EFFECTS OF *Striga asiatica* (L.) Kuntze AND *Rhamphicarpa fistulosa* (Hochst.) Benth. SEED DENSITIES ON PHYSIOLOGY AND YIELDING ABILITY OF RICE (*Oryza sativa* L.)

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE, SOKOINE UNIVERSITY OF AGRICULTURE.

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ABSTRACT

Striga asiatica and *Rhamphicarpa fistulosa* greatly affects rice productivity in infested fields. To address this problem, two screen house experiments were conducted at Sokoine University of Agriculture during September, 2012 to February, 2013 to study the effects of parasitic weed seed densities of *S. asiatica* and *R. fistulosa* on physiology and yielding aptitude of rice. In one of the experiments eight *S. asiatica* densities were planted with single host rice (variety IAC 165) while in the second experiment, seven *R. fistulosa* densities were planted with single host rice (variety IR64). Both experiments were laid out in a Completely Randomized Block Design (CRBD) with five replicataions. In addition, a supplementary experiment was conducted to study the intra specific competition between *R.fistulosa* plants under monoculture where six *R.fistulosa* seed densities (31, 62, 125, 250, 500 and 1000 seeds/pot) were sown without host. In the *S. asiatica* density experiment, the highest value on stomatal conductance was recorded in the parasite free pots (205.8 mmol/m^2 s) while the lowest was recorded in the plants with the highest *S. asiatica* infestation densities (21 mmol/(m^2s). At 60 DAS there was a significant difference ($P<0.05$) between the treatment means chlorophyll content from 20.8 in highest *S. asiatica* density (47 840 seeds/pot) to 34.1 in *S. asiatica* free pots. The highest average total rice biomass was recorded in non-infested pots (2.5 g/pot) while the lowest was recorded in the highest *S. asiatica* infestation density (0.5 g/pot). In *R. fistulosa* density experiment there was significant difference in stomatal conductance ($P<0.05$) at 60 DAS i.e. (202.8 mmol/(m^2s) from *R. fistulosa* free plants and (143.6 mmol/(m^2s) from lowest *R. fistulosa* infestation density. At 60 DAS, the highest average value of chlorophyll fluorescence (0.66) was recorded in *R. fistulosa* free

plants while the lowest (0.413) was recorded from plants in the highest *R. fistulosa* infestation density (1000 *R. fistulosa* seeds/pot). The highest rice biomass was obtained from *R. fistulosa* free plants (5.42 g/pot) while the lowest was recorded in the highest *R. fistulosa* infection levels (0.68 g/pot). On the basis of these results, it was concluded that *S. asiatica* and *R. fistulosa* affect rice physiology and yielding ability.

DECLARATION

I, **John Constantine,** do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is the result of my own original work and has never been submitted for a degree award in any other Institution.

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DEDICATION

This work is dedicated to my late father Constantine Ngalason, my mother Theresia Constantine, my wife Grace Sakala and my children, Veronica and Glory.

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LIST OF ABBREVIATIONS

AATF	African Agricultural Technology Foundation
ACC	1–aminocyclopropane–1–carboxylic acid Synthase
ACCO	1–aminocyclopropane–1–carboxylic acid oxidase
ACS	American Chemistry Society
APHIS	Animal and Plant Health Inspection Service
CDFA	California Department of Food and Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CRC	Clinical Research Center
CV	Coefficient of variation
DAS	Days After Sowing
DM	Dry Matter
DNMRT	Duncan's New Multiple Range Test
DW	Dry Weight
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO Statistical Databases (United Nations)
GM	Grand mean
ICRISAT	International Crops Research Institute for the Semi–Arid–Tropics
IITA	International Institute for Tropical Agriculture
IWM	Integrated Weed Management
KATC	Kilimanjaro Agricultural Training Centre
MAFSC	Ministry of Agriculture Food Security and Cooperatives
NERICA	New Rice for Africa
NPK	Nitrogen Phosphorus Potassium

PASCON	Pan–African *Striga* spp Control Network
PIER	Pacific Island Ecosystems at Risk
PPQ	Plant Protection and Quarantine
PSII	Photosystem two
RCBD	Randomized Complete Block Design
SE	Standard Error
SPAD	Soil and Plant Analysis Development
SSA	Sub Saharan Africa
SUA	Sokoine University of Agriculture
USDA	United States Department of Agriculture

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Approximately, half of the world's population depends on rice as a main staple food (Evans *et al.*, 2011). In the Sub–Saharan Africa, the total rice production by 2006 was estimated to be about 21.6 million tonnes (Africa Rice, 2007). Urbanization, dietary shift from conventional and the increase in population has resulted into rise in demand of rice at a rate of 4.4% per annum since 1970s (Jones, 1999).

In recent years, Tanzania has focused its agricultural investment in rice (*Oryza sativa* L.) production. The crop is among the major sources of employment, income and food security for Tanzania farming households. Rice (*Oryza sativa*) is the second most important food and commercial crop in Tanzania after maize. It has been ranked as a national strategic crop based on the area under cultivation, production and consumption (RLDC, 2011). According to Rural Livelihood Development Company (RLDC) report of 2011, Tanzania is the second largest producer of rice in Southern Saharan Africa after Madagascar with production level of 818 000 tones. The cultivated area is 681 000 ha, equivalent to 18 % of Tanzania's cultivated land. About 71% and 29% of the rice grown in Tanzania is produced under rain fed and irrigated conditions respectively (RLDC, 2011).

The average yield is very low, 1 – 1.5 t/ha compared to the potential yield of 4 – 5t/ha (MAFC, 1998). Farmers grow a number of traditional varieties, which have long maturity and yield is affected with irregular rainfall pattern and also prone to

effects of pests including serious parasitic weed infestation which contribute to the yield decline. Some of these varieties include India, Kilombero, Zambia and Mwabulu.

In Africa yield losses due to weeds in general, average 30% but losses of 50% or more are frequently reported in some parts of Sub–Saharan Africa. A review of crop pests in Sub–Saharan Africa indicated that weeds are the most important pests to control in all zones studied (Sibuga, 1997). Due to high losses caused by weeds. Sibuga (1999) argued that it is important to conduct systematic studies of the biology and ecology of important weeds in order to generate knowledge which is vital for the planning of management strategies in individual countries.

In recent years *Striga asiatica* and *Rhamphicarpa fistulosa* have been recognized as the main parasitic weeds hindering rice production (unpublished Kyela District Agricultural Reports). *Striga* is found in rain–fed uplands whereas *Rhamphicarpa fistulosa* is found in rain–fed lowlands (Rodenburg *et al.*, 2011). *Rhamphicarpa fistulosa*, a facultative hemi–parasitic weed, was first reported in Tanzania by Johnson *et al.* (1998) in Kyela and Mbinga Districts in the southern parts of the country. Kyela is mainly dominated by rice–based farming systems (Mussei *et al.*, 1999). *Rhamphicarpa fistulosa* and *Striga* spp infestation reduces yield of lowland and upland rice, respectively, up to total crop failure depending on the level of field infestation and susceptibility. Survey conducted in Kyela and Mbinga came up with results showing that the two weeds are widely spread (Kayeke *et al.*, 2010). Even though much has been done on the study of weeds, there is generally lack of

knowledge on the effects of *Striga asiatica* and *Rhamphicarpa fistulosa* densities on the physiology and yielding ability of rice.

1.2 Problem Statement

The productivity of rice is low (1 – 1.5 t/ha) compared to the estimated potential yield of 4–5t/ha (MAFC, 1998). The constraints which account for the low productivity include poor soil fertility, unreliable rainfall patterns and pests of which weeds are considered to be a major limitation (Vissoh *et al.*, 2004). Amongst the weeds, the parasitic weeds *Striga asiatica* and *Rhamphicarpa fistulosa* greatly affect rice productivity if left uncontrolled. *Rhamphicarpa fistulosa* has been reported to impose loses from 30 to 100% of rice in fields of Mbeya and Ruvuma regions where about 33% of the fields have been infested (Kayeke *et al.*, 2010). On the other hand, depending on infestation level, *Striga* causes the cereal crop loses from 5 to 30% or even up to 80% if left uncontrolled (KARI, 1997). Since *Striga asiatica* was introduced in the country in 1950s and *Rhamphicarpa fistulosa* in 1998 (Johnson *et al.*, 1998; Kayeke *et al.*, 2010), they have continued to infest rice fields until now in a wide range of agro–ecosystems in the country. This has led to farmers abandoning heavily attacked fields when the infestation reaches unmanageable levels, resulting in food insecurity and increased loss of cash income.

1.3 Justification

Over the past three decades rice production has increased in sub Saharan Africa (SSA) by 105% in area and 170% in production (FAO, 2010). This increase has resulted from inland valley improvements and recent technological advancement

such as the development of better and high yielding rice cultivars (Dalton and Guei, 2003). According to the survey done in Kyela, (Kayeke *et al.*, 2010) all of the respondents indicated to be familiar with *R. fistulosa* and *Striga* spp evidence of a progressive spread of the weeds. Farmers know the effect of the weeds but lack knowledge on biology of *Striga* as well as *R. fistulosa*. However, little is known about the effects of *S. asiatica* and *R. fistulosa* on the physiology and yielding ability of rice. Due to the high losses caused by weeds and in particular the two weed species, the results of this study will help to support national program efforts to develop integrated methods for the management of *Striga* spp and *Rhamphicarpa* spp. in rice production areas of Tanzania.

1.4 Objectives

1.4.1 Overall objective

The study aims at generating information on the effects of parasitic weed densities of *Striga asiatica* and *Rhamphicarpa fistulosa* in infested rice fields to be used for development of integrated weed management methods.

1.4.2 Specific objectives

i. To determine the effects of *Striga asiatica* seed densities on rice growth and yielding ability

ii. To quantify the physiological effects on rice in the presence of *Rhamphicarpa fistulosa* or *Striga asiatica*

iii. To determine the effect of intra–specific competition between *Rhamphicarpa fistulosa* plants in the absence of host

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 *Striga* spp

2.1.1 Origin of *Striga* spp

The genus '*Striga*' comprises more than 40 species (Kamal *et al.*, 2001) of parasitic weeds which belong to a group of hemi–parasites under the family Orobanchaceae (Nelson *et al.*, 1999) formerly placed under the family Scrophulariaceae. They are native to semi– arid, semi– tropical and some parts of America (Saurborn, 1991).

In the Southern Saharan Africa *Striga* spp. is believed to originate around Mountains of Ethiopia and Nubian hills of Sudan before spreading to other parts of the continent (Ejeta, 2007). This area is also known to be the origin of sorghum and pearl millet which are highly infected by *Striga* spp.

2.1.2 Geographical distribution

World–wide, *Striga asiatica* has an extremely large area of distribution: from tropical and southern Africa and Madagascar, through western Asia, India, Burma, Indo–China, southern China, Thailand, Peninsular Malaysia, Java, the Philippines New Guinea and Europe (APHIS, 2000; PIER, 2005). The species is also found in North and South Carolina in the United States of America (Parker and Riches, 1993). In Tanzania, *S. asiatica* and *S. forbesii* have been reported to infest regions of Tanga, Morogoro, Coast, Lindi, Mtwara, Ruvuma, Singida and Dodoma (Mbwaga and Massawe , 2002).

On the other hand, *Striga hermonthica* has been reported to be the most important parasitic weed species worldwide (Parker and Riches, 1993). It has been spread throughout the semiarid areas of the Northern Tropical Africa, stretching to South Western parts of Arabia, Southern Tropical Africa encompassing Namibia, Angola and Madagascar (Frost, 1995). It is also found around Lake Victoria in Both Tanzania and Kenya (Fasil Reda and Parker, 1994). In Tanzania *S. hermonthica* dominates regions of Mara, Kagera, Tabora and Shinyanga (Mbwaga and Massawe, 2002). According to AATF (2006), the total area infested with *Striga* spp. in Tanzania is 179 000 ha.

2.1.3 The life strategy of parasitic weeds

Parasitic weeds are higher plants which live at the expense of other higher plants through parasitism. Their parasitic way of life is accomplished by attaching themselves to their host plant to siphon photosynthates, water and even hormones from it. Most parasitic plants depend upon other vascular plants for food or water which flows from host to parasite through haustorium (Musselman, 1980). This drain of nutrients is sufficient to bring about stagnation of the host plants and thus low yield (Watson *et al.*, 1998; Cochrane and Malcolm, 1997).

2.1.4 Parasitic weeds common in Africa

Common parasitic weeds in Africa include *Striga* species, *Allectra vogelii*, *Buchnera hispida* and *Rhamphicarpa fistulosa*. *Striga* spp. affect mainly cereals with exception of *Stiga gesnorioides* which parasitizes legumes including cowpeas and other wild legumes (IITA, 1997). *Allectra vogelii* parasitizes groundnuts, cowpeas, as well as

soybean with a direct yield loss of up to 100% in cowpeas (Riches, 1988). According to Musselman (1987), *Buchnera hispida* is a facultative parasite (do not require a host to complete its life cycle, but it is photosynthetic and, when in association with host roots, form haustorial connections) which resembles *Striga* species by effecting similar hosts including sorghum, maize and millet though its damage is generally considered less significant (IITA, 1997). On the other hand, *Rhamphicarpa fistulosa* affects maize, rice, sorghum, cowpeas and millet (Kuijit., 1969; Cissé *et al.*, 1996; Quédraogo *et al.*, 1999).

2.1.5 Life cycle and germination requirements

Before responding to any germination stimulants, *Striga* spp. seed must undergo an after ripening period. This period is important for the transformation of phenolic compounds which act as germination inhibitors (Musselman, 1980). *Striga* spp. seed cannot germinate until conditioned and then supplied with germination stimulants. Muller *et al.*, (1992) reported that, different *Striga* species have got different conditioning periods though the reasons for the observed differences have not yet been documented. Muller argued that, the optimum conditioning period for *Striga asiatica* ranges from 9–45 days, 11–14 days for *S. hermonthica* and 4–7 days for *S. gesnorioides.*

According to Babiker *et al.* (1993), conditioning the seeds in warm moist environment and subsequent exposure to a stimulant are needed for induction of endogenous ethylene biosynthesis which is the vital compound liable for stimulating germination. The important steps in biosynthesis of ethylene before seed germination are catalysed by two enzymes which are 1–aminocyclopropane–1–carboxylic acid

(ACC) Synthase and ACC oxidase (ACCO). Okonkwo (1991), Logan and Sterwart (1991) and Heller and Wegman (2000) reported that, the temperature range for *Striga* spp.seed conditioning is between 20°C and 40°C whereas the optimum range is between 25 – 35°C.

