ASSESSMENT OF GERMINATION STIMULANTS FROM NON-HOST LEGUMINOUS CROPS FOR CONTROL OF *Striga asiatica* (L.) KUNTZE IN SEMI – ARID AREAS OF TANZANIA.

BY

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ABSTRACT

Striga asiatica is one of the most destructive parasitic weed species in the Semi Arid Zone of Tanzania. In an effort to come out with an appropriate and sustainable method of controlling the weed species, two laboratory/screen house and one field experiments were conducted to identify leguminous crop species/cultivars that are suitable for use as trap crops in the control of *Striga asiatica*. Effectiveness of root exudates of 56 cultivars from six leguminous species on germination of *S. asiatica* seeds were assessed in *vitro* using Petri Dish (PD) technique. A split plot design replicated four times was used. The second laboratory experiment, aimed at evaluating the effect of seed coat colour and different plant parts of selected leguminous species/cultivars on stimulating germination of the parasitic weed seeds was done. A Completely Randomised Design (CRD) with four replications was used. Both experiments were repeated three times. In addition, a 2-years field experiment was conducted to evaluate the efficacy in *situ* of the species/ cultivars identified in *vitro*. A Completely Randomised Block Design (CRBD) was used and the experiment was replicated four times. Results indicated that effectiveness of root exudates depends on *Striga* seed population, and cultivars within species differed in their capacity to stimulate germination of *S. asiatica* seeds. Pigeon pea cultivars ICEAP 00020 and ICEAP 00040; groundnut ex-Bukene; cowpeas white black eyed; bambara groundnut cultivars Nyandani spotted cream and Red ex- Makutupora were found to stimulate significantly ($P < 0.001$) higher germination percentages of *S. asiatica* seeds compared to the other tested cultivars within their respective species, hence were selected for further evaluation in field. Seed exudates from black seeded

bambara groundnut stimulated 66.8% germination of *S. asiatica* seeds, which was significantly ($P < 0.001$) higher compared to percent germination induced by the positive control (41.3%). Germination of *Striga* seeds exposed to exudates from different plant parts (roots, shoots and seeds) of bambara groundnuts, cowpeas and groundnut ranged from 15% to 63.4%, which was significantly higher compared to percent germination induced by the negative control (2.4%). Rotating legume trap crops with sorghum resulted into 38 - 48% reduction of *Striga* seeds in the soil as well as reduction of *Striga* infestation by 50% compared to continuous sorghum cropping and weed free fallow – sorghum rotation. Yields of sorghum grown after legumes ranged between 0.75 – 2.28 tons/ha, while yields from sorghum after weed-free fallow and sorghum continuous cropping were 0.53 tons/ha and 0.61 tons/ha respectively. Except for cowpeas, all other legume - sorghum rotations resulted into significantly ($P < 0.001$) higher yields compared with the weed free fallow and continuous sorghum cropping. It is concluded that crop rotation with pigeon pea cultivars ICEAP 00020 and ICEAP 00040; groundnut ex-Bukene; and bambara groundnut cultivars Nyandani spotted cream and red ex- Makutupora can serve as effective trap crops which would reduce *S. asiatica* seed bank and infestations. By inference, rotating sorghum with any of these legumes would boost yields, thereby sparing farmers limited resources, which would have otherwise been spent for other expensive *Striga* control measures.

DECLARATION

I, Fridah Nnekia Mbazi Mgonja, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work and that it has never been submitted for a degree award in any other university.

Signature.....

Date 21/10/2005.....

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DEDICATION

This work is dedicated to my late father Mbazi Yonaza Mgonja, my mother Niendiwe Mbazi Mgonja and my two children, Samson and Peter.

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LIST OF ABREVIATIONS AND SYMBOLS

ACC	Aminocyclopropane -1- Carboxylic Acid
ACCO	Aminocyclopropane –1-Carboxylic Acid Oxidase
ARI	Agricultural Research Institute
Asl	Above Sea level
AVG	Aminoethoxyvinyl glycine
CEC	Cation Exchange Capacity
cm	Centimetre
CRD	Completely Randomised Design
CV	Coefficient of Variation
DMBQ	Dimethoxy- p- Benzoquinone
FAO	Food and Agriculture Organisation
g	Grams
ICRISAT	International Centre for Research in Semi – arid Tropics
IITA	International Institute for Tropical Agriculture
K_2CO_3	Potassium Carbonate
TOSCA	Tanzania official Seed Certification Agency
ml	Millilitre
N2	Organic Nitrogen
PD	Petri Dish
SE	Standard Error
Spp	Species
TPRI	Tanzania Pesticide Research Institute

TTC	Triphenyl Tetrazolium Chloride
UCT	University of Cape Town
µl	Micro liter

CHAPTER ONE

INTRODUCTION

Witch weeds (*Striga* species) are angiospermous root parasites, which belong to the family *Scrophulariaceae*. The species attack several staple cereal crops like sorghum [*Sorghum bicolor* (L.) Moench], maize [*Zea mays* L.] and pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Other vulnerable crops include sugarcane and grain legumes.

Species of the most economic importance are *S. hermonthica* (Del.) Benth and *S. asiatica* (L.) Kuntze. As far as the African continent is concerned, the former is the most widely spread and the most destructive parasitic weed (Parker and Riches, 1993). In Tanzania, *S. asiatica* is the most dominant, spreading from the Lake Victoria regions (latitude 2.4^{0}S) down to Tabora, Singida, Dodoma, Morogoro and southwards to Ruvuma (latitude 12.5^{0}S), and along the Coastal regions from Tanga to Mtwara causing serious reduction in crop production (Mbwaga and Obilana, 1998).

It is roughly estimated that one third of the cereal cropping area in Africa is infested by *Striga*, causing annual losses of over four million tons of grains (Sauerborn, 1991). Crop losses from on farm studies are reported to be on average of 40% for all of Africa (Kim, 1991). Nevertheless, losses from individual areas range from: 20-95% in East Africa (Esilaba and Ransom, 1997), 20-35% in the Gambia, 35% in Nigeria, and 60% in the Sudan (Lagoke *et al.*, 1991). Depending on prevailing environmental conditions

and soil types yield losses at local levels are often extremely large, reaching 100% in heavily infested soils (Ejeta *et al.*, 1993).

Control strategies like application of herbicides, use of resistant varieties and biological agents developed for control of *Striga* have not yet been adequately adopted by smallholder farmers (Debrah, 1994; Kunjo, and Mudoch, 2001). This is due to the fact that they are not economically feasible and adaptable to the socio-economical conditions in the infested areas. Lack of a single sustainable *Striga* control method in the short term and the absence of integrated management strategies suitable for the existing farming systems are among the reasons for limited adoption of the developed technologies (Esilaba and Ransom, 1997).

Trap cropping is potentially very important as a *Striga* control measure because it can induce germination of *Striga* seeds, which then die in the absence of a suitable host crop. For *Striga* infested soils, rotation of a leguminous trap crop with a cereal crop has advantage over continuous cereal cropping. In such a system, *Striga* seed bank is depleted through suicidal germination (Odhiambo and Ransom, 1995; Ariga, 1996) and hence minimising the risk of seed shedding in the current year, and at the same time improving soil fertility through N fixation and improved microbial activities.

The control of *Striga* associated with cereal/legume rotation is an interesting and encouraging practice as it is quite feasible in the cropping systems of most subsistence farmers, who are the major producers of cereals. Previous results (Kim,

1991; Carsky *et al.*, 2000; Ransom, 2000; Oswald and Ransom, 2001; Gbehounou and Adango, 2003) have shown promising prospects in the use of leguminous trap crops for the control of *Striga* elsewhere in Africa. However, there is very little scientific information based on the effect of various leguminous trap crops on the control of *Striga* in Tanzania. The ability of different species or even different cultivars of the same species differ in their effectiveness in stimulating *Striga* seed germination. It is probable that the potential of the practice can be improved by selecting leguminous species/cultivars that induce higher suicidal germination through production of higher amounts of *Striga* germination stimulants for use in rotation with cereals in *Striga* control programs.

The main objective of this study is therefore to identify leguminous crop species and cultivars that are suitable for use in the control of *S. asiatica* in Tanzania. The specific objectives are to:

(a) Identify leguminous crop species and cultivars with high ability to stimulate germination of *S. asiatica* seeds.

(b) Assess the influence of different plant parts and seed coat colour of selected leguminous species on germination stimulation of *S. asiatica* seeds.

(c) Study the efficacy of the selected leguminous trap crops for the control of *S. asiatica* in the field.

Hypothesis of the study:

(a) Different legume species/cultivars differ in their capacity to stimulate germination of *Striga asiatica* seeds

(b) Different leguminous plant parts are capable of inducing germination of *S. Asiatica* seeds

(c) Leguminous trap crops with high germination stimulation ability are also more effective in controlling *S.asiatica* in the field.

CHAPTER TWO

LITERATURE REVIEW

Striga is among the most destructive parasitic weeds of cereals in the world, but most seriously in the Sub-Saharan Africa. For many years now, researchers have been trying to study the weed in an effort towards its eradication and yet the approach is still far from full success. The complexity of the parasite-host relationship is among the factors that hinder the fast development of technologies to combat the problem.

2.1 Species Description

The parasitic weed *Striga* has several species, the most common and economically important being *S. hermonthica* (Del.) Benth. *S. asiatica* (L.) Kuntze and *S. gesneroides* (Willd.) Vatke. Other species of less economical importance include *S. forbesii* (Del.) Berth and *S. aspera* (Willd.) Benth. *Striga hermonthica* and *S. asiatica* attack monocotyledons such as sorghum, millets, rice and maize, and thus being the most economically important root parasitic weeds of the Poaceae in the Semi arid Sub Saharan Africa. *Striga gesneroides* attacks several dicotyledons, including species of leguminoceae and fabaceae, and to lesser extent sweet potatoes (Parker and Riches, 1993).

2.2 Ecology of *Striga*

Striga species thrive best under conditions of erratic or limited rainfall and may be suppressed by irrigation or heavy continuous rainfall (Radosevich, *et al.*, 1997). A wide range of soil types has been reported to support *Striga* growth. Various studies

have indicated that incidence and severity of attack by *Striga* is greater in sandy, low infertile soils with low to moderate water holding capacity (Weber *et al.*, 1995). Moreover, Dogget (1988) observed that *S. asiatica* could not grow well on heavy clay soils.

Temperatures around 20 - 35°C are required for the survival of *Striga* (Patterson, 1990). However, dormant seeds could survive freezing temperatures (- 7°C to - 15°C) for a period of 49 days (Parker and Riches, 1993). Light intensity is not critical, as it has been shown that the species can grow to maturity in complete darkness although as a photosynthetic active plant they do show maximum growth in full sunlight (Parker and Riches, 1993).

2.3 Distribution of *Striga*

On a world scale, *S. hermonthica* is the most important parasitic weed species (Parker and Riches, 1993). It is mainly distributed throughout the semi arid areas of Northern Tropical Africa, extending to SouthWest Arabia, Southern Tropical Africa, including Angola, Namibia and Madagascar and around Lake Victoria in Kenya and Tanzania (Fasil Reda and Parker, 1994; Frost, 1995).

On the other hand, *Striga asiatica* is distributed throughout the semi arid regions of Africa, including Botswana, Swaziland, and South Africa, in some regions outside the tropics (down to 30°S) and also extensively in Asian countries including Bangladesh, Thailand, Vietnam, Indonesia, China and the Australian subcontinent. The species is also found in North and South Carolina in the USA (Parker and

Riches, 1993). It is the most predominant and destructive species in Tanzania where it spreads from the Lake Victoria regions (latitude 2.4^{0}S) down to Tabora, Singida, Dodoma, Morogoro and southwards to Ruvuma (latitude 12.5^{0}S), and along the Coastal regions from Tanga to Mtwara (Fig. 1). However, todate distribution of *Striga* species in the country has expanded to new areas like Mbeya region, where *S. asiatica* is now a serious parasitic weed affecting rice fields (Mbwaga, 2004).

2.4 Biology and Physiology of *Striga*

Striga is an annual obligate parasite that grows to a height of 15-50 cm depending on species and ecology (Parker and Riches, 1993). Mature plants produce numerous, very small seeds (0.1–0.3 mm). It is reported (Musselman, 1980; Obilana, 1983) that a well-grown and healthy *Striga* plant may produce over 50,000 seeds. The number of seeds per capsule is estimated to be over 700 and 800 for *S. hermonthica* and *S. asiatica* respectively, with the number of capsules per plant averaging at 60-70 for both species (Patterson, 1990). The seeds have a characteristic surface pattern of ridges, which is supposed to play a role at the uptake of germination stimulating substances (Musselman, 1980; Parker and Riches, 1993).

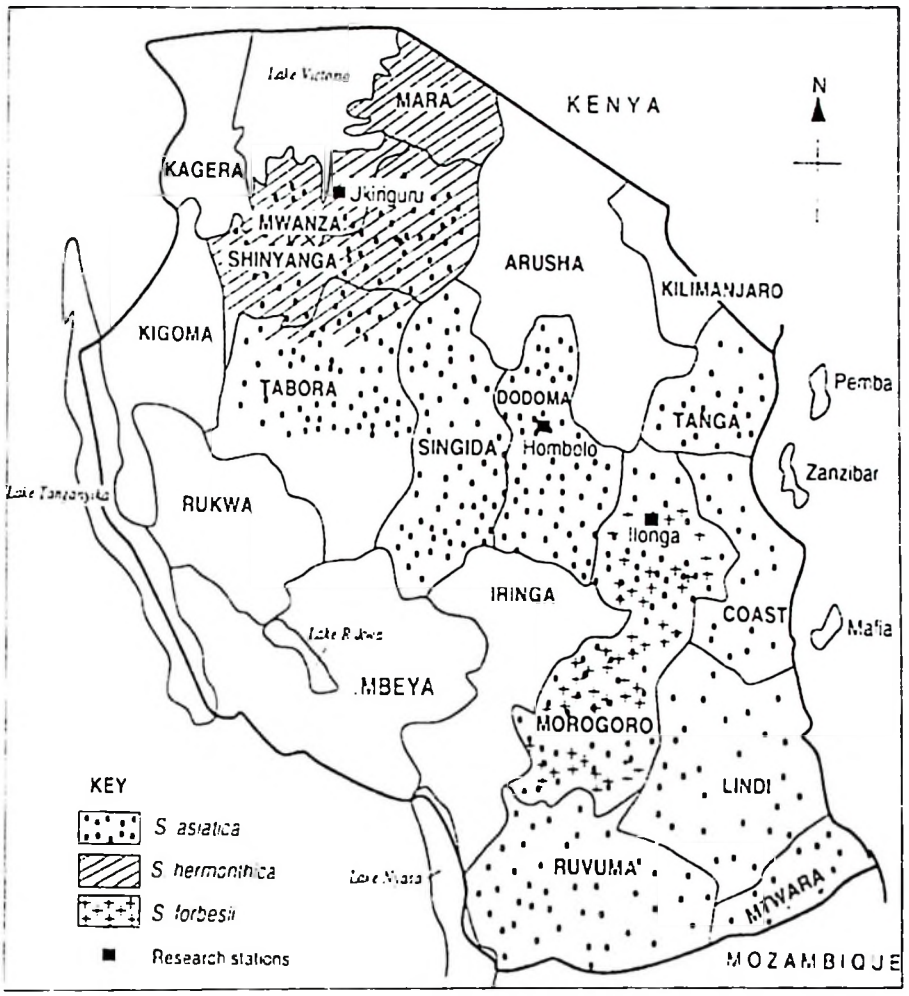

Figure 1. Distribution of *Striga* species in Tanzania (by regions)

Source: Mbwaga and Obilana (1998)

Mature seeds are dispersed by wind, rainwater, cultivation, soil on gardening tools, or even grazing animals and manure application (Ramaiah *et al.*, 1991; Parker and Riches, 1993). However, Berner *et al.* (1994) urged that despite *Striga* seeds being very small, they are not efficiently dispersed by wind (reasons unknown). This is fortunate because efficient and widespread dissemination of these parasites by wind would be virtually uncontrollable. Research done at IITA, showed that man is the primary disseminating agent of *Striga* seeds (Berner *et al.*, 1997) through crop seeds and the livestock he manages.

Prior to germination, *Striga* seeds must undergo an after - ripening period before responding to any germination stimulants. According to Musselman (1980), this period is necessary to transform phenolic compounds that act as germination inhibitors. After- ripened *Striga* seeds fail to germinate even in the presence of host stimulants unless they receive another conditioning treatment that sensitises the seeds prior to germination by exposing them to humid atmosphere at particular temperatures for some time. Babiker *et al.* (1993) suggested that, conditioning the seeds in warm moist environment and subsequent exposure to a stimulant are needed for induction of ethylene biosynthesis. The enzymes 1 – aminocyclopropane – 1 - carboxylic acid (ACC) synthase and ACC Oxidase (ACCO), catalyse the essential steps in ethylene biosynthesis before seed germination. The temperature range for conditioning is reported to be between 20 and 40^0C, but optimum temperatures are reported to range between 25- 35^0C (Okonkwo, 1991; Logan and Sterwart, 1991; Heller and Wegmann, 2000)). Conditioning period differs from one *Striga* species to another. Optimum conditioning period of some of the *Striga* species range from 9 –

45 days for *S. asiatica*, days, 11 – 14 days for *S. hermonthica* and 4 – 7 days for *S. gesneroides* (Muller *et al.*, 1992). So far, there is no documented report as for the reasons leading to the mentioned differences in conditioning period for the different *Striga* species.

After all requirements are met, *Striga* seeds will start to germinate. However, seeds further than 4 mm away from the host root zone or those buried deeper than 30cm in the soil, with less oxygen will not germinate and can remain viable for a long time (Worshum, 1987; Stewart and Press, 1990). According to available literature, there is some controversy concerning the longevity of witch weed seeds under field conditions. Mention is made of extremely long viability periods of up to 10 - 20 years (Eplee, 1992), but further studies have shown that seed longevity in soil may sometimes be shorter than commonly expected (Gbehounou *et al.*, 1996). Rapid decline in number of viable seed in the soil was found in the fields in Mali, Benin and Kenya where relatively larger number of newly shed *S. hermonthica* seeds died in the course of the subsequent rainy season. Speculations with respect to the cause of such rapid depletion include microbial activity and spontaneous germination due to old age (Okonkwo, 1991; Parker and Riches, 1993).

Once conditioned and exposed to germination stimulants under suitable temperature and moisture, *Striga* seeds will germinate within 24 hours. Attachment to the crop takes place 4 – 5 weeks after planting of the host crop, while above ground emergence normally occurs from the 6^{th} – 7^{th} week (Ramaiah *et al.*, 1991). The vegetative (aerial) part is yellowish green with rough hairs on the stem (Ramaiah *et*

al., 1991). Flowering of the parasitic weed can begin 2 weeks after emergence and seeds begin to mature 2-4 weeks later (Ramaiah *et al.*, 1983; 1991). Underground, the *Striga* plant appears to have thick tuft of roots but most of them are attached to the root system of the host by a thickened parasitizing nodule called haustorium. This structure functions in extracting water and nutrients from the host plant. Only the *Striga* roots attached to the host roots are functional and little direct soil absorption of water and nutrients occurs through the non- attached *Striga* roots (Worshum, 1987).

2.5 Crop/Parasite Relationship

After germination, *Striga* will extend an infection peg to the host, gluing to the root and invading the vascular system with specialized structures called haustoria where water, minerals, and carbohydrates are transported (Worshum, 1987). Once the connection to the host is secured, there is initiation of the shoot and additional roots (Worshum, 1987). About 35% of the carbon source for *Striga* plant growth is obtained from the host photosynthates. Also, *Striga* plants transpire much more water than is normal for other plants, even under moisture stress, thus maximizing the flow of water and nutrients from the host (Gurney *et al.*, 1997). These factors contribute to the 65% reduction in plant growth and 95 – 100% reduction in grain yield of the infested field crop (Gurney *et al.*, 1997). In addition, the low correlation between percent of infected roots and percent growth reduction (Kim, 1991; Stewart *et al.*, 1991) is a strong indication of the presence of unidentified toxins.

2.6 Germination Stimulants for *Striga* Seeds

Various researchers have attempted to isolate and identify natural germination stimulants. Germination stimulants such as strigol (Cook *et al.*, 1966; Siame *et al.*, 1993), sorgolactones (Hauck *et al.*, 1992), alectral, (Muller *et al.*, 1992; Weerasurya *et al.*, 1993; Yokota *et al.*, 1998), orobanchol (Yokota *et al.*, 1998) and dihydrosorgoleone (Chang *et al.*, 1986) have been isolated and characterised from host and non-host plants.

2.6.1 Germination stimulants from host plants

The natural germination stimulants so far reported from host plants are thought to be sesquiterpene lactones, and are collectively named strigolactones (Butler, 1995; Lynn *et al.*, 1981). The first host-derived stimulant was sorgoleone from sorghum (*Sorghum bicolor L. Moench*) root hair droplet (Chang *et al.*, 1986, Netzly *et al.*, 1988). The compound was an unstable dihydroquinone, which was rapidly oxidized to a stable inactive quinone (Hess *et al.*, 1992). Unlike strigol, sorgoleone is hydrophobic and not as active, with activity at a concentration as low as 10^{-7} M. Following this observation, Hess *et al.* (1992) concluded that *Striga* seed germination is controlled by stimulants that are water-soluble.

Furthermore, Hauck *et al.* (1992) identified a biochemical compound named sorgolactone, as the major water- soluble stimulant from sorghum root exudates. It was not until 1993 that strigol was isolated from the *Striga* host plants maize (*Zea mays L.*) and proso millet *(Panicum milliaceum* [L.]) by Siame *et al.* (1993). An additional *Striga* stimulant was found in cowpeas [*Vigna unguiculata* (L) Walp],

which is parasitized by *Striga gesnerioides*, a species that has evolved as being a legume specific parasite.

2.6.2 Germination stimulants from non-host plants

The first naturally occurring *Striga* germination stimulant to be characterized was strigol (Cook *et al.*, 1966), which is a sesquiterpene produced in cotton roots (*Gossypium hirsutum L.*), a non-host of *Striga*. Strigol is active in soil solution at a concentration as low as 10 – 15 mol m^{-3}. Recent studies have revealed more non-hosts plants with the ability to produce *Striga* germination stimulants. Muller *et al.* (1992) reported that large quantities of germination stimulants were recovered from cowpea cultivar Saunders upright, a non-host for *S. asiatica*.

