EFFECTS OF FODDER LEGUME SPECIES ON GERMINATION, INFESTATION AND PARASITISM OF *STRIGA HERMONTHICA* (DEL.) BENTH. ON MAIZE (*ZEA MAYS* L.)

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DECLARATION

I declare that the work presented in this thesis is original and has not been presented in any other university for the purpose of awarding a degree.

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To my late sister, Jane Wairimu Ndung'u, for all the love, kindness, and laughter you gave to us. You will always be at the very centre of our hearts and may your last days always be a reminder to us to love and care for each other always.

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ABSTRACT

Striga hermonthica (del.) Benth, a parasitic weed reduces maize yields in western Kenya. *Striga* infestation in maize can be reduced by use of legumes (i.e. *Mucuna pruriens*, *Stylosanthes guyanensis* and *Desmodium intortum)*. Controlled experiments were conducted between September 1999 and March 2000 at Kibos in Kisumu to determine the effects of these fodder legumes on germination and attachment of *Striga* on maize roots. A field experiment was also conducted to study the effect of the legumes on *Striga* emergence and maize growth and yield.

Laboratory petri-dish experiment showed that root exudates of fodder legumes stimulated more *Striga* seeds to germinate than exudates of maize or cowpea (*Vigna unguiculata*), suggesting that the amount of stimulant compound exuded by the roots of test plants followed the order: *Stylosanthes* > *Mucuna* ≈ *Desmodium* > maize > cowpea. In the root chamber experiment growth of *Desmodium* and *Stylosanthes* was a major problem and only maize and *Mucuna* stimulated *Striga* seeds to germinate.

Greenhouse pot experiments showed significant effect of fodder legumes on *Striga* attachment on maize roots. There was significantly higher number of *Striga* attached on maize roots when maize was intercropped with *Mucuna* (158 *Striga* germlings/plant) or *Stylosanthes* (153) compared to maize with cowpea (105), or *Desmodium* (81) or maize grown alone (61). There was a positive correlation (r^2=0.83) between *Striga* attachment on roots of maize and legume root biomass. However there were significantly fewer *Striga* attachments on maize where pots were previously grown with cowpea (25/plant), *Mucuna*

(24), *Stylosanthes* (7) or *Desmodium* (3) compared to the control (41). There was a negative correlation (r^2=-0.71) between legume root biomass and number of attached *Striga* on maize roots. *Striga* seed bank in the soil decreased in both the maize legume intercrop and undersowing systems compared to bare soil.

In the field experiment, fodder legumes did not reduce *Striga* emergence significantly in season 1 (16^{th} November to march 2000). However in seasons 2 and 3, (April-July 2000 and August -November 2000, respectively) they reduced *Striga* emergence significantly. *Stylosanthes* and *Desmodium* intercropped or undersown with maize suppressed *Striga* emergence by 92-100% in the second season. In the third season fodder legumes in both cropping systems gave 37 to 96% suppression. There was no significant difference in maize yield between all treatments in both systems in the first season. However, in the second season maize undersown or intercropped with *Mucuna* had higher grain yield (3060 and 2530 kg ha^{-1} respectively) than the control (2060 kg ha^{-1}). In the second season there was no significant difference in maize grain yield between the control and maize associated with *Stylosanthes* or *Desmodium* or cowpea in the undersowing experiment. However maize grain yield was lower where legumes were intercropped with maize. In the third season, lower maize grain yields were attributable to drought and termite damage and all treatments were not significantly different. Legume herbage yields, was 2.6 tons ha^{-1} for *Mucuna* and 2 tons ha^{-1} for *Desmodium* and *Stylosanthes.* Fodder legumes stimulated *Striga* seeds to germinate and reduced *Striga* seed bank.

CHAPTER 1

LITERATURE REVIEW

1.1 Introduction.

Agricultural production is the main source of livelihood for most of the population of sub-Saharan Africa. Cereal production, especially of maize, sorghum and millet is very important in many of the countries of this region and is usually the main source of income for most of the rural poor. There are many constraints to crop production in general in sub-Saharan Africa. These include drought, low soil fertility status, insect pests, diseases and weeds. However drought is one of the major constraints to crop production in this region. Since only 2% of sub-Saharan Africa is irrigated, (Ayoub, 1994) farmers heavily depend on the usually insufficient and erratic rainfall. Many of the soils cultivated by shifting cultivators and subsistence farmers, who form the bulk of the population in this region, are very poor. Therefore most of these soils are subject to fertility depletion through decline in soil organic matter, reduction in nutrient reserves by crop removal, leaching and acidification (Ayoub, 1994). Soil erosion is also a major problem in several areas, which further contributes to soil depletion and hence low crop yields. One of the weed pests of significant importance today within sub-Saharan Africa is *Striga* (witch weed). These constraints either individually or in combination cause enormous crop yield losses in the region.

Striga is a parasitic weed that grows on the roots of cereals and legumes in tropical and sub-tropical environment and greatly constrains food production in Africa, (Sauerborn, 1991), to a greater extent than insects, birds or plant diseases (Ejeta *et al.*, 1992). The five

Striga species that cause significant damage to crops are *S. hermonthica* (Del.) Benth, *S. asiatica* (L.) Kunze, *S. aspera* (Willd.) Vatke, *S. forbesii* Benth and *S. gesnerioides* (Willd.) Vatke. The first four species attack cereal crops with *S. hermonthica* being the most serious in sub-Saharan Africa (Kim *et al.*, 1994). *S. asiatica* is more widespread in Southern Africa, India and the USA. (Parkinson, 1985; Musselman *et al.*, 1991). *S. aspera* is present in the mid-altitude areas in West Africa (Kim, 1991) while *S. gesneroides* occurs mainly in West Africa and attacks cowpea (*Vigna unguiculata* (L) Walp) and other legumes (Aggarwal, 1985). In Kenya the most serious species affecting cereals is *S. hermonthica.* In Western Kenya, it infests approximately 158,000 ha, while *S. asiatica* (L) Kuntze is currently of minor significance but identified as a potential threat to future production of cereals in Busia district and Coast Province (Ransom *et al.*, 1990).

Striga is becoming increasingly more important, particularly in Africa where population pressure necessitates more intensive cultivation of the staple cereal crops and where few, if any, quarantine measures are in place to arrest it's spread to non-infested areas (Pieterse and Pesch, 1983). Traditionally, African cropping systems have included prolonged fallow, rotations, and intercropping, which were common practices that kept *S. hermonthica* infestations at tolerable levels (Badu-Apruku *et al.,* 1996). Recently however, prevailing scarcity of land as a result of population increase has minimized the length of fallow periods and rotations. This has led to continuous mono-cropping with no fallow leading to a gradual increase in populations of *Striga* species, which have become a serious threat to cereal production (Ariga, 1996). It is noteworthy that areas that have *Striga* problems are generally also characterized by low productivity, a shortened or nonexistent fallow period, low fertilizer inputs as well as lack of use of pesticides and improved seeds (Abayo *et al.*, 1997).

A conservative estimate of crop losses due to *Striga* species in Africa is 40%, representing an annual loss of cereals worth US$ 7 billion (Mboob, 1986). More recently, Lagoke *et al.* (1991) estimated annual cereal grain losses associated with *Striga* damage at about 40% when averaged across Africa. According to Sauerborn, (1991) the area cultivated with cereals and actually infested by *Striga* is estimated at 21 million ha. in Africa and the overall loss in grain production amounts to 4.1 million tons. The loss of revenue from corn, pearl millet, and sorghum due to the parasite infection could total 2.9 billion US$ (Table 1.1).

Table 1.1: *Striga* caused loss of revenue[1] in Africa

	Actually (million US$)	Potentially (million US$)
Maize (76)[2]	140	1513
Millet (73)	82	676
Sorghum	89	760
Total	311	2949

Source: Sauerborn (1991)
1 Data in FOB (freight on board) prices, FAO (1988)
2 Number in parenthesis=FOB price (US$/ton)

In India some 25,000 tons of sorghum grain is lost annually in the state of Andhra Pradesh alone (Doggett, 1988). Within sub-Saharan Africa, Doggett (1975) estimated a 20-95% total yield loss for sorghum and millet in East Africa; while in countries such as Ethiopia and Sudan, losses of 65-100% are common in heavily infested fields (Ejeta *et al.*, 1992).

In Nigeria losses of 10-91% with an average loss of 35% in sorghum and maize yields have been attributed to *S. hermonthica* (Parkinson, 1985). In Cameroon 15-20% of overall production was affected by *Striga* species and the losses in certain cases were as high as 50-90% (Lagoke *et al.*, 1991).

In regions of Kenya alone, 80,000 ha cropped to maize are severely infested, causing an estimated US$ 10 million in annual losses to maize production (Hassan *et al.*, 1995). However the total area in Kenya affected by *Striga* is approximately between 300,000 and 500,000 ha, and occurs in the most populous parts of the country like Nyanza; (Kisumu, Siaya, Suba, Rachuonyo, Nyando, Homa Bay, Migori and Kehancha districts) Western; (Busia, Teso, Kakamega, Vihiga and Bungoma districts) and Coast (Kwale, Kilifi and Mombasa districts) provinces. (PASCON, 1993). The main crops affected in the areas are sorghum, maize, millet (*Pennisetum glaucum* (L) R. Br., upland rice (*Oryza sativa L.*) and sugarcane (S*accharum officinarum*).

Maize, the most important staple food crop in Kenya, is grown in all agricultural zones with production covering about 40 per cent of the total area under crop production (Ariga, 1996). *S. hermonthica,* within the lake Victoria basin has been identified by farmers as the most important constraint to maize production (Hassan *et al.*, 1995). Of the total uninfested area in this region, sixty five percent is considered to be environmentally suitable for *Striga* development (Ransom *et al.*, 1990). *S. hermonthica* also continues to increase in severity and spread in many parts of the country (Frost, 1995). The threat caused by *Striga* to cereal production is therefore enormous if the spread to these uninfested areas is not checked.

1.2. Biology of *Striga*

1.2.1. Botany

The genus *Striga* belongs to the dicotyledonous family, Scrophulariaceae (order tubiflorae) with about 42 species, of which only a few are economically important (Ramaiah *et al.,* 1983, Raynal-Roques, 1991). Botanically the genus is characterized by opposite leaves, irregular flowers with a corolla divided into a tube and spreading lobes, herbaceous habit, small seeds, and parasitism (Musselman, 1987). *S. hermonthica*, has pink to pink-white flowers and is found throughout the tropics and sub-tropics of the old world and Australia (Pieterse and Pesch, 1983). There are 25 to 60 *Striga* species (Dogget, 1988; Ejeta *et al.,* 1992; Musselman, 1980 and Pieterse and Verkleij, 1991).

1.2.2. Distribution and intensity

Striga species occur in many areas of tropical Africa, Asia and some parts of America with the greatest diversification in Africa (Raynal-Roques, 1991). They are found to a limited extent in open savannah, with large populations in agricultural fields under cereal production (Odhiambo, 1998). Three species cause the greatest damage in Africa: *S. asiatica* and *S. hermonthica* are mainly found on grains, such as sorghum, corn, pearl millet, rice and others, while *S. gesneroides* parasitizes legumes such as cowpea and peanuts. The occurrence of the economically important *Striga* species has been reported in 59 countries (Sauerborn, 1991) and is distributed in more than 40% of the arable land in

Africa south of the Sahara (Mboob, 1986). *Striga hermonthica*, is the most devastating of all *Striga* species (Odhiambo, 1998) and is widespread in most parts of Eastern Africa and the savannah areas of West Africa. (Parker and Riches, 1993).

1.2.3. Lifecycle and mechanism of parasitism of *Striga*

1.2.3.1. *Striga hermonthica* seed, conditioning and germination

Striga produces a large number of seeds (500,000 seeds/ plant) that mature at different times and can stay dormant in the soil for more than 20 years in the absence of a suitable host (Andrews, 1945). The seeds are minute (0.2 mm x 0.3 mm), have distinctive ridges on the surface and require an after-ripening period after harvest before they can germinate (Valance, 1950). The after-ripening requirement is an excellent adaptation for *S. asiatica* and *S. hermonthica* to the semi-arid tropics, preventing the parasite seeds from germinating at the end of the rainy season in which they were produced (Doggett, 1984). Germination takes place after seeds have been exposed to moisture (conditioning) for some time (Visser, 1989). This survival mechanism helps build a seed bank of *Striga* seed in tropical soils (Ejeta *et al.*, 1992). The moisture conditioning period for *Striga* may last 7-15 days under optimum moisture and temperature conditions (Ramaiah *et al.*, 1983). After this period, the seeds germinate if stimulated by root exudates of a host or non-host (Dogett, 1988). During conditioning, the seed become progressively sensitive to the stimulant, after which wet dormancy results in decreased germination (Visser, 1989). At temperatures of around 30°C seed germination occurs within 24 hours in the presence of a stimulant. Numerous natural and synthetic compounds have been reported to induce

Striga germination (Egley, 1972; Brown, 1965) of which strigol is the best known ((Ejeta *et al.*, 1992).

1.2.3.2. Haustorial Initiation and attachment

Chemotrophic behavior appears to assist the parasite in making contact with the host root. Upon contact, the tip of the radicle transforms itself into a haustorium, apparently due to a chemical secretion from the host root known as the haustorial initiation factor (Ramaiah *et al.*, 1983). Compounds, such as 2,6-dimethoxybenzoquinone (Lynn and Chang, 1990) are active as haustorial initiation factors in *S asiatica*, but the natural signal produced by the host has not been identified (Ejeta *et al.*, 1992). The radicle of the seedling secretes enzymes that assist its penetration into the host root (Kuijit, 1991). Once established, the haustorium forms a morphological and physiological bridge between the host and parasite (Ejeta *et al.*, 1992) and this completes the successful establishment of the parasite on the host (Ramaiah *et al.*, 1983). *Striga* spp. also produce secondary adventitious haustoria (Musselman, 1980), which penetrate the host root along with the primary haustorium (Ejeta *et al.*, 1992). The haustoria attach themselves to the same root to which the primary haustorium is attached or more frequently, to another nearby host root (Pieterse and Pesch, 1983).