Upon stimulation by host derived chemicals i.e. strigolactones (Bouwmeester *et al.*, 2003; Yoneyama *et al.*, 2010), *Striga* spp. radical will grow towards the host root showing positive chemotropic response (Cheng *et al.*, 1986). In order for the seed to be able to germinate in the soil it should not be more than 4 mm away from the root zone and not buried deeper than 30 cm. However, the seeds can still maintain viability for a long time (Worshum 1987; Sterwart and Press 1990).

Following germination, the hydrolysed food reserve within the seed can sustain the seedling for 3 to7 days in the absence of host (Pieterse and Pesch, 1983; Worshum, 1987). After the lapse of 3 to 7 days, if the seedling does not successful attach to a host and establish a bridge for draining photosynthates, hormones, water and mineral salts, it dies. This can be accomplished by formation of a structure known as haustorium (Worshum, 1987).

2.1.6 Morphological characteristics

Morphologically, *Striga* spp. is a chlorophilous, small, annual, upright herb which depending on species and ecology can grow to a height of 15 to 50 cm (Parker and Riches, 1993). Its stem has got four sides with simple leaves which measures 5 – 15mm ×1–1.5mm. The plant produces numerous tiny seeds which measures 200

microns wide and 300 microns length (Saunders, 1933; Worshum, 1987) with broad spindle–shape. Characteristically the seeds have a surface pattern of ridges which supposedly play a role in the uptake of chemicals responsible for stimulation of *Striga* spp. seed germination (Musselman, 1980; Parker and Riches, 1993).

It has been estimated that a single capsule can bear over 700 and 800 seeds for *Striga hermonthica* and *Striga asiatica*, respectively. On average, the number of capsules per plant is 60 to 70 for both *S. hermonthica* and *S. asiatica* (Kudra, 2011). The arrangement of leaves is opposite to alternate, which lack green color but later change to green with densely hairy surface. The fruit is a spherical capsule which measures 3 – 5 mm long, which bears many seeds (*http//www.globinmed.com*, 2012). Mature *Striga* spp. seeds have various ways of dispersal including wind, rain water, soil, garden tools, manure application, grazing animals and machinery through cultivation (Ramaiah *et al.*, 1991; Parker and Riches, 1993). However, for unknown reasons, *Striga* seeds are not efficiently dispersed by wind (Berner *et al.*, 1994). According to the Research done at IITA and reported by Berner *et al.* (1997), man's economic activities like livestock rearing and handling of crop seeds are considered to be the principal disseminating agent of *Striga* spp. seeds.

2.1.7 *Striga* spp. seedling emergence and host symptoms development

Upon successful attachment and establishment of connections to the host root xylem, *Striga spp* grows for an extended period underground and it is during this period that much of the damage is done (Cochrane and Malcolm, 1997). The parasite seedling will take a period of 4 to 7 weeks to emerge above the ground. The draining of

growth carbon, water and mineral salts results into host symptoms development including chlorosis, necrosis, curling at the leaf margins, wilting and reduced growth (Vasudeva Rao, 1985; Kim, 1991; and Gurney *et al.*, 2001). In addition, the weed produces phytotoxins that adversely affect the growth of their host (Cochrane and Malcolm, 1997).

2.1.8 Ecology

Striga asiatica is a hemi–parasite on the roots of most plants under graminae family. It is a serious pest in crops like upland rice, sorghum, maize, millet and sugar cane. Under more natural situations, it occurs in deciduous forest, grasslands, along roadsides and in abandoned fields up to 2000 m a.s.l (Cochrane and Malcolm, 1997). *S. asiatica* grows well in areas with rainfall ranging from 400 to 1000 mm of annual rain. It does not grow well in areas characterised with high rainfall. Radosevich *et al.* (1997) observed that, *Striga* species can be suppressed by irrigation or heavy continuous rainfall. Areas characterized with sandy, infertile soils with low to moderate water holding capacity have shown to have higher incidence and severity of crop attack by *Striga* spp. (Webber *et al.*, 1995). Though it prefers sandy and well–drained soils, but can also grow on clayey soils. (*http//www.globinmed.com)*. However, *Striga* spp. does not grow well on heavy clay soils (Dogget, 1988). Although *S. asiatica* occurs widely in savanna grasslands the densities are relatively lower than those observed in areas under cultivation (Raynal–Roques, 1987). According to Patterson (1990), the optimum temperature range for survival of *Striga* spp. is 25 – 35 °C. However, dormant seeds can survive freezing temperatures of –7°C to –15°C for as long as 49 days (Parker and Riches, 1993).

Furthermore, studies have revealed that light intensity is not critical as the species can grow to maturity in complete darkness. Contrary to expectations, though *Striga* species are photosynthetic active plants, they do not show maximum growth in full sunlight (Parker and Riches, 1993).

2.1.9 Effects of parasitic weeds on host physiology

The degree of pathogenicity exhibited by various parasitic plants varies considerably from those which cause little impacts (e.g. *Epifagus* spp. on Fagus*)* to those which cause great damage to their hosts in terms of productivity and physiological attributes (e.g. *Striga* spp.). Pathogenicity is subject to several aspects such as (i) number of parasites bridged to a single host (ii) parasite to host biomass ratio (iii) the number of parasites attached to an individual host plant and (iv) the length of time required for the parasite to complete its life cycle (Nickrent , 2002). In *Striga* spp.–host association, the size of the parasite does not appear to be related to the extent of host physiological disturbance (Press *et al.*, 1996) but is probably associated to changes in host growth regulating (Drennan and El–Hiweris, 1979).

2.1.9.1 Effects of *Striga* spp. on plant chlorophyll content and photosynthesis

Phytotoxic effects is considered to be the cause of changes in partitioning of host photosynthates from shoot to root and general reduction in photosynthetic rate (Ransom *et al.*, 1996). Press and Sterwat (1987) and Graves *et al.* (1990) reported that lower photosynthetic rate is demonstrated by leaves of plants that are *Striga* spp. infected than uninfected ones. Leaves of *Striga* spp. infected plants have frequently reported to demonstrates lower rates of photosynthesis compared with uninfected

plants leaves (Graves, 1995). The rate of CO_2 fixation by *Striga* spp. infected plants has also been reported to be far less than that of uninfected plants, which account for about 80% of observed differences in productivity between affected and uninfected plants. According to Evans (1983) and Seeman *et al.* (1987), the amount of chlorophyll present in plant leaves can serve as an indicator of the overall condition of the plant itself and it is often well correlated with leaf N status and photosynthetic activity.

Chlorophyll fluorescence has been shown to represent variations in the health and function of the photosynthetic process (*http://www.optisci.com/cf.html*, 2013). The use of a chlorophyll fluorometer enable one to measure the influence of factors such as water and nutrient accessibility on plants for advancements of breeding, production programs, and to improve understanding of plant functions. Usually, healthier plants contain more chlorophyll than less healthier ones (*http://www.optisci.com/cf.html*, 2013).

2.1.9.2 Effects of *Striga* spp. on host stomatal conductance and movement of water and substrates

Striga spp. has been reported to affect maize physiologically through interference with stomata conductance, thus effect on photosynthesis (*Invasive.org*, 2006). Morphologically, root parasitic plants have vestigial root system which hinders their ability to absorb water and nutrients direct from the soil (Taylor and Seel, 1998). Raven, (1983) reported that parasitic plants that drain nutrients and water through the xylem transpires relatively large amount of water than their hosts. This higher rate of

transpiration not only diverts the xylem sap to the parasite but also reduces the water supply around the host rhizosphere. Further, Taylor and Seel (1998) indicated that while the stomatal conductance of infected maize plants was reduced, that of parasite (*Striga hermonthica*) remained higher. The implication of higher rates of stomatal conductance in parasites is the corresponding higher rates of derivation of host photosynthates, water and mineral salts to the parasites translocation systems.

2.1.10 Economic impacts

According to (Raynal–Roques, 1991), though eleven species of *Striga* spp. are considered as agricultural weeds, only four (*S. gesnerioides, S. asiatica, S. nsibera* and *S. hermonthica)* have been identified as serious economic pests. Generally, *Striga* and other parasitic weeds have a great effect on human welfare as their hosts are often sustenance food crops and particularly in marginal agricultural areas in semi–arid and sub–humid tropical regions characterized by low soil fertility (particularly nitrogen deficiency) and water stress (CDFA. 2006).

Infestations of fields by parasitic weeds result into lower harvests and lead to contamination of crops (Elzein and Kroschel, 2004). *S asiatica* has been reported to affect maize plants physiologically through impairment of photosynthesis through restriction on stomatal conductance and sensitizes infested plants to photo inhibition (*Invasive.org*, 2006). The weed has been reported to inflict yield losses from 40-100% if left uncontrolled (Bebawi and Farah, 1981; Lagoke *et al.*, 1991; Ejeta *et al.*, 1992). The growing severity of *Striga* infestation in Tanzania and Africa in general results from escalation of cereal production, essentially through mono–cropping

practice, in an effort to produce adequate food for the ever expanding population (Doggett, 1984; Butler, 1995; Berner *et al.*, 1996). Due to continuous decline in soil fertility in Africa, grain yield losses caused by *Striga* spp. are predicted to increase further (Kroschel, 1998).

Table 1: Possible *Striga* spp. control options

Control strategy	Specific action	Reference(s)
Biological	The use of catch crops e.g. cotton	Kroschel and Sauerborn, 1996
	Fungi e.g. *Fusarium* spp.	Abbasher and Sauerborn, 1992; Ciotola *et al.*, 1995
	Rhizobacteria – capable of suppressing germination of *Striga* seeds or destroying the seeds	Berner *et al.*, 1995; Miché *et al.*, 2000
	Insect pests (e.g. gall forming weevils like *Smicronyx albovariegatus*	Smith *et al.*, 1993; Parker and Riches, 1993
Chemical	The use of germination stimulants e.g. Ethylene	Eplee, 1975
	Post emergence herbicides e.g. 2,4D	Robert, 1996
	Anti–transipirant herbicides	Robert, 1996
	Pre emergence herbicides e.g. oxyfluorfen and dinitroaniline compounds	Berner *et al.*, 1997
Cultural	Crop rotation with legumes	IITA, 1997
	Growing of tolerant cereal varieties	CDFA, 2006
	Growing non host that stimulate *Striga* spp. germination as ethylene but do not support attachments	Berner *et al.*, 1995
	Mixed cropping	Carson, 1989); Sale *et al.*, 1987
	The use of *Striga* spp. free planting material	Berner *et al.*, 1994b
Physical Eradication	Hand pulling before *Striga* spp. produce seeds	CDFA, 2006
	Quarantine to prevent movement of the parasite to other areas	Sand and Manley, 1990

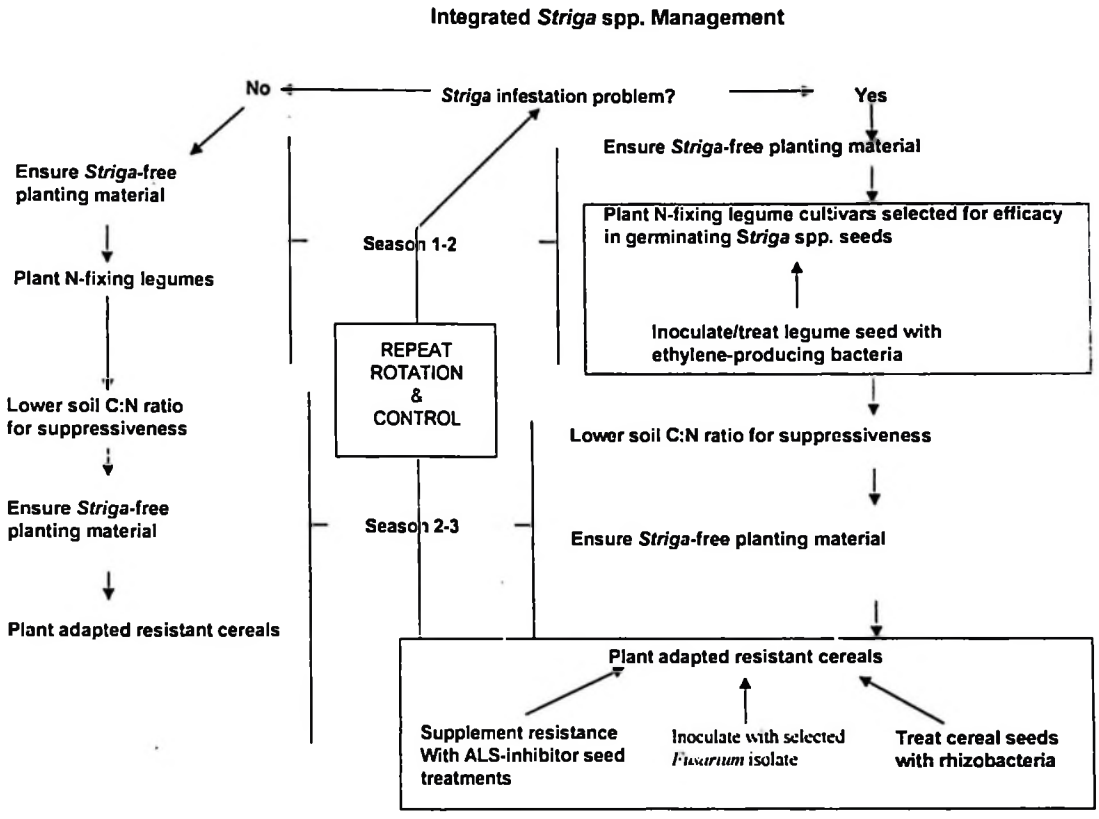

Figure 1: Decision tree and flow chart of basics to be employed for integrated management of *Striga* spp

Source: Berner *et al.*, 2002

2.2 *Rhamphicarpa Fistulosa*

2.2.1 General plant description

Rhamphicarpa fistulosa (Hochst.) Benth. is an annual, facultative hemi–parasite under family Orobanchaceae and subfamily Rhinanthoideae (Wettstein,1891). *R. fistulosa* is not dependent on the presence of a host to complete its life cycle although its reproduction is more favored by parasitizing an appropriate host plant.