Ma YongQing *et al.* (1996) reported that root cultures of *Menispermum dauricum*, DC (Menispermaceae) a broad-leaved plant and a non-host of *S. asiatica*, produced at least three active compounds. Other preliminary screening of plant tissue culture also revealed that root culture of *M. dauricum* was most potent in inducing germination of conditioned *Striga* seeds (Sugimoto *et al.*, 2001). Later on, Yasuda *et al.* (2003) reported the isolation and identification of strigol from *Mennispermum dauricum* root culture. Resent findings have shown that compounds other than strigolactones can induce germination of *Striga* seeds. Tsanuo *et al.* (2003) isolated and characterised isoflavanones from root cultures of *Desmodium uncinatum*, a non-host of *Striga*, and reported that fractions containing uncinanone B induced germination of the parasitic weed seeds of *S. hermonthica*.

In another study, root exudates from several bambara groundnuts and cowpea varieties were shown to stimulate germination of *Striga asiatica* seeds (Rambakudzibga and Mabasa, 1995). Cowpeas produce a variety of *Striga* germination stimulants, with the most prevalent compound being alectrol, which is a strigol analog (Muller *et al.*, 1993; Siame *et al.*, 1993). It is on these grounds that legumes are frequently used as trap crops for *Striga* species that parasitize cereals. However despite recent progress, the identities, number, and mode of action of most xenognosins remain unknown.

2.6.3 Sources of germination stimulants

Little is known about the biosynthetic origin of the germination stimulants. It was suggested that the roots synthesize germination stimulants and mainly exuded in a region 3 to 6 mm from the root apex (Logan and Stewart, 1991). Moreover, the progress in determining this origin is hampered by the extremely low concentration of the germination stimulants, which have so far been believed to be produced and exuded by the roots of host and non – host plants. In isolation and identification of *Striga* germination stimulants, most researchers have used young plant roots to extract exudates, which constitute these germination stimulants (Cook *et al.*, 1972; Netzly *et al.*, 1988; Hauck *et al.*, 1992; Muller *et al.*, 1992). More often, the root exudates are collected hydroponically from the young roots. Consequently, it was not very clear which part of the plant (hosts or non-host) constitutes the compounds for *Striga* germination stimulation.

Of recent however, reports have indicated that more germination stimulants of *S. hermonthica* were found in the excised stem pieces than in the roots of maize, cowpea and soybeans (Emechebe and Ahonsi, 2003). This was a good inference that not only root exudates from host and trap crops of *Striga* can stimulate the parasite's seeds to germinate, but also stem exudates and/ or sap of the same plants. Other reports of stimulation of *Striga* seeds germination by extracts of plant parts other than those of roots are available. Aqueous extracts of pulverized, oven - dried roots and stems of cotton (Ariga and Berner, 1993) and cowpeas (Ariga, 1996) have been found to stimulate germination of *S. hermonthica* seeds.

Several leguminous plant seeds, including cowpea and bambara groundnuts are reported to release considerable amounts of anthocyanins and flavonoids when soaked in water and aqueous methanol (Ndakidemi and Dakora, 2003). On the other hand, isoflavonoids from *D. uncinatum*, a non-host leguminous plant of *Striga*, have been found to stimulate germination of *Striga* seeds (Tsanuo *et al.*, 2003). Whether compounds released by non-host leguminous crop seeds also stimulate germination of *Striga* seeds remain to be determined.

2.6.4 Mechanisms of germination stimulation in *Striga*

Mechanisms by which strigol and its analogs stimulate *Striga* germination have just been elucidated. Much of the work has concentrated on the role of ethylene on germination. Since ethylene promotes germination of parasitic plants such as *Striga*, as well as many other non-parasitic angiosperms, it has been hypothesized that

strigol stimulates germination by promoting ethylene biosynthesis (Logan and Stewart, 1991). This could probably explain how the diverse artificial chemical stimulants could promote germination by indirectly initiating ethylene production via a wound response (Gabbar *et al.*, 1993).

Ethylene biosynthesis has been reported in preconditioned *Striga asiatica* seeds within three hours following application of strigol (Gabbar *et al.*, 1993). Both germination and ethylene production were inhibited by aminoethoxyvinyl glycine (AVG), an inhibitor of ethylene biosynthesis (Logan and Stewart, 1991) and 2, 5-norbornadiene, an inhibitor of ethylene action (Gabbar *et al.*, 1993). Addition of an ethylene biosynthesis intermediate, 1- amino- cyclopropane- 1-carboxylic acid (ACC) was demonstrated to override the inhibitory effect of AVG (Gabbar *et al.*, 1993). Strigol is thought to trigger activation and/or synthesis of ethylene forming enzymes like AVG for subsequent conversion of ACC to ethylene (Babiker *et al.*, 1987). Ethylene has been shown to stimulate germination in a number of plant species and is thought to initiate the biochemical cascade leading to germination (Logan and Stewart, 1991).

2.6.5 Haustoria initiation

It has been argued that host recognition in *Striga* is by chemical stimulation for seed germination and haustoria formation (Musselman, 1980). The fact that non-hosts such as cotton and cowpea can stimulate germination without allowing parasitic connection illustrates that there is an additional bio-chemical reaction. Haustorial initiation in *Striga asiatica* is in response to a single quinone, 2, 6 - dimethoxy - p -

benzoquinone (2, 6 - DMBQ), which is found in sorghum root extracts, but not in root exudates (Chang and Lynn, 1986). The compound extraction requires vigorous shaking of root tissues, which indicates that it is within the host tissues (Chang and Lynn, 1986). Since *Striga* utilizes cell wall degrading enzymes, it has been suggested that *Striga* lactase activity release quinones from the host root that stimulate haustoria initiation (Stewart and Press, 1990).

Once the parasite seed has germinated, its roots have to be in contact with a suitable host, short of which it will die. Non-host plants that produce stimulants for *Striga* germination but are not capable of releasing the quinones for haustorial initiation are termed trap crops; this forms the basis for "suicidal germination" technique employed in *Striga* control.

2.7 Control of *Striga*

Several control methods have so far been developed to alleviate the *Striga* infestation problem. These include the use of crop varieties that are resistant or tolerant to *Striga* species, (Ejeta *et al.*, 1993; Kim, 1991), biological control using insects, bacterial and fungal agent (Ariga, 1996). Others are use of chemical herbicides (Eplee and Noris, 1990), soil fertility management like nitrogen fertilization (Salle *et al.*, 1987); and various agronomic control options involving manual weeding (Doggett, 1988), rotation (Ariga, 1996) and mixed cropping (Parkinson *et al.*, 1986; Salle *et al.*, 1987; Carson, 1989; Kim, 1991).

2.7.1 Use of resistant and tolerant varieties

Field resistance to *Striga* species is the culmination of a sequence of interactions between host and parasite and is therefore, inherited as a quantitative trait (Ejeta *et al.*, 2000). Consequently, screening for field crop resistance to *Striga* has been slow and inefficient. One of the most understood mechanisms of resistance against *Striga* by sorghum and maize is low production of *Striga* germination stimulants (Hess *et al.*, 1992). Different crop species and different cultivars of the same species differ in the amounts and types of stimulant they produce.

A host plant that produces low amount of *Striga* germination stimulant will cause fewer *Striga* seeds to germinate and thus will be subject to less infestation. Agar gels assay (Hess *et al.*, 1992) and dilution assay (Weerasurya *et al.*, 1993) showed a 10^9-fold difference in the amount of stimulants' activities produced by two sorghum cultivars. This variation is part of the resistance against *Striga* in some of maize and sorghum cultivars. Pierce *et al.* (2003) found that two maize varieties, which are tolerant to *Striga* infestation, produced significantly little amount of germination stimulant compared to the susceptible ones. Other mechanisms of *Striga* resistance include avoidance by the root growth habit, presence of germination inhibitors and mechanical barriers e.g. lignification. Others include inhibition of the exuded radical exoenzyme, lacking haustorial inducers, phytoalexin formation and false phytohormone supply from the non- host (Heller and Wegmann, 2000).

The International Institute of Tropical Agriculture (IITA) in Nigeria has identified a number of resistant germplasm. Moreover, the International Centre for Research in

Semi – arid Tropics (ICRISAT), has selected more than 80 resistant sorghum lines for India and in Tanzania (Lagoke, *et al.*, 1991). Examples of resistant sorghum varieties are, Framida, Dobbs and N13 (Doggett, 1988), SRN39, SAR29, P9405, and Serena (Riches *et al.*, 1999). Despite the efforts made so far in identifying and releasing resistant/tolerant varieties for *Striga* control, resource poor farmers have not adequately adopted this method due to the fact that the farmers cannot afford to buy the improved seeds year after year.

2.7.2 Chemical control

A number of chemical control measures have been used successfully to control *Striga* in the developed countries. Parker and Riches (1993) reported a number of pre- emergence herbicides that are effective in controlling *Striga*. These include oxyfluorfen, fomesafen, metalachlor and pendimethalin as systemic herbicides. Other systemic herbicides such as dicamba are reported to be ineffective due to lack of a phloem-bridge between parasite and host.

In recent times, efforts on *Striga* control have been directed on identification of *Striga* germination stimulants with a view that synthetic compounds based on natural stimulants could be used to control *Striga* by stimulating suicidal germination. Vail *et al.* (1990) tested 15 terpenoids similar in structure to strigol and found that nine were active as germination stimulants of *S. asiatica*. In similar studies, four sesquiterpene lactones that share structural features with lactone ring of strigol were shown to induce *Striga* seed germination at concentrations comparable with those of strigol (Fisher *et al.*, 1989). Other compounds reported to stimulate *Striga* seed

germination include ethylene (Eplee, 1992), sulphuric acid, scopletin, inositol, and sodium hyperchlorite (Hsiao *et al.*, 1981).

Although these synthetics have been shown to be effective under controlled conditions, they have however, proved to be unstable under field conditions (Vail *et al.*, 1990). A further complexity in the behaviour of *Striga* seeds is that the application of germination stimulants either natural or synthetic before or during conditioning, results in reduced germination of the seed (Parker and Riches, 1993). Reasons for this behaviour are yet to be established.

A number of the chemical control measures that have been used successfully to control *Striga* in developed countries are not practical or are too risky to be used in developing countries (Lagoke, *et al* 1991; Dinar, 2000). Moreover, practices like soil sterilization by means of chemical stimulants (strigol and ethylene) are not practical in Tanzania because of the cost and the resulting delay in planting the food crop in areas where there is limited moisture. In general, most of the chemicals are too expensive for most small-scale farmers where the problem of *Striga* infestation exists.

2.7.3 Cultural control methods

2.7.3.1 Hand weeding

Hand weeding of *Striga* is considered to be a traditional control method commonly used by most smallholder farmers (Orgbom, 1970). However, controlling *Striga* species by hand weeding is difficult because *Striga* can do much of its damage to the

host crop before it emerges above the ground (Ramaiah *et al.*, 1991; Parker and Riches, 1993). The weed emerges late in the season when most of the main weeding has been done. It is therefore difficult to convince farmers to spend extra time and efforts needed to manage the weed so as to prevent seeding which leads to further intensification of the problem in the future.

Hand removal of newly emerged *Striga* usually results in re- emergence since the tender shoot breaks off without detaching from the root of the host (Ramaiah *et al.*, 1991). If farmers wait until the stem is mature, weeding is more effective, but by that time, the parasite has already weakened the host. Although weeding the small *Striga* plants is a tedious task and may not increase the yield of already infected plants, it is necessary to prevent seed production and re-infestation of the soil hence hand weeding should be used as part of the integrated control in managing *Striga* infestations (Lagoke *et al.*, 1998).

2.7.3.2 Nitrogen fertilization

Nitrogen in the soil is an important factor in the control of *Striga* because normally *Striga* infestation is often associated with infertile soils. The application of nitrogen fertilizers has proved to reduce *Striga* numbers and crop losses (Okonkwo, 1991). However, the effect of N on *Striga* incidence and its damage depends on the form, quantity, quality and time of application of the N- sources/fertilizers (Pieterse, 1996). It has been reported that nitrogen in the form of Urea (NH_4 (NH) $_3$ ismore effective in the control of *Striga* than any other inorganic nitrogen fertilizers like $(NH_4)_2SO_4$, NH_4NO_3 etc, as it inhibits *Striga* seed germination and radical extension (Bebawi *et*

al., 1991; Okonkwo, 1991). Appropriate amounts of organic soil amendments such as well decomposed compost, and plant residues have also been successfully used against *Striga* (Gacheru and Rao, 2001). Nevertheless, manure or organic residues, which are not well decomposed, is a source of phosphorus, which improves the host (and parasite) vigour without increasing tissue nitrogen (Raju *et al.*, 1990) hence are not effective in controlling *Striga*.

According to Ogborn (1970), host plant tissue nitrogen is a critical factor determining the crop resistance to *Striga*. Hence, adding inorganic or organic soil amendments to the soil can control *Striga*, but results are variable. Studies have shown that addition of nitrogen fertilizers reduced *Striga* infestation on fertile soils but increased *Striga* emergence in infertile soils (Dogget, 1988). In extremely poor soils, a small increase in soil fertility status increases host vigour without increasing its tissue nitrogen and the slight benefit to the host crop also benefits *Striga*. Controversially, Parker and Riches, (1993) reported that application of higher nitrogen levels enhanced growth of both the host and parasite regardless of N levels in the soil prior to application.

The time of application of organic or inorganic nitrogen fertilizers is very important for the effective control of *Striga*. If organic sources of N are to be effective in reducing *Striga* they should release N into the crop root zone early in the season. It was observed that, too early application of inorganic nitrogen fertilizer resulted into healthy development of *Striga* plants late in the season because during this time N

had already been leached out leaving healthy crop roots (Pieterse *et al.* 1996). On the other hand, too late application of N did not result into being useful as it just improved the already infested crop root system. It was therefore concluded that the appropriate time to apply N fertilizers is such that the release of N to the soil should coincide with the time of *Striga* germination and attachment to the host crop (Pieterse *et al.* 1996; Gacheru and Rao, 2001).

The mechanisms responsible for the reduced *Striga* infestation associated with N application are not fully understood. However, many researchers attribute the effect of N to the reduced production of *Striga* stimulant by the host plant (Raju *et al.*, 1990; Bebawi *et al.*, 1991) and inhibition of *Striga* seed germination (Bebawi *et al.*, 1991; Okonkwo, 1991; Cechin and Press, 1993). Other reported effect of nitrogen to *Striga* includes; damage of seeds and seedlings in the soil by toxic effects and slowing down the attachment process (Bebawi *et al.*, 1991; Parker and Riches, 1993). Other effects include alteration of the host root balance and alteration of osmotic pressure in the parasite relative to the host. Moreover, increased nitrogen supply reduces the dependence of parasite on the host for carbon and alleviates influence of the parasite on host photosynthesis (Gurney *et al.*, 1997). In general, nitrogen fertilization reduces the degree of *Striga* infestation by inhibiting both its germination and subsequent attachment and thus improvement in the host crop plant yield (Cechin and Press, 1990).

2.7.3.3 Mixed cropping

Mixed cropping is a viable way for controlling *Striga*. Mixed cropping is a frequent and important traditional farming system where more than one crops are grown together, in many *Striga* infested regions of Africa. There have been several studies showing that *S. hermonthica* is significantly reduced in mixed cropping in Gambia (Carson, 1989), Mali, Cameroon and Kenya (Salle *et al.*, 1987). One of the possibilities proposed mechanisims for reducing *Striga* infestation in mixed cropping is that the inter-crop acts as a trap crop and stimulates *Striga* seed germination ahead of the cereal roots (Oswald *et al.*, 2002). Other possibilities are: (i) the inter-crop produces germination inhibitors; (ii) some plants in mixed cropping create microclimate such as shading; which is unfavourable for *Striga* development and (iii) some may improve fertility status ofc the soil enabling the susceptible crops to escape the effect of *Striga* (Parker and Riches, 1993; Oswald *et al.*, 2002). In any case however, it is necessary to include crops that are capable of inducing suicidal germination, in a mixed cropping system, in order to improve the effectiveness of the crops in the control of *Striga*.

2.7.3.4 Crop rotation

Continuous cropping of a susceptible host crop favours the multiplication of *Striga* since *Striga* plants cannot survive without a host (Parker and Riches, 1993). Crop rotation, using non-host crops can be considered as a simple solution to *Striga* infestation (Esilaba and Ransom, 1997). However, rotation should aim at interrupting the production of new *Striga* seeds and improving soil conditions so as

to end up with depletion of *Striga* seed bank (Parkinson *et al*, 1986). This practice can be achieved through two ways namely catch cropping and trap cropping.

(a) Catch cropping

In a catch crop- system, a susceptible crop is established at high density at the beginning of the rainy season to induce *Striga* germination. After five to six weeks the crop is ploughed in as green manure and the *Striga* is killed before reaching maturity and the host crop can then be planted. However, this method is only possible where a long season permits the growth of the successive crops and where farmers have the equipment for incorporating the catch crop and the weed in the soil. This method is reported to be suitable only for large-scale farming and uneconomical for small- scale farming (Kim, 1991; Lagoke *et al.*, 1991).

(b) Trap cropping

In a trap – crop system host crops are rotated with false host or non- host plants (trap crops) which induce suicidal germination, whereby *Striga* is induced to germinate but dies for lack of a host plant (Ejeta *et al.*, 1993). Trap crops are capable of producing *Striga* germination stimulants, and yet they are not parasitised. Consequently, a large number of the germinated weed seeds are eliminated leading to reduced severity of the *Striga* infestation in the following season (Lagoke *et al.*, 1991).

It is suggested that, false or non- host plants are capable of inducing suicidal germination of the parasite, by releasing molecules that induce *Striga* germination.

This is followed by disruption of a specific early developmental step such as haustorial induction, attachment, penetration and/or connection to the vascular system (Lane *et al.*, 1993; Ejeta, 2001; Serghini *et al.*, 2001) leading to death of the *Striga* seedling. A parallel suggestion is that the non-host plant stimulates germination of the parasitic seeds and prevents tissue penetration and subsequent development (Lane *et al.*, 1993; 1997; Goldwasser *et al.*, 1997) through a necrotic browning of the non-host plant cell around the penetration site.

Crop rotation with trap crops offers good potential for the control of *Striga* (Ramaiah *et al.*, 1991; Rambakudzbga and Mabasa, 1995; Berner *et al.*, 1996; Radosevich *et al.*, 1997). However, leguminous crop species and even cultivars within the same species vary in their effectiveness in reducing seed population in the soil due to their differential capacity to produce the germination stimulants (Berner and Williums, 1998; Ariga, 1996; Abayo *et al.*, 1997; Gbehounou and Adango, 2003).

Moreover, in addition to their differential capacity in producing germination stimulants, *Striga* seeds of different populations also respond differently to stimulants from same crop species/cultivars. Parker and Reid (1979 moisture), reported that root exudates from cotton, cowpeas, jute, soybean, pigeon peas, kenaf, chickpeas and groundnuts, were as effective as the natural host sorghum in stimulating germination of a Sudanese population of *S. hermonthica* seeds. However, using the same crops to stimulate a sample of *S. hermonthica* from Nigeria, only cotton and jute caused germination comparable to that from sorghum and the rest of the crops proved relatively ineffective. Likewise, Gbehounou and

Adango (2003) reported similar results after evaluating the effectiveness of potential trap crops in stimulating germination of different populations of *S. hermonthica* seeds. In other studies by Rugutt and Berner (1998), *S. hermonthica* seed population from millet responded quite differently from those from sorghum and only germinated in response to cowpeas and pigeon peas. This confirms that a *Striga* population, which is specific to one crop species, responds differently to other germination stimulants and hence is likely to require a range of different trap crops.

It is interesting to note that among the false hosts are the leguminous crops, which are also capable of nitrogen fixation in the soil. Crops like groundnuts, bambara groundnuts cowpeas and many other legumes, do not only reduce the *Striga* reservoir in the soil, but also increase cereal yields because of the beneficial rotation effects like improving soil fertility through N-fixation and soil structure through improved microbial organisms (Ramaiah *et al.*, 1983; Carsky *et al.*, 2000; Tenebe and Kamara, 2002; Gbehounou and Adango, 2003, Oswald and Ransom, 2001). However, the ability of different leguminous trap crops to fix atmospheric N varies considerably between and within species (Table 1).

It is well known that *Striga* endemism is most prominent in areas that are low in fertility (Weber *et al.*, 1995). The use of inorganic fertilizers by small-scale farmers in Africa has declined further with the removal of subsidies in recent years. It is therefore important to manipulate the use of leguminous trap crops in controlling *Striga* for the resource poor farmers, who comprise the majority of cereal producers in most African countries. The challenge on hand is to identify and develop legume

genotyped with high capacity for stimulating suicidal germination of *Striga* and at the same time improve soil fertility through their ability to fix nitrogen.

Table 1. Estimates of N fixed by different symbiotic legumes in Africa

Legume species	Country	N fixed (Kg $ha^{-1}y^{-1}$)	Reference
Soybeans	Nigeria	15 – 125	Eaglesham *et al.* (1982)
Cowpeas	Ghana	201	Dakora *et al.* (1987)
	Nigeria	122	Eaglesham *et al.* (1981)
Groundnuts	Ghana	32 – 134	Dakora (1985b)
Bambara grondnuts	Ghana	40 – 62	Dakora (1985a)
Pigeon peas	Kenya	141	Onim *et al.* (1990)
Leucaena	Tanzania	110	Hogberg and Kvarnstrom (1982)

2.7.4 Research gaps

For many years now, researchers have been tying to study *Striga* in an effort towards its eradication. One of the fields, which have been researched, is the use of naturally occurring stimulatory compounds to control *Striga*. However, despite the good progress made so far, there still exist some research gaps, which need to be tackeled so as to achieve adequate levels of *Striga* management in this field. Some of the gaps are highlighted below:

(a) In isolating and identifying the natural stimulatory compounds of *Striga* from host and non-host plants, the identities, number and mode of action of many xenognosins still remain unknown.

(b) Some of the organic compounds extracted from roots and stems of host and non-host leguminous trap crops have been shown to stimulate germination of *Striga* seeds. Whether the compounds released from seeds of the same crop species also stimulate suicidal germination of *Striga* seeds remain to be determined.

(c) It is reported that xenognosins produced by several non – host plants are specific to *Striga* strains in terms of germination stimulation of the parasitic weed seeds. Conditions leading to this plant / parasite specificity are still not well documented.

(d) Nitrogen in the soil is an important factor in the control of *Striga* because normally *Striga* endemism is more prominent in areas that are low in N fertility. However, the mechanism responsible for the reduced *Striga* infestation with N application is still not fully understood.