1.2.3.3. Host parasite interaction

Once established, the parasite becomes a metabolic sink for the carbohydrates produced in the host, thus depriving the host of some of its photosynthates (Ramaiah *et al.*, 1983). The *Striga* seedling then grows parasitically underground for approximately 4-6 weeks, during which it wholly depends on the host for assimilates and water causing severe damage to the host plant (Pieterse and Pesch, 1983). On emergence from the ground, the *Striga* plants develop green leaves that produce their own photosynthates, however, there is continued flow of carbohydrates, water and minerals from the host (Ramaiah *et al.*, 1983). The period from conditioning to above ground emergence varies with the temperature, host crop and *Striga* species. Emergence of both *S. hermonthica* and *S. asiatica* occurs earlier in maize than in sorghum while *S. hermonthica* emerges earlier than *S. asiatica* (Ransom and Odhiambo, 1992).

Damage to the host from *Striga* far exceeds what might be expected based on the biomass of the parasite. The damage occurs through interference with movement of nutrients and water through the root system - and production of metabolic toxicants, that often leads to severe yield losses in the host (Eplee, 1983). *Striga* infestation increases growth inhibitors such as abscisic acid and fernasol but decreases cytokinins and gibberallins in the host plant (Ramaiah *et al.*, 1983). The growth inhibiting effects of *Striga* species on its host may be because of a toxin produced by the parasite (Press *et al.*, 1990). In maize and sorghum, *S. hermonthica* causes stunting, drought like leaf wilting, chlorotic lesions and leaf rolling even under high soil moisture supply (Graves *et al.*, 1989). Usually damage on heavily infested crop manifests as a chlorotic whorl before tassel formation prior to the emergence of the *Striga* flower stalks (Abayo *et al.*, 1998). Under severe infestation by *S. hermonthica*, there may be no yield and the host plant may be killed (Andrews, 1945). The biology and survival mechanisms of *Striga* make normal weed control practices available (hand weeding, crop rotation and trap cropping) to most small-scale farmers difficult.

1.2.4. Control strategies

Striga control has proved elusive in Africa due to diversity of farming / cropping systems. It has been almost impossible to develop one single *Striga* control package that can be extended throughout the region (PASCON, 1993). Effective control options must consider: (a) high number of *Striga* seeds produced (b) high levels of *Striga* seed in soils where *Striga* is a problem, and (c) long dormancy period (up to 20 years) of *Striga* seeds. The potential control options available include; host plant resistance/tolerance, chemical, biological and cultural practices.

1.2.4.1. Host plant resistance/tolerance.

The use of crop varieties that are tolerant or resistant to *Striga* species has been recommended as the most practical approach for resource-poor farmers (Kim, 1991). According to the definition of "resistance" and "tolerance" (Ejeta *et al.,* 1991), a crop genotype that, when grown under *Striga* infestation, supports significantly fewer *Striga* plants and has a higher yield than a susceptible cultivar is designated "resistant". "Tolerant" genotypes stimulate germination of *Striga* seeds and support as many *Striga* plants as do susceptible genotypes, without showing a concomitant reduction in grain production or overall plant productivity.

Some *Striga* resistant sorghum (Framida, SRN-39,) and maize varieties (S35, CS-54, CS-95) have been identified (PASCON, 1993). SRN-39, which exhibits broad-based resistance across *Striga* species and strains, is drought resistant and has good food attributes has been officially released for commercial cultivation by farmers in *Striga* endemic areas of Sudan (Ejeta *et al.,* 1992). Though resistance in maize is still elusive, some progress has been made in this area due to resistance in wild varieties of maize like teosinte (Odhiambo, 1998). Also, though resistance in maize has not been documented, field observations and surveys indicate that some maize lines grown by farmers are tolerant to *Striga* and are thus able to give some yield even under a high *Striga* infestation (Frost, 1995). Some tolerant maize varieties include 9022-13, 9021-18 and 7044-15 for West and Central Africa (PASCON, 1993). A maize genotype (B37), which was found to be a low stimulant producer, has also been identified (Ejeta *et al.,* 1992). In Kenya, some local maize land races (Rachar and Nyamula) have been identified as having some resistance to *Striga* (Odongo, 1997). KSTP94, a variety developed from land races from the farmers in *Striga* infested areas in lake Victoria basin has been selected for it's tolerance to *Striga* attack. Studies conducted show KSTP94 to be superior to available maize hybrids and has been selected for improvement. In West Africa continued research at IITA based on symptomology is trying to identify not only maize genotypes, but also host genotypes whose resistance is due to other resistance mechanisms (Berner *et al.,* 1993).

1.2.4.2. Biological control

There is insufficient data on the kinds of organisms that could be considered in a potential biological control program for *Striga* (Musselman, 1983). However, research at IITA has found that biotic agents cause pre-reproductive wilting of *Striga* plants (PASCON, 1993). In addition to wilts, several fungal and bacterial diseases have been identified on *S. hermonthica* causing symptoms such as tip die back, stem and leaf lesions, and floral necrosis (Berner *et al.,* 1993). Promising fungi (*Sclerotium* and *Fusarium*) and bacteria (*Pseudomonas* and *Xanthomonas)* have been identified (Berner *et al.,* 1993). Gall forming insects (*Smicronyx* species), the borers (Lepidopterus) and weevil species are also promising control agents (Ariga, 1996).

Biological control could give a lasting effect as its relatively cheap and does no harm to the environment. It could be a very attractive method for solving the *Striga* problem (Pieterse and Pesch, 1983) and especially with regard to the small-scale African farmer. However, a lot still remains to be done in seeking a lasting biological control solution that farmers in Africa could easily apply in the management and control of *Striga* infestations

1.2.4.3 Chemical control (Herbicides)

The use of herbicides in *Striga* control saves on labor costs (Ariga, 1996) and herbicides such as trifluralin (Treflan) (2,6-dinitro-N-N-dipropyYl-4- (triflouryethyl), benefin, fluchloralin and pendimethalin (Anon, 1983; Ross and Lembi, 1985) have been found to be effective. Dicamba was found to be effective against *S. asiatica* in the USA (Eplee and Norris, 1987). In Kenya it was effective when the time of application coincided with the peak of *Striga* hermonthica germination and attachment. However, it was not cost effective as it did not provide persistent and continual control (Abayo *et al.,* 1998). Several other herbicides and combinations of herbicides have been shown to give good control of *Striga* (Abayo *et al.,* 1996; Babiker *et al.,* 1990). Imazapyr as a seed treatment was reported to increase harvest index by 17% when maize plants in *Striga* infested soils were kept insect and disease free using insecticides and fungicides (Abayo *et al.,* 1998).

Complete control of *Striga* could be achieved at affordable cost ($ 5 ha^{-1}) to farmers in subsistence conditions.

The use of herbicides against parasitic weeds is restricted because of the negative effects on host crops. Many like 2,4-D and related compounds such as MCPA, which kill *Striga* without damaging the grassy host, cannot be used in mixed cropping with broad leaf crops (Pieterse and Pesch, 1983). The polycultural systems in most small-holder situations such as intercropping, mixed cropping and relay cropping limit the choice of herbicides that can be used to control weeds without injuring the crops. The few herbicides that may be used in polycultural systems have a narrow range of activity and are too expensive for the ordinary farmer.

1.2.4.4. Soil fertility management

There are strong indications that the use of nitrogen fertilizers decrease *Striga* infestation and their inclusion is often recommended in integrated control programmes (Verkleij *et al.,* 1993). Various investigations on the effect of nitrogen fertilizers on development of *Striga* suggest that inhibition could be related to germination. *In vitro* urea and ammonium sulphate have been shown to decrease the number of germinating seeds and the length of the *Striga* radicals (Pesch and Pieterse, 1982). Parker (1984) proposed that the effect could be related to the host's partitioning of resources between the root and shoot. He found that the root/shoot ratio increased as a result of *Striga* attack but this effect was significantly reduced in the presence of ammonium nitrogen. Host plants produce a smaller quantity of stimulant in the presence of N fertilizers (Raju *et al.,* 1990; Pieterse and Verkleij, 1991). Although it is uncertain how nitrogen inhibits *Striga* development under field conditions, three effects have irrefutably been shown *in vitro:* (Pieterse and Verkleij, 1991):

(i) an inhibitory effect caused by ammonium-nitrogen on germination and radicle length in *Striga* .

(ii) an inhibitory effect of ammonium-nitrogen and nitrate-nitrogen on stimulant production by the host crop.

(iii) a toxic effect caused by ammonium nitrogen on *Striga* development following attachment.

From the above it is possible that N-fertilizer could be bringing about an effect on the early development of *Striga* (Verkleij *et al.,* 1993). It is generally evident that wherever *Striga* is a problem there is likely to be some deficiency in the soil that needs addressing. Increased incidence of *Striga* in tropical countries has been attributed to a decline in soil fertility and intensity of land use (Vogt *et al.,* 1991). However most of the small-holder farmers in developing countries who produce cereals for home consumption cannot afford the price of artificial inorganic fertilizers, and moreover, the availability and distribution of those fertilizers is not guaranteed (Ariga, 1996). If mineral fertilizers are not available, then alternative means of improving soil fertility (farmyard manure or use of leguminous crops) should be considered. The use of leguminous crops has been identified as one of the potential methods available to improve soil fertility when most of the residues are returned or left in the fields (Odhiambo, 1998). Inclusion of legume crops in cereal or rotation mixtures in Africa still remains a major potential approach to manage cereal crops in the *Striga* zone (Berner *et al.,* 1993).

1.2.4.5. Agronomic control

Agronomic control options involving rotation, trap cropping, catch cropping, hand pulling, and hygienic procedures of various sorts all have been shown to reduce *Striga* infestations. Some of the agronomic options available include:

1. *Manual weeding (hand pulling)*

Hand pulling has been shown to reduce *Striga* incidence (Doggett, 1988), but the timing is usually a major problem for farmers. Many allow the parasite to flower and set seed before uprooting the stems. Since *Striga* produces enormous amounts of seed their efforts become of little significance. Furthermore once they uproot these plants with already mature seed, they place them on the roads and footpaths instead of burning them and the seeds eventually find their way back into the farms. In some cases the choice of crops available is often too limited, or the cropping season too short, or labour unavailable or unwilling for hand pulling work (Parker, 1983). Continuous hand pulling for up to 4 seasons is required before there is any significant reduction of *Striga* seed bank.

2. *Catch cropping*

"Catch crops" are crops that are parasitized by *Striga* but which are destroyed before the parasite sets seed. Catch crops are usually planted at high densities than is normal for crop production in order to induce greater germination of *Striga* seeds (Oswald *et al.,* 1997). After the parasite has germinated and emerged the catch crop is harvested or destroyed before the parasite sets seeds (Pieterse and Pesch, 1983). The crop can be used as forage or ploughed into the soil to improve soil fertility. This way reproduction of *Striga* is prevented as no *Striga* seeds return to the soil (Odhiambo, 1998). Sudan grass (*Sorghum halapense L.*) has been identified as an effective "catch crop" for *S. hermonthica* (Pieterse and Pesch, 1983, Oswald *et al.,* 1995).

3. *Crop rotation with "trap crops"*

Crop rotation is a farming system where different crops are grown in alternate seasons in a given field. This method of crop production is intended to help improve soil fertility and prevent the build up of dangerous diseases and pests (Odhiambo, 1998) 'Trap crops' or 'false host' crops stimulate germination of *Striga* or root parasites without themselves being parasitized (Visser and Beck, 1987). Usually in the case of *Striga* , the system involves growing of a trap crop in one year or season followed by maize or any other cereal thus reducing *Striga* seed bank in the soil. Major trap crops recommended for use against *Striga* include cotton (*Gossypium hirsutum* L.), cowpea (*Vigna unguiculata*), soybean (*Glycine max L.*), groundnut (*Arachis hypogeae L.*) and sunflower (*Helianthus annus L.*) (Ariga, 1996). Viable *Striga* control would be rotation of resistant cereal varieties with trap crops previously selected for high *Striga* seed germination stimulation (Ariga, 1996).

4. *Mixed cropping (intercropping)*

Inter-cropping, particularly of cereals with food legumes is a common practice in many parts of the semi-arid zones (Carsky *et al.,*1994). Intercrop cultivars which produce abundant *Striga* germination stimulant but fail to produce haustorial initiation factor for *Striga* are uniquely useful in *Striga* control (Butler, 1995). Careful selection of those cultivars with enhanced *Striga* germination stimulant production would play a major role in diminishing the *Striga* seed population in the soil.

The most encouraging reports on the benefits from mixed cropping on reducing incidence of *Striga* include those from Salle *et al.*, (1987) who observed reduced *S. hermonthica* in pearl millet when they interplanted four rows of groundnut to one of millet. Carson (1998 a) also found that the density of emerged *Striga* plants, and soil temperature were reduced when sorghum was associated with groundnuts. He also found that groundnut planted within sorghum rows had a much greater effect in reducing *S. hermonthica* than did interplanting with alternate rows. Parker (1991) suggested that shading and reduced temperature of the emerged parasite could be the most important effect from intercropping. Nitrogen fixed and released by some intercrops like cowpea (Eaglesham *et al.*, 1981) is also thought to contribute to *Striga* suppression in inter-cropping since the amount of available nitrogen apparently affects *Striga* density (Pieterse and Verkleij, 1991).

1.3. *Striga* problem in Kenya

Striga hermonthica is widely distributed in Western Kenya where it occurs at altitudes of between 1100 meters above sea level (masl) to 1600 masl (Odhiambo, 1998). It affects production of maize, sorghum, rice and sugar cane (Kiriro, 1991). Farmers in this region have identified *Striga hermonthica* as the most important constraint to maize production (Hassan and Corbett, 1993). Yield loss can range from 20% in low infested areas to 100% where infestations are high (Odhiambo, 1998).