R. fistulosa has round stem with thin rolled leaves. In the absence of a host, plants are smaller in size and are only able to produce small amount of seeds (Quédraogo *et al.*,

1999). It produces long white flowers after 140 days after sowing regardless of whether it is growing under screen house or under natural conditions. The plants have seeds which are oval shaped and brownish in color which measures 200×550 µm. The seeds resemble those of *Striga angustifolia* in size and in terms of requirement of light for germination (Krause, 1990). Seeds of *R. fistulosa* do not require stimulant from the host plant in order to germinate (Quédraogo *et al.*, 1999). The weed parasitizes the host through a haustorium connecting parasite and host root xylem (Neumann *et al.*, 1998). *R. fistulosa* has got a fibrous root system with adventitious roots which develop from the hypocotyl (Quédraogo *et al.*, 1999). According to Bouriquet (1933), *Rhamphicarpa fistulosa* was identified for the first time as an important parasitic weed in Madagascar where it was found attacking rice fields.

2.2.2 Geographical distribution

According to Kuijit (1969), *R. fistulosa* has been reported to be widely spread in Tropical Africa as well as Madagascar (Bouriquet, 1933) and New Guinea and Northern Tropical Australia (Hansen, 1975). The weed has also been reported to occur in South Africa (Kuijt, 1969; Parker and Riches, 1993). Also it exists in Zimbabwe (Johnson *et al.*, 1998), Benin (Gbèhounou and Assigbé, 2003), Senegal. Burkina Faso and Mali (Quédraogo *et al.*, 1999), Sierra Leone (Gledhill, 1970), Guinea (Cissé *et al.*, 1996) and in Congo DRC and Congo–Brazaville (Staner, 1938). In East Africa it occurs in Uganda (Jackson and Gartlan, 1965) and Tanzania (Kyela and Mbinga Districts) (Kayeke *et al.*, 2010).

2.2.3 Ecology of *Rhamphicarpa fistulosa*

Rhamphicarpa fistulosa exists both in crops and in natural vegetation (Muller, 2007). According to Quédraogo *et al.* (1999), *R. fistulosa* can grow on any type of soil like sand, clay and loam as well as on rocks and brackish water near the sea. It occurs at an altitude of up to 2100 m a.s.l (Quédraogo *et al.*, 1999). Wherever found, *R. fistulosa* does not occur alone but in combination with other plant communities (Kayeke *et al.*, 2010). In the early 1990s, *R. fistulosa* was still considered as a parasitic weed of minor importance but it was projected to become a major problem in the future (Raynal Roques, 1994).

R. fistulosa is adapted to seasonally wet, water–logged locations with open vegetation types (Hansen, 1975) and is therefore mainly found in hydromorphic zones and unimproved rain–fed low land rice fields (Rodenburg *et al.*, 2010). The roots show similar characteristics as for other plants adapted to semi–aquatic environment by having spaces between the cortical cells for gaseous exchange. This accounts for its ability to survive under water lodged conditions (Quedraogo *et al.*, 1999). According to Quedraogo *et al.* (1999), after successful establishment of connection and starting to parasitize, *R. fistulosa* does not require flooded environment as the water is well supplied by the host plant.

2.2.4 Germination and flowering

Rhamphicarpa fistulosa seeds can remain dormant but viable for a period of 6 months. However, when dormancy is broken in the presence of water it is capable of germinating (Quédraogo, 1995). According to Logan and Stewart (1991) *R. fistulosa*

shows similar characteristics with other parasitic weeds under Orobanchaceae family like *Casstilleja coccinea* (L.) Spreng and *Sopubia delphinifoli* by not depending on host derived germination stimulants but requires light for germination. The little food reserve and its small size (550 microns) justify the reason as to why *R. fistulosa* seed requires being near the soil surface for its fast emergence and photosynthesis initiation (Quédraogo *et al.*, 1995). Given the required conditions, germination occurs after 4 days developing a thin and transparent radical followed with flowering which occurs after 140 days regardless whether it is in the field or green house (Quédraogo *et al.*, 1995).

2.2.5 Host range

Rhampicarpa fistulosa is an important pest of cereals such as maize (*Zea mays* (L.)), rice (*O. sativa* (L.)) (Quédraogo *et al.*, 1999), sorghum (*Sorghum bicolor* (L.)) (Kuijit, 1969) and millet (*Eleusine coracana* (L.) Gaertn) (Cissé *et al.*, 1996) as well as legumes such as cowpeas (*Vigna unguiculata* (L.) Walp) (Quédraogo *et al.*, 1999).

2.2.6 Crop losses/Economic importance

According to the survey conducted in Kyela district in Mbeya region ; Songea and Mbinga districts in Ruvuma region by Kayeke *et al.* (2010), *R. fistulosa* has been reported to impose crop losses from 30 to 100% if left uncontrolled. In Kyela district, *Rhamphicarpa fistulosa* infested about 33% of rice fields resulting in farmers abandoning their fields (Kyela District Agricultural Report, 1998. Unpublished). The report further revealed that all efforts to increase rice production including introduction of lowland NERICA in the affected areas in the district is endangered by

the presence of *R. fistulosa*. Since the weed prefers inland valleys (Rodenburg *et al.*, 2010), future rice production in tropical Africa is seriously threatened (Sakurai, 2006) as these environments are best for lowland rice because of its preference to water logged conditions (Andriesse and Fresco, 1991).

2.2.7 Control of *Rhamphicarpa fistulosa*

Known strategies for the control of *R. fistulosa* include early weeding and the use of correct quantities of fertilizer and at the right time (Kayeke *et al.*, 2010). The use of transplanting practice rather than direct sowing has also been reported to reduce this weed problem through its easiness of weeding especially when plants are transplanted in rows compared to when they are broadcasted (Rodenburg and Johnson, 2009).

Future rice production in tropical Africa is seriously threatened by presence of limiting factors e.g. pests including *Striga* spp. and *R. fistulosa*. So this study will come up with results on the effects of these parasitic weed densities on physiology and yielding aptitude of rice to be used for planning of management strategies in infected fields.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Source of Seeds

3.1.1 Source of rice seeds

Rice seeds used in *S.asiatica* density experiment were from seed lot IAC 165 which were obtained from Kilimanjaro Agricultural Training Centre (KATC), Moshi during the 2011/2012 cropping season while seeds of rice used in *R. fistulosa* density experiment (IR64 – low land rice variety) were obtained from AfricaRice Dar es Salaam office. The IR64 rice seeds were collected from Kyella district, Mbeya region in Tanzania during the 2011/2012 cropping season.

3.1.2 Source of *Striga asiatica* and *Rhamphicarpa fistulosa* seeds

Striga asiatica seeds were obtained from Kyela, Mbeya region during the 2010/2011 cropping season while seeds of *R. fistulosa* were obtained from AfricaRice Dar es Salaam office. The *R. fistulosa* seeds were collected from Kyella district, Mbeya region in Tanzania during the 2011/2012 cropping season.

3.2 Description of the Study Area

The study was conducted in a screen house at Sokoine University of Agriculture (SUA), Morogoro from September 2012 to February 2013. Geographically, the area lies between 06° 50' S latitude and 37° 39' E longitude at an altitude of 526 m above sea level in Eastern zone of Tanzania. The day temperature in the screen house during the study time ranged from 27 to 35°C

3.3 Treatments and Experimental Design

3.3.1 Treatments

The treatments used in *S. asiatica* seed density experiment comprised eight *S. asiatica* seed densities (seeds/cm^3) (0.0, 0.25, 0.5, 1.0, 2.0, 4.0, 8.0 and 16.0) with the corresponding seed weight and estimated number of seeds as shown in Table 2:

Table 2: *Striga* spp. seed densities, estimated number of seeds and respective weight of the seeds

Densities (seeds/cm^3)	0.0	0.25	0.5	1.0	2.0	4.0	8.0	16.0
Estimated number of seeds/pot	0.0	748	1 495	2 990	5 980	11 960	23 920	47 840
weight (g)	0.0	0.003	0.006	0.011	0.022	0.044	0.089	0.177

In *R. fistulosa* seed density experiment, treatments involved seven *Rhamphicarpa fistulosa* seed densities (number of seeds/cm^3 of soil) (0, 31, 62, 125, 250, 500 and 1 000). The lower densities i.e. 31, 62 and 125 were manually counted with the aid of magnifying lens. The rest of the densities were estimated by considering the relationship that 1 000 *R. fistulosa* seeds weigh 11.3 mg. In this case the corresponding weights of *R. fistulosa* seeds for high densities in grams were 0.0 023, 0.0 046, and 0.0 091 for 250, 500 and 1 000 respectively. The *R. fistulosa* seeds were stored in labelled 1.5 µm vials based on their densities after counting and weighing.

3.3.2 Experimental design

The experimental design used in both *S. asiatica* and *R. fistulosa* seed density experiments was a Randomized Complete Block Design (RCBD) with 5 replications.

3.4 Soil type, Source, Ratio and Volume

The soil used in both *S. asiatica* and *R.fistulosa* seed density experiments was clay sandy in the ratio of 1:5. A soil sample was sent to Egerton University Nairobi Kenya for analysis of chemical and physical characteristics whereby the analysis indicated that the soil texture was sand: silt: clay with (88.5: 3.3: 8.2) % by composition. The soil chemical properties in terms of NPK content were 0.07 % (total N), (P) 5.28 ppm and (K) 85.3 ppm with moderate acidity (pH=5.92). Sand soil was obtained around Mindu dam, in Morogoro municipality approximately seven kilometres (7 km) from Morogoro town along the Morogoro– Iringa road while the clay soil was obtained from Kauzeni village near Mzinga Corporation around 12 km from Morogoro town. Kauzeni village is found at the lower slopes of Uluguru Mountain ranges. The size of the pots was 4 litres with height and diameter of 18.5 and 19 cm respectively and surface area of 283.385 cm^2.

3.5 Seed Sowing

3.5.1 Sowing of *S. asiatica* and rice (IAC 165) seeds

In *S. asiatica* seed density experiment, pots with capacity of 4 litres, which are 18.5 cm high, 19 cm diameter and surface area of 283.4 cm^2 were used for sowing *S. asiatica* seeds. The seeds were sown in the pots based on their densities whereby the upper 10 cm of soil was scooped from each pot mixed uniformly with corresponding amount of *Striga* spp. seeds and then placed back into the pot.

Three rice seeds were sown at a depth of 1 cm at the centre of the pot followed by watering of the pots once per day to maintain the pots at a pre–determined field

capacity. Since *Striga* spp. seeds are very small, watering was done by slowly pouring of water as closer to the surface of the soil as possible to prevent them from been drained away with water. Thinning was done at 5 days after emergence (10 DAS) to remain with one plant per pot.

3.5.2 Sowing of *R. fistulosa* and rice (IR 64) seeds

In *R. fistulosa* seed density experiment, sowing of *Rhamphicarpa fistulosa* seeds was done by scooping and pouring the upper one cm of soil previously filled in the pots into a separate container. The scooped soil was thoroughly mixed with the seeds based on their density and then returned back to the corresponding pots. Three rice seeds from seed lot IR64 were then sown at the centre of each pot whereby five days after emergence thinning was done to one plant/pot.

3.6 Water and Fertilizer Application

3.6.1 Water application

In *S. asiatica* seed density experiment, the pots were watered once per day to maintain the soil moisture level at field capacity. The amount of water to be added each time was determined by adding excess water to the pots (previously filled with dry soil), allowing water to drain out until when no more water was coming out. In this case the amount of water to be added during subsequent watering was determined by subtracting the weight of the pots from the original weight of pot with wet soil (weight at field capacity). In *R. fistulosa* seed density experiment, the pots were watered twice per day throughout the experimental period to maintain the soil at saturated condition. To attain saturated condition, maximum water was added to

the pots such that if any more had to be added it would lead to flooding. Having attained saturation condition, the weights of the pots were recorded and subsequent amount of water to be added as per watering schedule was determined by subtracting the weight of pots from the original weight (weight at saturated condition).

3.6.2 Fertilizer application

For both *S. asiatica* and *R. fistulosa* seed density experiments, foliar fertilizer application was done twice whereby the first application was applied at 23 DAS and the second at 51 DAS by using OMEX Foliar Feed liquid fertilizer with 24–24–18 NPK + trace elements. The fertilizer application rate was 50 kg N/ha. The dilution was one ml of commercial product (OMEX) per litre of water.

3.7 Data Collection

3.7.1 Rice growth variables

3.7.1.1 Rice plant height

During the study period, non–destructive measurements of rice plant height were taken by using a ruler from the base of the plant to the tallest leaf in *S. asiatica* experiment. The measurements were done at intervals of 10 days starting from 10 DAS. In *R. fistulosa* seed density experiment, plant height was recorded from the main stem of each rice plant measured from the ground level to the tip of the tallest leaf using a ruler. The measurements were taken at intervals of 10 days up to 60 DAS stating from two weeks after rice emergence.

3.7.1.2 Number of tillers per plant

Number of tillers for each rice plant was counted at interval of 10 days till 60 DAS when the first destructive sampling was done for both experiments.

3.7.2 Rice physiology

3.7.2.1 Rice chlorophyll fluorescence

In both experiments, leaf chlorophyll fluorescence was measured at 60 DAS were the most diagnostically parameter for the indication of stress in plants i.e. Fv / Fm, which represents the ratio of variable fluorescence to the maximum fluorescence was recorded. The measurements were taken from the fully opened young leaf by using a Pocket PEA Chlorophyll Fluorimeter.