CHAPTER THREE

MATERIALS AND METHODS

The study involved three experiments, two laboratory/greenhouse experiments and one-field experiment. One of the laboratory/green house experiments was carried out in South Africa and the second laboratory experiment and field experiments were conducted in Tanzania.

3.1 Determination of the Potential of Non-host Leguminous Crops Species as Germination Stimulants for *striga asiatica*

A laboratory and greenhouse experiment was conducted at theTanzania Official Seed Certification Agency (TOSCA) laboratories at SUA Morogoro. The experiment was carried out between November 2001, and March 2002 to investigate the ability of legumes to stimulate germination of *Striga asiatica* seeds. 56 cultivars of 6 leguminous species were used. The experiment was repeated three times. Test seeds used in the study were collected from various locations within Tanzania as detailed in Table 2. A susceptible sorghum variety (Pato) was included in the experiment as a check.

Table 2. Species/cultivars used in the experiment and their respective site of collection

Crop spp		Description/local name	Status	Site
Bambara groundnuts	1	Spotted cream	Landrace	Makutupora
(*Vigna subterranea* (L.) Thou)	2	Cream	Landrace	Makutupora
	3	Cream	Landrace	Mwanza
	4	Brown	Landrace	Bukoba
	5	Red	Landrace	Dodoma
	6	Nyandani spotted cream	Landrace	Dodoma
	7	Light brown	Landrace	Dodoma
	8	Light brown	Landrace	Mwanza
	9	Kyonda spotted	Landrace	Mwanza
	10	Brown	Landrace	Mwanza
	11	Spotted cream	Landrace	Botswana
Soybeans	1	TGX 1019 - 2EN	Breeders line	SUA
(*Glycine max* (L.) Merr.)	2	TGX 1805 - 31E	Breeders line	SUA
	3	TGX 1871 - 12E	Breeders line	SUA
	4	TGX 1871 - 5E	Breeders line	SUA
	5	TGX 1830 - 20E	Breeders line	SUA
	6	TGX 1835 - 10E	Breeders line	SUA
	7	TGX 1805 - 8E	Breeders line	SUA
	8	Duicker	Variety	SUA
	9	Kaleya	Variety	SUA
	10	Bossier	Variety	SUA
	11	TGX 1829 - 1E	Breeders line	SUA
	12	TGX 1799 - 8E	Breeders line	SUA
	13	TGX 1876 - 2E	Breeders line	SUA
	14	TGX 1448 - 2E	Breeders line	SUA
Common beans	1	Maharage kunde	Variety	SUA
(*Phaseolus vulgaris* (L.))	2	Kasuka nywele	Variety	SUA
	3	DN Bayo	Variety	SUA
	4	Rojo	Variety	SUA
	5	DN SEQ 41	Variety	SUA
	6	TMO 542	Variety	SUA
	7	DN 1008	Variety	SUA
	8	SUA 90	Variety	SUA
	9	PBS wanja	Variety	SUA
	10	EG 10	Variety	SUA
	11	DN 1007	Variety	SUA
	12	MCM 5001	Variety	SUA
Groundnuts	1	Tatu tatu	Landrace	Dodoma
(*Arachis hypogeal* (L.))	2	Mamboleo	Variety	Dodoma
	3	Johari	Variety	Dodoma
	4	Bukene	Landrace	Tabora
	5	Mani pinter	Variety	SUA
Cowpeas (*Vigna unguiculata* (L.)	1	Greyish cream	Landrace	Dodoma
Walp)	2	Cream	Landrace	Dodoma
	3	Red	Landrace	Dodoma
	4	Brown	Landrace	Dodoma
	5	Macho ya paka	Landrace	Dodoma
Pigeon pea	1	ICEAP 00040 (Mali)	Variety	ICRISAT
(*Cajanus cajan* (L.) Millsp)	2	ICEAP 00068	Breeders line	ICRISAT
	3	ICEAP 00020	Breeders line	ICRISAT
	4	ICEAP 00053	Breeders line	ICRISAT
	5	ICPL 87091	Breeders line	ARI Ilonga
	6	ICPL 86005	Breeders line	ARI Ilonga
	7	ICEAP 00073	Breeders line	ARI Ilonga
	8	ICPL 9145	Breeders line	ARI Ilonga
	9	ICPL 6927	Breeders line	ARI - Ilonga
Sorghum	1	Pato	Variety	Dodoma
(*Sorghum bicolor* (L.) Moench)				

3.1.1 Collection of test crop seeds

Leguminous crop seeds of different origins were obtained from Agricultural Research Institute (ARI) Makutupora and Sokoine University of Agriculture (SUA) Morogoro. Collection was based on: suitability of the species/varieties to the local conditions, availability of the seeds during the time of collection and seed coat colour as in the case of bambara groundnuts and cowpeas. Varieties that are currently recommended for planting in the affected areas were also collected for experimentation.

3.1.2 Collection of *Striga asiatica* seeds

Striga asiatica seeds were collected from infected fields in sorghum based cropping systems near ARI Makutupora in Central Tanzania while ARI Ilonga provided seeds from rice based cropping system (Kyela, Mbeya). The seeds from rice based cropping system were collected during the 2000-cropping season. *Striga* seeds from ARI Makutupora were collected from infested fields in May 2001. Dry heads were harvested out of mature plant and stored in paper bags. They were then sun dried and threshed in plastic bags. Large plant debris was manually separated and the remaining particles and seeds were sieved through 200 µm and then through 100 µm sieves to further remove larger and smaller particles. Seeds retained in the latter were collected for further cleaning as detailed in section 3.1.3.

3.1.3 Cleaning of the *Striga* seeds

Seeds were cleaned using the floatation method (Berner *et al.*, 1997). Fifty grams of Ammonium sulphate $(NH_4)_2SO_4$ were dissolved in 300 mls of water in a floatation cylinder. One gram of the seeds was then suspended in the solution. Soil particles sank while *Striga* seeds and other organic materials floated on the surface and were then skimmed off. The later was then washed through 90-µm-mesh sieve to further concentrate the *Striga* seeds. Final cleaning of residues was then carried out with tap water to eliminate salt solution and hence potential damage to the seeds during storage period. Seeds were then air dried and stored in dry glass containers for further evaluation.

3.1.4 Sterilization of *Striga* seeds

Thirty mL portion of 1% Sodium hypochlorite (NaH_2Cl) solution was dispensed into a petri dish (12 cm diameter). To break surface tension, a drop of Tween 80 was added to the mixture. About 1g of *Striga* seeds were added into the solution and stirred for 2 minutes. Floating seeds and debris were discarded and the remaining mixture was poured into a funnel lined with two layers of filter papers and washed with clean sterilized water.

3.1.5 Testing for *Striga* seed viability

Before the seeds were used in the laboratory studies, they were first tested for viability by using 2, 3 – 5 Triphenyl tetrazolium chloride (TTC). One teaspoonful of sterilized seeds (approximately 1000 – 3000ds) were put in a small glass tube and 5

ml of freshly prepared 1% TTC was added into it. The tube was then closed tightly to prevent evaporation and placed in a dark incubator at a setting of 33^{0}C for eight days. After the incubation period, excess TTC solution was removed using a pipette. Five milliliter of water was then added to the small tube and the tube shaken well. Samples of the suspension were then drawn using a 2.5-ml pipette and dropped on a petri dish, for evaluation under compound microscope at a magnification of X250.

3.1.5.1 Evaluation of percent germination

Approximately 100 *Striga* seeds were placed on a filter paper and non-viable seeds were counted out of the total number of seeds added. This was repeated four times and the average percent germination was calculated using the formula: (Average % Germination = Total no. of seeds – non- viable seeds/ total no of seeds) x 100. Through visual observation, seeds that revealed reddish or reddish yellow embryos were regarded as viable while empty seed shells, seeds with entirely white endosperm, and seeds with fungal and bacterial (mostly black) inclusions were counted as non-viable.

3.1.6 Conditioning of *Striga* seeds

As *Striga* seeds will not germinate either in the absence of a chemical stimulant or prior to conditioning, the seeds had to be conditioned as described by Berner *et al.*, 1997. Using a paper punch, small discs (0.6cm diameter) were punched out of glass fibre filter papers (used to minimize microbial growth). A small number (25 – 50) of clean sterile *Striga* seeds were put on the glass fibre filter paper using a sterile

forceps and counted under compound microscope (x 250). Two large pieces of regular filter paper were moistened and placed in a sterile petri dish 9.5 cm in diameter. The discs containing the seeds were then placed on the wet filter paper and the petri dishes, wrapped with parafilm and aluminum foil to conserve moisture and incubated at 33^{0}C for 14 days.

3.1.7 Growing of crop seedlings

Before planting, the crop seeds were first surface sterilised using 1% Sodium hypochlorite solution. The seeds were left in the solution for 5 minutes and then thoroughly rinsed with distilled water. Ten seeds were planted in plastic pots (12 cm diameter x 12 cm depth) filled with sand that was sterilized by heating. After planting the sand was kept moist by watering, for 21 days after which the plants were uprooted by carefully pulling and all sand washed from the roots using sterile water.

3.1.8 Preparation of root cuttings as source of germination stimulants

After uprooting and cleaning the roots of the test crops with sterile water, using a sharp razor blade the roots were cut into one-centimeter long pieces and one gram for each cultivar was weighed. A circular hollow aluminium foil ring (1.5cm diameter x 1.5cm depth) was prepared out of aluminium foil. The ring was then placed at the center of the petri dish (Fig. 3). Each gram of the cut roots was placed in the hollow ring. Three hundred µl of sterile de-ionized water was added to the roots at the center of the well. For control, one gram of the susceptible host sorghum, variety Pato was used as positive control and 300 µl of sterile de-ionized

water as a negative control. The petri dishes were then wrapped with parafilm and aluminum foil and placed in an oven at 33^{0}C for 48 hours after which the number of germinated seeds out of total number of seeds in each disc was used to calculate germination percentage for each cultivar.

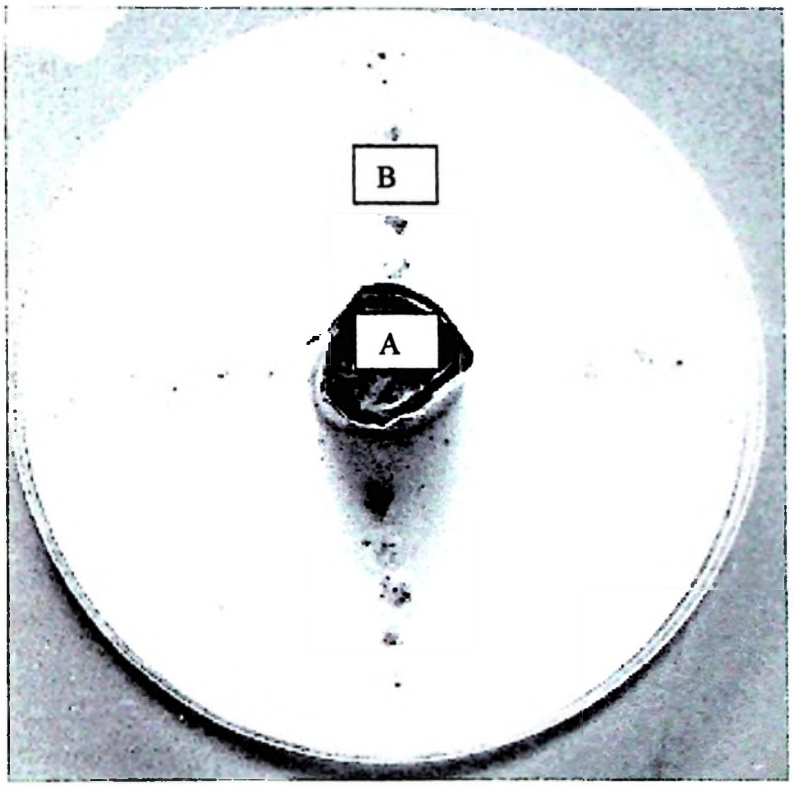

Figure 2. Illustration of the arrangement of Petri Dish technique showing A: Central well with cut roots and B: *Striga* seeds in discs

3.1.9 Experimental set up and design

The experimental set up used in the study was a split plot with the main factor being cut roots of a cultivar of one particular legume specie (factor A) and the sub factor

being distances (1.3cm, 1.9cm, 2.5cm, 3.1cm and 3.7cm) from the source of stimulant (factor B). Each of the variety - distance combinations had four replicates as illustrated in Figure 3. Glass fibre discs with the *Striga* seeds were arranged in four rows radiating out from the central well to form a cross section of discs with the well as the central point. Each row contained five discs placed edge to edge with the first disc touching the edge of the central well. The single disc was regarded as distances away from the stimulant source, with the distance closest to the source of stimulant regarded as distance 1=1.3 cm, the next as distance 2 =1.9 cm, distance 3 = 2.5 cm, distance 4 = 3.1 cm and distance 5 = 3.9 cm. The petri dishes were then arranged in the oven in a completely randomised design (CRD). The experiment was repeated three times.

3.1.10 Data analysis and statistical model

Data collected from the experiment were pooled together and subjected to analysis of variance using MSTAT - C statistical software program. Factorial CRD for factor A (Varieties/cultivars) as the main plot and factor B (Distance) as a sub-plot in A was used. Significant means ($P< 0.05$) were separated using Turkeys Honest Significant Test (THST).

The statistical model was:

$$Y_{ijk} = \mu + \rho_i + \alpha_j + \omega_{ij} + \beta_K + \alpha\beta_{jK} + \varepsilon_{ijk}$$

Where: μ is overall mean of all observation

ρ_i is the effect due to block i

α_j is the main plot treatment effect

ω_{ij} is the main plot error

β_K is the subplot treatment effect

$\alpha\beta_{jK}$ is the interaction between subplot and subplot effect

ε_{ijk} is the subplot error

3.2 Testing the Efficacy of Selected Leguminous Crop Species in the Control of *Striga asiatica* Under Field Conditions

3.2.1 Experimental site

The study was conducted at Mchemwa village near ARI Makutupora, Dodoma during the 2002/03 and 2003/04 rain seasons. The experimental area lies between latitude 6^0 02' 20"S and longitude 35^0 45' 23.5" E at an altitude of 1050 masl, in Central Tanzania. The climate in the area is hot, semi- arid to arid with a uni – model type of rainfall. The average annual rainfall is 607.9 mm and usually falls between November and May. About 90% of the total annual rainfall however, falls within the months of December to March. Monthly means of maximum temperature ranges from 26.9^0C to 31^0C, and the corresponding minimum temperatures range from 14.10C to 19.5^0C. The mean monthly rainfall and minimum and maximum temperatures for the study area for the past ten years obtained from the Tanzania Meteorological Agency, Dodoma is shown in Appendices 2 and 3, respectively.

The soils in the experimental site are deep, well-drained sand loam, classified as Ferocious acrisols according to FAO classification. Chemical characterisation of the soil showed that the soil is of low fertility status, the major limitation being nitrogen. Total N content ranged between 0.09% to 0.13% and CEC varying between 13.2 and 14.5 Cmol/kg soil.

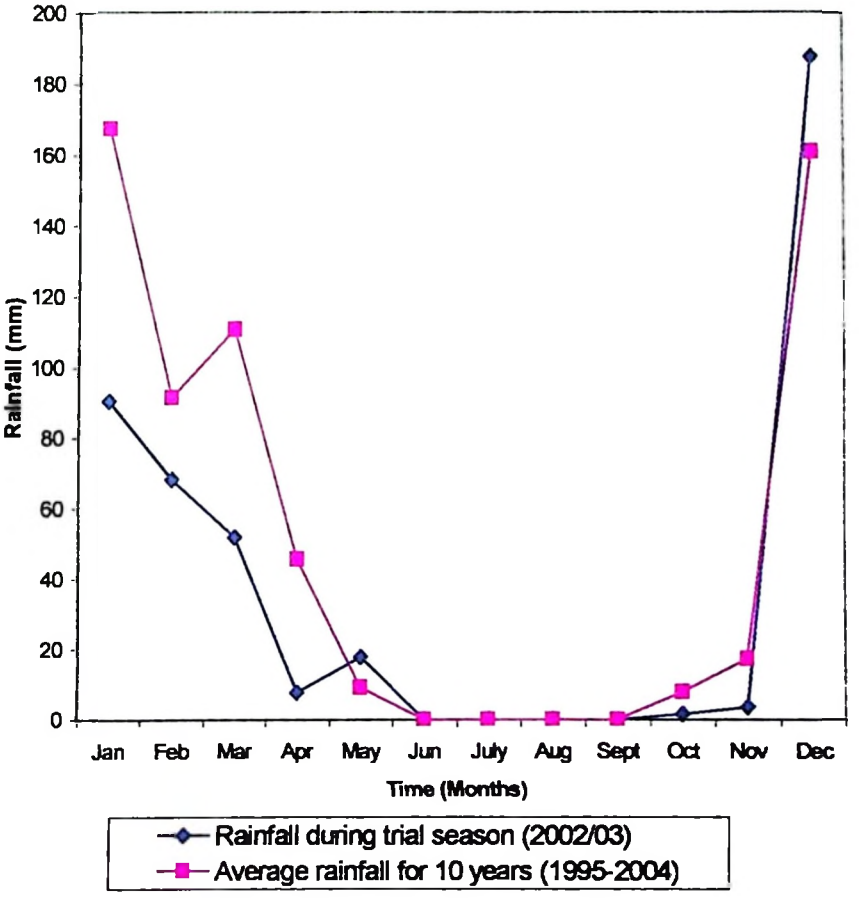

Figure 3. Rainfall distribution (by months) for the experimental site

The experimental site had previously been under sorghum for three consecutive seasons and was heavily infested with *Striga asiatica*. In both years of the trial, the experimental site was protected with a perimeter fence of thorny branches to prevent animals from grazing on the plant residues.

3.2.2 Treatments and experimental design

Treatments used during the first year (2002/03) were: two pigeon pea breeding lines (ICEAP 00020 and ICEAP 00040), two bambara groundnut landraces (Nyandani spotted cream and red ex - Makutupora), one groundnut cultivar (ex-Bukene) and one cowpea cultivar (white black eyed). A weed free fallow (maintained by immediate hand weeding as soon as weeds emerged) was included in the experiment. This was to check whether the legume trap crops have significant effects on *Striga* seed bank as compared to the natural dying – off process as reported by Gbehounon *et al.* (1996); Gbehounon, (1998) and Pieterse, (1996).

The experimental design used in both years (2002/03 and 2003/04) was Randomized Complete Block (RCBD) with eight treatments and four replications (Appendix 1). Layout of plots was done during the first year and was marked with permanent labels for use in the second year. Plot size was 5 m x 3 m while blocks were 24m x 5m (120 m^2). Space between blocks was 1 m making the total experimental area to be 24m x 23m (552 m^2). Sampling area was 3.8 m x 1.8m (6.84 m^2) at the middle of the plot, and hence the total sampling area adding up to 15.2 m x 14.4 m (218.88 m^2).

Spacing used for the different treatments were as follows:

Pigeon pea Var. ICEAP 00020 and Var. ICEAP 00040 (0.90m x 0.45m), Bambara groundnut land race Nyandani spotted cream and land race red Ex - Makutupora (0.60m x 0.30m), Ground nut land race Ex. Bukene (0.45m x 0.30m), Cowpea land race white black eyed ex - Makutupora (0.60m x 0.30m) and Sorghum Var. Pato (0.60m x 0.30m). In the second year (2003/04), sorghum (Pato) was planted as sole crop on the same pre- marked plots where leguminous crops were planted in the first year. The same spacing (0.60m x 0.30m) was used.

3.2.3 Experimental management

3.2.3.1 Soil characterisation

Soil samples were taken from each plot before the onset of rains in the first year, to determine the level of *Striga* seeds in the soil and the fertility status of soil. By using a shovel, eight samples were taken in a zigzag pattern at a depth of 0 – 15 cm. Samples were then bulked and mixed thoroughly and thereafter a sub-sample taken for weighing, drying and chemical analysis in laboratory. Soil samples were similarly taken before setting up of the experiment in the second year.

Soil pH in water was determined by a pH meter using a soil to water ratio of 1:1 as described by Peech (1965). Available P was extracted following Bray I procedure (Bray and Kurtz, 1945) and P in the extract was determined by the ascorbic acid-molybdate blue method of Murphy and Rilley (1962). Total N was determined by micro-Kjeldahl method (Bremner, 1965). The exchangeable K in the ammonium

acetate leachates was determined by atomic absorption spectrophotometer as described by Hesse (1971).

3.2.3.2 Site preparation

In both years site preparation was done using a hand hoe before the onset of the seasonal rains. Experimental site preparation was done on 26th December and 16th December for 2002/03 and 2003/04 experiments, respectively. The first land preparation was followed by field layout in the following day while in the second year preparation of land was followed by field re-demarcation using the same plots as used in the previous year.

3.2.3.3 Sowing

Sowing of sorghum was done on the 28th and 20th of December for the 2002/03 and 2003/04 experiments, respectively. The different leguminous crops and sorghum were spaced as described in section 3.2.2. Two to four seeds were sown per hill, which were later thinned to one plant per hill for pigeon peas and two plants per hill for sorghum, groundnuts, cowpeas and bambara groundnut. Thinning was done two weeks after sowing.

3.2.3.4 Weeding

Weeding was done twice in both years using a hand hoe and/or hand pulling when/where necessary. Weeding was done to remove all weeds except *Striga* plants. The first weeding was done two weeks after sowing (11th January, 2003 for

the first year experiment, and 5th January 2004 for the second year experiment), while the second weeding was done five weeks later (18th February, 2003 and 11th February, 2004 for the first and second years' experiments, respectively).

3.2.3.5 Harvesting

Except for the pigeon pea cultivars, which did not attain maturity in the first year due to inadequate rainfall, other crops were harvested after reaching maturity. Groundnuts and bambara groundnuts were harvested by pulling the mature plants after easing the surrounding soil by using a hand hoe. The plants were turned upside down and left to dry in the sun for seven days. After drying the nuts were hand picked and shelled and weighed. On the other hand, cowpeas were harvested by removing individual ripened pods. The pods were sun dried then shelled, and then grains were weighed. Plant debris was not removed from the plots. Pigeon pea plants rejuvenated in the following rain season, after which they were removed before land preparation for the 2003/04 experiments.

3.2.4 Data collection

3.2.4.1 *Striga* seed extraction by gravimetric method (Berner, *et al.*, 1997)

(a) Determination of soil (dry weight)

Before extraction of *Striga* seeds from the soil, a small soil sub sample of 20g (from section 3.2.3.1) was weighed and placed in oven at 70° C for 48 hours. After drying, the samples were re-weighed and moisture content calculated from the formula: Mc = {(W wc - W ds) / W ws} x 100. Where Mc = percent

moisture content, Wds = Weight of dry sample (g), and Wws = Weight of wet sample (g).