Despite much research work on control of *Striga* in Kenya, achievements so far are of little benefit to the Kenyan farmer. Most strategies developed for *Striga* control have not been adopted by the predominantly small-holder farmers (Abayo *et al.*, 1997) and low input control techniques that can be combined in integrated management systems are seldom available. There is also a general lack of knowledge on *Striga* biology on the part of the farmers and hence they do not understand the infection and development processes of the parasite. The conventional methods of controlling *Striga* such as physical eradication (hand pulling) and herbicides have also not been successful because of the insidious physiological relationship of *Striga* with its host (Dogget, 1988).

1.4. Fodder legumes: an option for *Striga* control in Kenya

Though a lot of work has been done on intercropping and crop rotation of food legumes with cereals in order to reduce *Striga* infestation, little has been done on the role fodder legumes can play in the management of *Striga* . Whereas fodder legumes are becoming increasingly important in Nyanza and Western provinces of Kenya as farmers shift to mixed farming systems, little has been done to encourage them to grow fodder legumes both as livestock feed and for weed management. Much of the land currently abandoned due to high *Striga* infestations could be converted to crop production with improved fallow using herbaceous fodder legumes. For example, experiments carried out at the International Centre for Insect Physiology and Ecology (ICIPE) in Nyanza province, suggest that *Striga* does not parasitize maize when grown together with silver leaf

Desmodium (ICIPE Research Bulletin 2000) probably due to smothering of the parasite, or production of a *Striga* germination-inhibiting chemical by the *Desmodium* roots.

Fodder legumes can be grown as intercrops, in rotation with maize or any other cereal crop, or simply as "cover crops". "Cover crops" have long been used to reduce soil erosion, improve soil structure, fix nitrogen and alter physical and chemical soil characteristics (Worsham *et al.,* 1995). It is also possible that the fodder legumes could have allelopathic traits, which could be important in the control of weeds as noted in some legumes (Lehman, 1993, Worsham, 1989). *Mucuna* for example has been found to give good control of itchgrass (*Rottboellia cochinchinensis*) when intercropped with maize (Valverde *et al.,* 1999) and itchgrass suppression also usually corresponded with increased grain yield.

Apart from controlling weeds the fodder legumes are good sources of green manures, which are increasingly becoming important for restoring soil fertility especially in small-holder systems where inorganic fertilizers are inaccessible due to their high cost. *Mucuna* for example has demonstrated great potential for supplying N to the soil (Legume research project bulletin issue no.3). Interestingly, *Mucuna* is not new in Western Kenya as farmers in Maseno have already encountered the wild varieties, and have used them before for beverage, soil fertility improvement and fodder. (Legume research project bulletin issue no.3)

1.5 Justification and objectives

1.5.1 Justification

Farmers in Western Kenya are increasingly turning to more cereal cropping especially maize after the decline of production of sugar cane and cotton. Most of these small-holder farmers also grow the cereals in association with other crops, mainly legumes as they try to maximize productivity of land. Many of the food and fodder legumes have great potential for weed control as "trap crops". Nitrogen fixed by the legumes might also interact with the *Striga* growth since the amount of available nitrogen apparently affects density (Pieterse and Verkleij, 1991). Another more dicisive factor could be the lowering of soil temperatures due to soil shading of the intercrops which might interfere with *Striga* germination. This will provide an effective and low input option for *Striga* control through intercropping and / or crop rotation of cereals with legumes. It is possible to incorporate many of these intercrops in an integrated management system for *Striga* control. Such a system would usually include, host plant tolerance and resistance, improved soil fertility management and a cereal-legume rotation and inter-cropping in which the legume acts as a trap crop (Kim *et al.,* 1994) to reduce the *Striga* seed bank in the soil.

A major problem in implementing intercropping or rotation cropping as an option for *Striga* control is acceptance by farmers. Farmer acceptance of any inter-crop will usually depend on its economic value. One of the options then would be to introduce fodder legumes as most farmers also keep dairy animals. Fodder legumes species selected for their ability to suppress *Striga* yet enhance soil fertility and provide livestock feed for enhanced milk production would be uniquely useful. Since the fodder legumes are low input, farmers are most likely to adopt the technology. They can play a big role in helping reclaim vast areas where maize production has ceased or is very low due to ultra high levels of *Striga* infestations. Some potential multipurpose legumes (*Desmodium*, *Stylosanthes* and *Mucuna*) that have been screened by the Legume Research Project will be tested for their effectiveness in *Striga* control.

1.5.2 General Objective: The objectives of this study were to develop a cereal/ foddder legume combination for management of *Striga* in order to increase maize yields of the small holder subsistence farmer in Western Kenya.

1.5.2.1 Specific Objectives

i) To test *in vitro*, the ability of fodder legume species to stimulate germination of conditioned *S. hermonthica* seed.

ii) To determine the effect of a fodder legume/maize- inter-crop on *S. hermonthica* infestation on maize and yield of maize.

iii) To determine effectiveness of the fodder legume/maize undresowing system on the parasite seed bank in the soil, *Striga* parasitism and maize yield.

1.5.3 Experimental approach

Laboratory experiments were set up to compare ability of the roots of different fodder legume species (*Desmodium*, *Stylosanthes* and *Mucuna*) to stimulate conditioned *Striga* seed and to compare them with the host crop maize and a food legume, cowpea. Pot experiments were also set up in order to study the below ground effect of the roots of the fodder legumes on *Striga* attachment on maize roots and *Striga* seed depletion. In addition a field experiment was initiated to evaluate the effect of the fodder legumes on *Striga* infestation and maize yield. Data on *Striga* emergence, maize grain yield, legume biomass and *Striga* seed numbers in the soil was collected.

1.5.4 Experiments conducted

The following experiments were conducted:

a) A laboratory incubation in petri dishes and a root chamber experiment.

b) A greenhouse pot experiment.

c) A field experiment.

The results and discussion of the above experiments are reported in chapters 2,3 and 4 respectively. The overall discussion and conclusions of the study are summarized in chapter 5.

1.5.4.1 Legumes tested

Three pasture legumes, *Mucuna pruriens*, *Stylosanthes guyanensis* and *Desmodium intortum,* and a food legume, cowpea were investigated. A local, hybrid H511 maize variety was used as a control. Seeds of the legumes were acquired from farmers within the locality. Maize seed was bought from the local seed company.

1.5.4.2 Experimental site characteristics

All experiments were conducted at the Kenya Agricultural Research Institute (KARI) National Sugar Research Centre-Kibos near Kisumu. The station lies between a high-populated area adjacent to Kisumu town and the large estates used for sugar cane cultivation. Kibos is situated on the equator (latitude 0° 04S) (Table 1.2) and consequently day-length does not vary significantly during the season. Site elevation is 1214 masl. The site is naturally infested with *Striga* , which also parasitizes sugarcane. Kibos has a bimodal rainfall distribution (1200-1580 mm per year), most of which falls between March and June; the second peak, occurring between October and January, is less reliable (Fig.1.1). Soils are composed of a layer of sediment eroded from adjacent hill areas overlying a black cotton soil. These soils are imperfectly drained, very deep, very dark grey to black, subject to cracking when dry, gravelly clay to clay with calcareous deeper gravelly sub-soil in some places.

Table 1.2. Summary of the geographic information of the KARI National Sugar Research Centre, Kibos, Kenya.

Parameter		
Altitude above sea level (masl)		1214
Location bearing (latitude/longitude		0° 02" S/34° 49E
Length of growing period per season-	1st rains	>170 days
	2nd rains	105-120 days
Annual precipitation in mm (range)		1,200-1,580
Mean number of dry months		4
Mean annual (min-max) temperature(°C)		15.4-28.9
Potential evapotranspiration per year(mm)		2,150
Soil type		vetro-eutic planosol
AEZ		LM2

Masl-metres above sea level
AEZ-agroecologocal zone.
LM2-lower midland sugarcane agroecological zone
Adapted from Odhiambo (1998)

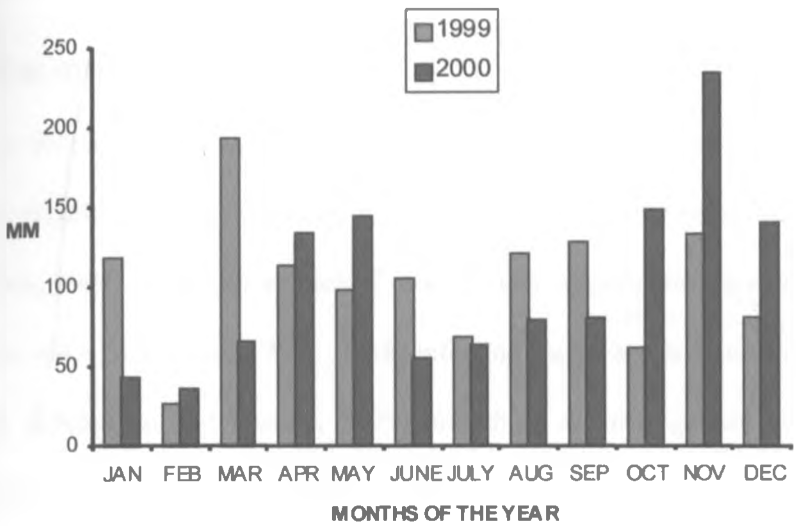

Figure 1.1. Monthly total rainfall for the period 1999 and 2000 at Kibos, Western Kenya.

Data source: KARI-National Sugar Research Station, Kibos.

CHAPTER 2

STRIGA SEED GERMINATION BY FODDER LEGUME ROOT EXUDATES

2.1 INTRODUCTION

Striga is propagated through seed and control methods which affect seed germination or seedling establishment are expected to be more effective than those affecting later stages (Okonkwo, 1991). Previous studies of root parasitic angiosperms have mostly used plants grown in soil (Lane *et al.,* 1992). Early infection stages are difficult to observe with this medium, (Okonkwo and Nwoke, 1975) and thus, *in vitro* growth systems have been developed to investigate the parasitism of *Striga.*

Two of the most promising methods of *Striga* control namely (a) inducing germination in the absence of host plants ("suicidal" germination) and (b) developing resistant varieties of the hosts are mainly concerned with seed germination and seedling establishment stages (Musselman, 1980; Ramaiah, 1979). One of the most effective methods of *Striga* seed demise applied in the USA was the use of ethylene gas (Eplee, 1975). Ethylene was injected into the soil when *Striga* seeds were pre-conditioned causing them to germinate. In absence of a suitable host crop the germinated seeds died (suicidal germination). Other methods involving demise of *Striga* seed from the soil, include fumigation, e.g. methyl bromide (Eplee and Langston, 1971, Eplee and Norris, 1987), trap and catch crops.
Application of these control methods requires a thorough knowledge of the physiology and biochemistry of seed germination and seedling growth, including the efficacy of germination stimulants from a wide variety of host and non-host plants (Okonkwo, 1991).

Many crop cultivars are capable of inducing germination of *Striga* seed without promoting attachment. Such "trap crops" which induce suicidal germination of *Striga* seed are important in helping reduce the *Striga* seed bank in the soil.

A rapid methodology developed at IITA to screen germplasm for potent parasite seed germinating ability has identified cultivars and accessions of several grain and forage legume species as efficacious in stimulating *S. hermonthica* seed germination (Berner *et al.*, 1997). With this initial screening, promising material can then be tested under field conditions and, if found to be good in depleting the *Striga* seed bank, they can be introduced for adoption into farmers' intercropping or rotation systems.

The objective of this experiment was to test the roots of different fodder legume species for their ability to stimulate germination of conditioned *Striga* seeds. Two different laboratory techniques were used: (a) a petri dish technique and (b) a root chamber technique.

2.2 MATERIALS AND METHODS

2.2.1 Petri-dish (cut root or ring) laboratory study

This technique involves conditioning *Striga* seeds on glass micro-fibre filter paper and then stimulating them to germinate using exudates from the root cuttings of the test species. The test species were screened using a technique developed at IITA (Berner *et al*, 1996), which is claimed to have good differentiating ability and to give excellent reproducible results. The procedure includes:

2.2.1.1 Growing of test plant seedlings

Stored surface-sterilized test plants seeds and the standard check (maize var. H511) were grown in wooden trays containing sterile sand. These seeds were drilled in a 1-m row to provide enough root cuttings to evaluate their ability to stimulate conditioned *Striga* seeds to germinate. After 4 weeks of growth, the seedlings were gently uprooted and the sand was washed off their root surfaces using sterile distilled water. These roots were then cut into 1-cm lengths using a clean sterile scalpel. For each species, one gram (1 g) of cuttings were placed in a circular hollow well (ring) made of aluminium foil, (about 2 cm diameter and 1.5 cm high) placed at the centre of a 9 cm diameter petri-dish with underlying Whatman No. 1 filter paper.

2.2.1.2 Conditioning of *Striga* seed

Striga seeds, which had been previously surface-sterilized, were placed on small 6 mm diameter discs of glass fibre filter paper (GF/A Whatman) prepared using a paper-punch. The discs were previously placed on moistened Whatman No. 1 filter paper in 9 cm diameter sterilized petri dishes and the *Striga* seeds were then sprinkled onto the discs (about 25 seeds per disc). Petri dishes were covered with lids and edges sealed with parafilm to keep the medium moist. The Petri dishes were placed in a dark incubator at a temperature of 29°C for 14 days to condition the *Striga* seeds. This conditioning period coincided with the 4 weeks growth period of the test plants. The experiment consisted of 6 treatments (a) *Desmodium*, (b) *Stylosanthes,* c) *Mucuna,* (d) cowpea, (e) maize (control) and (f) pure distilled water (negative control) in a completely randomized design replicated three times

2.2.1.3. Stimulant testing for *Striga* seed germination

Roots of the 4-week old test plants were cut and placed in an aluminum ring in the centre of the petri-dish described above (Figure 2.1). Discs with conditioned *Striga* seed were placed radially outwards from the centre ring as shown in Figure 2.1. Four radii of the discs were formed; each radius contained 4 discs placed edge to edge with the first disc touching the edge of the well. This arrangement enabled an evaluation of the effect of distance from stimulant source on *Striga* germination. Sterile distilled water (2ml) was added to the roots in the well.