N.B

Fv = Fm – Fo ; where, Fo= initial minimum fluorescence, Fm = maximum fluorescence and Fv = variable fluorescence.

3.7.2.2 Rice stomata conductance (mmol/(m^2·s)

Stomata conductance of the rice leaf surfaces i.e. the rate of passage of carbon dioxide (CO_2) and water vapour through the stomata of a leaf was measured at 45 DAS and at 60 DAS by using leaf porometer in both experiments. For each rice plant, the measurements were taken from a fully opened young leaf.

3.7.2.3 Rice leaf chlorophyll content measurements

Data on rice leaf chlorophyll content in both *S. asiatica* and *R. fistulosa* seed density experiments were taken at an interval of two weeks starting from 31 to 60 DAS by

using Minota Soil Plant Analysis Development Model (SPAD)–502 Chlorophyll Meter, a compact light weight meter which is used to determine the amount of chlorophyll present in plant leaves. Triplicate measurements were taken from the young fully developed leaf of each plant i.e. top, middle and bottom parts and the average readings were recorded.

3.7.3 Rice yield components

3.7.3.1 Rice shoot and root dry matter

During the first destructive sampling (60 DAS) and at final harvesting (120 DAS) in both *S. Asiatica* and *R. fistulosa* seed density experiments. rice dry matter (DM) from each infection density were determined separately. Rice shoot and root dry mater were determined independently whereby the shoots were cut from the ground level, withered and then followed by drying in the oven for 72 hours before weighing. The roots were obtained by washing using a jet of running tap water, separated from the *S. asiatica* and *R. fistulosa* roots and then withered. After withering, the roots were put in paper bags to be dried in the oven for 48 hours followed by weighing.

3.7.4 Rice yield

In both *S. asiatica* and *R. fistulosa* seed density experiments, at final harvesting (120 DAS), rice grains were detached from the panicle (s) of each plant separately and their number determined through manual counting. Thereafter, filled rice grains were separated from unfilled ones followed by weighing to determine weight of filled grains.

3.7.5 Weed variables

3.7.5.1 *Striga asiatica* and *Rhamphicarpa fistulosa* shoots count

In *S. asiatica* seed density experiment, the number of germinated *S. asiatica* shoots was recorded by counting the number of germinated plants in each pot every three days starting from the 5th week when *S. asiatica* started to emerge. To determine *S. asiatica* infestation level, *S. asiatica* shoots counting continued until 60 DAS when the first destructive sampling was done. In *R. fistulosa* seed density experiment, number of emerging *R. fistulosa* seedlings were counted first at 7 DAS and thereafter every 3 days for 30 Days.

3.7.5.2 *Striga asiatica* root and shoot dry weight

In *Striga asiatica* seed density experiment, root and shoot dry weights were determined separately whereby the shoots from each pot were cut using a pair of scissors. The cut shoots were placed in paper envelopes, dried in oven for 48 hours followed by weighing using a sensitive balance. The roots were obtained from the soil, washed using a jet of running tap water, and then carefully separated from rice roots. They were then withered before put in the oven for 48 hours followed by weighing. In each sampling time all plants in the pots were harvested.

3.7.5.3 Number of *Striga asiatica* capsules per plant and capsule dry weight

During the final harvest (120 DAS), *S. asiatica* capsules were picked, counted and then dried in ventilated oven for 48 hours after which, dry weights were determined by using sensitive weighing balance.

3.7.5.4 *Rhamphicarpa fistulosa* total biomass (Shoot DW, root DW, capsule DW)

During first sampling (60 DAS) and at final harvesting (120 DAS), *R. fistulosa* capsules from each pot were picked, counted and placed in paper sachets for drying in the oven for 48 hours and then weighed to determine capsule dry weight. The rest of the aerial parts of *R. fistulosa* plants from each pot were then cut at ground level placed in paper bags and then dried in the oven for 48 hours at 70°C followed by weighing to determine dry matter. The roots were obtained by washing using a jet of tap water .The combined root system of both *R. fistulosa* and rice were placed in plastic bags, stored in a fridge for 36 hours and then separated into rice and *R. fistulosa* roots. While stored in a fridge, the rice roots maintained their colour whereas those of *R. fistulosa* turned black, which made it easy to differentiate between the two during separation. After separation, they were placed in khaki envelopes and then dried in an oven for 48 hours followed by weighing.

3.7.5.5 Intra–specific Competition Between *Rhamphicarpa fistulosa* Plants

A separate experiment was conducted to study intra–specific competition between *R. fistulosa* plants in the absence of a host. The treatments comprised six (6) *R. fistulosa* seed densities (31, 62, 125, 250, 500, and 1000) sown alone. The procedure for *R. fistulosa* seed sowing was as for *R. fistulosa* + Rice experiment (Section 3.2.5). Soil type, source and volume were as per section 3.1.4, except that the *R. fistulosa* were sown alone and all the *R. fistulosa* plants were harvested during the first destructive sampling where the above ground and below ground biomass was determined.

3.7.5.5.1 Aboveground *Rhamphicarpa* biomass

The *R. fistulosa* plants in each pot were cut at ground level (at 60 and 120 DAS), placed in paper bags followed by drying in the oven at 70°C for 48 hours before weighing to determine above ground biomass.

3.7.5.5.2 Belowground biomass

Data for below ground biomass (at 60 and 120 DAS) were determined by washing the roots using a jet of tap water, followed by placing them in khaki bags ready to be dried in the oven at 70°C for 48 hours in order to have dry weight measurements at constant moisture.

3.7.6 Data Analysis

Data obtained from the two pot experiments were subjected to analysis of variance using GenStat statistical software 14 Edition. Significant means ($P< 0.05$) were separated using Duncan's New Multiple Range Test (DNMRT). The statistical model used was: $y_{ij}= \mu + Ti+ \beta j+ Eij$

Where, Y_{ij} is the response,

μ = General mean to all treatments,

Ti = treatments effect for treatments I=1, 2..., t

βj = block effect for block j=1,2...,b

E_{ij}= general error term in the i^{th} treatment and j^{th} block.

CHAPTER FOUR

4.0 RESULTS

4.1 Effects of *Striga asiatica* and *Ramphicarpa fistulosa* Seed Densities on Rice Growth Variables

4.1.1 Rice plant height at 60 DAS

In *S. asiatica* seed density experiment, results of rice plant height at 60 DAS (Table 3) revealed that across all the treatments rice plants were significantly affected ($P<0.05$). The tallest rice was recorded in the control rice pots. The second tallest rice plant was recorded from pots with the lowest *S. asiatica* infestation density 374 seeds/pot which was similar ($P>0.05$) to *S. asiatica* infestation density 748 seeds/pot. The shortest rice plants were in pots with the highest density *S. asiatica* infestation density 47 840 seeds/pot. Generally, the results showed that rice plant's height decreased with increase in *S. asiatica* infestation densities.

Table 3: Average rice growth variables under *Striga* spp. infestation

Treatments (Number of *S. asiatica* seeds/pot)	Rice plant height (cm) 60 DAS	Rice leaf area (cm^2)	Number of tillers per plant
0.0	44.7 ^{e}	16.7 ^{e}	1.8 ^{de}
748	40.6 ^{d}	14.8 ^{de}	1.0 ^{bc}
1 495	39.6 ^{d}	13.3 ^{d}	2.4 ^{e}
2 990	30.3 ^{c}	8.9 ^{c}	0.8 ^{b}
5 980	29.5 ^{c}	8.4 ^{c}	1.6 ^{cd}
11 960	25.4 ^{b}	7.5 ^{bc}	0.4 ^{ab}
23 920	22.5 ^{ab}	5.7 ^{ab}	0.0 ^{a}
47 840	21.3 ^{a}	3.8 ^{a}	0.0 ^{a}
GM	**31.7**	**9.9**	**1.0**
CV (%)	**2.5**	**7.5**	**25**
SE ±	**1.8**	**1.1**	**0 .3**

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

In *R. fistulosa* seed density experiment, results on average rice plant height at 60 DAS were significantly different (P<0.05) as shown in Table 4. The highest rice height was recorded in *R. fistulosa* free rice plants followed by rice plants in the pots infested with 31 *R. fistulosa* seeds/pot. Plants in the highest *R. fistulosa* infestation density (1 000 seeds/pot) were the most affected rice plants whereas the rice plants in 62, 123 and 250 *R. fistulosa* seeds/pot were not significantly different (P>0.05).

Table 4:Average rice growth variables under *R. fistulosa* infestation at 60 DAS

Treatments (Number of *R. fistulosa* seeds/pot)	Average rice plant height (cm) 60 DAS	Average rice leaf area (cm^2) 60 DAS
0.0	48.3 ^{d}	11.4 ^{bc}
31	44.7 ^{c}	10.0 ^{ab}
62	43.5 ^{bc}	12.0 ^{c}
125	43.1 ^{bc}	11.8 ^{c}
250	43.7 ^{bc}	9.3 ^{a}
500	40.4 ^{b}	9.3 ^{a}
1000	36.5 ^{a}	12.2 ^{c}
GM	**42.9**	**10.8**
CV (%)	**2.5**	**7.5**
SE±	**1.838**	**1.141**

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

4.1.2 Rice leaf area (cm^2) at 60 days after sowing

In *S. asiatica* seed density experiment, the average rice leaf area on different *S. asiatica* infestation densities (Table 3) at 60 DAS ranged from 3.826 to 16.654 cm^2. Rice plant in the control treatment had the highest leaf area (16.654 cm^2) and

differences were significant (P<0.05) when it was compared with the rest of the treatments except in pots infested with 748 seeds/pot. On the other hand, the lowest measured leaf area was obtained from rice plants with the highest seed density. Seed densities (2 990 seeds/pot), (5 980 seeds/pot) and 11 960 seeds/pot) had similar influence on rice leaf area.

In *R. fistulosa* seed density experiment, the results in Table 4 indicate that there were significant differences (P<0.05) among the levels of *R. fistulosa* infestation in rice leaf area.

4.1.3 Number of tillers per plant

In *S. asiatica* seed density experiment, at rice maturity (120 DAS) when the second sampling was done, the data indicate that seed densities significantly (P<0.05) influenced the number of rice tillers (Table 3). The highest number of tillers were recorded from pots infested with 1495 *S. asiatica* seeds/pot; and differences were significant (P<0.05) when compared with all the other treatments except the control.

4.2 Effects of *Striga asiatica* and *Ramphicarpa fistulosa* seed densities on rice physiology

4.2.1 Rice leaves stomata conductance

In *S. asiatica* seed density experiment, the average values for rice stomata conductance 60 DAS are presented in Table 5. There was significant difference between the treatment means (P<0.05). The stomata conductance was highest in control plants (205.8 mmol/m^2.s). However, the control did not differ (P>0.05) from

rice plants in pots with 748, 1495 and 5980 *S. asiatica* seeds/pot which had averages of 177.4, 173.3 and 172.6 (mmol/(m²·s) respectively. Stomata conductance in pots with higher *S. asiatica* infestation densities were 31.8 and 21(mmol/(m²·s)) for 23 920 and 47 840 *S. asiatica* seeds/pot respectively, which were similar (P> 0.05).

Table 5: Average rice physiology variables under *S. asiatica* infestations at 60 DAS

Treatments (Number of *S. asiatica* seeds/pot)	Rice stomata conductance (mmol/(m²·s))	Rice chlorophyll content 60 DAS	Rice chlorophyll fluorescence
0.0	205.8 ^{c}	27.1 ^{bc}	0.6 ^{a}
748	177.4 ^{c}	29.8 ^{cd}	0.6 ^{a}
1 495	173.3 ^{c}	28.3 ^{cd}	0.7 ^{a}
2 990	115.6 ^{b}	34.1 ^{d}	0.6 ^{a}
5 980	172.6 ^{c}	32.2 ^{cd}	0.7 ^{a}
11 960	68.3 ^{ab}	30.3 ^{cd}	0.7 ^{a}
23 920	31.8 ^{a}	22.1 ^{ab}	0.6 ^{a}
47 840	21.0 ^{a}	20.8 ^{a}	0.5 ^{a}
GM	**136.7**	**28.71**	**0.6**
CV (%)	**26.8**	**2.2**	**12.9**
SE±	**30.7**	**2.7**	**0.1**

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

In *R. fistulosa* seed density experiment, stomata conductance of the rice leaf surfaces at 60 DAS indicated that there was no significant difference among the treatment means (P>0.05). The highest conductance was recorded in *R. fistulosa* free rice i.e. 202.8 mmol/(m²·s) and the lowest conductance was recorded in the highest *R. fistulosa* infestation density i.e. 1000 seeds/pot (143.6 mmol/(m²·s)). Stomata conductance of rice plants in 31, 62, 125 and 500 seeds/pot (Fig. 2) were similar to each other.

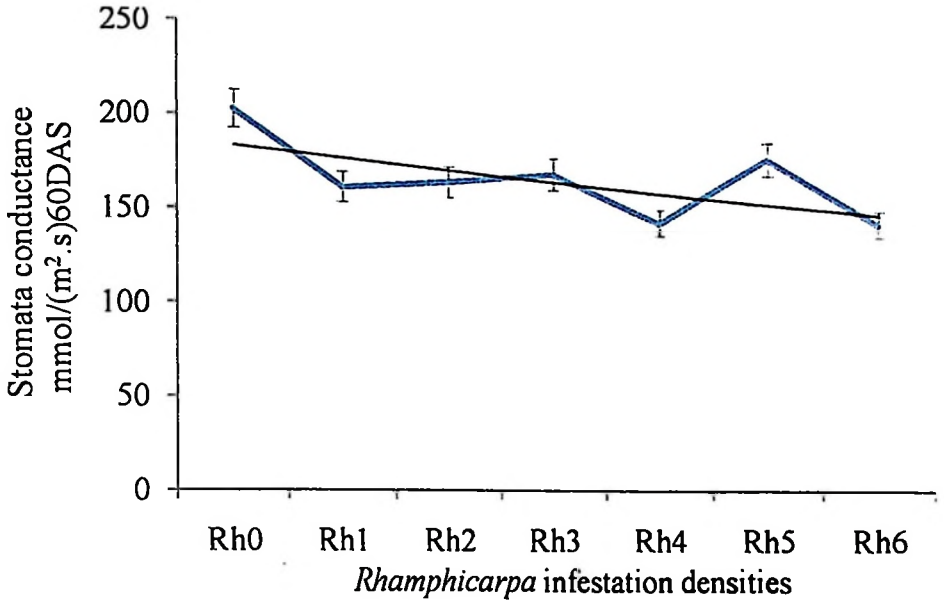

Figure 2: Average stomata conductance (mmol/ (m²s)) at 60 DAS

Rh0= Zero density of *Rhamphicarpa* seeds, Rh1= 31 seeds, Rh2= 62 seeds, Rh3= 125 seeds, Rh4= 250 seeds, Rh5= 500 seeds, Rh6= 1000 seeds

4.2.2 Rice chlorophyll content at 60 DAS

In *S. asiatica* seed density experiment, results show that chlorophyll content from plants infested with 748, 1495, 2990 and 5980 *S. asiatica* seeds/pot was similar (Table 5). However, differences were significant ($P<0.05$) when they were compared with the control and highest levels of *S. asiatica* infestation (23 920) and 47 860 seeds/pot).