The remaining samples were then weighed and soil dry weight calculated by using a formula:

$$Dw = Ws (1 - Mc)$$

Where: Dw = Dry weight of soil (g)

Ws = Weight of sample (g)

Mc = Moisture content (%)

The amount of seeds extracted from the sample in the subsequent steps was then expressed as number of *Striga* seeds per oven dry weight of the soil.

(b) Separation of *Striga* seeds from larger and smaller size soil particles

This was done sequentially by first sieving the *Striga* size particles from larger and smaller ones by placing a series of sieves of different sizes starting from 250. 212 and 90 microns. A small sheet of coarse screen was placed over the 250-micron sieve, to remove the largest particles. Once stacked, the weighed soil sample (200 g each) was poured onto the course screen. The stacked sieves with soil were then placed under flowing tap water, and particles washed sequentially through the sieves. After washing the soil on the course screen, the screen was removed and washing was continued on the 250-micron screen. The procedure was repeated until the soil on each of the sieves had been washed off completely. The soil in each sieve was washed over running water for five

minutes. All of the *Striga* size particles were then collected on the 90-micron sieve. *Striga* seeds were then separated from other particles of similar size using potassium carbonate floatation method as described by Berner *et al.* (1997).

3.2.4.2. *Striga* counts (number of emerged *Striga* plants per plot)

The number of germinated *Striga* was recorded by counting the number of germinated plants in each sampling plot, after every two weeks starting from the 7th week after planting (WAP) of sorghum when *Striga* started to emerge from the soil. The counting continued until the 13th WAP when more than 90% of *Striga* plants started to decline due to scenescence in all experimental plots.

3.2.4.3. *Striga* plant height (cm)

Data was collected at the 10th WAP. Ten *Striga* plants per sampling plot were randomly selected and height measurements ware taken by using a ruler. At this period, most of the plants were at the flowering stage. The sampled plants used were marked so that subsequent measurements were taken from the same plants.

3.2.4.4. Number of capsules per plant and *Striga* dry weight (g/m^2)

The sampling area was visited every week beginning with the time when mature *Striga* plants were seen (10 WAP). Mature *Striga* plants which appeared to be slightly dark, slightly greyish, purplish or yellowish) in each sampling plot were

selected, counted and their capsules per plant counted and recorded before they were cut and put in a plastic bag. The bags were then labelled with the plot number and were left at the site in a wind-protected place, awaiting the follow up counts. The procedure was repeated every week until all mature plants were harvested. In each sampling date, the mature plants were added to the same bag designated for that sample at the first harvest. Plants were then thoroughly sun dried in a wind-protected place, after which they were further dried in a ventilated oven at 70^{0}C for 48 h before determination of dry weight.

3.2.4.5 Sorghum plant height (cm/plant)

Throughout the period of study non-destructive measurements were made at two weeks intervals from the 3rd to 11th WAP. Five plants selected at random were measured (from the base of the stem to the youngest visible ligules). At the first measurement, sampled plants were marked using a red manila rope, to facilitate taking measurement from same plants during subsequent height sampling. Plant height is known to be a sensitive indicator of infection and the parameter has previously been shown to be a good correlate of biomass for sorghum (Press *et al.*, 1987).

3.2.4.6 Sorghum yield and yield components

After maturity, sorghum heads were harvested and total number of heads were counted and weighed. Average weight per head was calculated by dividing the weight by total number of heads. The head lengths were then measured before they

were sun dried, shelled and grain yield per plot determined. Threshing percentages were computed by subtracting the weight of grains from the head weight and multiplying by one hundred. Grain weight was then converted into kg/ha.

3.2.5 Statistical analysis

All data were subjected to analysis of variance (ANOVA) using MSTATC statistical package. Linear regression analyses were conducted to compare the relationship between *Striga* and sorghum growth parameters and yield components. Significant differences were compared using Turkey's honest significant difference ($P < 0.05$)

The statistical model used for CRBD was:

$$Y_{ij} = \mu + \beta_i + \Psi_j + \varepsilon_{ij}$$

Where $Y_{ij} = j^{th}$ observation on the i^{th} treatment

μ = Overall mean of all observation

β_i = Block effect

Ψ_j = Treatment effect

ε_{ij} = Random error

3.3 Influence of Exudates From Seed Coat and Other Plant Parts of Selected Legumes on Germination of *S. asiatica* Seeds

Glasshouse and laboratory experiments were conducted in South Africa between June and October 2004, to investigate the influence of seed coat colour and other plant parts on germination of *Striga asiatica* seeds. Glasshouse experiments were carried out in Cape Town, at the Cape Technikon (CAPETECH) Horticulture unit, while the laboratory trials were conducted at the University of Cape Town (UCT).

3.3.1 Experimental materials

Except for the black bambara groundnut seeds which were obtained from the Tanzania Pesticide Research Institute (TPRI) Arusha, all other crop and *Striga* seeds used in this experiment were same lot as those used in experiment one (Table. 2). Due to limited number of black bambara groundnut seeds, bioassay on *Striga* seed germination was only done on seed exudates. The GR- 24 used as a standard control in these experiments was obtained from the Department of Plant Production, Wageningen University in the Netherlands.

3.3.2 Collection of Crop Seed Exudates

Three hundred grams of seeds of each species/landrace were soaked in a beaker containing 600 ml of de- ionized water to extract the seed exudates. After 12 hours the exudates from each beaker were collected and air-dried under pressure for 24 hours. The dried exudates were then refrigerated at 0^{0}C to await further observations.

After collection of the seed exudates, the seeds were then pre-germinated on filter papers for 36 hours at 25^0C before being planted in pots.

3.3.3 Planting of crop seeds

The pre-germinated legume seeds were sown into pots (20 - cm diameter, 20 -cm high) filled with industrial sand. Fifteen seeds were sown in each pot. The seeds were inoculated with bradyrhizobium strain CB756. Pots were irrigated daily with equal volumes of water to keep the sand constantly moist. The glasshouse temperatures were 20^0 – 25^0C and 10^0 – 15^0C for days and nights, respectively, during the experimental period. Twice each week, the plants were supplied with 400 ml of half strength N- free Hoagland's nutrient solution per pot (Hewitt, 1966). This provided elemental supplements of 6.14mg K, 3.24mg Ca, 4.24 mg Mg, and 1.18 mg P per kg dry sand. Thirty days after sowing the plants were transferred to hydroponics, which were filled with 0.25L of the nutrient solution. Aeration of the plant roots was facilitated by use of air pumps. The hydroponic containers were arranged into six blocks of five pots each.

3.3.4 Collection of root exudates

Collection of root exudates was done twice during the growing period. The first collection was done ten weeks (70 days) after sowing. The second collection was done two weeks after the first collection. Fresh root exudates were collected in large sterile bottle (5L) each. After the first collection, the hydroponic containers were refilled with freshly prepared nutrient solution. The exudates from the hydroponics

in each block were pulled together in one bottle. After collection, the exudates were refrigerated at 0^0C.

3.3.5 Collection of root and shoot extracts

Just after the second collection of the root exudates, plants were separated into roots and shoots. The different parts were collected and labeled according to the corresponding blocks where root exudates were collected. They were then weighed and stored in a refrigerator at 0^0C.

3.3.6 Extraction of organic compounds from fresh root and shoot extracts

Fresh roots and shoot materials were first cut into small pieces (less than 1 mm) to facilitate grinding. The tissues were then ground in a motor and the grounded material soaked in 50% methanol using a ratio of 1g tissue: 10 ml methanol. The mixture was then refrigerated for three days at 0^0 C to facilitate further extraction of the organic materials into the solvents, after which it was filtered using Filter paper Whatman No 2. The filtrate was then dried by using air blowers (Fig. 4) and was kept under room temperatures before they were subjected to *Striga* germination bioassay.

3.3.7 Treatments and experimental design

In the first set of experiment to determine the effect of seed coat colour on percent germination of *S. asiatica* seeds, a total of seven treatments were used. These included: i) seed exudate from black bambara groundnut; ii) seed exudate from red

Figure 4. Preparation of plant materials for extaction of stimulants for *Striga* germination bioassay, A: hydroponically grown crops B: author collecting samples C: separating roots from shoots and D: drying exudates/extracts by air blowers

bambara groundnut; iii) seed exudate from cream bambara groundnut; iv) root exudate from red bambara groundnut; and v) root exudates from cream bambara groundnuts.vi) Sorghum (Pato) and vii) de-ionized water were used as positive and negative controls respectively.

In the second set of experiment to compare the influence of different legume plant parts on germination stimulation of *S. asiatica* seeds, 14 treatments were used. These were: seed exudates, shoot extracts, root exudates and root extracts each from bambara groundnuts (red ex-Makutupora), cowpeas (white black-eyed ex-Makutupora) and groundnuts (ex- Bukene). Synthetic strigol (GR –24) was used as positive control and deionized water as a negative control. The experimental design used in both experiments was a Completely Randomized Design (CRD) with four replications and both sets of experiments were repeated three times.

3.3.8 Germination bioassay

Germination tests were performed on the crude samples in accordance with Berner *et al.* (1997). Conditioning of *Striga asiatica* seeds was done as described in section 3.1.6. Crude extracts from legume seeds, roots and shoot were reduced to 0.1 ml and made up to 0.5 ml with de-ionized water. One milligram of GR – 24 was first dissolved in one ml of acetone before being diluted with 100 ml of de-ionized water to make a concentration of 10 mg/l (Berner, *et al.*, 1997).

The glass fibre filter paper discs containing the conditioned seeds were placed on filter paper (Whatman No. 1) to remove excess moisture. The discs were then returned to the petri dishes and 50µl of test solution applied to each disc. Petri dishes with *Striga* seeds were then sealed with parafilm and put in an incubator at 30^0C. After 48 hours germinated seeds in each petri dish were counted under stereomicroscope and the percentage of germinated seeds computed.

3.3.9 Radical growth inhibition of *Striga* seeds by crude exudates/extracts

A piece of thin-layered paper was calibrated at a magnification of X20. This scale was used in all radical length measurements. Each glass fibre disc containing 40-50 conditioned *S. asiatica* seeds were placed on petri dishes lined with two pieces of moist filter papers. The seeds were then exposed to 50µL of the test solution to induce germination. GR 24 was used as control. The petri dishes were sealed with parafilm and aluminium foil and kept in an incubator at 30^0C. Using the mounted scale on stereomicroscope, radical length was measured after three days. Percent of inhibition of radical lengths of *S. asiatica* seeds exposed to crude extracts/exudates relative to the control were computed.

3.3.10 Data analysis

Data for the germination bioassay and radical length reduction were based on *Striga* counts. However, since nearly all data for percentage germination computed from *Striga* counts lied in the range of 30% and 70%, it was not necessary to conduct angular transformation of the data, as doing so was unlikely to produce a noticeable

change in the conclusion (Snedecor and Cochran, 1989). Therefore, percentages were subjected to analysis of Variance using MSTAT - C statistical software program. Significant means ($P < 0.05$) were separated using Tukey's Honest Significant Test (THST). The statistical model used was: $Y_{ij} = \mu + \Psi_i + \varepsilon_{ij}$

Where Y_{ij} = j^{th} observation on the i^{th} treatment

μ = Overall mean of all observation

Ψ_i = Treatment effect

ε_{ij} = Random error

CHAPTER FOUR

RESULTS

4.1 Evaluation of the Potential of Non-host Leguminous Crops Species as Germination Stimulants of *S. asiatica*

4.1.1 Viability test for *S. asiatica* seeds

Results for viability test are shown in Table 3. There was no significant difference between the percent viability of seeds obtained from the two localities.

Table 3. Percentage germination of *Striga asiatica* seeds collected from two localities in Tanzania

Sample number	Percent Viability	
	Kyela (Southern Tz)	Makutupora (Central Tz)
1	90.00	86.67
2	89.66	79.71
3	91.04	82.56
4	85.45	87.06
5	85.96	88.00
Mean	**88.42a**	**84.80a**

Means followed by the same letters are not significantly different according to students t-test ($P > 0.05$)

4.1.2 Effects of crop varieties on germination of *S. asiatica* seeds

4.1.2.1 General observations

Germination was not observed in the negative control, indicating that no spontaneous germination occurred. *Striga* seeds from rice- based cropping system were not induced to germinate by any of the species/cultivars tested. Like wise, all soybean varieties tested did not stimulate germination of the *Striga* seeds from either locality. For this reason results from the data were not subjected to statistical analysis. Other cultivars that did not induce germination of *Striga* seeds and not included in statistical analysis were: Bambara groundnuts landraces (Brown - Ex Makutupora, Cream spotted – Ex Botswana, Kyonda spotted – Ex Mwanza); Common bean varieties (DN 1008 and MCM 5001) and ground nut cultivar (Tatu tatu). Results for the species/cultivars that stimulated *Striga* seed germination are presented below.

4.1.2.2 Pigeon peas (*Cajanus cajan*)

Pigeon pea breeders' lines differed very highly significantl ($P < 0.001$) on their ability to stimulate germination of *S. asiatica* seeds (Fig.5). Overall, cultivar ICEAP 00020 gave the highest percent germination (41.1%), which was very highly significantl ($P < 0.001$) higher compared to the positive control (sorghum -Pato), which induced only 29.0%. Breeders' line ICEAP 00040 was not significantly different from the test crop in inducing germination of the *Striga* seeds. Other breeders' lines were very highly significantl ($P < 0.001$) less effective in stimulating germination of the parasitic weeds compared to the control.

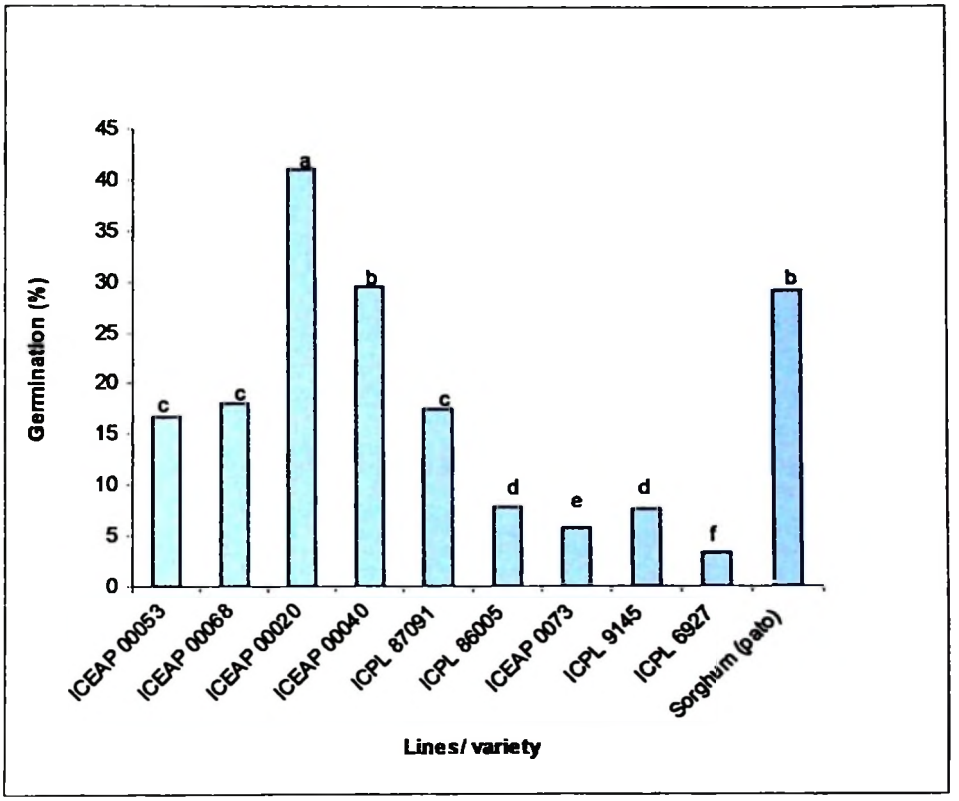

Figure 5. Overall effect of pigeon pea cultivars compared to test crop (sorghum) on germination of *S. asiatica* seeds

Table 4 shows the interaction effect between pigeon pea breeders' lines and distance from source of stimulant on germination of the *Striga* seeds. Generally, there was a decrease in percentage germination stimulation induced by the different cultivars with increasing distance from the source of stimulants as was demonstrated by the test crop. However, some few lines behaved differently from this general trend. For example, significantly ($P < 0.001$) highest germination percent (58.1%) was observed from breeders line ICEAP 00020 at a distance of 2.5cm away from the

source of the germination stimulant compared to the distance of 1.3cm. The same trend was observed in other breeding lines e.g. ICEAP 00068, ICLP 86005 and ICLP 9145. Other lines such as ICEAP 00040, ICEAP 00053, ICPL 87091 and ICEAP 00073 showed the same trend as the test crop cultivar (sorghum, *Pato).*

Both pigeon pea lines (ICEAP 00020 and ICEAP 00040) stimulated germination of the *Striga* seeds up to the furthest distance (3.7cm) away from the source of stimulant. However, pigeon pea breeders line ICEAP 00020 stimulated significantly ($P < 0.001$) more *Striga* seeds (24.5%) at the furthest distance compared to breeders' line 00040 (5.1%) and the control crop sorghum, variety Pato, which induced stimulation of only 16.0% at the same distance.

4.1.2.3 Common beans (*Phaseolus vulgaris*)

There was a very highly significant difference ($P < 0.001$) among the different common bean varieties and between the varieties and the control (sorghum - *Pato*) in their ability to stimulate germination of the *Striga* seeds (Fig. 6). Variety DN Bayo did not differ significantly with the test crop. Variety Rojo, performed very highly significantly ($P < 0.001$) better compared to varieties SUA 90 DN SEQ 41, Maharage kunde, PBS wanja, EG 10, DN 1007, Kasuka nywele, and TMO 542. Nevertheless, all these varieties were significantly ($P < 0.001$) less effective in stimulating germination of the *Striga* seed compared to the positive control. The significantly ($P < 0.01$) least effective variety was Kasuka nywele, which induced germination of only 5.0% of the *S. asiatica* seeds.

Table 4. Interaction effect between pigeon pea cultivars/sorghum and distance from source of stimulant on germination percentage of *Striga asiatica* seeds

Cultivars	Distance from source (cm)				
	1.3	1.9	2.5	3.1	3.7
ICEAP 00053	22.2 klm	26.2 h	21.4 lmn	8.9 uv	4.6 x
ICEAP 00068	11.7 rst	23.3 jkl	36.0 fg	13.4 qr	5.4 wx
ICEAP 00020	43.1 de	45.1 cd	58.1 a	34.4 g	24.5 h
ICEAP 00040	47.5 c	45.8 c	42.3 e	6.9 o	5.1 x
ICPL 87091	25.4 ij	22.0 klm	19.1 no	10.2 stu	10.3 stu
ICPL 86005	12.7 rs	21.7 lm	4.5 x	0.0 y	0.0 y
ICEAP 00073	20.1 mn	7.9 uvw	1.0 y	0.0 y	0.0 y
ICLP 86005	15.7 pq	30.2 h	21.6 lmn	20.6 mn	0.0 y
ICLP 6927	9.7 tu	6.9 vwx	0.0 y	0.0 y	0.0 y
Sorghum (Pato)-control	50.2 b	38.2 f	23.5 h	17.6 i	16.0 i

CV (%) = 6.91
SE = 0.64

Means in the same column and rows followed by the same letter(s) are not significantly different according to Turkey's Honest Significant Difference Test (THSDT, $P > 0.05$)

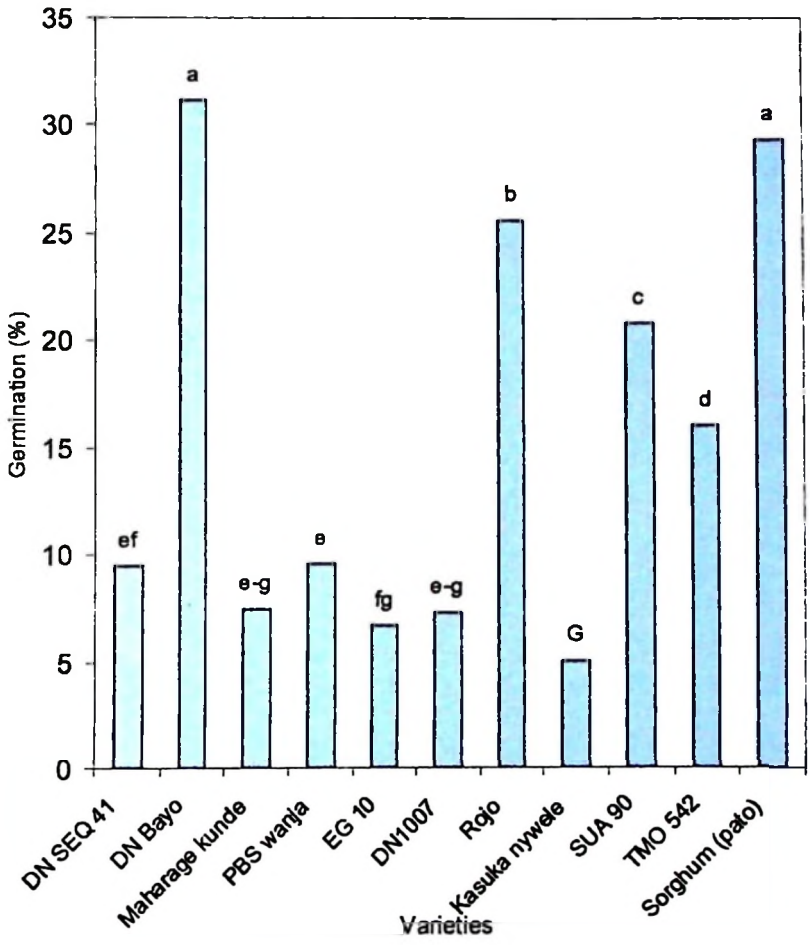

Figure 6. Overall effect of common bean varieties and test crop (sorghum) on germination of *S. asiatica* seeds

The influence of distance from source of stimulant on germination of the *Striga* seeds varied with different common bean varieties (Table 5). Overall, the closer the *Striga* seeds were to the source of stimulant, the higher the germination percentage observed. As demonstrated by the positive control (sorghum variety Pato), there was a decrease in percent germination with increase in distance for most of the common bean varieties tested. However, with variety DN Bayo, which was not significantly different from the test crop (sorghum) in inducing germination of *S. asiatica* seeds, there was an increase in germination percentage with the increase in distance from the source of stimulant.