The petri dishes were then incubated under the same conditions as those for conditioning *Striga* seeds. After 48 hours the total number of *Striga* seeds and the number of germinated seeds and on each disc were counted. The disc closest to the central ring was considered as "distance 1", the next as "distance 2", and so on. Both distance of discs and germination of *Striga* seed were recorded. Since each disc was 6 mm in diameter, distances 1 to 4 were taken to be from the edge of the centre ring to the middle of each disc, that is, 3 mm, 9 mm, 15 mm and 21 mm respectively. For each cultivar the experiment was repeated three times and total germination for each petri dish averaged and data was entered into a SAS programme for analysis. Means were compared using Duncan's multiple range test.

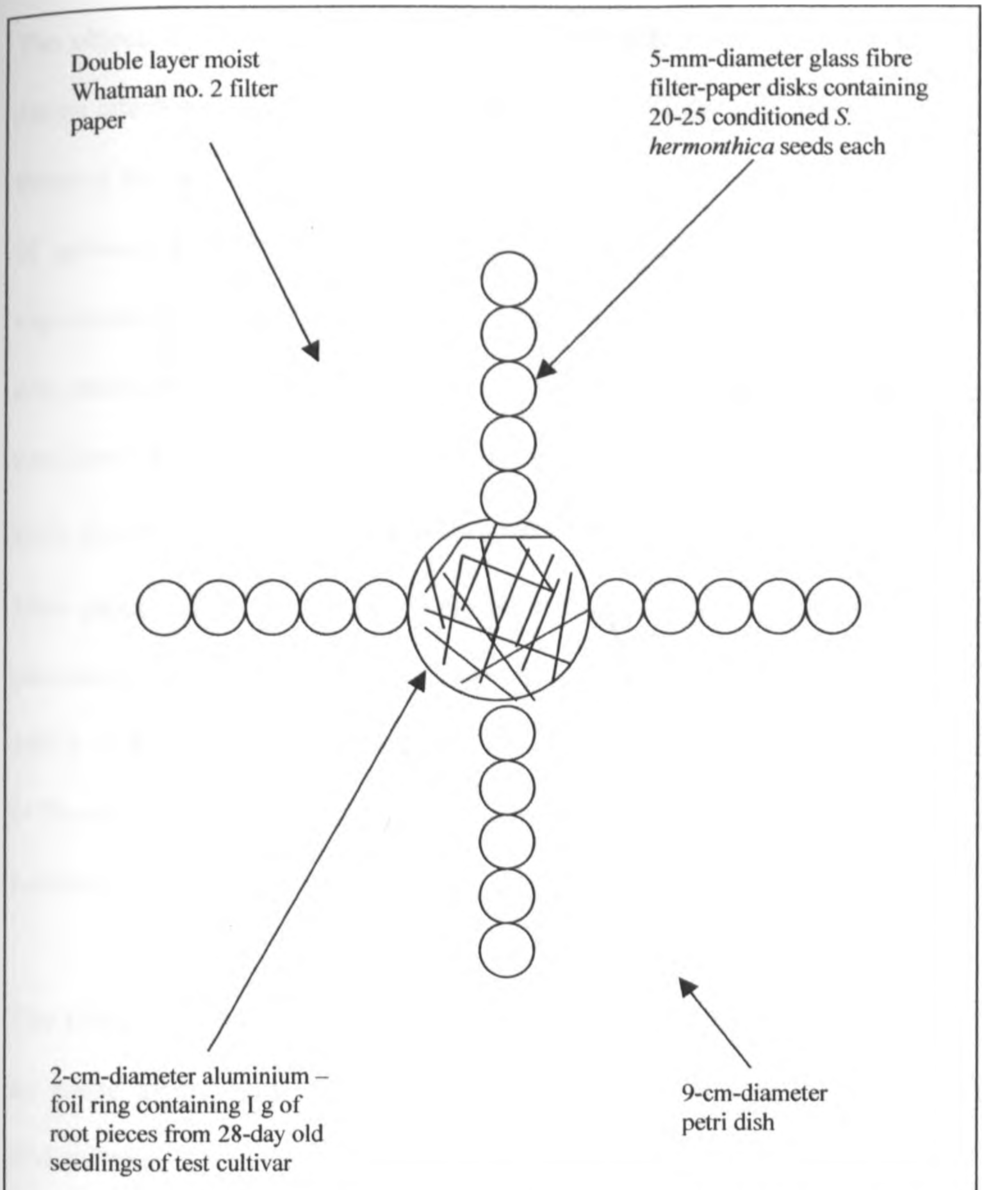

Figure 2.1 Diagram of setup for testing efficacy of different cultivars in stimulating *Striga spp.* seed germination.

2.2.2 Laboratory root chamber technique

The objective of this experiment was to observe effect of the legumes on the process of *Striga* attachment (Linke and Vogt, 1987), and to compare the root chamber results with those of the petri dish technique. The use of root chambers allows continuous observation of germination and early development of root parasites, which is not possible in pot experiments or under field conditions. The root chambers used had backs and sides of non-transparent hard plastic (PVC) whereas the front was closed with a transparent plexiglass (Figure 2.2). Their dimensions were 21 cm high x 7 cm wide x 3 cm thick. In each chamber, *Striga* seeds were sprinkled evenly by hand onto moist glass microfibre filter paper (GF/A Whatman) and placed in the root chamber facing the plexiglass. The remaining cavity between the pexiglass and back of the PVC plastic was then filled with 100 g of dry steam sterilized sand and moistened by adding about 17 ml of distilled water (17% saturation). The chamber was maintained at 29°C for 14 days in a dark incubator to condition the *Striga* seeds.

The following treatments were introduced into separate root chambers as described below: a) maize alone, b) maize with *Mucuna*, c) maize with *Desmodium*, d) maize with *Stylosanthes*, e) maize with cowpea, f) *Mucuna* alone, g) *Desmodium* alone, h) *Stylosanthes* alone and i) cowpea alone. There were three replications in a completely randomised design and the experiment was done once. Pre-germinated seedlings of susceptible maize (H511) and legume forages were transplanted into the chamber between the filter paper and the plexiglass 5 days after the start of *Striga* seed conditioning. The chambers were then wrapped in black polyethylene sheets and placed obliquely to encourage the "host" roots to elongate along the plexiglass and to avoid growing through the filter paper. The chambers were kept in wire-meshed cabinets at ambient temperatures (about 30/20°C day/night, respectively). Germination was assessed 2 weeks after transplanting using a dissecting microscope at a magnification of 20.

The evaluation area was along the main root, which was divided into 1-cm lengths starting from the root crown. Small 1 cm^2 squares were drawn on the glass lid using a water-soluble marker. *Striga* seeds that were found in the marked area across the main root were used for observation. Total and germinated *Striga* seeds or seedlings were counted and percent germination calculated. Any attachments taking place were also noted. Data was analysed using SAS and means separated using Duncan's multiple range test ($p \leq 0.05$).

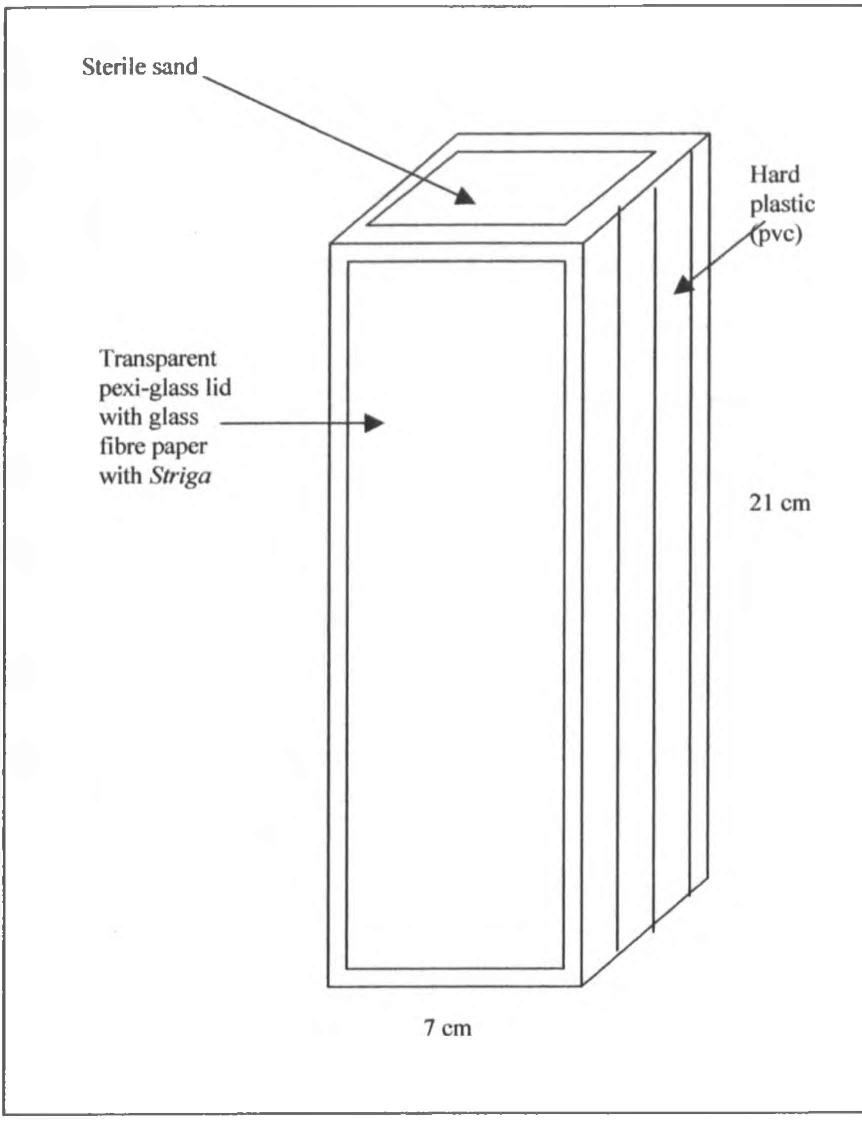

Figure 2.2. An illustration of the root chamber technique

2.3. RESULTS

2.3.1 Petri dish technique

Plants differed significantly in their ability to stimulate *Striga* seeds to germinate using the petri dish technique (Figure 2.3 and Appendix 1). Root exudates of the fodder legumes, green leaf *Desmodium*, *Mucuna* and *Stylosanthes* induced a higher number of *Striga* seeds to germinate compared to maize or cowpea. Root cuttings of *Stylosanthes* were most effective in stimulating *Striga* seed germination. *Mucuna* and *Desmodium* root cuttings did not differ in ability to germinate *Striga* seed. Cowpea stimulated significantly less *Striga* to germinate than maize. Effect of distance from stimulant source was significant (Figure 2.4 and Appendix 1). *Striga hermonthica* seed germination did not differ significantly between distance 1 (3 mm), 2 (9 mm), 3 (15 mm) and 4 (21 mm) but differed between distance 5 and the first 3 distances 1, 2 and 3. *Striga* seed germination did not differ between distance 5 and distance 4.

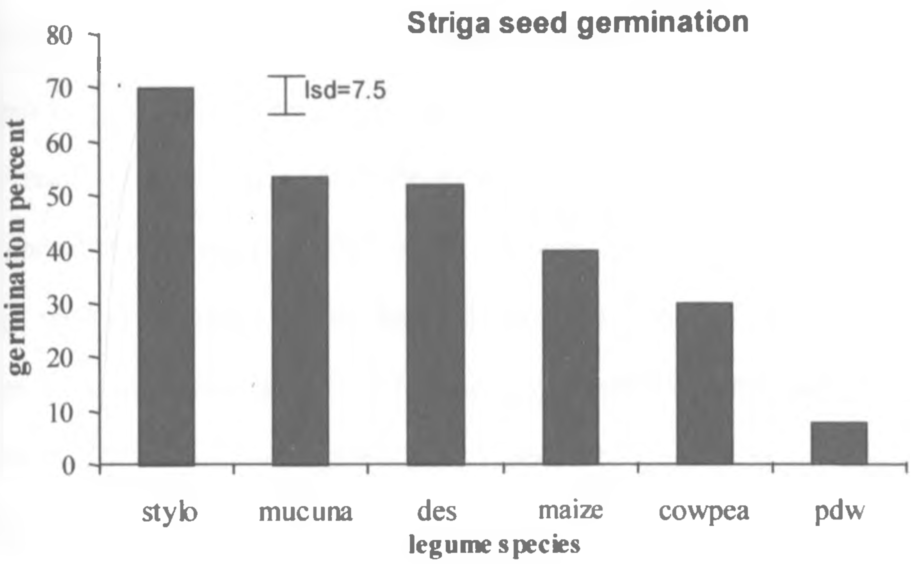

Figure 2.3 Germination of *Striga* seeds using the petri-dish technique. Key stylo-*Stylosanthes*, des-*Desmodium*, pdw-pure distilled water.