In *R. fistulosa* seed density experiment, there were significant differences between the treatments ($P<0.05$) in chlorophyll content across the six *R. fistulosa* infestation densities at 60 DAS. The highest rice chlorophyll content (Fig. 3) was recorded in the *R. fistulosa* free pots while the lowest chlorophyll content was recorded in the highest *R. fistulosa* infestation density (1 000 *R. fistulosa* seeds/pot). Chlorophyll

content of rice plants in the pots infested with 31, 62 and 500 were similar (P>0.05). Similarly, rice plants in the control pots and pots infested with 250 *R. fistulosa* seeds/pot shown similar average chlorophyll content.

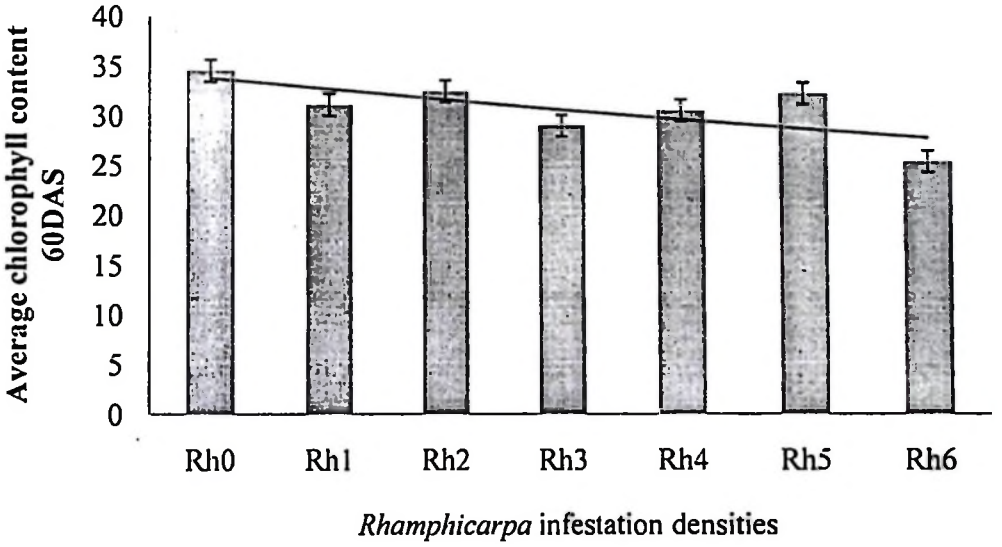

Figure 3: Average rice chlorophyll content 60DAS

Rh0= Zero density of *Rhamphicarpa* seeds, Rh1= 31 seeds, Rh2= 62 seeds, Rh3= 125 seeds, Rh4= 250 seeds, Rh5= 500 seeds, Rh6= 1000 seeds

4.2.3 Rice chlorophyll fluorescence at 60 days after sowing

In *S. asiatica* seed density experiment, results indicated that at 60 DAS, there were no significant differences in chlorophyll fluorescence (Table 5). However, the highest average fluorescence was obtained from the rice plants in pots infested with 1495 seeds/pot (6.6) followed by pots infested with 11 960 seeds/pot (0.7) while the lowest average value was obtained from the highest *S. asiatica* infestation (47 840 seeds/pot) density (0.5).

In *R. fistulosa* seed density experiment, Average values of Pocket PEA measurements on chlorophyll fluorescence at 60 DAS indicated that there was a significant difference among the treatment means ($P<0.05$). The maximum chlorophyll fluorescence was recorded in the *R. fistulosa* free rice plants (0.66); however, was similar ($P>0.05$) to plants in pots infested with 250 *R. fistulosa* seeds/pot (Fig. 4). The lowest value was recorded in rice plants in the highest *R. fistulosa* infestation density i.e. 1000 *R. fistulosa* seeds/pot (0.413). However, the general trend was a decrease in chlorophyll fluorescence as *R. fistulosa* infestation densities increased.

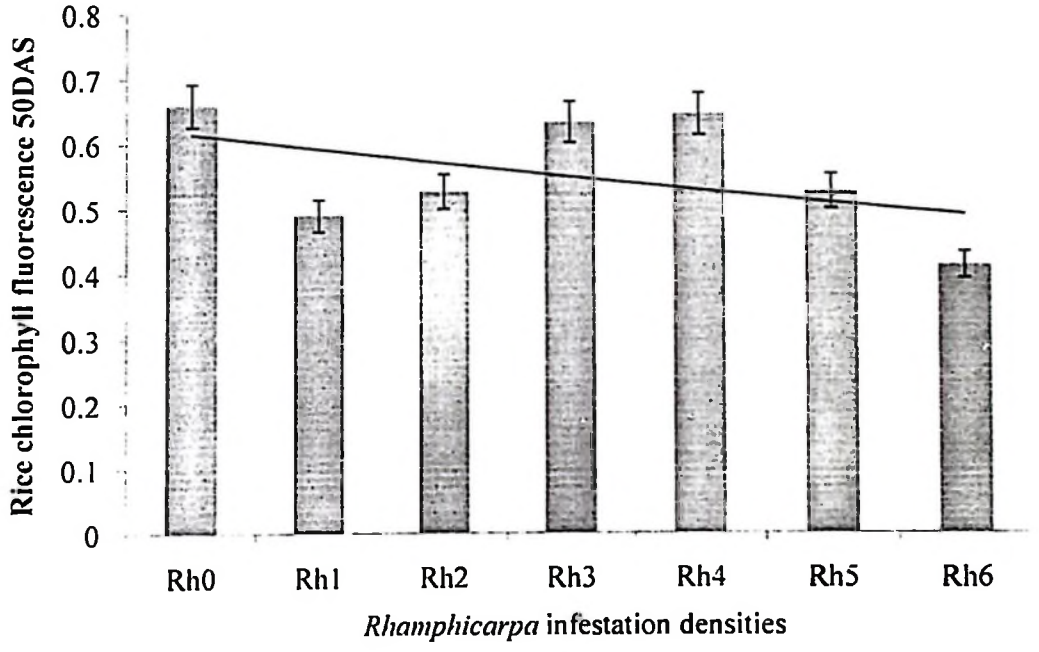

Figure 4: Rice chlorophyll fluorescence at 60 DAS

Rh0= Zero density of *Rhamphicarpa* seeds, Rh1= 31 seeds, Rh2= 62 seeds, Rh3= 125 seeds, Rh4= 250 seeds, Rh5= 500 seeds, Rh6= 1000 seeds

4.3 Rice Yield and Yield Component Variables

4.3.1 Total rice biomass at 60 and 120 days after sowing

In *S. asiatica* seed density experiment. there were significant differences (P<0.05) among the treatment means with regards to total rice biomass (g/pot) at 60 and120 DAS. The highest average values in the two sampling dates were recorded from plants in the control pots followed by the lowest *S. asiatica* infestation densities i.e. 748 *S. asiatica* seeds/pot (Table 6). Generally, results indicated that there was a general decrease in rice biomass with increase in *S. asiatica* infestation densities.

Table 6: Average total Rice yield and yield component variables under *S. asiatica* infestation

Treatments (Number of *S.asiatica* seeds/pot)	Total rice biomass (g/pot) 60 DAS	Total rice biomass (g/pot) 120 DAS	Rice roots DW (g/pot) 60 DAS	Rice roots DW (g/pot) 120 DAS	Rice shoots DW (g/pot) 60 DAS
0.0	1.4 ^{d}	2.5 ^{e}	0.7 ^{de}	0.6 ^{cd}	0.7 ^{e}
748	1.3 ^{cd}	1.9 ^{d}	0.8 ^{e}	0.7 ^{d}	0.5 ^{d}
1495	1.1 ^{c}	1.9 ^{d}	0.5 ^{cd}	0.6 ^{cd}	0.6 ^{d}
2990	0.6 ^{b}	1.3 ^{c}	0.4 ^{bc}	0.5 ^{bc}	0.3 ^{c}
5980	0.7 ^{b}	1.2 ^{c}	0.5 ^{cd}	0.5 ^{cd}	0.2 ^{bc}
11 960	0.4 ^{a}	0.8 ^{b}	0.2 ^{ab}	0.3 ^{b}	0.1 ^{abc}
23 920	0.2 ^{a}	0.3 ^{a}	0.1 ^{a}	0.1 ^{a}	0.1 ^{ab}
47 840	0.1 ^{a}	0.5 ^{a}	0.1 ^{a}	0.2 ^{a}	0.04 ^{a}
GM	**0.73**	**0.99**	**0.4**	**0.43**	**0.32**
CV (%)	**9.4**	**7.3**	**15.4**	**7.3**	**10.2**
SE±	**0.13**	**0.13**	**0.13**	**0.08**	**0.09**

Means in the same column followed with same letter(s) are not significantly different according to DNMRT (P < 0.05) , DW= dry weight

In *R. fistulosa* seed density experiment, results in Fig. 5 indicated that there were significant differences between the treatment means (P<0.05) at 60 DAS. The highest biomass was obtained from the *R. fistulosa* free rice plant (2.58 g/pot) while the lowest biomass was obtained from the highest *R. fistulosa* infestation density i.e. 1000 *R. fistulosa* seeds/pot (1.006 g/pot). However, at the same sampling date (60 DAS), the results on rice root DW (Table 9) shown that there was no significance difference among the treatment means (P>0.05). There were significant differences (P<0.05) among the treatment means for rice shoot and leaves biomass (Table 7).

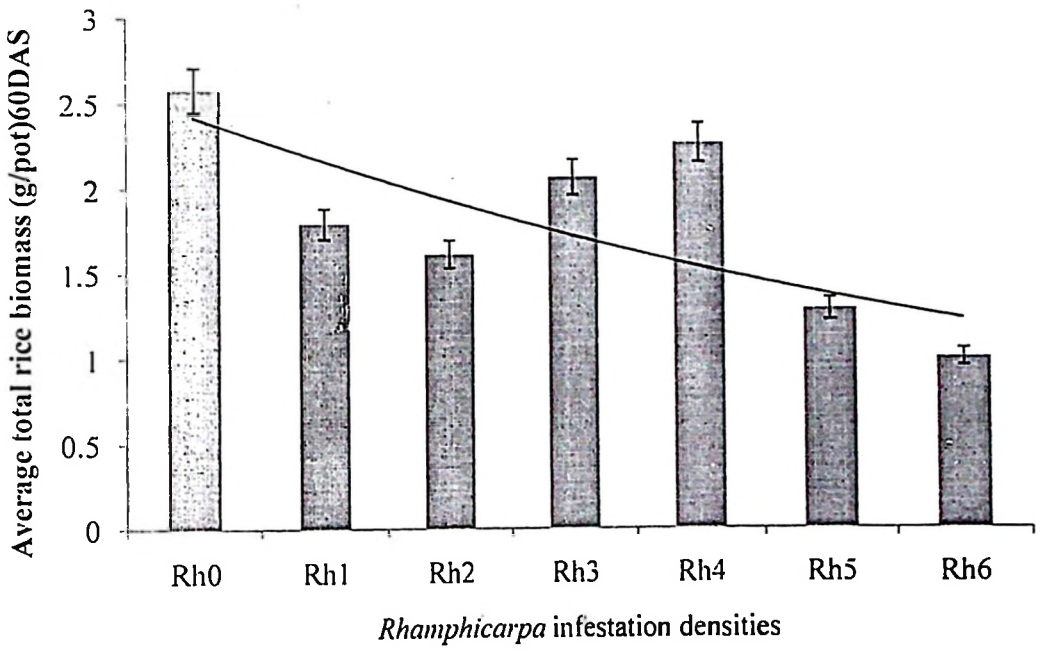

Figure 5: Average total rice biomass (g/pot) at 60 DAS

Rh0= Zero density of *Rhamphicarpa* seeds, Rh1= 31 seeds, Rh2= 62 seeds, Rh3= 125 seeds, Rh4= 250 seeds, Rh5= 500 seeds, Rh6= 1000 seeds

At 120 DAS there were significant differences of rice total biomass among treatments (P<0.05). The highest rice total biomass was obtained from plants in the

control pots (5.2 g/pot) (Fig. 6) followed by plants in the lowest *R. fistulosa* infestation density i.e.31 *R. fistulosa* seeds/pot (2.9 g/pot). However, differences were not significant (P>0.05). The lowest significant biomass was recorded in the highest *R. fistulosa* infestation density i.e. 1000 *R. fistulosa* seeds/pot (0.7 g/pot).