Highest significant ($P < 0.001$) germination percentages were recorded in the positive control crop - sorghum (50.2%) and SUA 90 (45.2%) at a distance closest to the source (1.3cm) (Table 5). Only DN Bayo, Rojo and SUA 90 stimulated germination of *Striga* seeds up to 3.7 cm and TMO 542, up to 2.5cm. Germination percentages induced by DN Dayo were significantly higher ($P < 0.001$) at 3.7 cm than at 1.3 cm away from the source of the germination stimulant. The rest of the varieties induced germination of the *Striga* seeds only up to 1.9 cm.

Table 5. Mean germination percentages of *Striga asiatica* seeds exposed to root exudates of common bean varieties at different distances

Cultivars	Distance from source (cm)				
	1.3	1.9	2.5	3.1	3.7
DN-SEQ 41	25.7 hij	21.6 jkl	0.0 uv	0.0 uv	0.0 uv
DN Bayo	14.4 mno	26.5 hij	34.0 efg	36.7 de	35.2 def
Maharage kunde	11.9 nop	16.5 mno	7.3 qr	1.7 tu	0.0 uv
PBS wanja	25.7 hij	22.3 jk	0.0 uv	0.0 uv	0.0 uv
Rojo	42.0 bc	32.8 efg	31.4 fgh	16.9 lmno	5.0 qr
TMO 542	17.6 lmn	7.6 qr	0.0 uv	0.0 uv	0.0 uv
EG 10	23.4 ij	10.2 pq	0.0 uv	0.0 uv	0.0 uv
DN 1007	28.9 ghi	7.7 qr	0.0 uv	0.0 uv	0.0 uv
Kasuka nywele	38.9 cd	25.4 hij	15.9 no	0.0 uv	0.0 uv
SUA 90	45.2 ab	21.5 kl	19.8 lm	10.1 pq	7.4 qrs
Sorghum (Pato)-control	50.2 a	38.3 cd	33.5 defg	17.6 lmno	16.0 mno

CV (%) = 9.31
SE = 0.70

Means in the same columns and rows followed by the same letter(s) are not significantly different according to THSDT ($P > 0.05$)

4.1.2.4 Bambara groundnuts (*Vigna subterranea*)

Of the eleven bambara groundnut landraces screened, none proved to be as effective as the test crop sorghum variety Pato in stimulating germination of *S. asiatica* seeds. Comparison among the landraces themselves showed that landrace Nyandani spotted cream stimulated germination of 24.9% and red ex - Makutupora 24.7%, which was significantly ($P < 0.001$) higher compared to other bambara groundnut cultivars (Fig. 7). The two cultivars did not significantly differ from one another in their capacity to stimulate the parasitic weed seeds. Cultivar red ex- Dodoma and light brown brown ex- Mwanza were the least effective as they stimulated only 6.0% and 6.5 % of the *Striga* seeds, respectively.

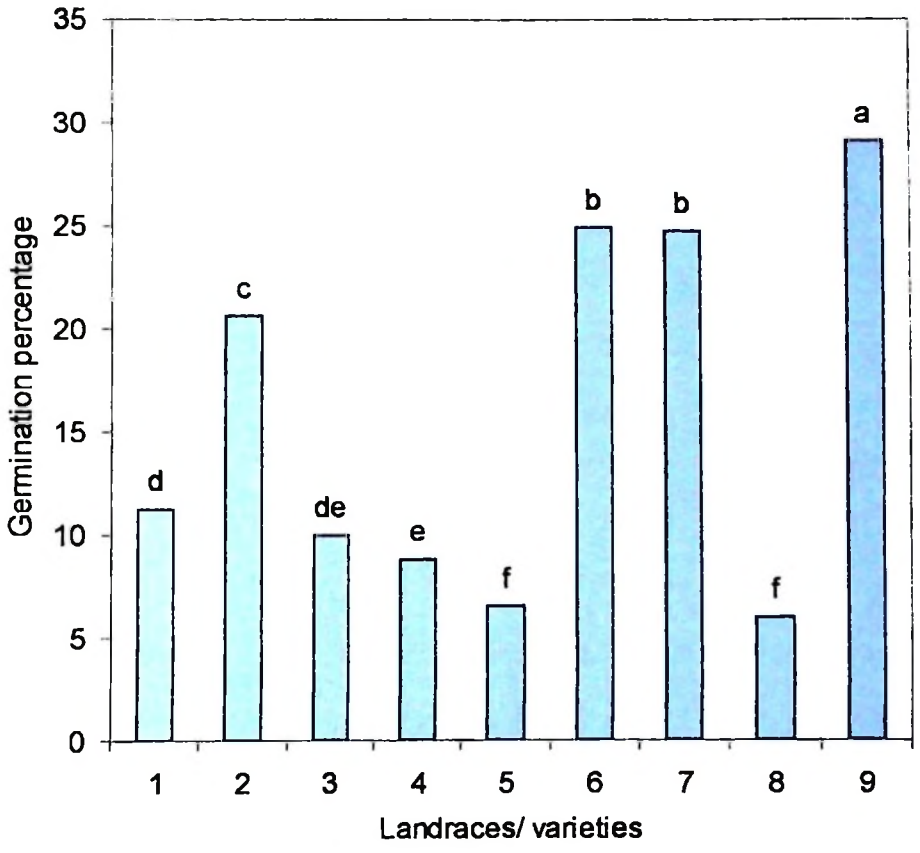

Figure 7. Overall effect of bambara groundnut cultivars compare to the test crop (sorchum) on germination of *S. asiatica* seeds

1 = Spotted cream – Ex Makutupora; 2 = Cream – Ex Makutupora;
3 = Cream -Ex Mwanza; 4 = Brown – Ex Bukoba;
5 = Red – Ex Dodoma; 6 = Nyandani spotted cream
7 = Red – Ex Makutupora; 8 = Light brown – Ex -Mwanza;
9 = Sorghum (Pato).

The effect of different bambara groundnut landraces on germination percentage of the *S. asiatica* seeds as influenced by distance is shown in (Table 6). Generally, increasing the distance from the source of stimulant resulted into decreasing number of germinated *S. asiatica* seeds. Individual observation of each landrace showed that, all bambara groundnut landraces stimulated significantly ($P < 0.001$) higher percentage germination of the seeds closer to the source than further from the source of stimulant. Nyandani spotted cream however, was an exception, as it stimulated significantly more seeds to germinate away from source of stimulant compared to seeds closer to the source.

Overall, the test crop induced significantly higher ($P < 0.001$) *Striga* germination percent compared to any of the bambara groundnut cultivars. However, landrace ex – Makutupora (with red coat) induced significantly ($P < 0.001$) more germination percent (53.9 %) of the *Striga* seeds at a distance of 1.3cm compared to the test crop (sorghum) and Nyandani spotted cream at the same distance (Table 6). Except for the spotted cream ex- Makutupora and red ex- Dodoma that induced germination of the *Striga* seeds up to 3.1cm away from the source, all other tested bambara groundnut cultivars induced germination of the *Striga* seeds up to the furthest distance (3.7cm).

Table 6. Mean percent germination of *Striga asiatica* seeds exposed to root exudates of bambara groundnut cultivars and test crop sorghum at different distances

Cultivars	Distance from source (cm)				
	1.3	1.9	2.5	3.1	3.7
Spotted cream ex-Makutupora	26.7 fg	15.0 l	8.6 opq	6.2 rstu	0.0 v
Cream ex- Makutupora	26.9 f	24.7 gh	21.1 i	19.5 ij	11.1 mn
Cream ex-Mwanza	14.7 kl	12.4 m	10.3 nop	6.7 qrst	5.7 stu
Brown ex- Bukoba	23.9 h	10.6 mno	6.4 qrst	3.3 u	0.0 v
Red ex- Makutupora	53.9 a	34.3 e	19.3 ij	10.9 mn	5.0 stu
Nyandani spotted cream	6.4 qrst	9.6 opq	27.1 f	38.1 d	43.2 c
Red ex- Dodoma	10.3 mno	8.3 pqr	6.7 qrst	4.8 stu	0.0 v
Light brown ex-Mwanza	7.9 pqr	7.8 qrs	7.2 qrst	5.5 stu	4.2 tu
Sorghum (Pato) – control	49.9 b	38.2 d	23.5 h	17.6 jk	16.0 kl

CV (%) = 10.53
SE = 0.83

Means in the same column and rows followed by same letter(s) are not significantly Different according to THSDT ($P > 0.05$)

4.1.2.5 Groundnuts (*Arachis hypogea)*

The level of germination of *S. asiatica* seeds induced by the three groundnut cultivars varied between 2.0% and 38.5% (Fig. 8). Overall, Cultivar Bukene induced significantly ($P < 0.01$) more germination of *Striga* seeds (38.5%) compared to the control (sorghum variety *Pato*) which induced only 29.1%). Groundnut variety Mamboleo and land race Ex Singida were the least effective ($P < 0.01$) in stimulating the germination of the parasitic weed seeds. Variety Mamboleo induced germination of 2.0% while cultivar Ex- Singida induced germination of only 2.8% of the *S. asiatica* seeds.

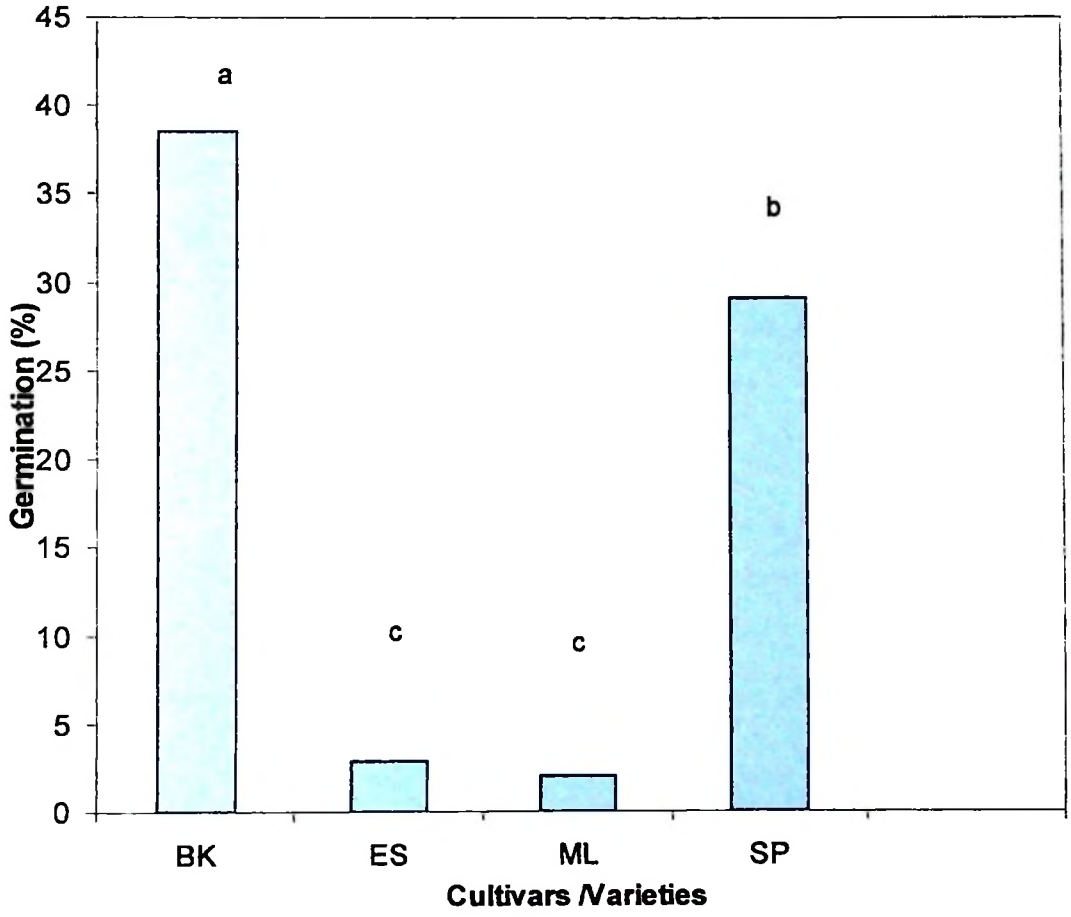

Figure 8. Overall effect of groundnut cultivars and test crop sorghum on germination of *S. asiatica* seeds

B K = Bukene; ES = Singida; ML = Mamboleo; Sorghum (Pato)

The general trend showed that percent germination of *Striga asiatica* seeds decreased with increasing distance from the source of stimulant (Table 7). Bukene induced significantly ($P < 0.001$) highest germination percentage of 61.6% and 54.4% at 1.3cm and 2.5cm, respectively, compared to germination percentages induced by the test crop (sorghum), which stimulated 50.2% and 38.2% at the same respective distances (Table 7). Germination of *S. asiatica* seeds was observed up to a distance of 1.3cm and 1.9 cm only for the variety Mamboleo and land race Ex – Singida, respectively.

Table 7. Mean percent germination of *Striga asiatica* seeds exposed to root exudates of groundnut cultivars

Groundnut cultivars	Distance from source (cm)				
	1.3	1.9	2.5	3.1	3.9
Ex- Bukene	61.6 a	54.6 b	48.2 c	25.1 e	3.1 l
Ex- Singida	7.7 gh	6.4 h	0.0 j	0.0 j	0.0 j
Mamboleo	9.9 g	0.0 j	0.0 j	0.0 j	0.0 j
Sorghum (Pato) Control	50.2 c	38.2 d	23.5 e	17.6 f	16.0 f

CV (%) = 13.94
SE = 0.90

Means in the same column and rows followed by same letter(s) are not significantly different according to THSDT ($P > 0.05$)

4.1.2.6 Cowpea (*Vigna unguiculata*)

The overall effect of Cowpea cultivars and the test variety *Pato* on stimulating germination of *S. asiatica* seeds in *vitro* is presented in Fig. 9. There was a significant difference ($P < 0.01$) among cowpea cultivars in their capacity to stimulate germination of *S. asiatica* seeds. However, the white black eyed (Ex Makutupora) had similar effect on *Striga* seed germination compared to the control sorghum variety (*Pato*). Overall, black eyed ex-Makutupora induced germination of 27.39% which was not significantly different from 29.11% induced by the control.

Table 8 shows the effect of distance on germination of *S. asiatica* seed exposed to root exudates of cowpea cultivars. Germination percentage for all cultivars decreased with increasing distance. White black- eyed (Ex Makutupora) induced significantly ($P < 0.01$) highest germination percentage (81.9%) at 1.3cm compared to other landraces. The test crop sorghum (Pato) stimulated significantly less (50.1%) germination of the *Striga* seeds at the same distance. Land race Greyish cream and "Mbegu ya pamba" were the least effective, by inducing germination of *Striga* seeds only at a distance of 1.3cm and 1.9cm, respectively (Table 8).

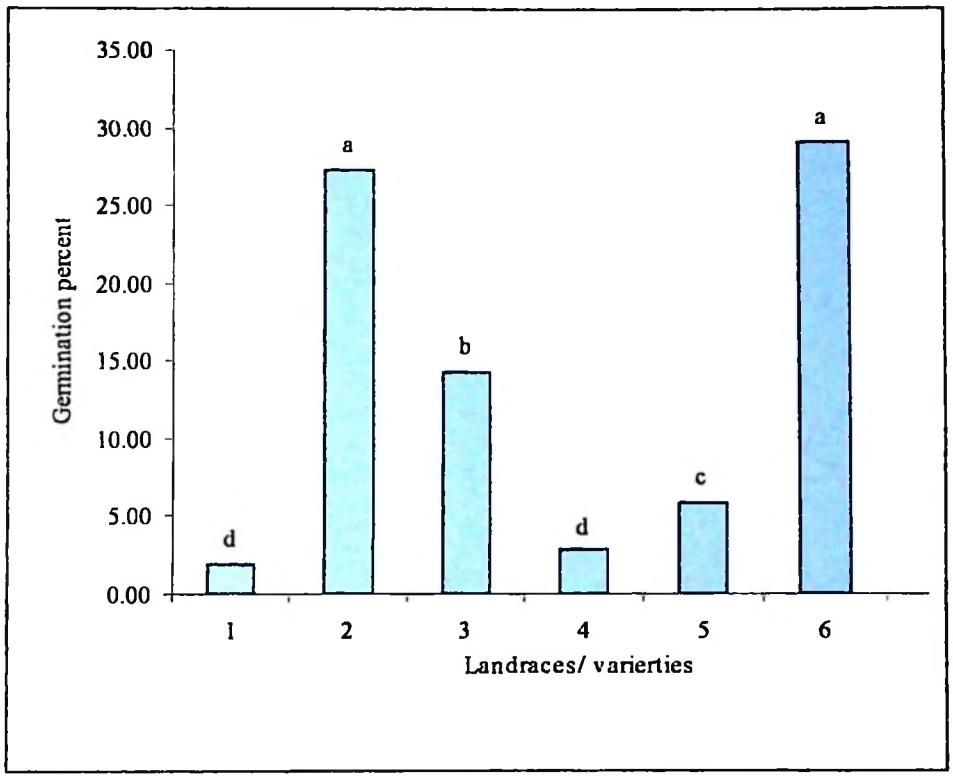

Figure 9. Overall effects of cowpea cultivars and test crop sorghum on germination of *S. asiatica* seeds

1= Greyish cream, 2 = White black eyed, 3 = Red ex Makutupora,
4 = "Macho ya paka", 5 = "Mbegu ya pamba, 6 = Sorghum (Pato)

Table 8. Mean germination percentages of *Striga asiatica* seeds exposed to root exudates of cowpea cultivars and sorghum variety (pato)

Cowpea cultivars	Distance from source (cm)				
	1.3	1.9	2.5	3.1	3.7
Greyish Ex- Makutupora	9.9 j	0.0 m	0.0 m	0.0 m	0.0 m
Black eyed white- Ex	81.9 a	42.2 c	12.8 i	0.0 m	0.0 m
Makutupora	32.1 e	24.7 f	14.7 h	0.0 m	0.0 m
Red –Ex Makutupora	11.0 ij	3.6 l	0.0 m	0.0 m	0.0 m
Mbegu ya pamba (Reddish	11.1 ij	6.9 k	7.3 k	3.9 l	0.0 m
brown)	50.2 b	38.2 d	23.5 f	17.6 g	16.0 gh
Macho ya paka					
Sorghum -Pato (control)					

CV (%) = 9.55
SE =0.57

Means in the same column and rows followed by same letter(s) are not significantly different according to THSDT (P > 0.05)

4.2 Efficacy of Selected Leguminous Crop Species/ Varieties in the Control of *Striga asiatica* Under Field Conditions

4.2.1 General observations

Mean rainfall distribution of the study area for the past ten years 1995 – 2004 and rainfall distribution by months during the study period (2002/03) are shown in Appendix 2 and 3, respectively. Normally seasonal rains start in November/ December and end in April/May, but unexpectedly during the 2002/03 cropping season rains started in October. Consequently, pigeon pea plants, which did not reach maturity during the preceding year, rejuvenated and continued to grow until they were removed during land preparation in December. The rainfall during the cropping season in 2002/03 was very high in December (187.5mm) and first half of January (90.4mm) and very low during the later part of the season 68.2mm,

51.9mm, 7.7mm, for February, March and April, respectively. Total rainfall received during the whole cropping season was only 428.5mm.

4.2.2 Soil characterization

Results of soil of soil characterisation of the study area are as shown in Table 9.

Table 9. Characterisation of soil fertility status in the study field

Chemical property	Status (range)
Soil pH	6.0 – 8.1
Available P (mg/kg)	58.2 – 165.5
Exchangeable K (Cmol/kg)	3.1 – 5.6
Total N (kg/ha)	25 – 155

4.2.3 *Striga* seed depletion in the soil

The number of *Striga* seeds in the top 15cm layer of the soil at the experimental field before planting of the leguminous crops in year one was not significantly different in all plots (Table 10). However, after one-year rotation of sorghum with the legume trap crops, number of *Striga* seeds in the top 15cm layer of the soil varied with the different treatments. *Striga* seed depletion was not significantly different among leguminous trap crops and between leguminous trap crops and sorghum, a susceptible crop. However, there was a highly significant difference ($P < 0.01$) in *Striga* seed depletion between the leguminous trap crops and the land left under weed free fallow. Likewise, the difference in *Striga* seed depletion between

sorghum and the weed free fallow was highly significant ($P < 0.001$). Whereas in the fallowed plots depletion was only 6.8%, the highest depletion percentage (48.0%) was observed in plots previously planted with bambaranut red - ex Makutupora.

Table 10. Increase in percent nitrogen, mean number of *S. asiatica* seeds per 100g soils before, after and percent change in depletion after one-year rotation of sorghum with legumes

Rotational crop	Increase in % N after rotation	No.of seeds before rotation	No.of seeds after rotation	Depletion (%)
Pigeon pea (00020)	0.15 a	40.0 a	24.0 b	38.2 a
Pigeon pea (00040)	0.10 ab	36.0 a	21.0 b	39.8 a
Fallow	0.02 c	40.0 a	38.0 a	6.8 b
Bambaranut (cream)	0.11 ab	39.0 a	22.0 b	44.7 a
Bambara nut (red)	0.12 ab	43.0 a	22.0 b	48.0 a
Groundnut Bukene	0.13 a	41.0 a	21.0 b	47.5 a
Cowpea (white black eyed)	0.02 c	39.0 a	24.0 b	38.2 a
Sorghum (Pato)	0.04 c	41.0 a	23.0 b	41.6 a
CV (%)	**30.96**	**11.89**	**15.32**	**21.05**
SE	**1.34**	**2.36**	**1.86**	**4.05**

Means in the same column followed by same letter(s) are not significantly different according to THSDT ($P > 0.05$)

4.2.4 *Striga* emergence

In the first year of the trial (2002/03), *Striga* emerged in sorghum crop only and no *Striga* plants were observed in any of the plots planted with legumes or on the fallow plots. In the second year of the trial, *Striga* plants started to emerge from the soil in all plots at the 7th WAP and continued to increase in number up to the 13 WAP when the number of *Striga* plants was at maximum (Fig.10, Appendix 5). Throughout the growing season, the level of *Striga* infestation was generally more severe on sorghum mono cropping and fallow – sorghum rotation compared to any of the legume – sorghum rotations. However, it was only during the time of emergence (7 WAP) that significantly ($P < 0.01$) less *Striga* plants (12.4 plants/m^2) emerged on bambara groundnut (red) - sorghum and 12.8 *Striga* plants/m^2 on cowpea - sorghum rotations compared to the sorghum mono - cropping (18.0 plants/m^2). Fallow - sorghum, groundnut – sorghum, bambara groundnut (cream) - sorghum, pigeon pea (both cultivars) rotations were not significantly different from the control in terms of number of emerged *Striga* plants.