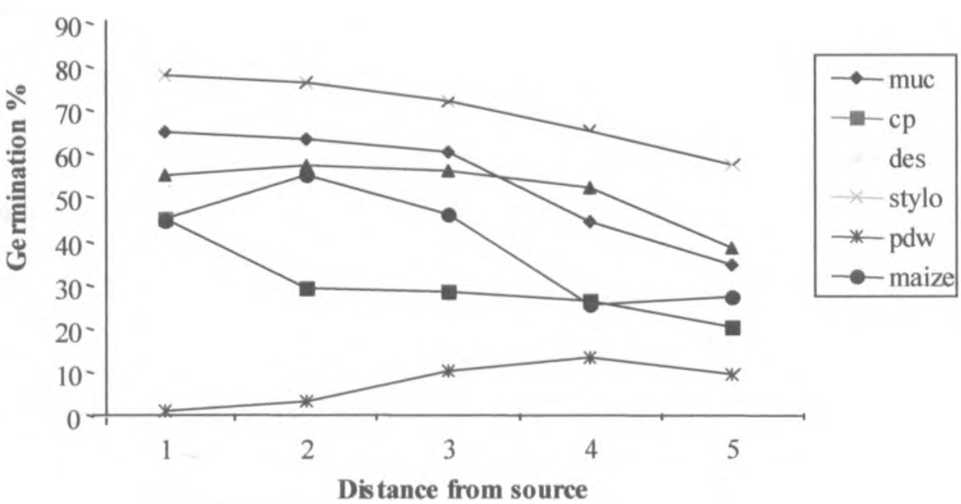

Figure 2.4 Effect of distance on *Striga* germination in the petri-dish technique. (key: muc-*Mucuna*, des-*Desmodium*, stylo-*Stylosanthes*, pdw-pure distilled water, cp-cowpea)

2.3.2 Root chamber technique

Effect of legumes was significant on *Striga* seed germination (Table 2.1 and Appendix 2). *Desmodium* and *Stylosanthes* developed very small root systems due to the small size of their seed. The slow growth made it difficult to compare them with maize which germinated at the same time. *Desmodium* and *Stylosanthes* grown alone did not stimulate *Striga* seed to germinate. When they were grown together with maize, the number of *Striga* seed that germinated did not differ significantly from the number of seeds that germinated when maize was grown alone (Table 2.1). *Mucuna* grown alone germinated less *Striga* seed than when it was grown together with maize. Cowpea grown alone or together with maize germinated significantly lower number of *Striga* seeds than all the other combinations. Cowpea grown together with maize however, germinated less *Striga* than the other legumes grown together with maize or the maize control.

Due to the generally low number of *Striga* seeds that germinated using the root chamber technique very few *Striga* germlings attached to the roots of the different species. *Mucuna,* was the only legume that had *Striga* attachments when planted alone. There was no significant difference in number of attached *Striga* germlings when maize was grown alone or associated with fodder legumes or cowpea.

Table 2.1 Mean percent germination of *Striga hermonthica* seed and attachments of *Striga* germlings using the root chamber technique.

Species	*Striga* seed germination (%)	Number of *Striga* Attachments
Maize/ *Mucuna*	19 a	5 ab
Maize/*Desmodium*	17 ab	4 ab
Maize	16 ab	6 a
Maize/*Stylosanthes*	15 ab	4 ab
Mucuna	13 b	2 c
Maize/cowpea	8 c	4 ab
Cowpea	6 c	0 d
Desmodium	0 d	0 d
Stylosanthes	0 d	0 d

[a] **Values followed by the same letter (s) down the column are not significantly different at ($p < 0.05$).**

2.3.3 Comparison of petri dish and root chamber techniques.

Petri-dish technique gave significantly higher percent germination of *Striga* than the root chamber technique for all plant species (Figure 2.3 and Table 2.1). All the test species stimulated less than 20% of *Striga* seeds in the root chamber experiment while in the petri dish technique germinations of up to 70 % as in the case of *Stylosanthes* were recorded. Whereas *Stylosanthes* stimulated the highest germination of *Striga* seeds in the petri dish technique it did not stimulate any in the root chamber technique. On the contrary maize did not perform very well under the petri dish technique but ranked among the highest in the root chamber technique. *Desmodium* and *Stylosanthes* did not stimulate any *Striga* seed in the root chamber technique and *Striga* germination when they were interplanted with maize was most probably due to the effect of the maize and not the legumes. Cowpea ranked lowly in both techniques but stimulated more seeds to germinate than *Desmodium* and *Stylosanthes* in the root chamber experiment.

2.4.4 DISCUSSION

The petri-dish experiment suggests that the amount and /or efficacy of stimulant compound exuded by the roots of test plants followed the order:

Stylosanthes > *Mucuna* ≈ *Desmodium* > maize > cowpea

Though the actual stimulant and rate of exudation from plant roots was not determined, it is possible the species differed according to the concentration of the stimulant in the roots. Oliver and Leroux, (1992) tested different cultivars of sorghum for the stimulation of *Striga* seeds and concluded that cultivars tested differed according to the concentration of sorgoleone present in the exudate on a root dry biomass basis. Stimulation of *Striga* seeds differed between the first three distances 1, 2, and 3, and distance 5. This suggests a dilution effect of *Striga* germination stimulant. Possibly the concentration of stimulant from the roots of the different species becomes less concentrated as it moves outwards to a minimum beyond which germination of *Striga* seed starts decreasing. Though *Striga* will usually germinate in response to very low concentrations of stimulant, excessively low concentrations may result in low germination. Mobility of *Striga* stimulant through the media may also be due to differences in molecular structure.

Poor legume root growth in the case of *Stylosanthes* and *Desmodium* obscured treatment effects in the root chamber technique. *Striga* germination when maize was grown in mixture with either of these fodder legumes was probably as a result of the maize and not the fodder legume since they did not stimulate *Striga* seed to germinate on their own. *Mucuna* developed a larger root system than the other cultivars. *Striga* germination was higher where *Mucuna* was grown together with maize as compared to when it was grown alone. This was probably as a result of increased stimulation from increased production of germination stimulant from combined maize and *Mucuna* roots. The root exudates could be complementary in parasite seed germination resulting in increased germination when *Mucuna* and maize are grown together. However, the effects of maize and *Mucuna* together were not additive. This probably suggests that increased amount of stimulant from root exudates will probably increase germination of *Striga* seed to an optimum beyond which further increase has no effect on *Striga* seed germination.

Cowpea grown together with maize however, stimulated less *Striga* germination than the other legumes grown together with maize. Possibly, combined root exudates of maize and cowpea have lower *Striga* stimulation ability as a result of increased germination inhibitory substances when the extracts of cowpea and maize are combined. Ariga, (1996), suggested existence of *S. hermonthica* germination inhibitors in aqueous cowpea extracts. In his experiments, *Striga* germination increased as the concentration of the extracts increased to an optimum beyond which germination decreased with further increase in concentration. He suggested the possibility of presence of both inhibitory and stimulatory substances in the aqueous extracts of cowpea. He also found that mixtures of two or more aqueous extracts of cotton root, stems or leaves were antagonistic to germination of *Striga* seeds and suggested that interaction of germination inhibitors and stimulants resulted in the antagonism.

The generally lower germination in the root chamber technique compared to petri-dish technique was probably as a result of differences in the amount of stimulants exuded from damaged cut roots of the plants compared to the natural exudation of intact roots in the root chamber technique. Abayo *et al.*, (1997) reported similar results when they compared the two techniques. A major constraint of the root chamber technique was the different growth rates of the different test species. Maize and *Mucuna* developed much faster than *Desmodium* and *Stylosanthes*. Within a week, roots of both *Mucuna* and maize covered the whole surface of the pexi-glass and were in close proximity to the conditioned *Striga* seeds. *Stylosanthes* and *Desmodium* developed less than 1 cm length of root system and could therefore not stimulate *Striga* seed. Most probably they also exuded very little amount of stimulant, which was not enough to cause *Striga* seeds to germinate. The low germination of the *Striga* seeds could have obscured any effects of the fodder legumes on *Striga* attachments and a more reliable method should be used in the future to investigate this process. Generally, the different rates of root development meant comparing the test species was very difficult.

Although the petri-dish technique was easier and faster than the root chamber technique, however it does not reflect the natural conditions of exudate release in undamaged roots. Modification of the root chamber technique will have to be done for it to be reliably used especially when dealing with small seeded plants as was the case with *Desmodium* and *Stylosanthes*. One possible way of making reliable comparisons would be to use undamaged roots with the same root mass or to use equal quantities of root sap for germination stimulation studies. Both techniques however can be used to screen large number of species or varieties of crops for *Striga* stimulation ability before they are tested in the field.

CHAPTER 3

EFFECT OF FODDER LEGUME SPECIES ON *STRIGA* ATTACHMENT ON MAIZE ROOTS AND ON *STRIGA* SEED BANK DEPLETION IN THE SOIL

3.1. Introduction

Striga seeds germinate only when stimulated by a chemical exuded by the roots of a host plant. Upon germination, a *Striga* rootlet close to a host root develops an organ of attachment called the haustorium, which forms a morphological and physiological bridge between the host and parasite (Ejeta *et al.,* 1992) resulting in attachment. The formation of the haustoria has been found to be under the control of an external chemical signal produced by the host root (Edwards, 1979; Okonkwo, 1966). Processes leading to attachment are important because only then can the parasite start inflicting damage on the host. Legume species are known to stimulate *Striga* germination without allowing attachment to take place on their roots. In the absence of a host the germinated *Striga* seed dies. This has been termed "suicidal germination" of *Striga* seed.

Legumes are known to deplete seed bank in the soil by enhancing *Striga* seed "suicidal germination"(germination without attachment) and therefore reducing infestation to the succeeding crop. Yaduraju and Hosmani (1979) reported that cowpeas, groundnuts, and linseed decreased the incidence of *S. asiatica* on the succeeding crop with cowpea and groundnut being the most effective. Intercropping of sorghum with a trap or catch crop was found to be an efficient cultural strategy of reducing *Striga* in the soil (Singh *et al.,* 1991). They observed that intercropping of sorghum with cowpea, millet or soybean was effective in increasing the overall land productivity under *Striga* infestation.

More often than not investigations into the role that leguminous plants play in control of *Striga* have focused mainly on trap cropping or depletion of *Striga* seed bank through suicidal germination (Bebawi and Micheal, 1991, Singh, *et al.*, 1991, Abayo, *et al.*, 1997, Ransom *et al.*, 1997 and Oswald *et al.*, 1997). Other investigators have focused on the effect of shading and lowering of soil temperature (Salle *et al.*, 1989, Carson, 1989, and Oswald *et al.*, 1997). However, little if any is known whether the legumes play a role in the attachment process of the parasite onto host roots in host/legume intercropping systems. It is possible that legume roots increase stimulation of conditioned *Striga* seeds resulting into increased *Striga* seed germination which in turn causes increased attachment to maize roots present in the vicinity. Also the intricate entwinement of host and legume roots may have a role in the number of *Striga* seeds that attach on host roots.

Legumes intercropped or undersown with maize may decrease *Striga* infestation on maize by reducing *Striga* attachment on roots of maize and by depletion of *Striga* seed in the soil. The objective of this study was to determine effect of three different fodder legumes either intercropped or undersown with maize on *Striga* attachment on maize roots and on *Striga* seed bank in the soil.

3.2. MATERIALS AND METHODS

Two separate pot experiments were set up in the screen house at Kibos. Soil for the experiment was obtained from an area within the station not contaminated with *Striga* . In one experiment maize and legumes were sown together (intercrop system) and in the other, maize was sown into an established legume stand (undersowing system). In both experiments, 15 litre buckets were filled with the *Striga* free soil. The soil in each pot was then inoculated with approximately 30,000 germinable *Striga* seeds (8 g) and thoroughly mixed into soil to ensure uniform distribution of the seeds in the soil.

In the intercropping experiment maize was planted together with *Mucuna*, *Desmodium*, *Stylosanthes*, or cowpea in the same pots. There were two maize, *Mucuna* and cowpea plants per pot. *Desmodium* and *Stylosanthes* were drilled into small furrows and later thinned to 10 plants per pot. Treatment combinations were: a) maize alone, b) maize with *Mucuna*, c) maize with *Desmodium*, d) maize with *Stylosanthes*, e) maize with cowpea, f) *Mucuna* alone, g) *Desmodium* alone, h) *Stylosanthes* alone, i) cowpea alone, j) and infested soil alone (control). The experimental design was a completely randomised design replicated thrice. Pots were watered every other day and plants allowed to grow for 8 weeks after which the soil was washed off using water at low pressure from a hosepipe. Plant roots were taken to the laboratory for observation of *Striga* attachments.

For the undersowing experiment, soil was infested as in the inter-cropping experiment. Maize, *Mucuna, Desmodium, Stylosanthes* and cowpea were sown in separate pots like in the intercropping experiment and allowed to grow for 8 weeks. *Mucuna*, *Desmodium*, and

Stylosanthes were then cut back to 5 cm above ground level while maize and cowpea were cut back at ground level. Maize was then planted between the legumes in all pots with fodder legume. In pots where maize and cowpea were cut back they were replanted. All the plants were then allowed to grow for a further 4 weeks. The treatment combinations were: a) *Mucuna* undersown with maize b) *Stylosanthes* undersown with maize, c) *Desmodium* undersown with maize, d) Cowpea undersown with maize, and e) maize undersown with maize (control). The experiment was replicated three times and laid out as a complete randomized design.

In both experiments data collected included number of *Striga* attachments on maize roots, above ground dry matter for maize and legumes and maize and legume root dry weights. Legume and maize roots were separated manually using hands. 250 g of soil was sampled from the whole bucket of each pot for elutriation (washing) (Odhiambo, 1998) at the end of the experiment to recover and determine the number *Striga* seeds in the soil. The experiment was done once. Data was analysed using SAS and means compared using Duncan's multiple range test ($p \leq 0.05$) to determine differences between treatments.

3.3. RESULTS

3.3.1. Intercropping experiment

Legumes had an effect on *Striga* seed attachment (Table 3.1 and Appendix 3). Maize interplanted with *Mucuna* or *Stylosanthes* had more *Striga* germlings attached on the roots than maize/*Desmodium*, maize/cowpea combinations or the maize control (Table 3.1). Root biomass differred significantly among the legume species (Appendix 3). Root biomass of *Mucuna* and *Desmodium* differed when they were grown alone or together with maize (Table 3.1). In both cases, when either of the legumes was planted together with maize they had higher root biomass than when they were planted alone. However, legume root biomass did not differ significantly when *Stylosanthes* or cowpea were grown alone or together with maize. *Striga* attachments and legume root biomass were significantly correlated (R^2=0.83) (Table 3.3). *Striga* attachments were also correlated with maize root biomass. The number of *Striga* attached on to the roots of maize intercropped with *Desmodium* or cowpea did not differ from the sole maize (table 3.1).

Shoot biomass of maize was not significantly different across the treatments (Table 3.1 and Appendix 3). Maize shoot biomass was not different for maize interplanted with fodder legume or that of sole planted maize (Table 3.1). There was no significant difference in maize root/shoot ratios between all the treatments. Legume shoot biomass was not significantly different across all treatments (Appendix 3). Legume shoot biomass did not differ between legumes grown together with maize or alone (Table 3.1).