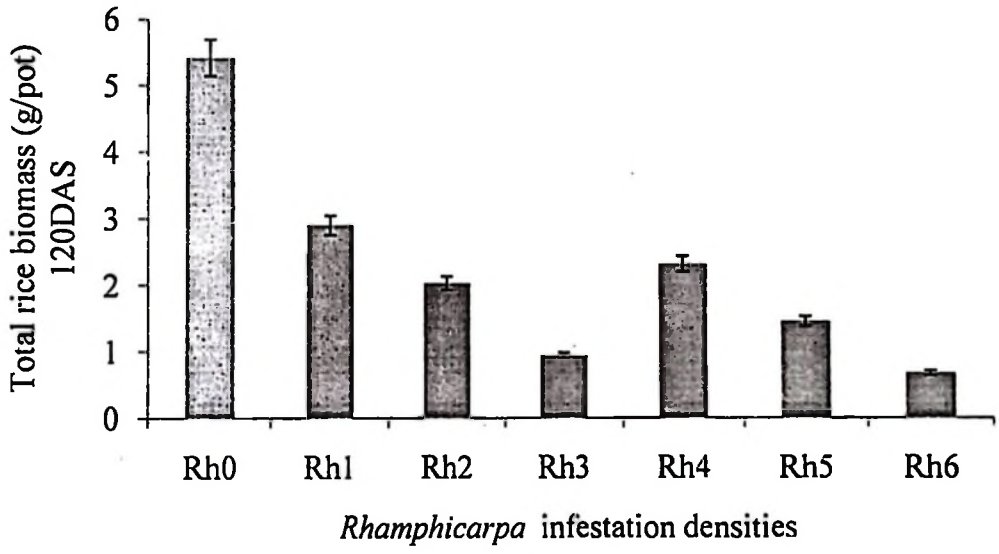

Figure 6: Total rice biomass (g/pot) at 120 DAS

Rh0= Zero density of *R.fistulosa* seeds, Rh1= 31 seeds, Rh2= 62 seeds, Rh3= 125 seeds, Rh4= 250 seeds, Rh5= 500 seeds, Rh6= 1000 seeds

4.3.2 Below–ground rice biomass at 60 and 120 days after sowing

In *S. asiatica* seed density experiment, results of below ground rice biomass at 60 and 120 DAS (Table 6) showed there was a significant difference at (P<0.05) among the treatment means. The highest root biomass at 60 DAS was recorded in pots infested with 748 *S. asiatica* seeds/pot (0.8 g/pot) followed by plants in control pots (0.7 g/pot) while at 120 DAS the highest root biomass was obtained in the lowest *S. asiatica* infestation plants i.e. 748 *S. asiatica* seeds per pot followed by control (0.6

g/pot) but was not significant different. Generally there was a decrease in root biomass with increase in *S. asiatica* infestation levels.

In *R. Ramphicarpa fistulosa* seed density experiment, results of below ground rice biomass 120 DAS (Table 7) indicated that there were significant differences between the treatment means ($P<0.05$). The highest root biomass was obtained from the lowest *R. fistulosa* infestation density i.e. 31 *R. fistulosa* seeds/pot (1.4 g/pot) followed by rice plants from the control pots (1.4 g/pot). The lowest significant average root biomass was obtained from plants in the pots with the highest *R. fistulosa* infestation density i.e.1000 *R. fistulosa* seeds/pot (0.4 g/pot)

Table 7: Average rice dry weight (g/pot) at 60 and 120 days after sowing

Treatments (Number of *Rhamphicarpa* seeds/pot)	Rice root DW (g/pot) 120 DAS	Rice leaves DW (g/ pot) 120 DAS	Rice stem DW (g/pot) 120 DAS	Rice roots DW (g /pot) 60DAS	Rice stem DW (g/pot) 60DAS	Rice leaves DW (g/pot) 60DAS
0.0	1.3 ^{de}	0.7 ^{d}	1.4 ^{d}	1.6 ^{bc}	0.5 ^{d}	0.4 ^{d}
31	1.4 ^{e}	0.4 ^{c}	0.5 ^{c}	1.2 ^{abc}	0.3 ^{bc}	0.3 ^{bc}
62	0.9 ^{bcd}	0.3 ^{bc}	0.4 ^{bc}	1.1 ^{ab}	0.2 ^{bc}	0.2 ^{bc}
125	0.5 ^{ab}	0.2 ^{ab}	0.2 ^{ab}	1.5 ^{bc}	0.3 ^{bc}	0.3 ^{c}
250	0.9 ^{cde}	0.4 ^{c}	0.5 ^{c}	1.6 ^{c}	0.3 ^{c}	0.3 ^{c}
500	0.6 ^{abc}	0.3 ^{ab}	0.3 ^{abc}	0.9 ^{a}	0.2 ^{b}	0.2 ^{ab}
1 000	0.4 ^{a}	0.2 ^{a}	0.1 ^{a}	0.7 ^{a}	0.1 ^{a}	0.1 ^{a}
GM	**0.9**	**0.4**	**0.5**	**1.2**	**0.3**	**0.3**
CV (%)	**26.5**	**13.4**	**22.1**	**21.4**	**12.9**	**11.7**
SE±	**0.25**	**0.069**	**0.138**	**0.266**	**0.05**	**0.044**

Means with same letter(s) in each *Rhamphicarpa* infestation density are not significantly different at 5% probability level according to Duncan's Multiple Range Test

4.3.3 Above ground rice biomass at 120 DAS

In *S. asiatica* seed infestation densities experiment, above ground significant ($P<0.05$) rice biomass was attained in the control pots followed by plants from the pots with 1495 *S. asiatica* seeds/pot. However, the biomass obtained from the pots infested with 748 and 1495 *S. asiatica* seeds/pot were not different from each other. The lowest above ground rice biomass was obtained from the pots infested with 23 920 seeds/pot which had an average of 0.2 g/pot (Fig. 7).

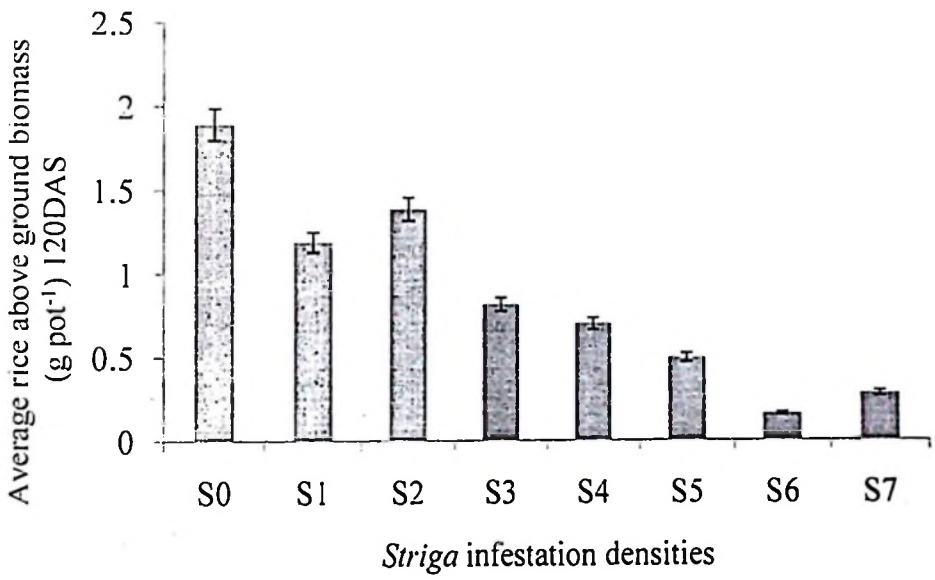

Figure 7: Above ground rice biomass (g/pot) at 120 DAS

S0=zero density (0.0 *Striga* seeds), S1= 748 seeds, S2= 1495 seeds, S3= 2990 seeds, S4= 5980 seeds, S5= 11 960 seeds, S6= 23 920 seeds, S7= 47 840 seeds

In *R. fistulosa* seed density experiment, results showed that at 120 days after sowing there were significant differences ($P<0.05$) among all the treatment means with regards to above ground rice biomass (Table 8). The highest significant value was obtained from *R. fistulosa* free hosts (4.058 g/pot) followed by the lowest parasite infested pots i.e. 31 *R. fistulosa* seeds/pot (1.5 g/pot). With regard to total biomass,

the lowest average biomass was obtained from rice plants in the highest *R. fistulosa* infested pots i.e. 1 000 *R. fistulosa* seeds/pot (0.3 g/pot) whereas plants from weed free seeds had the highest average biomass.

Table 8: Above ground and total rice biomass at 120 DAS

Treatments (Number of *R.fistulosa* seeds/pot)	Above ground rice biomass (g/pot) 120 DAS	Total Rice biomass 120 DAS
0.0	4.0 ^{d}	5.4 ^{e}
31	1.5 ^{c}	2.9 ^{d}
62	1.1 ^{bc}	2.0 ^{bcd}
125	0.5 ^{ab}	0.9 ^{ab}
250	1.4 ^{c}	2.3 ^{cd}
500	0.8 ^{abc}	1.5 ^{abc}
1000	0.3 ^{a}	0.7 ^{a}
GM	**1.6**	**1.8**
CV (%)	**20.9**	**18.4**
SE±	**0.44**	**0.423**

Means in the same column followed by the same letter(s) are not significantly different at 5% probability value according to DNMRT.

4.3.4 Panicle dry weight

In *S. asiatica* seed density experiment, the effect on panicle dry weight varied with different *S. asiatica* infestation densities (Table 9). The highest significant ($P<0.05$) average panicle dry weight was obtained from plants in *S. asiatica* free pots (control) followed by plants in pots infested with 1495 *S. asiatica* seeds/pot. The lowest average panicle dry weight was recorded in the plants from the pots with highest *S. asiatica* infestation density i.e. 47 840 *S. asiatica* seeds/pot which was also not significant different to plants in pots infested with 23 920 *Striga* seeds/pot.

Table 9: Average rice yield variables under *S. asiatica* infestation at 120 DAS

Treatments (Number of *S. asiatica* seeds/pot)	Rice above ground biomass (g/pot) 120 DAS	Panicle dry weight (g/plant)	Total number of grains/plant	Filled grain number	Filled grains DW (g/ pot)
0.0	1.9 [f]	0.8 [e]	33.6 [d]	27.2 [e]	0.8 [e]
748	1.2 [e]	0.4 [d]	14.6 [c]	14.6 [d]	0.4 [d]
1495	1.4 [e]	0.5 [d]	17.6 [c]	17.2 [d]	0.5 [d]
2990	0.8 [d]	0.3 [c]	8.6 [b]	8.6 [c]	0.2 [c]
5980	0.7 [cd]	0.2 [bc]	7.6 [b]	6.8 [c]	0.2 [bc]
11 960	0.5 [bc]	0.1 [ab]	5.8 [ab]	5.0 [bc]	0.1 [ab]
23 920	0.2 [a]	0.02 [a]	0.8 [a]	0.8 [a]	0.02 [a]
47 840	0.3 [ab]	0.1 [a]	3.0 [ab]	3.0 [ab]	0.1 [ab]
GM	**0.6**	**0.3**	**12**	**10**	**0.29**
CV (%)	**11.3**	**21.7**	**24.3**	**17**	**22**
SE ±	**0.07**	**0.05**	**30.67**	**1.72**	**0.05**

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

In *R. fistulosa* seed infestation densities, the average means for panicle dry weight are provided in Table 10. There were significant differences among the treatment means at (P<0.05). The highest panicle dry weight was recorded in the *R. fistulosa* free rice plants (1.9 g/pot) followed by those in the pots infested with 31 *R. fistulosa* seeds/pot (0.6 g/pot). The average panicle dry weights from the pots infested with 31, 62, 250 and 500 *R. fistulosa* seeds/pot did not show significant differences (P>0.05).The lowest panicle dry weight was obtained from plants infested with 1000 seeds/pot; however, significant differences were only noted when it (1000 seeds/pot) was compared with the control and plants with lowest number of *R. fistulosa* seeds/pot.

4.3.5 Total number of grains per plant

In *S. asiatica* seed density experiment, the highest grain number was obtained from the control plants (approximately 34 grains/plant) followed by plants in the pots infested with 1495 *S. asiatica* seeds/pot which was not significant different to the plants in pots infested with 748 *S. asiatica* seeds/pots (approximately 15 rice grains/plant (Table 9). The lowest number of grains (approximately 1 grain/plant) was from the plants in the pots infested with 23 920 *S. asiatica* seeds/pot. Generally there was a decrease in grain number with increase in *S. asiatica* infestation densities.

In *R. fistulosa* seed density experiment, number of rice grains/pot (Table 10) showed that there were significant differences among the treatment means at ($P<0.05$). The average highest number of rice grains per pot was recorded in *R. fistulosa* free rice plants (69 grains/pot) and the lowest number of grains was obtained from the highest *R. fistulosa* infestation density i.e. 1000 *R. fistulosa* seeds/pot (0.06 seeds/pot). Number of rice grains in the pots infested with 62 and 500 *R. fistulosa* seeds was not significantly different. Similarly, number of grains in the pots infested with 31 and 250 *R. fistulosa* seeds. Generally, the data exhibited a significant decrease in number of grains per pot as *R. fistulosa* infestation densities increased.