Nevertheless, with time *Striga* plant populations in sorghum mono – cropping and fallow - sorghum rotation increased more steadily thus showing significant difference ($P < 0.001$) compared to any of the legumes - sorghum rotation at 9, 11 and 13 WAP (Fig.10, Appendix 5). There was no significant difference among the different legume - sorghum rotations, and between sorghum - fallow and sorghum continuous cropping after one-year rotations at the same weeks after plant.

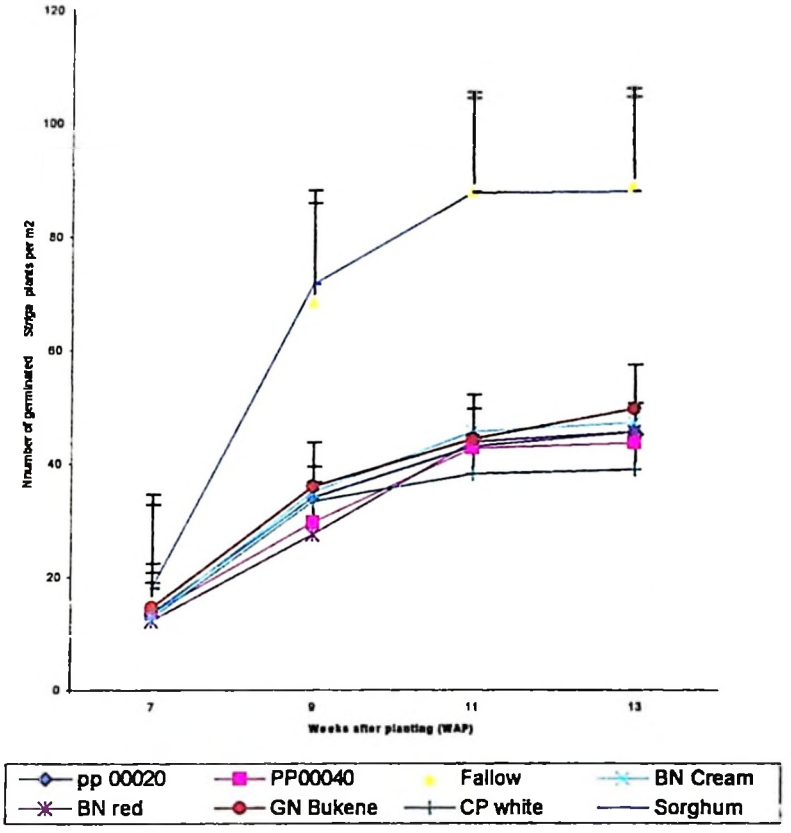

Figure 10. Effect of one-year rotation of sorghum with legumes on *Striga* popolation on the subsequent sorghum crop

4.2.5 *Striga* height and biomass

Effect of one- year rotation of sorghum with legume trap crops on *Striga* height, biomass and number of capsules per plant is presented on Table 10. Height of *Striga* plants on sorghum mono cropping (control) and fallow - sorghum rotations were 30.5cm and 31.2cm respectively. These heights were significantly ($P < 0.001$) bigger compared to the height of the parasitic plants that emerged on all legume-sorghum rotations except cowpeas – sorghum rotations. Height of *Striga* plants that emerged on sorghum plots planted one year after legumes ranged from 14.1 to 24.4cm. Nevertheless, height of *Striga* plants after bambara groundnut (red) were 19.2cm which was not significantly different from cowpeas – sorghum rotations. The same trend was observed in biomass of *Striga* plants that emerged on the different rotation systems (Table 11)

4.2.6 Number of capsules per plant

Number of capsules per *Striga* plant on different legume - sorghum rotations, ranged between 36.0 capsules and 52.9 capsules, did not significantly differ from one another (Table 11). However, significantly ($P < 0.01$) more capsules per *Striga* plant resulted from *Striga* on fallow followed by sorghum (89.7), and sorghum continuous cropping (86.8) compared to any of the legume – sorghum rotations. The numbers of capsules produced by *Striga* plants on the former two rotation systems were not significantly different from one another (Table 11).

Table 11. Effect of one-year rotation of sorghum with legume trap crops on *Striga* height, biomass and number of capsules per plant

Spp\ cultivar	*Striga* height (m)	*Striga* dry matter biomass (g/m^2)	Number of capsules/ plant
Pigeon peas ICEAP 00020	0.15c	24.5 c	39.0 bc
Pigeon peas ICEAP 00040	0.14c	27.9 c	45.3 bc
Weed free fallow	0.31a	82.2 a	89.7 a
Bambara groundnut (cream)	0.16c	39.1 bc	41.9 bc
Bambara roudnut (red)	0.19bc	44.9 b	36.0 c
Ground nuts	0.15c	25.0 c	38.7 bc
Cowpeas (white black eyed)	0.24ab	39.6 bc	52.9 b
Sorghum (control)	0.30a	78.8 a	86.8 a
CV (%)	16.49	14.92	11.51
SE	1.71	3.38	3.09

Means in the same column followed by same letter(s) are not significantly different according to THSDT ($P > 0.05$)

4.2.7 Sorghum height

The various rotational crops did not significantly influence sorghum plant height early in the season (Table 12). At 3 WAP, there was no significant difference in sorghum height between all rotation systems. The difference in height of sorghum as influenced by different treatments was only observed from the 5 WAP onwards. At 5 WAP, except for the sorghum planted after pigeon pea cultivar ICEAP 00020, which was significantly taller ($P < 0.05$) compared to sorghum continuous cropping,

the rest of the treatments did not significantly differ from one another in terms of sorghum height (Table 12).

From the 7 - 11WAP sorghum planted in rotation with pigeon peas (line 00020) were significantly ($P < 0.001$) taller compared to the rest of the treatments except at the 7 WAP where the two pigeon pea lines did not significantly differ from one another. Moreover, planting sorghum after fallow and sorghum continuous cropping had similar effect on the height of the crop. At the end of the growing phase (11 WAP), Sorghum height after weed free fallow was 82.4 cm, and height of sorghum on sorghum continous cropping rotation system was 83.5cm. On the other hand, height of sorghum grown after legumes ranged between 94.5cm and 145.8cm.

Table 12. Mean sorghum height (cm) after one-year rotation of sorghum with legume trap crops

Rotation systems	3WAP	5WAP	7WAP	9WAP	11WAP
PP 00020	31.6 a	54.6 a	90.2 a	118.5 a	145.8 a
PP 00040	25.7 a	49.6 ab	79.1 ab	93.8 b	124.1 b
Fallow	25.6 a	45.3 ab	58.6 cd	69.5 cd	82.4 cd
BN Cream	27.1 a	47.5 ab	69.0 bc	88.1 b	108.4 b
BN Brown	28.3 a	48.0 ab	74.8 b	90.6 b	119.7 b
GN Bukene	26.5 a	48.1 ab	71.9 b	96.8 b	124.1 b
CP black eyed	25.9 a	42.9 ab	68.6 bcd	86.1 bc	94.8 bc
Sorghum (control)	27.1 a	38.3 b	54.2 cd	68.7 d	83.5 cd
CV (%)	**14.89**	**13.00**	**8.12**	**7.94**	**7.56**
SE	**2.03**	**3.04**	**2.87**	**3.53**	**4.17**

Means in the same column followed by same letter(s) are not significantly different according to THSDT ($P > 0.05$)

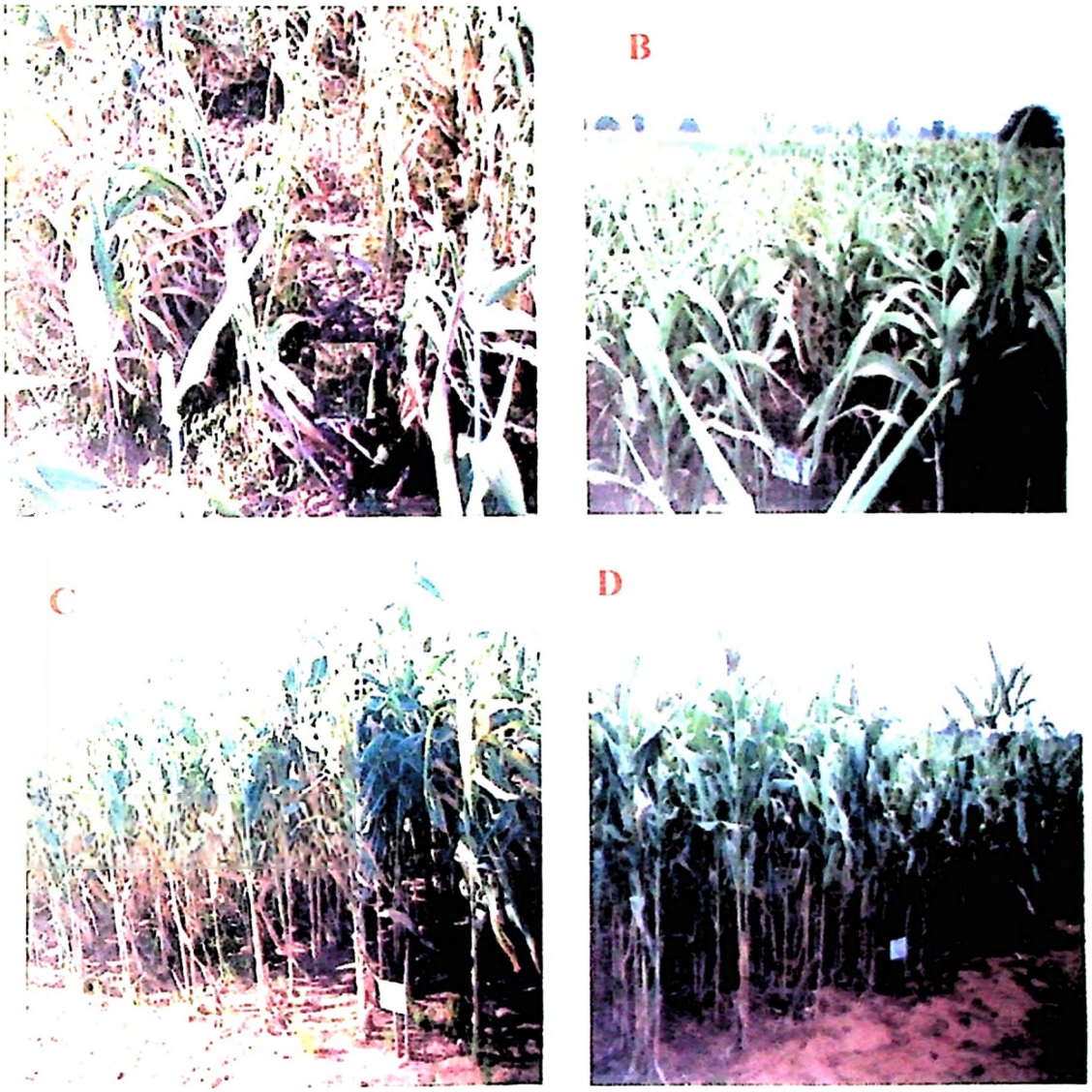

Figure 11. Rotating trap crops (legume) with sorghum A: sorghum after sorghum B: sorghum after weed free fallow C: Shading effect of healthy sorghum on *Striga* and D: Sorghum after pigeon pea (left) and sorghum after bambara groundnut (right) – Note the difference in sorghum height at same age.

4.2.8 Days to 50% flowering, plant population and threshing percentages of sorghum

Results on the 50% flowering of sorghum planted after one-year rotation with different leguminous trap crops are presented in Table 13. Different crop rotation systems did not have any significant effect ($P < 0.05$) on days to 50% flowering of sorghum in the consequent year. However, sorghum continuous cropping (control) and sorghum after fallow took slightly longer to flower (88 and 89 days respectively) compared to the sorghum grown after legumes, which took between 80 to 84 days to flower. Likewise, percent threshing and plant population at harvest were not influenced by any of the rotation systems.

Table 13. Mean number of days to 50% flowering, plant population and threshing percentages of sorghum after one-year rotation with legume trap crops

Spp/ cultivars	Days to 50% flowering	Plant population per m^2	Threshing percentage
Pigeon pea ICEAP 00020	84	9.7	58.6
Pigeon pea ICEAP 00040	84	9.5	55.1
Weed free fallow	89	9.4	51.0
Bambara groundnut (cream)	83	9.1	55.9
Bambara groundnut (red)	81	8.7	55.2
Ground nut ex- Bukene	80	9.0	57.8
Cowpeas white black - eyed	81	8.6	53.7
Sorghum (Pato) - control	88	8.4	54.2
	NS	NS	NS
CV (%)	14.94	11.46	9.10
SE	2.07	0.52	2.46

NS = Not Significant

4.2.9 Yield and yield components of sorghum

Mean number of head, head length, head weight and sorghum grain yield of sorghum grown one year after different rotations are presented in Table 14. The number of sorghum heads after one-year rotation was positively influenced by the different rotation systems. There was a very highly significant ($P < 0.001$) difference between number of sorghum heads after leguminous trap cropping compared to the control (continuous sorghum cropping).

The number of heads for the legume – sorghum rotation ranged between 60.0% for the least effective legume cultivar (cowpea, black eyed) to 112.5% for the most effective cultivar (bambaranut, red), compared to the continuous sorghum cropping). The number of sorghum heads on the fallow – sorghum rotation was not significantly different from the control (Table 14).

Weight of the individual sorghum heads was also positively influenced by the different legume- sorghum rotations. Planting sorghum after one-year rotation with pigeon pea ICEAP 00020 resulted into significantly ($P < 0.001$) heaviest heads. The individual heads weighed 54.5g, which was very highly significant ($P < 0.001$) heavier compared to the control - sorghum mono - cropping (22.67g/head), fallow – sorghum (24.4 g/head) and cowpeas – sorghum (30.17g) rotations. Sorghum after pigeon pea (cultivar ICEAP 00020), groundnuts and the two bambara groundnut cultivars were not significantly different from one another. However, pigeon pea cultivar ICEAP 00040 was very highly significant ($P < 0.001$) less effective than Pigeon pea cultivar 00020 in terms of number and weight of the individual heads of

sorghum planted after these legumes. Planting sorghum after a weed free fallow had similar effect on number of heads and head weight as the sorghum mono cropping system (Table 14).

Sorghum grown after pigeon pea (cultivar ICEAP 00020) and groundnut (cultivar Bukene) resulted into very highly significant ($P < 0.001$) higher grain yields (2.28 and 2.21 tons/ha respectively) compared to the control (0.61 tons/ha) and rest of the cropping systems. Sorghum after cowpea yielded (0.75 tons/ha) which was significantly ($P < 0.001$) less compared to other legume – sorghum rotations (Table 14). Fallow – sorghum rotation resulted into very highly significant ($P < 0.001$) reduced sorghum grain yield (0.53 tons/ha) compared to the legume – rotations and not statistically different from the control (sorghum continuous cropping). Relationship between sorghum and *Striga* growth and yield parameters is shown in Table 15.

Table 14. Mean number of heads, head length, weight per head and yield of sorghum after one-year rotation with legume trap crops

Spp/ cultivars	Head length (m)	Number of heads/ m^2	Wt per head (g)	Yield tons/ha
Pigeon pea ICEAP 00020	0.20a	8.8 a	54.5 a	2.28a
Pigeon pea ICEAP 00040	0.20a	8.4 a	38.1 bc	1.72b
Weed free fallow	0.10b	5.4 b	24.4 cd	0.53c
Bambara groundnut (cream)	0.18a	8.0 a	39.7 ab	1.63b
Bambara groundnut (red)	0.18a	8.4 a	41.5 ab	1.81b
Ground nut ex - Bukene	0.22a	9.0 a	44. 0 ab	2.21a
Cowpeas white black - eyed	0.11b	5.3 b	30.2 bcd	0.75c
Sorghum (Pato) – control	0.10b	5.6 b	22.7 cd	0.61c
CV (%)	12.89	9.00	17.04	11.11
SE	1.06	0.33	3.14	80.18

Means in the same column followed by same letter(s) are not significantly different according to THSDT ($P > 0.05$)

Table 15. Correlation matrix between sorghum and *Striga* growth and yield characteristics as influenced by different rotation systems

	1[a]	2	3	4	5	6	7	8	9
1[a]	-								
2	0.499	-							
3	0.545	0.737	-						
4	0.526	0.869	0.867	-					
5	0.508	0.854	0.857	0.919	-				
6	-0.248	-0.624	**-0.745****	**-0.768***	**-0.717***	-			
7	-0.645	-0.682	**-0.757****	**-0.790***	**-0.812****	0.622	-		
8	-0.284	-0.573	**-0.711***	-0.679	-0.645	**0.836***	0.641	-	
9	-0.359	-0.617	**-0.823***	-0.741	**-0.742***	**0.845***	0.690	**0.849***	-

(Significant regression correlates between sorghum and *Striga* variables {$P < 0.05$ (*), $P < 0.01$ (**) are in bold type}

[a] = treatments

1 = Number of *Striga* seeds in the soil/m^2

2 = Number of emerged *Striga* plants/m^2

3 = *Striga* height/plant

4 = *Striga* dry matter (g/m^2)

5 = *Striga* number of capsules/plant

6 = Sorghum height/plant

7 = Number of sorghum heads per plot

8 = Weight of sorghum per head

9 = Sorghum yield (tons/ha)

4.3 Influence of Different Plant Parts and Seed Coat Colour of Selected Leguminous Species on Germination Stimulation of *Striga asiatica* Seeds

4.3.1 Effect of different plant parts on germination of *S. asiatica* seeds

The first set of experiment aimed at determining the influence of exudates/extracts from different plant parts on germination stimulation of *Striga* seeds. Results showed that all plant parts (seed, shoot and root) extracts of all three leguminous trap crops (Bambara groundnut, cowpea and groundnut) very highly significant ($P < 0.001$) stimulated germination of *S. asiatica* seeds compared to distilled water check (Table 16). Germination percentages obtained from bambara groundnut red – Ex Makutupora, seed exudates (26.40%) and root extracts (26.5%) were each very highly significant ($P < 0.001$) higher compared with germination percentages obtained from their shoot extracts (15.0%).

However, percent germination of *S. asiatica* seeds obtained from root exudates (19.8%) was not significantly different from those obtained from the shoot and root extracts and seed exudates. In cowpea, white black eyed ex-Makutupora, root exudates stimulated very highly significant ($P < 0.001$) highest (63.4%) germination percentage compared to the other plant parts, followed by root extracts (39.4%). Seed exudates and root extracts were the least effective in influencing germination of *Striga* seeds as they induced germination of only 26.8% and 25.3% respectively. Similarly, in groundnut, root exudates induced very highly significant ($P < 0.001$) higher germination percentages (51.1%) of *S. asiatica* seeds compared to root extracts (35.6) shoot extracts (28.7%) and the seed exudates (37.1%).

Table 16. Percent germination of *S. asiatica* seeds exposed to stimulants from different plant parts of selected legume species

Legume spp/ cultivar	Plant part	Percent germination
Bambara groundnut red ex- Makutupora	Seed exudate	26.4 fg
	Shoot extracts	15.0 h
	Root extacts	26.5 fg
	Root exudate	19.8 gh
Cowpea white black eyed ex-Makutupora	Seed exudate	26.8 fg
	Shoot extract	25.3 fg
	Root extract	39.4 d
	Root exudate	63.4 b
Groundnut ex – Bukene	Seed exudate	37.1 de
	Shoot extract	28.7 ef
	Root extract	35.6 de
	Root exudate	51.1 c
GR 24 (positive control)	-	74.2 a
Distilled water (negative control)	-	2.4 i
CV (%)		**10.01**
SE		**1.68**

Means in the same column followed by the same letter(s) are not significantly different according to THSDT ($P > 0.05$)

4.3.2 Effect of seed coat colour on germination of *S. asiatica* seeds

From the preliminary tests, seed and root exudates of bambara groundnut cultivars with different seed coat colour significantly ($P < 0.01$) stimulated germination of *S. asiatica* seeds, compared to distilled water check (Table 17). Exudates from black seeded bambara groundnut seeds stimulated significantly higher germination percentage (66.8%) of *Striga* seeds compared to the positive control –Sorghum (roots exudate) which stimulated 41.3% germination. Red and cream seeded bambara groundnut root and seed exudates did not differ with the positive control in induction of germination of *S. asiatica* seeds.

Regardless of their seed coat color, root and seed exudates from the cream and red seeded bambara groundnut cultivars were equally effective in inducing germination of *Striga* seeds. However, the radicals from germinated *Striga* seeds induced by the seed exudates of both black and red seeded bambara groundnut started to turn brow in the third day after germination followed by stunting and eventually dying of the growing radicals. However, radicals of *S. asiatica* seeds exposed to GR 24 a synthetic strigol analog continued to elongate until the sixth day.

Table 17. Percentage germination of *S. asiatica* seeds exposed to stimulants from seed and root exudates of legume species with different seed coat colour

Legume spp/cultivar	Colour	Source	Percent germination
Bambaranut ex –Makutupora	Black	seed exudate	66.8 a
	red	seed exudate	30.8 bc
	red	root exudate	19.9 c
	cream	seed exudate	24.5 c
	cream	root exudate	18.8 c
Sorghum (positive control)	cream	root cuttings	41.3 bc
Water (negative control)	-	-	1.8 d
CV (%)			**26.54**
SE			**2.54**

Means in the same column followed by same letter(s) are not significantly different ($P > 0.05$) by THSDT

4.3.3 Effect of seed coat colour on radical growth inhibition of *S. asiatica* seeds

Figure 12 shows radical growth inhibition of *S. asiatica* seeds exposed to seed and root exudates of black, red and cream seeded bambara groundnuts. Seed exudates from black seeded bambara groundnuts resulted into significantly ($P < 0.01$) highest percent inhibition of *S. asiatica* radical growth (40.3%) compared with seed exudates from red (29.1%) and cream (19.6%) bambara groundnuts. Exudates from cream seeded bambara groundnut seeds inhibited significantly ($P < 0.01$) less radical growth compared to black and red seeded bambara groundnuts seed exudates. Likewise, root exudates from cream seeded bambara groundnut inhibited

significantly ($P < 0.001$) less radical growth compared to root exudates from black and red seeded bambara groundnut (Fig. 12).