Table 3.1. ***Striga*** **attachment, root and shoot biomass of maize and legumes: intercropping experiment.**

Treatment	Maize root wt.(g)	Maize shoot (g)	Maize root/ shoot ratio	legume		Number of *Striga* attached	*Striga* attached/g maize root
				Root wt. (g)	Shoot wt. (g)		
Maize/*Mucuna*	27 b	13 a	2.2 b	29 ab	43 ab	158 a	6a
Maize/*Desmodium*	25 b	11 a	2.1 b	30 a	39 ab	81 b	4 b
Maize/*Stylosanthes*	47 a	14 a	3.4 a	14 de	24 cd	153 a	3 b
Maize/cowpea	26 b	11 a	2.6 ab	10 e	18 d	105 b	4 b
Maize (control)	34 ab	12 a	2.9 ab			61 b	2 c
Mucuna				20 cd	45 a		
Desmodium				23 bc	32 bc		
Stylosanthes				14 de	34 bc		
Cowpea				10 e	14 d		

Values followed by the same letter are not significantly different down the columns at ($p < 0.05$) by DMRT

3.3.2. Undersowing pot experiment

Results for the undersowing pot experiment are presented in Table 3.2 and Appendix 4. Legume species had significant effect on *Striga* attachments (Appendix 4). The number of *Striga* attachments on maize roots was lower when maize was undersown with fodder legumes or with cowpea (Table 3.2). Maize planted with *Stylosanthes* and *Desmodium* had the lowest number of *Striga* attachments (between 3-7 germlings). However the number of *Striga* germlings attached per gram of maize roots did not differ significantly between maize planted alone and maize planted with fodder legumes. *Stylosanthes* and *Desmodium* had the lowest number of attached *Striga* germlings per gram of maize roots. *Stylosanthes* and *Desmodium* fodder legumes had higher root biomass than *Mucuna* or cowpea and corresponding lower *Striga* attachments. *Striga* attachments were negatively correlated with legume root biomass (Table 3.3). However, *Striga* attachments and biomass of maize roots were only slightly correlated (Table 3.3). Maize planted together with fodder legumes had lower root biomass compared to the maize planted alone (control) or maize planted together with cowpea. Parasite germlings were also found to attach in considerable numbers to *Mucuna* roots. Maize root/shoot ratio was not significantly different between the maize only control and maize planted with *Stylosanthes* or *Mucuna* but maize planted together with cowpea had the highest ratio while maize planted with *Desmodium* had the lowest (Table 3.2). Maize planted together with fodder legumes had lower shoot biomass than the maize only control or maize planted with cowpea. However there was no significant difference in shoot biomass of maize grown together with *Mucuna, Stylosanthes* or *Desmodium* fodder legumes.

Table 3.2. Effect of fodder legume species on *Striga* attachment, root and shoot biomass of maize.

Treatment	Maize root mass g/pot	Legume root mass g/pot	Maize shoot mass (g)	Legume shoot mass (g)	Maize root /shoot ratio	*Striga* attach-ments/ pot	*Striga* attach-ed /g. maize root
Maize/maize(control)	29 b		23 a		1.2 b	41a	1 ab
Maize /*Mucuna*	12 d	25.5 b	11 c	40 b	1.2 b	24 b	2 a
Maize/*Desmodium*	9 d	38.3 a	10 c	50 a	0.9 c	3 c	0 c
Maize/*Stylosanthes*	10 d	33.8 a	9 c	46 ab	1.2 b	7 c	1 b
Maize/cowpea	38 a	11 c	15 b	11 c	2.6 a	25 b	1 b

Values followed by the same letter down the column are not significantly different at ($p < 0.05$).

Table 3.3. Correlation coefficients for *Striga* attachment on maize roots versus maize and legume root weights for the intercrop and undersowing pot studies.

experiment	*Striga* attachments /maize root		*Striga* attachments /legume root	
	R^2	P level	R^2	P level
Intercrop	0.50	0.01	0.83	0.0001
undersowing	0.62	0.0025	-0.71	0.0028

3.3.3. *Striga* seed recovery from soil

The number of *Striga* seeds recovered from soil planted with fodder legume species alone was significantly lower than in the treatments planted with maize alone in the intercrop experiment (Table 3.4). The number of *Striga* seeds recovered from soil planted with fodder legumes together with maize was lower than in soil planted with fodder legume only. However, there was no significant difference in number of *Striga* seeds recovered between soil planted with the different fodder legume species. The undersowing experiment did not show any difference in number of recovered *Striga* seeds from soil planted with maize alone (control) and that planted with maize and fodder legumes together (Table 3.4). However all treatments differed from the bare soil control but not from each other. *Striga* seeds recovered for the different treatments in the undersowing experiment were lower compared to the intercrop experiment.

Table 3.4 *Striga* seed recovery from soil planted with different crop species.

Plant species	No. of *Striga* seeds/250 g soil	
	Intercrop experiment	Undersowing experiment
Control (bare soil)	272 a	75 a
Maize/*Mucuna*	125 c	46 b
Maize/*Desmodium*	128 c	42 b
Maize/*Stylosanthes*	138 c	44 b
Maize/cowpea	123 c	51 b
Maize	260 a	46 b
Stylosanthes	184 b	
Desmodium	205 b	
Mucuna	208 b	
Cowpea	123 c	

[a] Values followed by the same letter down the column are not significantly different at ($p < 0.05$).

3.4 DISCUSSION

3.4.1. Intercropping experiment.

Maize planted together with *Mucuna* or *Stylosanthes* had more *Striga* germlings attached on the roots than other combinations. In the case of *Stylosanthes,* this effect was expected because it was found to stimulate more *Striga* seed to germinate in the petri-dish laboratory technique indicating probably more stimulant production. In the case of *Mucuna* increased attachment was probably as a result of higher legume root biomass producing more germination stimulant hence stimulating more *Striga* seeds to germinate and attach onto maize roots. It was not possible to explain the higher legume root biomass when *Mucuna* or *Desmodium* were planted together with maize (Table 3.1). The high postive correlation between *Striga* attachments and legume root biomass may probably indicate that legume roots enhanced *Striga* seed germination as a result of increased stimulant production and distribution. Increased legume root biomass probably enhanced germination of *Striga* seeds leading to increased attachment of germinated *Striga* seeds onto maize roots.

The short duration of the experiment (4 weeks) probably meant that any effects of competition of the fodder legumes or effect of *Striga* infestation on maize shoot weight was minimal and therefore not evident. The non-significant difference of maize root/shoot ratios between all the treatments was also probably as a result of this. Legume shoot biomass did not differ significantly when they were grown alone or together with maize probably because maize does not offer any serious competition for available nutrients to the fodder legumes when they are grown together.

3.4.2 Undersowing pot experiment

Lower number of *Striga* attachments on maize roots when maize was undersown with fodder legumes or with cowpea could imply that the delicate entwinement of legume and maize roots may be a hindrance to *Striga* attachment when fodder legumes are planted together with maize. Increased legume root biomass probably increased entwinement of the roots of both the legume and those of maize and in the process reduced the number of attachment sites for the parasite on the maize roots. Increased maize root biomass increased the number of attachment sites for *Striga* germlings and that was probably why maize root biomass was positively correlated with *Striga* attachments.

Striga was observed to attach onto *Mucuna* roots although it is not a host plant. No further investigation into this aspect was done because it was not the focus of our attention and for lack of time. However this should be a focus of attention in a future study. Bebawi and Micheal, (1991) found that hyacinth bean exhibited significant parasitizition by *Striga* compared to a cotton control. These results are in agreement with those reported by Andrews (1945). However they also showed that sesame and sunflower may be parasitized by *Striga,* contrary to the report by Andrews (1945). Guar has also been found to be parasitized by *Striga* (Andrews, 1945) and by *Alectra Vogelii* Benth, (Visser and Beck, 1987) another root parasitic weed. Dawoud, (1995) also reported *Striga* attachment on roots of plants that are not hosts to *Striga*. However in no case were the parastized non host crops reported to be able to support above ground emergence of *Striga* plants. Evidently the *Striga* plants were unable to complete their life cycle. In the long term the leguminous plants are able to rid the soil of a large proportion of its *Striga* seed because the germinated *Striga* seed in the soil are not being replaced by new volunteers (Bebawi and Micheal, 1991).

Maize root/shoot ratio is known to increase with *Striga* attack (Abayo *et al.*, 1997) however this effect was most likely not evident because of the short period that test plants were grown. Maize root/shoot ratio was expected to be highest in the control, which had the highest number of *Striga* attachments. However this was not evident probably because the legumes and the short duration of the experiment interfered with growth rate of maize. Competition for available nutrients between maize and legumes could have resulted in lowered maize and shoot weights.

In the intercrop experiment fodder legumes increased attachment by enhancing stimulation of *Striga* seed in the soil. However growing them for a longer period as in the undersowing experiment probably resulted in the fodder legume roots interfering with *Striga* attachment because of increased entwinement of maize and legume roots. The pot experiments suggest that legume roots probably played a major role in the attachment process of *Striga* on maize roots when they are grown together with maize. However fodder legumes can be effective in enhancing *Striga* seed depletion from *Striga* -infested soils.

3.4.3. *Striga* seed recovery from soil

Generally, the undersowing experiment did not show any difference in number of recovered *Striga* seeds from soil planted with maize alone (control) and that planted with maize and fodder legumes together. However all treatments differed from the bare soil control but not from each other. Numbers for *Striga* seeds recovered from the undersowing experiment as a whole were lower compared to the intercrop experiment and this possibly masked any treatment effects of the fodder legumes in this experiment. Though the experiment was ongoing for a longer period (8 weeks) than the intercrop experiment (4 weeks) it is possible the much lower numbers were as a result of natural attrition (seed decay), germination and loss through watering.

Fodder legume species probably stimulated more *Striga* seeds to germinate than maize and this resulted in lower number of *Striga* seeds being recovered in soil planted with fodder legumes alone. This would seem to confirm the results of the petri-dish experiment where fodder legumes germinated more *Striga* seeds than maize. However, fewer number of *Striga* seeds recovered from soil planted with fodder legumes together with maize, than in soil planted with fodder legume only suggests that combined maize and legume roots germinated more *Striga* seed. This probably was as a result of increased stimulant production from combined roots of maize and legume. The similarity in the number of *Striga* seeds recovered in soil planted with the different fodder legume species was probably because the rate of exudation of stimulant for *Striga* germination is equal for the different fodder legumes. *Striga* seed reduction was probably higher in the undersowing experiment due to the longer period plant species were grown in this experiment.

CHAPTER 4

EFFECT OF FODDER LEGUME SPECIES ON *STRIGA* PARASITISM AND PRODUCTION OF MAIZE UNDER FIELD CONDITIONS.

4.1. Introduction

Results of the laboratory experiments showed that the fodder legumes stimulate conditioned *Striga* under *in vitro* conditions (petri-dish experiment). Therefore they could be effective in ridding *Striga* infested soils off *Striga* seed. The pot experiments suggested that fodder legume roots could have a profound effect on *Striga* attachment on maize roots when they are grown together with maize. These experiments indicated that legume roots may initially increase *Striga* attachment on maize roots due to enhanced stimulation from the fodder legume roots, but the roots can also serve as a hindrance to *Striga* attachment probably by their physical entwinement with the roots of maize. *Striga* attachment on roots of maize was therefore enhanced in the intercrop pot experiment while it was impeded in the under sowing pot experiment, which took a longer while. The two pot experiments also showed that the fodder legumes could be effective in decreasing soil *Striga* seed in the soil.

A field experiment was therefore important to verify the laboratory and pot experiment results and to test the fodder legumes under natural conditions. The objective of this study was to determine the effects of fodder legume species on *Striga* infestation and parasitism and on maize growth and yield under field conditions.

4.2. MATERIALS AND METHODS

Maize and legumes were planted in two cropping systems; one involved planting maize and the fodder legumes together from the first season (intercropping) while the other involved planting maize into an already established crop of fodder legume (undersowing). In the undersowing system fodder legumes were first grown in sole stand in the first season (16th November 1999 to 30th March 2000) and then cut back after which maize was planted into the fodder legume in the second and third season.

The experiment was started on the 16th of November 1999. There were a total of eight treatments: a) maize/*Mucuna* intercrop, b) maize/*Stylosanthes* intercrop, c) maize/*Desmodium* intercrop, d) maize/cowpea intercrop, e) sole maize (control), f) *Mucuna* alone in the first season then undersown with maize in the second and third (undersowing), g) *Desmodium* alone in the first season then undersown with maize in the second and third (undersowing) and, h) *Stylosanthes* alone then undersown with maize in the second and third. The experimental design was a randomized complete block design with three replications. Treatments where maize and legumes were planted together from the first season are referred to as "intercropping" while those where maize was relayed into the fodder legumes from the second season are referred to as "undersowing".

Land preparation was done by a hoe to obtain a good seed bed which is important in achieving uniform *Striga* infection (Berner *et al.*, 1997) and to prevent movement of soil from one plot to another. Plots were 5 m by 3.75 m. The inter and intra-row spacing was 0.75 m and 0.5 m respectively with 2 maize plants per hill corresponding to a maize population of 53,000 plants/ha. The legumes were planted in double rows between the maize with an inter-row spacing of 0.25 m. *Desmodium* and *Stylosanthes* were drilled while *Mucuna* and cowpea were spaced at 25 cm. Insecticide (furadan) was applied to stop damage to sown seed. Di-ammonium phosphate (DAP) and calcium ammonium nitrate (CAN) were applied for planting and top dressing respectively to give a rate of 50 kg N/ha and 50 kg P_2O_5 /ha in all the three seasons. CAN was applied at 45 days after planting. Rains were supplemented with irrigation especially in the short season (between September and December) with total rainfall of 467 mm. Manual weeding using a hand hoe was done twice (14 and 28 days after planting). After this, hand rouging was done continuously to avoid weed interference with *Striga*. Hand rouging was done because it poses little risk to *Striga* plants developing just under the soil surface. The area around the experimental site was cleared constantly to prevent damage by rodents and other small animals. Human guards were posted to prevent bird damage and wild animals. At the end of the first season maize and cowpea were harvested while the fodder legumes were cut back to 5 cm above ground level and allowed to re-grow. The legume biomass was not incorporated in the soil but was instead given to a local farmer for fodder.