Table 10: Average rice yield variables under *R. fistulosa* infestation

Treatments (Number of *R.fistulosa* seeds/pot)	Total number of grains/pot	Filled rice grains DW (g/pot)	Number of panicles/pot	Panicle DW (g/pot)
0.0	68.6 ^{c}	1.7 ^{c}	2.2 ^{e}	1.9 ^{c}
31	35.8 ^{b}	0.5 ^{b}	1.0 ^{cd}	0.6 ^{b}
62	19.6 ^{ab}	0.3 ^{ab}	0.8 ^{bcd}	0.4 ^{ab}
125	2.9 ^{a}	0.03 ^{a}	0.2 ^{ab}	0.04 ^{a}
250	30.6 ^{b}	0.4 ^{ab}	1.4 ^{d}	0.4 ^{ab}
500	13.6 ^{ab}	0.2 ^{ab}	0.6 ^{abc}	0.2 ^{ab}
1000	0.06 ^{a}	0.00 ^{a}	0.002 ^{a}	0.001 ^{a}
GM	**24**	**0.5**	**1**	**0.5**
CV (%)	**24.3**	**22**	**8.6**	**21.7**
SE±	**2.86**	**0.05**	**0.138**	**0.05**

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

4.3.6 Filled grain number and filled grain dry weight

In *S. asiatica* seed density experiment there were significant differences (P<0.05) between the different *S. asiatica* densities with regards to filled number of grains/plant and grain dry weight DW (Table 9). The highest number of grains was from *S. asiatica* free plants (≈28 seeds/plant) and the lowest was obtained from the pots infested with 23 920 *S. asiatica* seeds/pot (≈1grain/plant). The number of filled grains and filled grains DW in the pots with 748 and 1495 *S. asiatica* seeds/pot were not significantly different (P>0.05) as shown in Table 6. The highest filled grain DW was from control pots (0.8 g/plant) while the lowest average grain DW was obtained from the plants in pots infested with 23 920 *S. asiatica* seeds/pot which was not significant different from the pots infested with 47 840 *S. asiatica* seeds/pot. Results from *R. fistulosa* seed density experiment indicated that at 120 DAS there were

significant differences in filled grains among the treatments (P<0.05) DW (g/pot) as shown in Table 10. The highest filled rice grain dry weight/pot were recorded from the rice in the control pots (1.7 g/pot) followed by plants from pots infested with 31 *R. fistulosa* seeds/pot (0.5 g/pot). The lowest filled rice grains DW/pot were recorded from the pots with the highest *R. fistulosa* infestation density i.e. 1000 *R. fistulosa* seeds/pot (0.001 g/pot). However, the rice grain dry weight/pot obtained from 62, 125 250, 500 and 1000 *R. fistulosa* seeds/pot were not significantly different from each other (P>0.05)

4.3.7 Number of panicles/pot

In *R. fistulosa* seed density experiment results on number of panicles/pot (Table 10) showed significant differences (P<0.05) among the treatment means. The highest number of panicles (≈2 panicles/plant) was obtained from the control pots followed by the pots infested with 250 *Rhamphicarpa* seeds/pot (≈1 panicles/plant).

4.3.8 *Striga asiatica* total biomass at 120 days after sowing

Results on *S. asiatica* total biomass at 120 DAS (Fig. 8) indicated that there was significant difference (P<0.05) between the treatment means. The highest biomass was recorded in the lowest *S. asiatica* infestation density equivalent to 748 *S. asiatica* seeds/pot while the lowest *S. asiatica* biomass was recorded in the pots with the highest *Striga* infestation density equivalent to 47 840 *S. asiatica* seeds/pot.

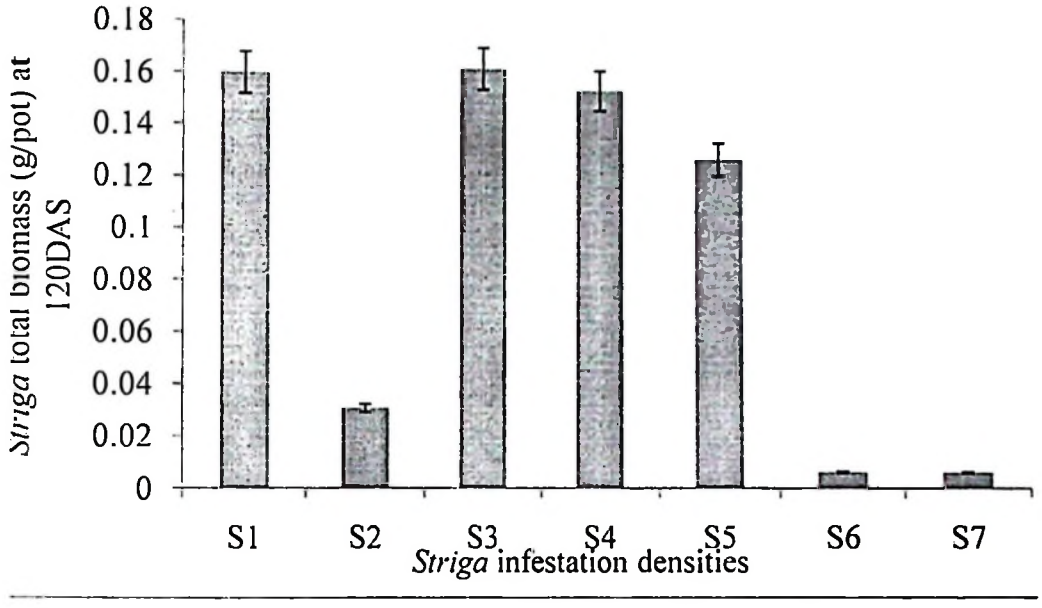

Figure 8: *Striga asiatica* total biomass (g/pot) at 120 Days after sowing

S1= 748 seeds, S2= 1495 seeds, S3= 2990 seeds, S4= 5980 seeds, S5= 11 960 seeds, S6= 23 920 seeds, S7= 47 840 seeds

4.3.9 Average *Striga asiatica* numbers per pot at 120 days after sowing

At 120 DAS results from *S. asiatica* counts showed that, there were significant differences between treatment means (Fig. 9). The highest average *S. asiatica* counts were in the pots infested with 2990 *S. asiatica* seeds/pot while the lowest *S. asiatica* emergence numbers were in pots infested with 1495 *S. asiatica* seeds/pot.

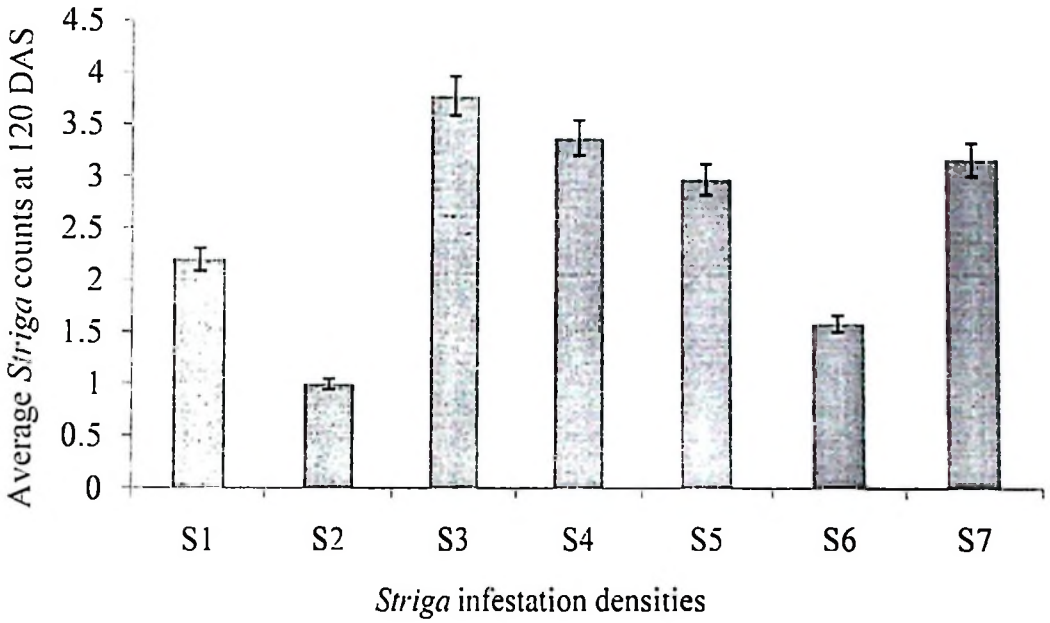

Figure 9: Average *Striga asiatica* numbers per pot at 120 days after sowing

S1= 748 seeds, S2= 1495 seeds, S3= 2990 seeds, S4= 5980 seeds, S5= 11 960 seeds, S6= 23 920 seeds, S7= 47 840 seeds

4.3.10 Relationship between rice biomass loss and *Striga asiatica* biomass accumulation at 120 DAS

At 120 DAS the average total biomass in non-infested rice plants was significantly higher as compared to infested rice host plants. The trend (Fig. 10) was that, there was general decrease in total host biomass with increase in *S. asiatica* infestation densities. However, the biomass accumulation in *S. asiatica* was not in accordance with increase in infestation densities.

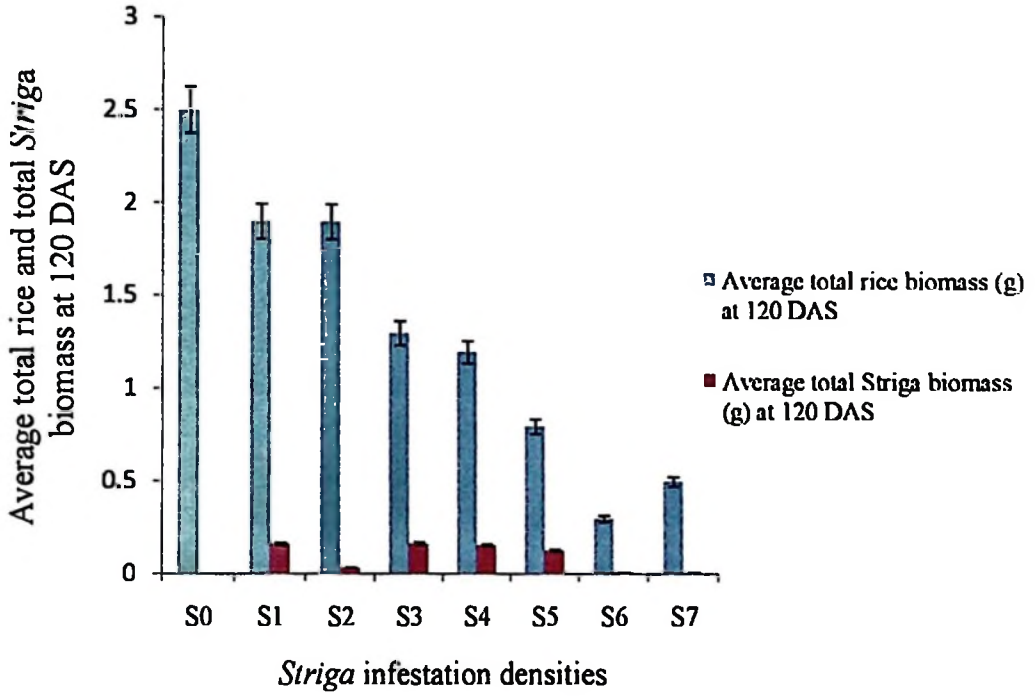

Figure 10: Average total rice and total *S. asiatica* biomass at 120 DAS

S1= 748 seeds, S2= 1495 seeds, S3= 2990 seeds, S4= 5980 seeds, S5= 11 960 seeds, S6= 23 920 seeds, S7= 47 840 seeds

4.3.11 Relationship between rice biomass loss and *Rhamphicarpa fistulosa* biomass accumulation at 120 DAS

Results indicated highly significant difference ($P<0.05$) in biomass accumulation between infected and non- infested rice (Fig 11). Except in the lowest *R. fistulosa* infestation density (31 seeds/pot) where rice biomass was greater than that of the parasite, the rest of the plants in higher densities (125, 250, 500 and 1 000 *R. fistulosa* seeds/pot) biomass accumulated by *R. fistulosa* greatly outweighed that of rice.

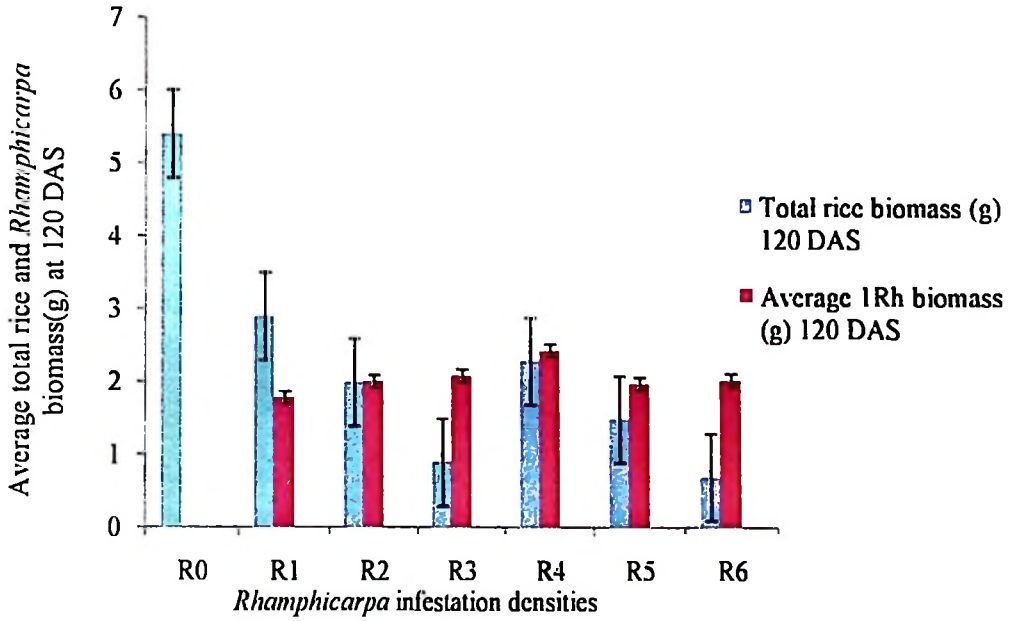

Figure 11: Average total rice and *Rhamphicarpa* biomass at 120 DAS

Rh0= Zero density of *Rhamphicarpa* seeds, Rh1= 31 seeds, Rh2= 62 seeds, Rh3= 125 seeds, Rh4= 250 seeds, Rh5= 500 seeds, Rh6= 1000 seeds , 1Rh= *Rhamphicarpa* with host

4.3.12 Intra–specific competition between *Rhamphicarpa fistulosa* plants in the absence of host

4.3.12.1 *Rhamphicarpa fistulosa* plant height (cm) without host at 60 DAS

At 60 days after sowing *R. fistulosa* plants height without host (Table 11) did not show significant differences ($P>0.05$). The maximum weight was recorded from plants in the pots infested with 62 *R. fistulosa* seeds/pot (0.8 cm) and differences were significant ($P<0.05$) when compared with plants infested with weed seed densities commencing from 250 seeds/pot.