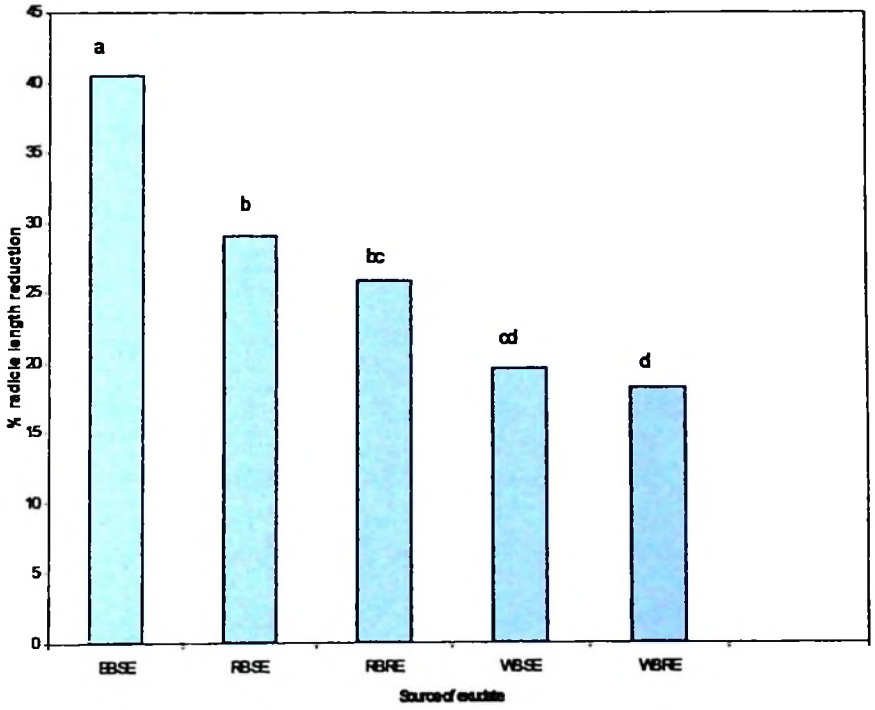

Figure 12. Radical growth inhibition of *S. asiatica* seeds exposed to root and seed exudates of bambara groundnut of different seed coat colour

BB = Black seeded bambara groundnut
RB = Red seeded bambara groundnut
WB = Cream seeded bambara groundnut

SE = Seed exudate
RE = Root exudate

CHAPTER FIVE

DISCUSSION

5.1 Evaluation of the Potential of Non-host Leguminous Crop Species as Germination Stimulants of *S. asiatica*

5.1.1 Effect of leguminous species on *S. asiatica* seed germination

5.1.1.1 Host / Non host -Parasite Specificity

Results from this study showed that legume species and varieties/ landraces within species differed in their capacity to stimulate germination of *Striga asiatica* seeds from the two sources where *Striga* seeds were collected. Indeed, all varieties, which were observed to stimulate germination of the *S. asiatica* seeds from sorghum - based cropping system failed to stimulate germination of *Striga* seeds from rice based cropping system despite the fact that seeds from both localities were equally viable (Table 3). The ability of some tested leguminous species/ cultivars to induce germination of the *Striga* population from sorghum based cropping system and not population from rice based cropping system can be attributed to failure of *Striga* seeds from rice based cropping system to recognize xenognosins produced by the same legume species/ cultivar (Yoder, 1999; 2001; Bouwmeester *et al.*, 2003; Pierce *et al.*, 2003;)

It is known that legumes especially cowpeas produce several *Striga* germination stimulants (Muller *et al.*, 1992; Rambakudzibga and Mabasa, 1995) with the most prevalent compounds being alectrol, and other strigol analogs, some of which are

more active than others. Results from this study imply that, xenognosins produced by the tested cultivars were recognized by *Striga* strains from sorghum based cropping systems but not by the *Striga* strain from rice based cropping systems. These results are in accordance with previous reports (Parker and Reid, 1979; Ariga *et al.* 1997; Ruggut and Berner, 1998; Gbehounou and Adango, 2003) who also observed variation in the effectiveness of same trap crops in stimulating germination of *S. hermonthica* seeds from different locations. Soybean has been reported to induce abortive germination of *Striga* seeds, with a consequent reduction in infestation when grown in rotation with a susceptible host in fields (Parker and Riches, 1993; Kim, 1991; Parkinson *et al.*, 1986).

Lack of germination of *Striga* seeds when subjected to root exudates from soybean varieties in this study could be explained as lack of the right germination stimulants from the tested varieties or could also be attributed to specificity of the *Striga* seeds for the tested varieties. Different legume species and/ or varieties are known to exhibit specificity to *Striga* populations from different sources (Parker and Reid, 1979; Ariga *et al.*, 1997).

Conditions leading to this type of non host- parasite specificity are still not yet clearly documented. However, ecology could play a major role in such phenomenon. Ecological consequences of plant parasitism of hosts containing different levels of bioactive substances have been reported in other type of host parasites relationships (Alder, 2000). In one particular study for example, alkaloid

intake from different ecological zone differed in increased fitness in a hemi-parasitic plant. Parasites that infected high alkaloid lupines underwent less insect damage than those attached to low alkaloid lupines (Alder, 2000). The differential responses to stimulation of *Striga* seed from rice based farming system by same leguminous spp/cultivars, which were demonstrated in the present study, is an indication of different levels of bioactive compounds from those collected from sorghum based farming system.

5.1.1.2 Variation in germination stimulation within Species

Except for the soybean, of which none of its varieties tested stimulated germination of *Striga asiatica* seeds from the two localities where the parasitic seeds were collected, all other legume species tested showed variable degrees of effectiveness in stimulating germination of the *Striga* seeds from sorghum based cropping system. However the level of germination stimulation differed between cultivars even of the same species. Other cultivars like pigeon pea ICEAP 00020 (Fig. 5), and groundnut ex- Bukene (Fig. 8), even induced higher germination percentages than the positive control Sorghum (Pato), which is said to be very susceptible to *S. asiatica* (Mbwaga and Obilana, 1998). The differential stimulation of germination of *Striga* seeds between variety/landraces of the same species could be ascribed to differential production of the germination stimulants responsible for triggering germination of that particular parasitic weed seed. Previous reports by Abayo *et al.* (1997), Ariga *et al.* (1997), Berner and Williams (1998); and Rambakudzibga and Mabasa (1995); also showed variations within bambara groundnut, cowpea and bean varieties in

inducing germination of *S. asiatica* and *S. hermonthica* seed hence have potential to be used as trap crops in the control of *Striga*.

It is reported that resistance to *Striga* infestation in some sorghum and maize varieties is partially associated with low production of germination stimulants (Pierce *et al.*, 2003; Heller and Wegmann, 2000; Koyama, *et al.*, 2000). Cowpea varieties with differential resistance to strains of S. *gesneroides* have been identified in various regions of West Africa (Parker and Polniaszek, 1990; Aggarwal, 1991). Resistance/ susceptibity to *S. gesnoreides* in cowpeas is also partially attributed to differential production of germination stimulants. This indicates that high production of germination stimulants in host plants confers susceptibility to the parasite, while in non-host plants the same confers ability to induce suicidal germination of the parasitic seeds. Results further indicated that, pigeon pea cultivars ICEAP 00020 and ICEAP 00040, common bean cultivar DN Bayo, bambara groundnut cultivars nyandani spotted cream and red ex- Makutupora, groundnut cultivar ex- Bukene and cowpea black eyed ex Makutupora induced higher germination percentages of *Striga* seeds. Hence, the cultivars have high potential of inducing suicidal germination of *S. asiatica* seeds in the field.

5.1.1.3 Effect of distance on *Striga* seed germination

From the laboratory study, germination of *Striga* seeds decreased with increase in distance from the source of stimulants, i.e. more seeds were induced to germinate closer to the source of stimulants than further away from the source. Sorghum

(Pato), which was the positive control in this study, induced germination of the *Striga* seeds at the furthest distance (3.7cm) although, like most of the legumes, more seeds germinated near the source than further away from the source. This indicates that there was higher concentration of germination stimulants near the source, and hence *Striga* seeds near the source (less than 2.5cm) are more likely to germinate than *Striga* seeds placed further from the source.

On the other hand however, few species/ cultivars behaved quite the opposite from the general trend that is decreasing percent germination with increase in distance from source of stimulant. The low germination percentage of the *Striga* seeds close to the source of stimulants indicates a possible presence of inhibitors or the inhibitory effect of the germination stimulants at higher concentrations. Species/cultivars that tended to stimulate more germination of *Striga* seeds further from the source of stimulants than closer to the source included common beans varieties DN Bayo and Kasuka nywele, bambara groundnut landrace Nyandani spotted cream and pigeon pea breeding line ICEAP 00068, ICEAP 00020 and ICPL 9145. This suggested that the cultivars produced high concentations of germination stimulants and/or inhibitors near the source.

The possible effect of strigol and its analogous compounds as regulators in the germination / non-germination equilibrium has been demonstrated by many authors (Kust, 1966; Hsiao *et al.*, 1981; Worshum, 1987). Muller *et al.* (1992) repeatedly observed the inhibitory effect of highly concentrated solution of germination

stimulants like strigol and alectral on germination of *Striga* seeds. Whitney, (1979) advocated that there is a possible delicate balance between stimulants (germination promoters) and inhibitors, which is dependent on their respective concentration at a particular distance from the source. This could explain the observed increase in germination of the *Striga* seeds with increase in distance from the source, suggesting that increased distance might have tipped the balance of inhibitors in favour of germination stimulants. The results obtained in this study are in consistence with findings by Ariga *et al.* (1997) who observed the same trend in germination of *S. hermonthica* seeds when stimulated by root exudates from different varieties of bean (*Phaseolus vulgaris* L.), linseed (*Linum usatatissimum* L.) and cotton (*Gossypium hirsutum* L.)

5.2 Efficacy of Selected Leguminous Crop Species/ Varieties in the Control of *Striga asiatica* Under Field Conditions

5.2.1 Soil fertility

The total N in the soil before rotation with legumes ranged from 0.09 - 0.13% (Table 9). The proposed critical level for most crops in Tanzania is 0.2%. This means that total N in the soils tested is not enough to support good plant growth and microbial activities. Hence, application of N in the form of organic and/or inorganic fertilizer was necessary. Other essential elements such as potassium and phosphorus were above the recommended levels of 15 mg/kg, and 0.2 Cmol/kg for available P and exchangeable K, respectively (Anderson, 1973; FMANR, 1990). The soil pH ranged from neutral to slightly alkaline, which is slightly above the favorable pH of 5.5 - 7.0, for most crops grown in Tanzania (Sanchez *et al.* 2003).

After one year rotation with legumes, the increase in total N ranged between 0.10 and 0.15 for pigeon pea, bambara groundnut and groundnut cultivars (Table 10), implying that implies that total N in the soil after these cultivars increased to meet the recommended levels of 0.2%. Increase in total N in the soil after cowpea black - eyed and the weed free fallow rotation was only 0.02%, making the levels in the soil to remain below the critical levels. The same applied to N levels after sorghum continous cropping.

5.2.2. Effect of legume - sorghum rotations on *Striga* seed bank depletion.

In this study one-year rotation of sorghum with leguminous trap crops resulted into reduced numbers of *Striga* seeds in the topsoil (15cm) when compared to a fallow (Table 10). However, despite the fact that sorghum is the perfect homologous host crop for *S. asiatica*, it was equally as effective as the leguminous crops in reducing the number of the parasitic weed seed in the soil in the first year. This could be explained by the fact that very little rainfall was received during March and April (45.4mm and 47.0mm respectively), coinciding with the development, maturity and reproductive phase of *Striga* thus resulting into poor and abortive flowering of the weed. Consequently, the sorghum crop acted as catch crop rather than a host crop i.e. sorghum stimulated germination of *Striga* seeds, which germinated but could not complete their life cycle due to inadequate rainfall during the growing season. This resulted into reduced number of *Striga* seeds in the soil than was normally expected (Table 10).

Berner *et al.* (1996) suggested that crop rotation with efficacious grain legumes is the key to integrated *Striga* control programs. He also emphasized on the usefulness of *in vitro* screening of the potential legume species /cultivars before testing them in the field. He further reported that when four cultivars of soybean were tested in the field, the results were positively correlated with laboratory screening results. Results from this experiment demonstrated that five cultivars, which were screened in vitro, showed similar effectiveness in reducing the number of *S. asiatica* seeds in the soil after one-year rotation with sorghum.

The 38 – 48% reduction in the number of *Striga* seeds in the soil after one-year rotation with the tested legumes compared to the weed free fallow, could to a large extent, be attributed to suicidal germination of the seeds after being stimulated to germinate by the legume crops. The five legume species used in this experiment were selected from 56 cultivars tested for their high ability to stimulate germination of *S. asiatica* seeds in the laboratory. The fact that the five tested legumes were equally effective in reducing the number of seeds is an indication of their effectiveness in stimulating germination of the seeds by exuding a germination stimulant under field conditions. Therefore, the five legume varieties/landraces provide alternatives for use by farmers in *Striga* infested areas. Cársky *et al.* (2000) obtained similar results after testing a soya bean cultivar TGx 1740-7F, which was previously identified as being effective for *S. hermonthica* seed germination after screening *in vitro*.

Generally, levels of *Striga* seed depletion by legume trap crops, from other studies are quite variable. Kim (1991); Ariga *et al.* (1994) and Berner *et al.* (1996) reported 90% reduction of *Striga* seeds in a single season whereas, whereas Oswald and Ransom, (2001) reported a reduction of 87% in two seasons. Results from this study revealed that legume trap crop rotations reduced *Striga* seed number in the soil by 38 – 48% in one season. The relatively low percent reduction in *Striga* seeds in the soil could be due to the low amount of rainfall (428.5mm) received during the growing season. This in turn could have attributed to low production of the germination stimulants by the tested legumes, and hence resulted into poor suicidal germination of the parasitic weed seeds (Parker and Riches, 1993; Berner *et al.*, 1996).

Unless *Striga* seeds are subjected to a germination stimulant, they will stay viable in the soil for as long as 14 - 20 years (Ramaiah *et al*, 1983; Worshum, 1987; Stewart and Press, 1990; Eplee, 1992; Parker and Riches, 1993). In this study, fallowing the field for one year resulted in very low reduction of *Striga* seed reservour in the soil. The small percentage (6.8%) that resulted from leaving the field without a crop for one year could be attributed to effect of soil microbial organisms and/or spontaneous germination of the seeds during the rain season. Microbial organisms in the soil are reported to produce ethylene, which stimulate germination of *Striga* seeds (Parker and Riches, 1993, Gbehounou *et al.*, 1996; Joel, 2000), and spontaneous germination of *Striga* seed through the dying – off process was previously reported (Gbehounou, 1998).

5.2.3 Effect of legume - sorghum rotations on *Striga* emergence and development

In addition to the reduction of *Striga* seed bank, the one-year rotation of sorghum with legumes also resulted into reduced number of emerged *Striga* plants. Early in the season, the number of *Striga* plants that emerged in most of the legume - sorghums crop was not significantly different from the control and fallow - sorghum rotation, probably due to the limited root distribution of the crop in the soil. According to Ramaiah, *et al.* (1991), *Striga* seeds will only germinate within 4mm of the host root zone. The influence of legume - sorghum rotation was more pronounced later in the season when they reduced *Striga* infestation by about 50% which was significantly different compared to the sorghum mono - cropping and fallow - sorghum rotations.

In the first year of the study, sorghum was as effective as the legume trap crops in depletion of the *Striga* seed bank in the soil. However, in the subsequent sorghum crop, *Striga* infestation on sorghum mono - cropping was about twice (88.85 plants/m^2) compared to that on legume – sorghum rotation with infestation ranging between 39.12 and 49.97 plants/m^2, and as severe as that on the weed free fallow – sorghum rotation (89.37 plants/m^2). Moreover, there was no significant correlation ($r = 0.499$) between *Striga* seed in the soil and the germinated *Striga* plants (Table 15). These results indicate that there was a carry over effect of the leguminous trap crops on the germination and emergence of *S. asiatica* seeds on the subsequent crop.

The carry over rotational effects include increased microbial activities in the soil, improved soil stucture and nitrogen fixation (Ramaiah, *et al.*, 1983; Carsky, *et al.*, 2000; Oswald and Ransom, 2001; Tenebe and Kamara, 2002; Gbehounou and Adango, 2003). Microbial activities have been reported to reduce the number of *Striga* seeds in the soil (Parker and Riches, 1993). Nitrogen in the soil also influences *Striga* infestation through damaging *Striga* seeds and seedling by toxic effect and slowing down the attachment of germinated *Striga* to the host plant (Parker and Riches, 1993, Okonkwo, 1991). The reduced *Striga* infestation observed in this study could therefore, be attributed to suicidal germination of *Striga* seeds and the carry- over rotational effects following trap cropping with legumes.

Reduction of *Striga* populations as an effect of rotating cereals with leguminous trap crops has been reported in other situations. Sauerborn, (1991), when comparing the development of *Striga* populations under low – input mono-cropping systems and high – input crop rotations found a tremendous increase in *Striga* population under mono-cropping while crop rotations decreased *Striga* populations. Oswald and Ransom, (2001) observed reduced *Striga* populations when maize was planted after a two season rotation that included pigeon peas compared to continuous cereal cropping. Carsky *et al.* (2000) showed that *S. hermonthica* parasitism on maize was significantly lower after unfertilised soybean than after sorghum mono cropping. In a study to compare the effect of trap cropping with cowpea, groundnuts and soybeans with maize continuous cropping, results demonstrated that legume-maize

inter-cropping reduced *Striga* infestations compared to maize continuous cropping (Gbehounou and Adango, 2003).

Previous reports have shown shading to have a negative effect on *Striga* germination and development (Oswald *et al.*, 2002; Tenebe and Kamara, 2002; Kuchinda, *et al.*, 2003). Therefore, in this study the reduced height and biomass of *Striga* that emerged on sorghum following leguminous trap crops was probably due to the fact that sorghum grew more vigorously. Consequetly, shading of the *Striga* plants that emerged late were more intensively shaded compared to those that emerged on continuous sorghum cropping and fallow – sorghum rotation.

Number of seeds per capsules in a well-established *Striga* plant is reported to be over 800 and the average number of capsules per plant range was estimated to be 60 – 70, (Musselman, 1980; Obilana, 1983). In this study, the number of capsules per *Striga asiatica* plant on sorghum – sorghum and fallow sorghum rotation was in the range of 86 – 89, which was significantly higher compared to number of capsules on the sorghum following legumes (39 – 42 capsules per *Striga* plant). The reduced number of *Striga* plants and capsules that emerged on legume – sorghum rotations is not only advantageous in that it means a reduced potential for overall flower and capsule development, rather the reduced number of capsules implies reduced fecundity of *Striga*. If such a rotation system is maintained over an extended period of time, *Striga* seed return into the soil could be minimized.

5.2.4 Effect of legume - sorghum rotations on sorghum performance

Rotating sorghum with leguminous trap crops increased sorghum height (Table 12); number of heads m^{-2}, weight per head and consequently the sorghum grain yield (Table 14). Plant height of sorghum is one of the growth characteristics contributing to dry matter yield Gworgwor (1993). The stunting of sorghum plants associated with *Striga* infestation is an indication of how injurious *Striga* parasitism is to sorghum plants. At the 11WAP plant height was significantly reduced in sorghum mono cropping (83.5cm) and weed free fallow rotation (82.4 cm) compared to sorghum following most of the legumes like sorghum after pigeon pea ICEAP 00020 (145.8cm), sorghum after pigeon pea ICEAP (124.1cm) and sorghum after groundnut ex Bukene (124.1cm). In this experiment, sorghum height was negatively correlated, with *Striga* height (r = - 0.745) and *Striga* biomass (r = - 0.768). These results indicate that *Striga* height and *Striga* biomass increased at the cost of the crop performance.

The reduction in sorghum height as a result of *Striga* infestation can be partially associated with the role of *Striga* as an additional sink for host carbon, inorganic solutes and water. Previous results, Press *et al.* (1988) and Stewart *et al.* (1991) indicated that *Striga* reduces host growth by impairment of photosynthesis of the host crop and by competing for carbon. Although *Striga* plants are chlorophylous, their photosynthetic rates are generally low associated with high rates of dark respiration (Press, *et al.*, 1987, 1988) leading to little or no gain by the parasite, and hence a reliance on host – driven sources. Other studies (Press *et al.*, 1987; Graves

et al., 1990) demonstrated lower rates of photosynthesis in leaves of *Striga* infected plants compared to the uninfected ones. Gurney *et al.* (1997) also reported that about 35% of the carbons for *Striga* plants come from the hosts' photosynthates. *Striga* was also found to transpire much more water than is normal for other plants, even under moisture stress, thus maximizing the flow of water and nutrients from the host (Gurney *et al.*, 1997). Results from this study, suggests that the 51 – 77% reduction in plant height on sorghum continuous cropping and sorghum planted after fallow (Table 12, Fig. 11 A& B) was a result of sink – source relationship partially associated with the parasite / host interactions.

Sorghum grain yields were generally higher after trap cropping with legumes (1.63 – 2.28 tons/ha) compared with the continuous sorghum cropping (0.61 tons/ha) and to the plots where it had been maintained as weed free fallow during the previous year (0.53 tons/ha). The results suggest that trap cropping with legumes resulted in reduced *Striga* infestations, which contributed to the increased sorghum yield after one-year rotation.

However, irrespective of the *Striga* populations, sorghum after pigeon pea (00020) and sorghum after groundnuts, yielded significantly higher (2.28 and 2.21 tons/ha respectively), compared to other legume- sorghum cropping systems with yields ranging from 0.75 - 1.81 tons/ha (Table 14). The higher yields associated with the two legume species/cultivars could also be attributed to rotational benefits other than reduced *Striga* infestation as already explained in section 4.2.2.3. In this

context, it should be noted that symbiotic fixation, which depends on *Bradyrhizobium* and *Rhizobium* strains, may provide sufficient nitrogen for the leguminous crop for its own use and may increase soil reserve for the subsequent crop (Ledgard and Stelle, 1992; Dakora and Keya, 1997; Rochester *et al.*, 2001; Sanginga, 2003).

On the other hand, it is not in all cases that the N benefit following legume cultivation includes the sparing of soil N. A nodulated legume may fail to make a net positive contribution to soil N content either due to high N harvest index of the genotype or poor N – fixing ability (Dakora *et al.*, 1987). In the current study change in N following one-year rotation with cowpea black-eyed ex- Makutupora (not inoculated) was only 2%, which was significantly less compared to other legumes (Table 10). This could explain the reasons for low yields obtained from sorghum following cowpea despite reduction of *Striga* infestation.