In the second season (April 6th to July 10th 2000) maize was planted in between the already established fodder legume species that had been cut back and allowed to regrow. Plots that had maize intercropped with cowpea or maize alone in the first season were replanted in exactly the same way as in the first season. At the end of the second season legume species were cut back again and allowed to re-grow as at the beginning of the second season. In the third season (August 13th to November 19th 2000) planting was done exactly as in the second season.

4.2.1 Data collected

4.2.1.1 Ground cover measurements

In the first and second season ground cover measurements to determine rate of ground cover for the different legumes was done using a 75 cm x 50 cm grid divided into 35 small squares. The grid was held 1 metre above the ground and from above, all grids where legume foliage appeared were counted and the % ground cover calculated. This was done randomly at 3 points in each plot every 7 days until there was total ground cover.

4.2.1.2 *Striga* emergence counts and seed recovery

In all seasons, counts of *Striga* plants were made at bi weekly intervals on the 3 centre rows of each plot, leaving out the last maize plant at the end of each row. Counts were done from the time *Striga* plants started to emerge (approximately 6 weeks after planting) until a few weeks before harvest when *Striga* numbers began to decline. At the end of the third season soil samples using an auger were taken from each plot for washing to recover *Striga* seed. Soil samples were taken at 0-15 cm, and 15-30 cm depth. Soil samples were collected from 10 spots in each plot, bulked and then a 1 kg soil sub-sample taken. After drying and sieving a 250 gm sample was taken for washing to recover any *Striga* seeds in the soil (Ndung'u *et al*., 1993).

4.2.1.3 Maize and fodder yield

Maize grain yield was determined by harvesting three middle rows within each plot. Maize cobs were shelled by hand and the grain was sun dried. Data on maize grain yield and legume biomass was also taken from the same area where *Striga* counts were taken. Data collected was analysed using SAS and means separated using Duncan's multiple range test ($p \leq 0.05$)

4.3. RESULTS

4.3.1. Ground cover measurements

Treatment effect was significant on rate of ground cover (Figure 4.1 and Appendix 5). The rate of establishment of *Desmodium* and *Stylosanthes* in the first season was a problem since they grew very slowly and did not cover the ground effectively. However in the second season after they were cut back they covered the ground faster since they were already well established. *Mucuna* however was well established in the first season and was able to cover the ground at a much faster rate than either *Stylosanthes* or *Desmodium* (Figure 4.1). Cowpea took the least number of days to cover the ground in both the first and the second season.

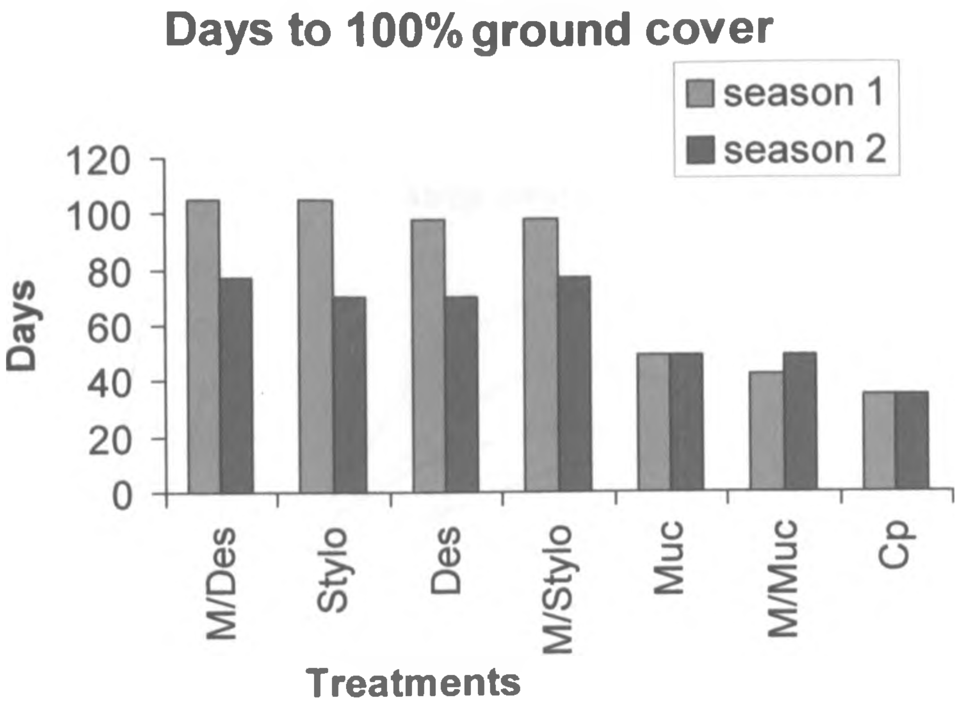

Figure 4.1. Rate of ground cover for legumes in sole stand and or intercropped with maize. Key: M/des-Maize *Desmodium* intercrop; Stylo-*Stylosanthes* undersowing; Des-*Desmodium* undersowing; Maize/Stylo- Maize *Stylosanthes* intercrop; Muc-*Mucuna* undersowing; M/Muc-maize *Mucuna* intercrop; CP-cowpea.

4.3.2 *Striga* emergence

Striga counts were done 5 times in the course of each season. However data analysis was done using the third count, which is usually the peak for *Striga* emergence and occurred between 70 and 80 days after planting (DAP). Figure 4.2 shows the effect of fodder legumes intercropped with maize in the first season.

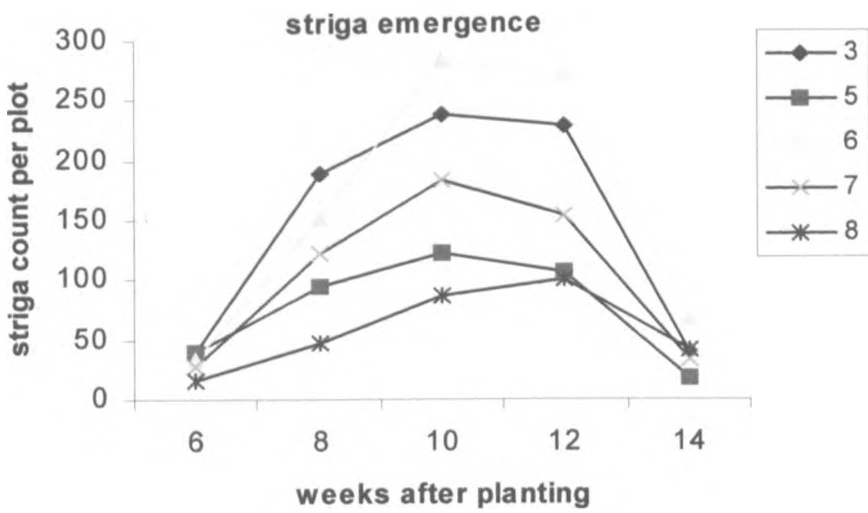

Figure 4.2 *Striga* emergence intercropping experiment season 1. key: 3-maize/*Desmodium*, 5-maize/ *Mucuna*, 6-maize sole (control), 7-maize /*Stylosanthes*, 8-maize cowpea.

In the second and third seasons fodder legumes significantly reduced *Striga* density except where maize was undersown in *Mucuna* (Figures 4.3-4.6). Maize intercropped or undersown with *Stylosanthes* or *Desmodium* had the lowest number of emerged *Striga* shoots in the second season (figure 4.3 and 4.4). In the third season *Striga* incidence was still significantly lower in all cases where maize was associated with the fodder legumes (Figure 4.5 and 4.6).

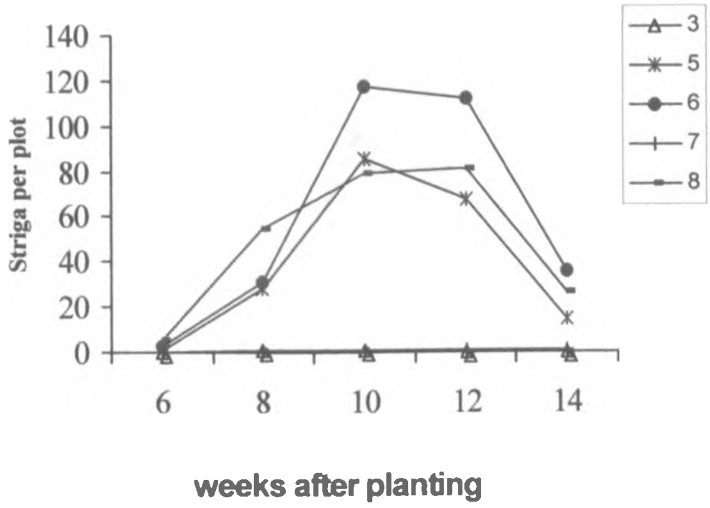

Figure 4.3 Effect of fodder legumes on *Striga* emergence. Intercropping experiment season 2. Key: 3-maize/*Desmodium*, 5-maize/*Mucuna*, 6-maize sole (control), 7-maize /*Stylosanthes*, 8-maize/cowpea. N.B. Values for treatments that are not visible are zero or very close to zero.

Figure 4.4 Effect of fodder legumes on *Striga* emergence. Undersowing experiment season 2. Key: Treatment 1-*Mucuna*, 2-*Desmodium*, 4- *Stylosanthes*, 6-maize sole (control). N.B. Values for treatments that are not visible are zero or very close to zero.

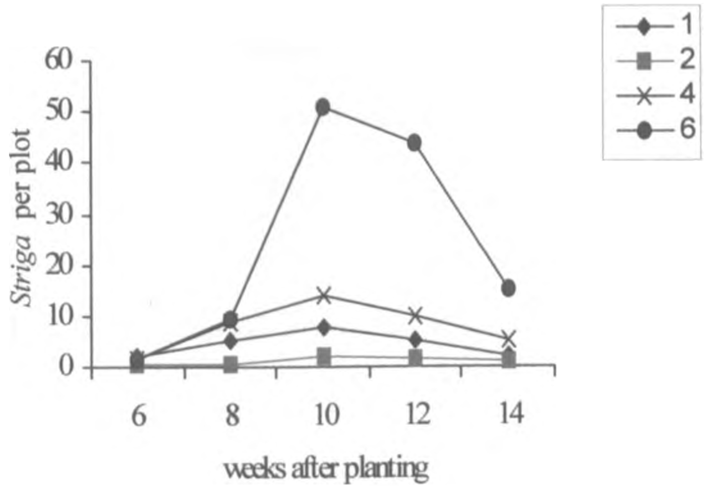

Figure 4.5 Effect of fodder legumes on *Striga* emergence. Undersowing experiment season 3. Key: 1-*Mucuna*, 2-*Desmodium*, 4- *Stylosanthes*, 6-maize sole (control). N.B. Values for treatments that are not visible are zero or very close to zero

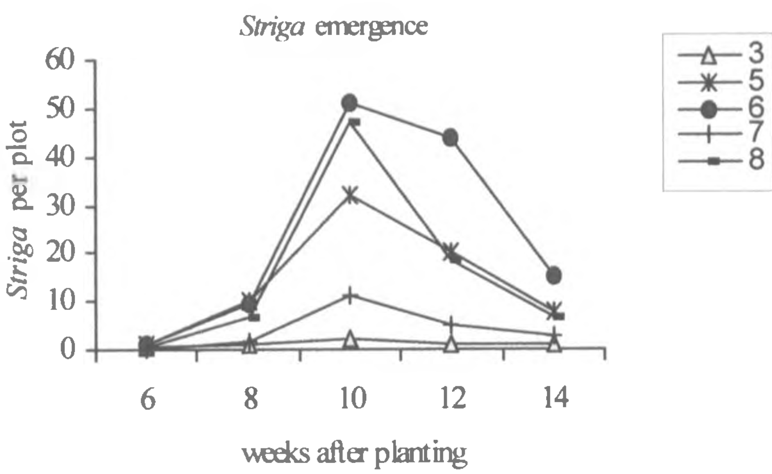

Figure 4.6 Effect of fodder legumes on *Striga* emergence. Intercropping experiment season 3. Key: 3-maize/*Desmodium*, 5-maize/ *Mucuna*, 6-maize sole (control), 7-maize /*Stylosanthes*, 8-maize cowpea.
N.B. Values for treatments that are not visible are zero or very close to zero.

4.3.3. Grain and stover yield of maize

Effect of fodder legumes on grain yield was not significant in the first season but was significant in seasons 2 and 3 (Table 4.1 and Appendix 7). Maize grain yield was not significantly reduced by fodder legume intercrops in the first season (Table 4.1) In the second season, maize intercropped or undersown with *Mucuna* yielded more than maize planted alone or maize intercropped or undersown with any of the other fodder legumes. In the second season, yield of maize undersown with *Stylosanthes* or *Desmodium*, did not vary from maize planted alone. However maize undersown with *Desmodium* or *Stylosanthes* yielded lower than maize planted alone. Grain yield in the third season was lower compared to the second season. Grain yield in this season did not differ significantly across all treatments (Table 4.1). Maize planted alone in this season yielded more than maize grown together with any of the fodder legumes though the yield difference was not significant. Maize stover yield did not differ significantly between maize planted together with fodder legumes and maize planted alone in both season 1 and 2 (Table 4.1). Grain yield for these two seasons was also not significantly different across all treatments.

Table 4.1. Effect of fodder legumes on maize grain and stover yield.

