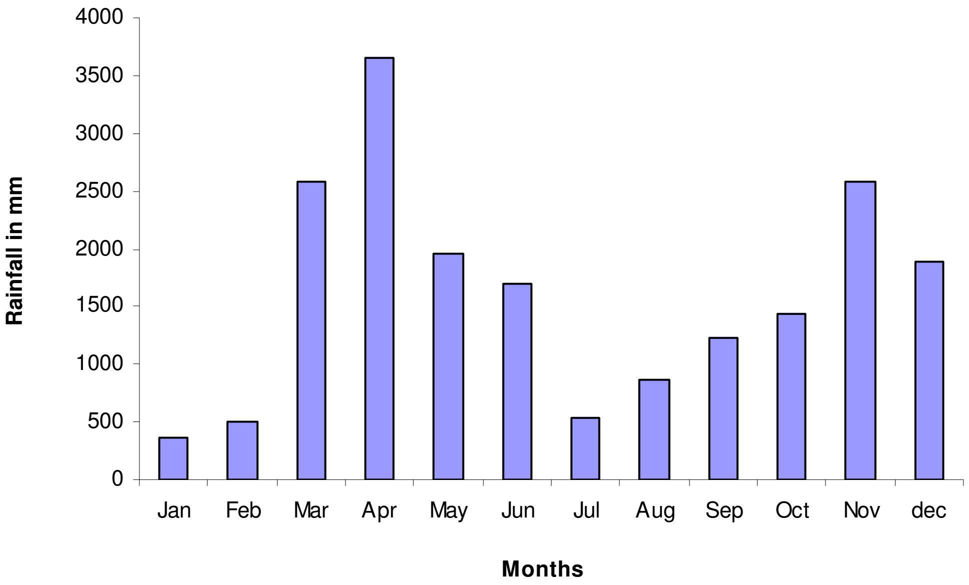


Figure 12: Rainfall distribution during the study period