There is a considerable variation between various leguminous species and locations in their ability to fix N due to differences in soil factors, legume genotypes, bradyrhizobial strains and cropping patterns. Dakora, (1985b) reported that, simple N budgets of 10 groundnut cultivars grown in the African savannah demonstrated large differences regarding potential N returns to soil. For example, Groundnut cv. Manipintar fixed 134 kg N ha^{-1} and potentially enriched the soil with 102 kg N ha^{-1}. In contrast, the other tested cultivar fixed only 51 kg N ha^{-1} and depleted the soil of 2 kg N ha^{-1}. In the current study, growing sorghum after pigeon pea cultivar

ICEAP 00020 (not inoculated) resulted into significantly higher yields of sorghum planted after it compared with cultivar ICEAP 00040. This suggests that the slight difference in N increase between the two cultivars attained after one year rotation prior to sorghum (Table 10) resulted to the difference in yields.

5.3 Influence of Seed Coat Colour and Different Plant Parts of Selected Leguminous Species on Stimulation/ Inhibition of *Striga asiatica* Seed Germination

5.3.1 Effect of different plant parts on germination of *S. asiatica* seeds

Roots are the most used host and non-host plant parts in inducing germination of *Striga* species as well as in extracting germination stimulants of the parasitic weed seeds (Cook, *et al.*, 1972; Netzly, *et al.*, 1988; Muller, *et al.*, 1992; Tsanuo, *et al.*, 2003). Other plant parts reported to induce germination of *Striga* seeds are stems of cotton and cowpea (Ariga and Berner, 1993; Ariga, 1996). The current study showed that all exudates/ extracts derived from all plant parts (seeds, shoots, and roots) of the tested three leguminous species (bambara groundnut, cowpea and groundnut) were more effective ($P < 0.01$) in stimulating germination of *Striga asiatica* seeds compared to the negative control. This suggests that seeds of the tested non – host trap crops, like other parts (roots and stems) are capable of stimulating germination, and hence contain compounds responsible for the germination of the *Striga* seeds. Basing on available literature, this is probably the first report of germination of *Striga* seeds by exudates derived from seed materials.

5.3.2 Influence of seed coat colour on germination/inhibition of *Striga asiatica* seeds

The seed coats of legume crops such as common bean, soybean and peas, have been shown to play a mojor role during imbibition and germination (Bewley and Black, 1994). The roles ranged from simple nutritional, and or a more complex biological role in the context of seeking mutualistic symbionts or repelling antagonistic and predatory microbes and insect pest. Ndakidemi and Dakora (2003) found that black bambara groundnut contained significantly higher percentages of flavonoids compared to brown and cream, in that order.

In the current stidy, seed coat colour showed influence on both germination of *Striga* seeds and inhibition of their radical growth after germination. Seed exudates from black bambara groundnut stimulated high percentage germination (66.8%) of *S. asiatica* seeds, which was significantly higher compared to the percentages induced by the red and cream seeded bambara groundnut. Inhibition of radical growth of the *Striga* seeds by bambara groundnuts of different coat colour, also showed a trend similar to that of germination. Black seeded bambara groundnut > red seeded > cream seeded. The results implies that seed coat colour in bambara groundnuts plays a major role in influencing induction of suicidal germination of the *Striga asiatica* seeds.

Several authors (Lane *et al.*, 1993; Ejeta, 2001; Serghini *et al.*, 2001) have suggested that host and non - host plants are able to stimulate suicidal germination of the

parasite by releasing compounds for the induction of *Striga* germination, followed by disruption of a specific early developmental stage. In recent years (Tsanuo, *et al.* 2003) reported that isoflavonones from *Desmodium uncinatum* a non-host plant of *Striga* were effective in both stimulating and inhibiting germination and growth of *Striga* seeds. In the current study exudates from the black, red and cream seeded bambara groundnuts demonstrated possession of both germination stimulation and radical growth inhibition activities. This combination may comprise part of the mechanism of suicidal germination of *S. asiatica* seeds when exposed to the non-host leguminous crops.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

(a) Results from this study showed that the effectiveness of the root exudates depended on *Striga* seed population. The non host /parasite specificity observed implies that legumes with a high potential in controlling *Striga* species in one locality can not necessarily be as effective in controlling the same species in another locality.

(b) The variation among varieties within the tested leguminous species in stimulating germination of *S. asiatica* seeds demonstrated in this study shows that even their effectiveness as trap crops under rotation with cereals would differ. Cultivars that induced high germination percentage of *Striga* seeds in laboratory were equally effective in reducing the number of *Striga* seeds in the soil, and resulted in reduced *Striga* population after one-year rotation with sorghum. Pigeon pea cultivars ICEAP 00020 and ICEAP 0040 (*Mali*); bambara nut landraces Nyandani spotted cream and light brown Ex- Makutupora; groundnut cultivar ex- *Bukene* as well as cowpea landrace Black eyed ex- Makutupora have the potential of being used as trap crops in controlling *Striga asiatica*.

(c) Based on the current results, trap cropping with the selected leguminous crop species was effective in reducing *Striga* seed bank and infestation on the

concurrent sorghum crop. However, the practice does not lead to complete depletion of the *Striga* seeds in the soil and neither does it ensure complete control of *Striga* infestation in a single season. If such a rotation system is maintained over an extended period of time, *Striga* seed re - infestation into the soil could be minimized. To enhence the effectiveness and sustainability of the practice, intergration with other *Striga* control methods such as hand weeding of mature plants to avoid replenishment of the *Striga* seed bank in the long term is of paramount importance.

(d) In addition to *Striga* control, rotating sorghum with the selected leguminous trap crops resulted into better performance of sorghum in terms of height, number of heads, weight of heads, size of heads, and eventually sorghum yield. Pigeon pea cultivar 00020, and groundnut ex- Bukene, were the best followed by pigeon pea 00040, bambara groundnut, (Nyandani spotted cream and red ex-Makutupora). Legumes are also important in that they are good source of protein for human and livestock, and can be used as a source of income. Therefore, the five legume varieties/landraces provide alternatives for use by farmers in *Striga* infested areas.

(e) Pigeon pea cultivar ICEAP 00040 (Mali) was recently identified as a variety that combines high yielding potential with resistance to fusarium wilt and considerable tolerance to pigeon pea insect pests (Mligo *et al.*, 2004). The fact that it has also shown good potential as a trap crop in controlling *Striga*, makes

the cultivar a perfect choice for farmers when choosing crops to be used in rotation with sorghum for *Striga* control.

(f) Plant parts including seeds, shoots and roots of the tested cultivars stimulated germination of considerable number of *S. asiatica* seeds. Exudates from black and red bambara groundnuts seeds have shown germination stimulation and radical growth inhibition activities. This combination may comprise part of the mechanism of suicidal germination of *S. asiatica* seeds when exposed to the non- host leguminous crops. Hence, incorporation of the legume trap crop residues to the soil, after harvesting; instead of the conventional practice of burning plant residues is important to enhence *Striga* control.

6.2 Recommendations

(a) It is recommended that farmers in the Semi arid areas of Tanzania should rotate sorghum with pigeon pea cultivars ICEAP 00020 and ICEAP 00040 (*Mali*); bambara groundnut landraces Nyandani spotted cream and light brown Ex-Makutupora; groundnut cultivar ex- *Bukene* as well as cowpea landrace Black eyed ex- Makutupora for the control of *Striga asiatica*.

(b) The above mentioned legume trap crops should however be screened at other localities if they are to be recommended for use in *Striga* control programs in the respective areas.

(c) Farmers are recommended to incorporate these legume trap crop residues into the soil instead of the conventional practice of grazing livestock and/or clearing and burning the residues during land preparation.

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APPENDICES

Appendix 1. Field layout of the experiment (not to scale): 1-8 Treatments, I-IV Blocks

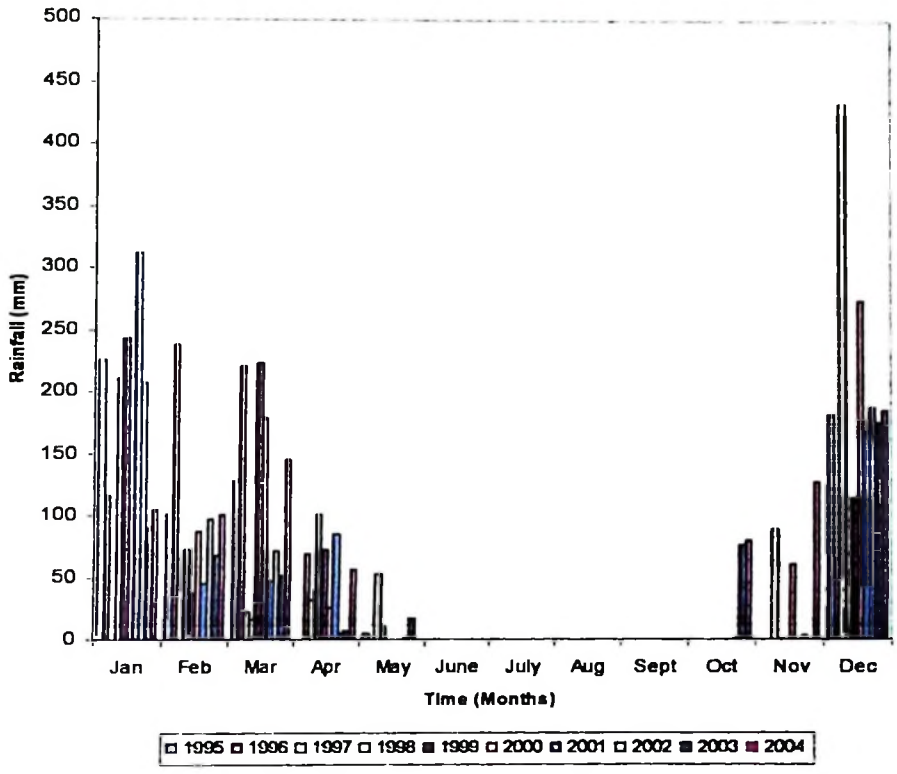
I	II	III	IV
8	2	6	3
7	5	4	1
6	1	2	8
5	3	1	2
4	7	5	6
3	8	7	5
2	4	3	7
1	6	8	4

Appendix 2. Mean monthly maximum and minimum temperatures (1995 – 2004) in the study area (^{O} C)

Year	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	MEAN
1995	30.0	25.4	28.0	27.8	29.3	28.0	27.0	26.4	29.4	31.2	31.0	29.8	28.6
	18.7*	**19.1**	**19.3**	**18.2**	**16.7**	**15.9**	**13.5**	**15.6**	**15.1**	**19.0**	**17.8**	**18.6**	**17.2**
1996	29.5	28.7	26.3	26.4	25.8	26.1	26.3	29.9	30.0	31.4	29.8	29.0	28.3
	18.6	**18.4**	**18.8**	**17.3**	**15.0**	**14.9**	**13.5**	**16.2**	**13.8**	**13.5**	**12.9**	**13.8**	**15.6**
1997	30.5	28.5	31.0	28.2	27.0	26.4	30.1	28.0	NA	30.1	29.4	31.5	29.1
	18.2	**19.0**	**18.2**	**17.5**	**16.8**	**16.8**	**15.7**	**13.7**	**15.6**	**17.2**	**17.6**	**19.4**	**17.2**
1998	27.7	29.0	31.0	28.9	NA	27.5	26.4	27.5	28.6	29.8	30.7	27.4	28.6
	19.3	**19.3**	**18.4**	**17.5**	**16.9**	**15.0**	**14.5**	**16.3**	**15.9**	**17.6**	**18.9**	**18.7**	**17.4**
1999	28.3	29.4	30.0	28.3	28.6	27.5	26.8	27.5	28.8	30.6	31.3	32.7	29.1
	20.0	**19.4**	**19.3**	**19.1**	**16.8**	**15.7**	**13.8**	**14.8**	**16.1**	**16.5**	**19.0**	**18.7**	**17.3**
2000	30.6	31.6	28.3	26.2	27.2	NA	25.4	26.4	28.4	30.5	31.5	30.6	28.8
	19.1	**19.1**	**19.4**	**17.8**	**16.2**	**14.8**	**13.8**	**15.3**	**15.5**	**16.4**	**18.3**	**18.7**	**17.1**
2001	30.7	31.1	28.4	28.7	26.7	26.4	26.3	27.2	28.8	30.7	30.7	27.7	28.6
	19.7	**19.1**	**18.3**	**17.4**	**20.7**	**14.3**	**13.7**	**14.8**	**15.4**	**17.2**	**19.1**	**18.9**	**19.0**
2002	27.1	28.9	25.4	26.3	27.9	25.8	27.3	27.5	29.3	30.7	31.7	31.8	28.3
	19.4	**18.5**	**18.7**	**18.0**	**16.7**	**14.3**	**14.5**	**14.1**	**15.5**	**17.2**	**18.6**	**19.6**	**17.1**
2003	27.6	28.9	28.4	28.2	28.8	27.4	27.3	26.9	29.0	30.4	31.9	30.8	28.8
	19.4	**18.8**	**17.6**	**17.9**	**14.2**	**15.4**	**14.6**	**14.7**	**15.8**	**17.2**	**18.9**	**19.3**	**16.9**
2004	29.5	30.5	31.4	29.4	27.6	27.5	26.6	28.3	29.2	30.9	32.3	31.2	29.5
	20.3	**18.9**	**19.4**	**19.4**	**18.1**	**17.2**	**14.1**	**14.5**	**16.0**	**17.2**	**19.1**	**18.5**	**17.7**
MEAN	29.1	29.2	28.3	27.8	27.1	26.9	26.9	27.6	29.0	30.96	31.0	30.2	28.8
	19.3	**18.8**	**18.4**	**18.4**	**16.7**	**15.5**	**14.1**	**14.9**	**15.5**	**16.96**	**18.0**	**18.5**	**17.2**

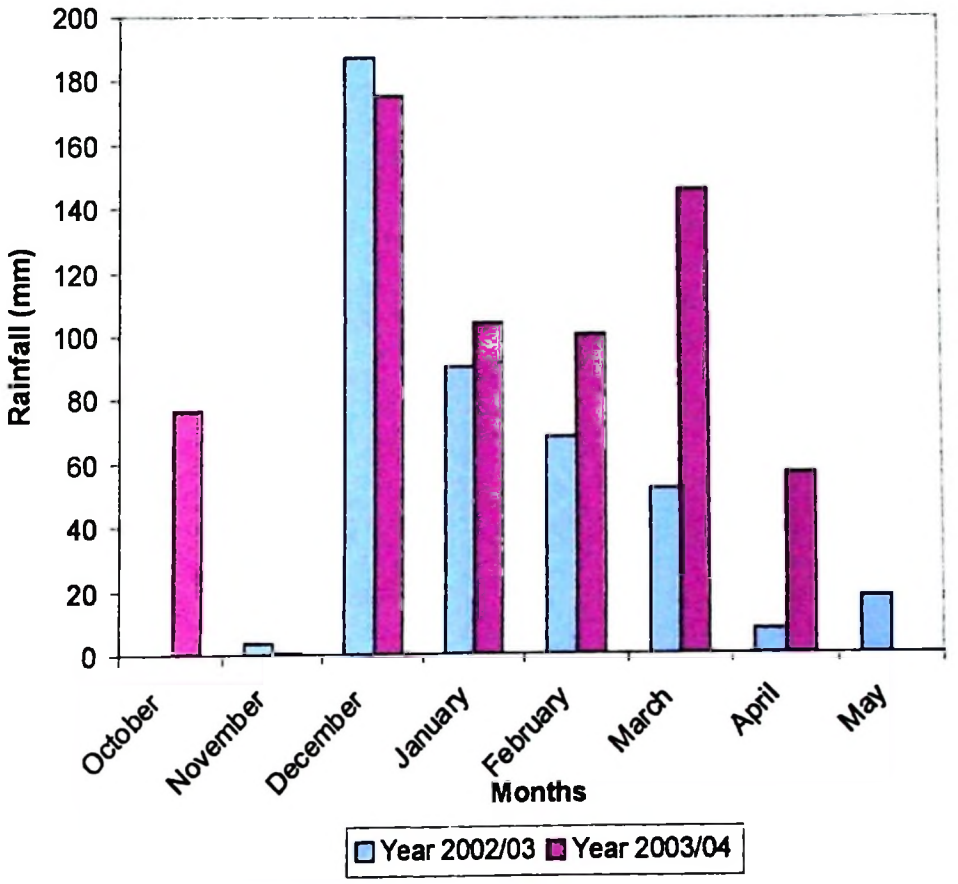
* Bolded figures apply to minimum temperatutes

Appendix 3. Mean monthly rainfall distribution (1995 - 2005) in the study area



Source: Tanzania Metrological Agency – Dodoma

Appendix 4. Rainfall distribution for the two cropping seasons in the study area



Source: Tanzania Metrological Agency – Dodoma

Appendix 5. ***Striga*** **emergence at different stages of sorghum planted after one-year rotation with leguminous trap crops**

Rotation systems	No of plants/ m^2			
	7WAP	9WAP	11WAP	13WAP
PP 00020	13.6 ab	34.2 b	43.3 b	45.9 b
PP 00040	13.7 ab	29.8 b	42.9 b	43.9 b
Fallow	15.5 ab	68.8 a	88.5 a	89.4 a
BN Cream	13.2 ab	35.1 b	45.9 b	47.5 b
BN Brown	12.4 b	27.7 b	44.0 b	45.8 b
GN Bukene	14.7 ab	36.1 b	44.6 b	50.0 b
CP Black eyed white	12.8 b	33.5 b	38.4 b	39.1 b
Sorghum (pato)	18.0 a	71.8 a	88.2 a	88.8 a
CV (%)	**14.13**	**18.88**	**10.78**	**10.68**
SE	1.00	3.98	2.94	2.98

Means in the same column followed by same letter(s) are not significantly different according to THSDT ($P < 0.05$)

Appendix 6. Mean percent germination of ***S. asiatica*** **seeds subjected to root exudates of pigeon pea breeders lines and and sorghum cultivar at different distance from source**

Breeders lines/cultivar	Mean germination (%)/Distance					
	1.3	1.9	2.5	3.1	3.7	Total
ICEAP 00053	15.7	30.2	21.6	20.6	0.0	17.6
ICEAP 00068	11.7	23.3	36.1	13.4	5.4	17 9
ICEAP 00020	43.1	45.1	58.1	34.4	24.5	41.1
ICEAP 00040	47.5	45.8	42.3	6.9	5.1	29.5
ICPL 87091	25.4	21.9	19.1	10.2	10.3	17.4
ICPL 86005	12.7	21.7	4.4	0.0	0.0	7.8
ICEAP 00073	20.4	7.9	1.0	0.0	0.0	5.8
ICPL 9145	22.2	26.2	21.4	8.9	4.6	16.6
ICPL 6927	9.7	6.9	0.0	0.0	0.0	3.3
Sorghum (pato)	50.2	38.2	23.5	17.6	16.0	29.1
Total	**25.8**	**26.7**	**22.7**	**11.2**	**6.6**	**18.6**

Appendix 7. Mean percent germination of *S. asiatica* seeds subjected to root exudates of common bean and sorghum varieties at different distance from source)

Varieties	Germination percent / distances					
	1.3	1.9	2.5	3.1	3.7	Total
DN SEQ 41	25.7	21.6	0.0	0.0	0.0	9.5
DN Bayo	14.4	26.5	34.4	36.7	35.2	29.3
M.kunde	11.9	16.5	7.3	1.7	0.0	7.5
PBS wanja	25.7	22.3	0.0	0.0	0.0	9.6
EG	23.4	10.5	0.0	0.0	0.0	6.7
DN 1007	28.9	7.7	0.0	0.0	0.0	7.3
Rojo	42.0	32.8	31.4	16.9	4.9	25.7
K. nywele	17.6	7.6	0.0	0.0	0.0	5.0
SUA	45.3	21.5	19.8	10.1	7.4	20.8
TMO 542	38.9	25.4	15.3	0.0	0.0	16.0
Sorghum (pato)	50.2	38.2	33.5	17.6	16.0	31.1
Total	29.4	20.9	12.9	7.5	5.8	15.8

Appendix 8. Mean percent germination of *S. asiatica* seeds subjected to root exudates of bambara groundnuts and sorghum cultivar at different distance from source

Cultivars	Distance from source (cm)					
	1.3	1.9	2.5	3.1	3.7	Total
Spotted cream ex-Makutupora	26.7	15.0	8.6	6.2	0.0	11.3
Cream ex- Makutupora	26.9	24.7	21.1	19.5	11.1	20.7
Cream ex-Mwanza	14.7	12.4	10.3	6.7	5.7	9.9
Brown ex- Bukoba	23.9	10.6	6.4	3.3	0.0	8.8
Red ex- Makutupora	53.9	34.3	19.3	10.9	5.0	24.9
Nyandani spotted cream	6.4	9.6	27.1	38.1	43.2	24.7
Red ex- Dodoma	10.3	8.3	6.7	4.8	0.0	6.0
Light brown ex-Mwanza	7.9	7.8	7.2	5.5	4.2	6.5
Sorghum (Pato) – control	49.9	38.2	23.5	17.6	16.0	29.6
Total	24.5	17.9	14.5	12.5	16.0	15.9

Appendix 9. Mean percent germination of S. *asiatica* seeds subjected to root exudates of groundnuts and sorghum cultivar at different distance from source

Groundnut cultivars	Distance from source (cm)					
	1.3	1.9	2.5	3.1	3.9	Total
Ex- Bukene	61.6	54.6	48.2	25.1	3.1	38.5
Ex- Singida	7.7	6.4	0.0	0.0	0.0	2.9
Mamboleo	9.9	0.0	0.0	0.0	0.0	2.0
Sorghum (Pato)	50.2	38.2	23.5	17.6	16.0	29.1
Total	25.9	19.9	14.3	8.5	4.8	18.1

Appendix 10. Mean percent germination of *S. asiatica* seeds subjected to root exudates of cowpeas and sorghum cultivar at different distances from source

Cowpea cultivars	Distance from source (cm)					
	1.3	1.9	2.5	3.1	3.7	Total
Greyish Ex- Makutupora	9.9	0.0	0.0	0.0	0.0	1.9
Whte black eyed white	81.9	42.2	12.8	0.0	0.0	27.4
Red –Ex Makutupora	32.1	24.7	14.7	0.0	0.0	14.3
Mbegu ya pamba	11.0	3.6	0.0	0.0	0.0	2.9
Macho ya paka	11.1	6.9	7.3	3.9	0.0	5.8
Sorghum (pato)	50.2	38.2	23.5	17.6	16.0	29.1
Total	28.0	16.5	8.3	3.1	2.3	13.6