Cropping system	Yield (kg ha^{-1})					
	Season 1		Season 2		Season 3	
	Grain	Stover	Grain	Stover	Grain	Stover
Sole maize	730 a	3200 a	2060 c	2667 ab	1090 a	2613 a
Mucuna (undersowing)			3060 a	2453 ab	1050 a	2827 a
Mucuna (intercropping)	680 a	2667 a	2530 b	3200 a	950 a	3093 a
Stylosanthes (undersowing)			1930 c	1696 b	940 a	2667 a
Stylosanthes (intercropping)	660 a	2667 a	770 d	1333 b	920 a	2560 a
Desmodium (undersowing)			1760 c	1707 ab	890 a	2933 a
Desmodium (intercropping)	640 a	2667 a	990 d	1493 b	840 a	2293 a
Cowpea (intercropping)	430 a	2667 a	1710 c	2827 ab	680 a	2187 a

Values followed by the same letter down the column are not significantly different at ($p<0.05$). Key: Intercropping experiment-maize was intercropped with legume in the 1st, 2nd and 3rd seasons. Undersowing-legume was planted as a sole crop in the 1st season then maize was under sown in the 2nd and 3rd seasons.

However in the second season, maize stover yield was higher when *Mucuna* was grown together with maize for two seasons but was only significantly different from maize grown together with *Desmodium* or *Stylosanthes* for two seasons and maize grown together with *Stylosanthes* for one season.

4.3.4 Fodder legume herbage yield

Table 4.2 shows the amount of herbage yield for the different legume species in seasons 1 and 2. *Mucuna* produced significantly more herbage dry matter than *Stylosanthes* or green leaf *Desmodium*. *Stylosanthes* and *Desmodium* did not differ in the amount of herbage yield produced in both seasons.

Table 4.2 Fodder legume herbage yield

Legume species	Legume herbage yield (t ha^{-1})	
	Season 1	**Season 2**
Mucuna	2.6	2.9
Stylosanthes	1.7	1.7
Desmodium	1.8	2.0
LSD (0.05)	0.3	0.6

4.3.5. *Striga* Seed recovery from soil

Striga seeds recovered from the soil did not differ significantly between all the treatments in both 0-15 cm and 15-30 cm levels (Table 4.4). However for both depths, lower seed numbers were recovered where maize was grown together with the fodder legumes than where maize was grown alone though the difference was not significant.

Table 4.4. Effect of fodder legumes on *Striga* seed bank in the soil.

Cropping system	*Striga* seeds/250g soil	
Cropping system	0-10 cm	15-30 cm
Maize sole	173 a	84 a
Mucuna (undersowing)	137 a	58 a
Mucuna intercropping)	93 a	78 a
Stylosanthes (undersowing)	130 a	54 a
Stylosanthes (intercropping)	115 a	48 a
Desmodium (undersowing)	115 a	37 a
Desmodium (intercrooping)	95 a	44 a
Maize/cowpea	161 a	45 a

Values followed by the same letter down the column are not significantly different at (p < 0.05).

4.4. Discussion

In the first season cowpea covered the ground much faster than the fodder legumes and probably smothered *Striga* plants, and this was probably why *Striga* incidence was lower when it was intercropped with maize. However growing maize together with fodder legumes did not interfere with the rate of ground cover for the legumes. Fodder legumes did not reduce *Striga* incidence in the first season probably because they took a longer period to establish compared to cowpea and hence, were less efficient in smothering *Striga* plants. However, in the second season fodder legumes reduced *Striga* infestation probably because they had much better ground cover compared to the first season. Also they could have had an effect on *Striga* seed bank by germinating more *Striga* seeds in the soil in the first season than the maize control. Lower number of emerged *Striga* plants was recorded where maize was associated with *Stylosanthes* or *Desmodium* either in the intercropping and undersowing systems. Possibly because their rooting system was more extensive compared to *Mucuna* where up to 50% of plants died and had to be reseeded in the second and third seasons. *Striga* incidence was much higher in the first and third seasons probably because these two had lower total rainfall than season 2 (Figure 1.1). *Striga* incidence is usually higher when a short period of high rainfall is follwed by a dry spell (Odhiambo, 1998).

In the first season effect of drought and hailstorm damage resulted in low maize yields across all the treatments obscuring treatment effects of fodder legumes on grain yield. Data from the second season indicated that *Mucuna* is probably better in supplying N and hence improving productivity of maize compared to *Stylosanthes* or *Desmodium*. Experiments elsewhere have shown *Mucuna* to improve grain yield of maize by between 1.2 and 1.5 t ha^{-1} after incorporation of the legume biomass into the soil in small-holder systems (Legume Research Network Project Newsletter issue no.3). Lower grain yield attained when maize was grown together with *Desmodium* or *Stylosanthes* for two seasons continuously was probably because of intense competition for moisture and some nutrients from the two legumes. Therefore, growing them continuously with maize for more than one season may not be beneficial to maize production.

Overall low maize grain yield and variability as a result of termite damage probably masked treatment effects of the fodder legumes on grain yield in the third season. In future more thorough pest control will need to be done to avoid damage to the crop. In this season also maize planted alone yielded more than maize grown together with any of the fodder legumes including *Mucuna,* though the yield difference was not significant. This probably indicates that over a period of three seasons *Mucuna* like *Desmodium* or *Stylosanthes* can become a serious competitor to maize for moisture and some nutrients.

Biomass production of the legumes was not very different from those reported in other areas. In Embu for example, *Mucuna* and *Desmodium* produced approximately 2 t ha^{-1} when they were intercropped with maize (Legume Research Network Project Newsletter iss. No. 3). In an experiment with several other green manure legumes, *Mucuna* was found to be the best in terms of growth vigour, biomass production and ground cover (Legume Research Network Project Newsletter iss. No. 3, 2000).

In this study, despite artificially infesting the site to reduce non-uniformity, there were still large variations in *Striga* seed bank within and between treatments. Data from elsewhere indicates much variability in *Striga* seed numbers between fields and within fields (Smith and Web, 1996; Kim *et al.,* 1997; Odhiambo, 1998). This variability probably masked treatment effects. One of the options available is fumigation of experimental plots to get *Striga* free plots which are then artificially infested with known number of *Striga* seeds (Ransom *et al.,* 1996). Lower seed numbers were recovered for both depths where maize was grown together with the fodder legumes than where maize was grown alone. This is possibly an indication that the fodder legumes could have enhanced *Striga* seed depletion by germinating *Striga* seeds in the soil (suicidal germination). *Striga* seed numbers as expected were lower in the 15-30 cm level compared to the 0-15 level as most *Striga* seeds are usually found in the 0-15 cm plough level.

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSIONS

Root exudates of fodder legume species were more effective in inducing germination of conditioned *Striga* seeds than root exudates of maize or cowpea as indicated by the petri-dish technique. *Stylosanthes* root exudates were more effective in inducing germination than *Desmodium* or *Mucuna* root exudates. However the root chamber experiment was not very successful since *Desmodium* and *Stylosanthes* developed extremely slowly owing to the small nature of their seed. It was therefore not possible to observe any germination of *Striga* seed for these two species. Since germination in root chambers was also very low the number of *Striga* germlings attaching was very low and this masked any effect of the fodder legumes on *Striga* attachment. However the petri-dish experiment indicates the fodder legumes have much potential as *Striga* "trapcrops". *In vitro* screening of herbaceous legumes for *Striga* germination has become an integral part of research for effective crops for rotation or intercropping. Investigators, (Abayo *et al.,* 1997, Berner *et al.,* 1997 and Ariga, 1996) are constantly employing this technique developed at IITA for preliminary screening of different legumes before testing them in the field. The technique has been recognised as a rapid *in vitro* screening method that can quantitatively distinguish between cultivars, breeding lines and other germplasm for potent parasite seed germinating ability (Badu-Apraku *et al.,* 1996).

In the case of the root chamber technique, it could be modified to allow longer growing time for small seeded, slow growing seedlings or initially grow plants to obtain substantial root growth. Also plants should be selected that have comparable root systems other than comparing those with similar chronological age.

In the intercrop pot experiment *Stylosanthes* and *Mucuna* increased *Striga* attachment on to maize roots probably as a result of higher root biomass of these legumes. All the fodder legumes also stimulated more *Striga* seed to germinate than maize in the petri-dish study and this could have contributed to the enhanced attachment of *Striga* on to the roots of maize. There was a positive correlation ($R=0.83$, $p<0.0001$) of legume root biomass with *Striga* attachment onto maize roots. This is probably because the legume roots increased *Striga* seed stimulation and germination, which led to increased *Striga* attachment on maize roots. The number of *Striga* seeds recovered in soil planted with maize together with fodder legumes was lower than in soil planted with maize alone. This supports the results of the petri-dish experiment where fodder legume species stimulated more *Striga* seeds to germinate than maize.

In the undersowing pot experiment on the other hand, fodder legume species decreased *Striga* attachment on maize roots. The fodder legumes had already developed much larger root systems that physically impeded *Striga* attachment on maize roots. This could have been brought about by entwining of the roots of legume and maize roots. From these results, it seems that the root systems of the fodder legumes play a major role in the process of *Striga* attachment onto maize roots. A strategy to deplete *Striga* seeds within the soil therefore would be to encourage development of a large root biomass by allowing a longer period of growth or by fertilization.

In view of the above the following observations and recommendations can be deduced:

1. Fodder legumes are efficacious in stimulating *Striga* seed to germinate though *Stylosanthes* was the most effective.
2. Fodder legume roots play a major role in the process of attachment of *Striga* on maize roots and, when grown for a period of up to 16 weeks they can decrease *Striga* attachment on maize roots.
3. Investigation of *Striga* attachment on roots of *Mucuna* was beyond the scope of this thesis but a more thorough investigation is necessary to ascertain why *Striga* germlings do not develop any further on attachment, with a view of possibly transferring this genetic trait into cereals.
4. Fodder legumes grown together with maize reduce *Striga* infestation on maize under field conditions. Intercropping therefore has the potential of reducing *Striga* infestation and reproduction.
5. *Stylosanthes* and *Desmodium* may reduce grain yield of maize when grown together with maize for more than two seasons. However, climatic conditions probably affect the effectiveness of this technique considerably. Furthermore intercropping may be problematic if competition stress and *Striga* infestation interfere with maize growth. The competition effects of the intercrop should be at least compensated for by the positive effects on *Striga* suppression, so that maize

yields are more stable over time. Possibility of lowered grain yield must be taken into account when devising management strategies for this system.

6. Fodder legumes can reduce *Striga* seed banks in *Striga* infested soils by enhancing suicidal germination of *Striga* seed in the soil.

It will be important in the future to come up with a cropping system for maize and fodder legume that will maximize benefits of fodder legumes to maize, improve grain production, and at the same time be effective in reducing *Striga* incidence. A possible system would be to intercrop maize in the long rainy season to avoid moisture stress on the maize.

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APPENDICES

Appendix 1:Anova table for stimulation of germination of *Striga* seed by legume species in the petri-dish technique

Source	DF	Sum of squares	mean square	F Value
SP	5	140881	28176	72.90**
DIST	4	15477	3869	10.01**
SP*DIST	20	12463	623	1.61*
Error	330	127541	386	
Total	359	296362		

C.V. 47%. Key SP-Species. Dist- Distance from source.

Appendix 2: Anova table for stimulation of germination of *Striga* seed by fodder legumes in the root chamber.

Source	DF	Sum of Squares	Mean Square	F Value
REP	2	18	9	1.17ns
TRT	8	1264	158	20.70**
Error	16	122 8		
Corrected Total	26	1404		

R-Square 0.913018 . C.V. 26% Root MSE 2.763016 germ mean 10.62963
Rep-replication. TRT-Treatment Germ-Germination

Appendix 3: Anova table for effect of fodder legumes on *Striga* attachment on maize, maize root weight, legume root weight, maize shoot weight, and maize root:shoot ratio (intercrop pot experiment).

Source	DF	Att.	Maizrt	legrt	Maizst.	Mrt:sht
TRT	4	9374 **	411*	819**	6.6ns	1.3ns
Error	20	1381	111	32	6.6	0.6
Corrected Total	24					

Att-Attachment, Maizrt-maize root weight, Legrt-Legume root weight, Maizst.-Maize shoot weight, Mrt:Sht-Maize root:shoot ratio. C. V.-23%

Appendix 4: Anova for effect of fodder legumes on *Striga* attachment on maize roots, maize root weight, maize shoot weight, maize root:shoot ratio, legume root weight and legume shoot weight (Undersowing experiment).

Source	DF	Att.	Maizrt.	Maizsh.	Maizrt:Sh	Legrt.	Legsh.
Trt	4	1178**	633**	195**	2**	605.8**	1215ns
Error	19	14	7.3	2.7	0.02	24.4	15
Total	23						

Key, Att-Attachment, Maizrt-maize root weight, Legrt-Legume root weight, Maizsh.-Maize shoot weight, Maizrt:Sht-Maize root:shoot ratio, legsh.-legume shoot weight.
C. V. 19%

Appendix table 5: rate of ground cover for fodder legumes

A. Season 1.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
REP	2	0.7	0.3	0.60	0.5645
TRT	6	354	59	106.34	0.0001**
Error	12	6.7	0.6		
Corrected Total	20	361.8			

R-Square 0.98 C.V. 6.8% Root MSE 0.75 WKSA Mean 10.9

Key WKSA- weeks after planting

B. Season 2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
REP	2	0.4	0.2	0.22	0.8040
TRT	6	90.0	15.0	17.50	0.0001**
Error	12	10.3	0.9		
Corrected Total	20	100.7			

R-Square 0.89 C.V. 11.1% Root MSE 0.93 WKSB Mean 8.3

Key WKSAB- weeeks after planting

Appendix 6: Anova for effect of fodder legumes on *Striga* emergence for the three seasons.

	DF	Mean squares		
Source		Season 1	Season 2	Season 3
REP	2	216	344	281
TRT	4	3472ns	4560**	4240**
Error	8	758	1046	907
Total	14	7349	9543	8435
C.V.		36.9%	12.7%	43.1%

Appendix 7: Anova for maize grain yield for the three seasons

	DF	Mean squares		
Source		Season 1	Season 2	Season 3
REP	2	22441ns	61469ns	25328ns
TRT	4	14683 ns	1672880**	82706*
Error	8	121337	55144	75294
Total	14			
C.V.		36.9%	12.7%	19.3%