Table 11: *Rhamphicarpa fistulosa* plant height and total biomass with and without host at 60 DAS

Treatments (Number of *R. fistulosa* seeds/pot)	0 Rh height (cm) 60DAS	1Rh height (cm) 60DAS	Total 0 Rh biomass (g/pot) 60 DAS	Total 1Rh biomass (g/pot) 60 DAS
0.0	0.6 [a]	1.2 [ab]	0.00 201 [a]	0.5 [a]
31	0.8 [b]	1.5 [ab]	0.00 481 [a]	0.6 [a]
62	0.6 [ab]	1.5 [b]	0.00 541 [a]	0.7 [a]
125	0.6 [a]	1.6 [a]	0.0 106 [ab]	0.4 [a]
250	0.6 [a]	1.6 [a]	0.02 719 [c]	0.6 [a]
500	0.6 [a]	1.8 [ab]	0.01 839 [bc]	0.6 [a]
GM	**0.6**	**1.5**	**0.011**	**0.5**
CV (%)	**7.6**	**7.6**	**82.8**	**23.8**
SE±	**0.29**	**0.293**	**0.007**	**0.204**

Means in the same column followed by same letter(s) are not significantly different according to DNMRT (P>0.05)
0Rh=*Rhamphicarpa* without host 1Rh = *Rhamphicarpa* with host

4.3.12.2 *Rhamphicarpa fistulosa* total biomass at 60 days after sowing

The results of total biomass (g/pot) of *R. fistulosa* plants without host at 60 DAS are presented on (Table 11). There were significant differences (P<0.05) between the treatment means. The highest biomass was obtained from the pots infested with 500 *R. fistulosa* seeds (0.03 g/pot) followed by *R. fistulosa* plants in the pots with highest density i.e. 1000 *R. fistulosa* seeds (0.02 g/pot). The lowest *R. fistulosa* biomass was obtained from lowest *R. fistulosa* infestation density i.e. 31 seeds/pot (0.002 g/pot).

4.3.12.3 Comparison between *Rhamphicarpa fistulosa* plant height and biomass accumulation with and without host at 60 days after sowing

Results of *R. fistulosa* performance in terms of dry mater accumulation and plant height with and without host are presented in Fig. 12 and 13 for biomass and height

respectively. There was a great variation between dry mater accumulation and parasite height under the two growing situations. The highest average height of *R. fistulosa* plants without host was 0.8 cm while the highest average *R. fistulosa* plant height with host was 1.8 cm. Similarly, there was a great difference in respect of biomass accumulation at the two growing environments. While the highest attained dry matter for *R. fistulosa* without host was 0.03 (g/pot) the corresponding dry matter accumulation for the plants grown with host under the same parasite density was 0.6 (g/pot) (Fig. 12).

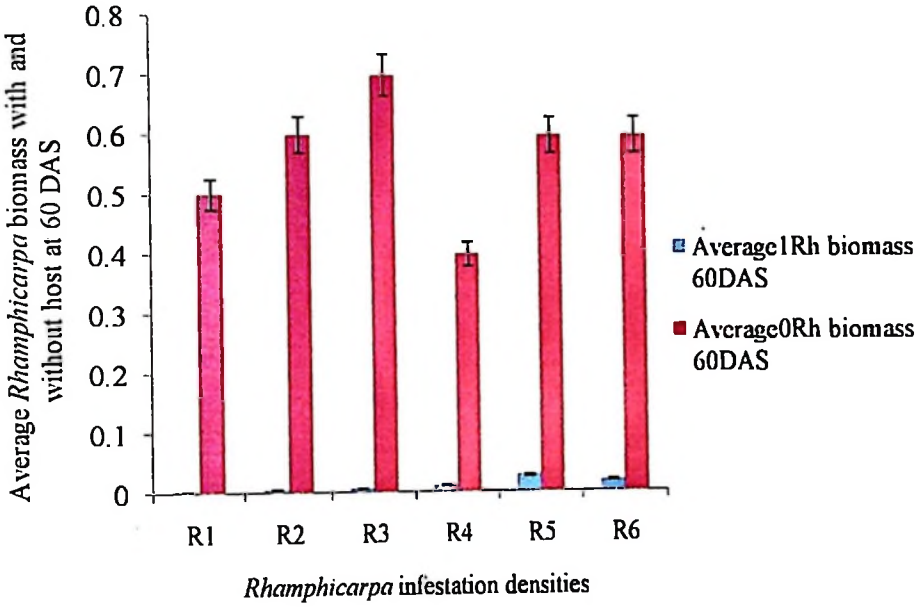

Figure 12: ***Rhamphicarpa fistulosa*** **biomass accumulation with and without host at 60 days after sowing**

Rh= *Rhamphicarpa*, Rh1= 31 seeds, Rh2= 62 seeds, Rh3= 125 seeds, Rh4= 250 seeds, Rh5= 500 seeds, Rh6= 1000 seeds, 0Rh = *Rhamphicarpa* without host, 1Rh = *Rhamphicarpa* with host.

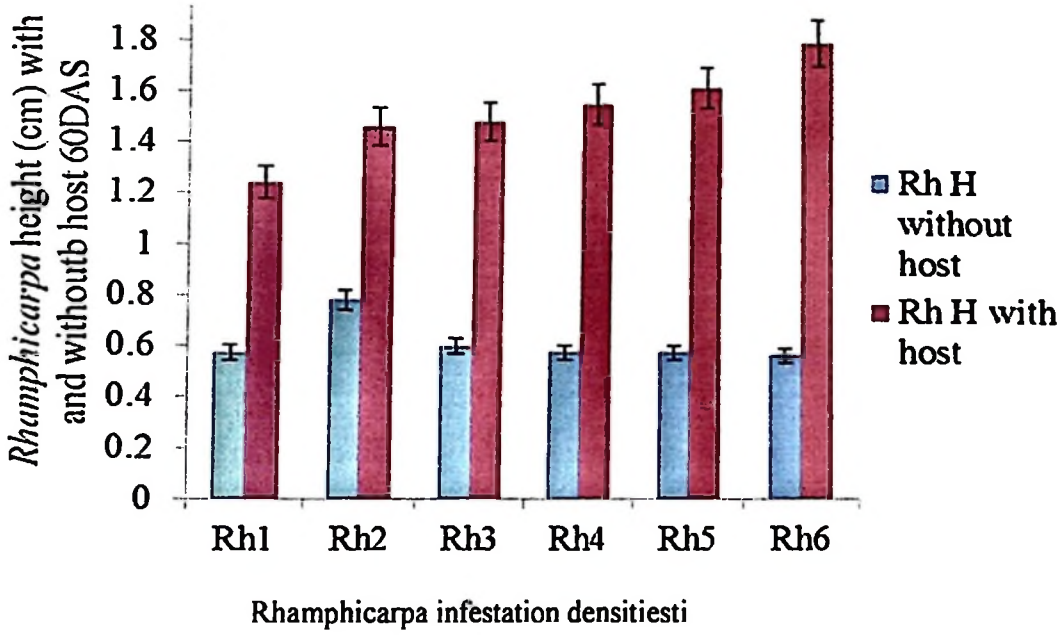

Figure 13: ***Rhamphicarpa fistulosa*** **plant height (cm) with and without host at 60 days after sowing**

Rh= *Rhamphicarpa* Rh1= 31 seeds, Rh2= 62 seeds, Rh3= 125 seeds, Rh4= 250 seeds, Rh5= 500 seeds, Rh6= 1000 seeds, H= Height

4.3.13 Maximum *Rhamphicarpa fistulosa* weed counts

The *R. fistulosa* infestation densities significantly ($P<0.05$) affected the emergence of *R. fistulosa*. The highest *R. fistulosa* number was recorded from the pots sown with the highest *R. fistulosa* density i.e. 1000 seeds/pot (Fig. 14) while the minimum number was recorded from the lowest *R. fistulosa* density i.e. 31 *R. fistulosa* seeds/pot. There was a strong relationship between the number of *R. fistulosa* sown and the number of emerged *R. fistulosa* plants.

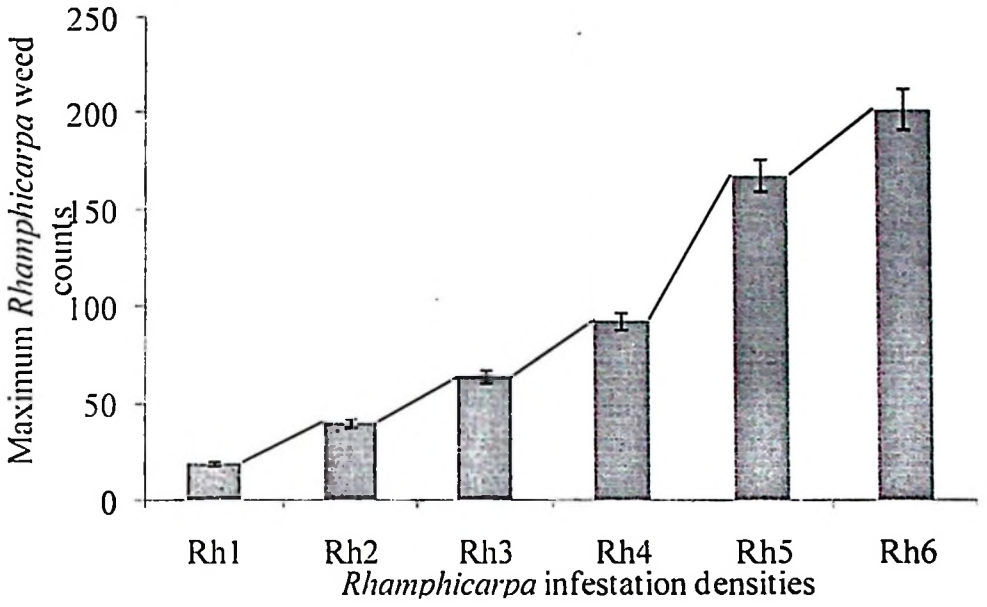

Figure 14: Maximum *Rhamphicarpa fistulosa* weed counts

Rh1= 31 seeds, Rh2= 62 seeds, Rh3= 125 seeds, Rh4= 250 seeds, Rh5= 500 seeds, Rh6= 1000 seeds

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effects of *Striga asiatica* and *Rhamphicarpa fistulosa* Seed Densities on Rice Growth Variables

At 60 days after sowing results showed that there was a decrease in rice plant height with increase in *S. asiatica* as well as *R. fistulosa* infestation densities. Results considered were those from 60 DAS though the significant reduction in rice plant height started to appear 40 DAS. This general decrease in rice plant height was a result of increased competition of rice with parasites (as appeared in both *R. fistulosa* and *S. asiatica* experiments) by direct syphoning of nutrients, water and photosynthates. These results are in agreement with Vasudeva–Rao (1985); Kim *et al.* (1991) and Gurney *et al.* (2001) who reported that among the symptoms expressed by parasitized host plants include chlorosis, necrosis, curling at the leaf margins, wilting and reduced growth. These findings were also similar to those reported by Cochrane and Malcolm (1997); Watson *et al.* (1998) that among the effects of parasitic weeds to host plants is reduced growth (stunted growth). Rodenburg *et al.* (2011) also did research on *R. fistulosa* and reported similar results.

The differences of average rice leaf area (cm^2) measured at 60 DAS were ascribed to reduced solar radiation interception and photosynthesis, thus stunted growth and ultimately reduced leaf area. The reduced solar radiation interception could also account for the reduced rice plant height for both *S. asiatica* and *R. fistulosa* infected plants as was also reported by Sterwart and Press (1990); Press and Sterwat (1987) that *Striga* spp. reduces host growth through diminishing of photosynthesis.

Similarly, Frost *et al.* (1997) reported that *Striga hermothica* reduced rice leaf area of infected sorghum plants. For the rice leaf being a photosynthetic organ, the reduction in area was accompanied by reduced photosynthetic rate which is directly related to solar radiation interception as was also reported by Smith *et al.* (1995). The pots with high *S. asiatica* infestation densities i.e. 23 920 and 47 840 *S. asiatica* seeds/pot did not tiller at all. Since *Striga* spp. ability to photosynthesize is limited (Press *et al.*, 1987), it is therefore associated with high rates of dark respiration which leads to more reliance on host driven sources and thus affect the host tillering ability as the parasite is the additional sink for host photosynthates, inorganic nutrients and water (Press and sterwat, 1987). However, contrary to the expectations rice plants in the pots infested with 1495 *S. asiatica* seeds/pot had higher number of tillers compared to rice plants in the pots infested with 748 *S. asiatica* seeds/pot and the non- infested (control pots). This shows that though the soil may be infested with *S. asiatica* yet the effect to the host depends on how successful the parasite seeds have been stimulated and attached to the host.

The significant reduction of rice plant height and number of tillers per plant in *R. fistulosa* affected rice could be ascribed to diversion of host carbon inorganic nutrients and water. Similar results were reported by Rodenburg (2011), that *R. fistulosa* infection significantly affected host plant height. Similarly, the observed significant reduction of rice leaf area contributed to the reduced rice grain as the ability of host to photosynthesize was limited. Furthermore, in *R. fistulosa* seed density experiment rice leaf area in pots infected with 61, 125 and 1000 seeds/pot had almost same average leaf area and this was due to the fact the effect of parasite

to the host is not only parasite seed density dependent but also how successful the parasite has attached to the host. However, also this study has shown that earlier attachment of parasites (*R. fistulosa*) causes more serious effect to the host regardless of the density of seeds in the soil.

5.2 Effects of *Striga asiatica* and *Rhamphicarpa fistulosa* Seed Densities on Rice Physiology

The significant decrease in rice leaf chlorophyll content with increase in *S. asiatica* infestation densities were ascribed to increased phytotoxicity. The results from this study were similar to findings reported by Cochrane and Malcolm (1997) that decrease in chlorophyll content is caused by phytotoxicity effects experienced by the host in association with *Striga* spp. Since inorganic minerals such as N, P, K, and Mg are among the essential components of leaf chlorophyll. the competition for these nutrients between *S. asiatica* and rice through direct syphoning, could account for the observed reduction in rice chlorophyll content with increase in *S. asiatica* infestation densities.

In the case where *R. fistulosa* parasitized rice, the observed decrease in rice leaf chlorophyll content with increase in *R. fistulosa* infestation densities were ascribed to reduced photosynthetic rate and hence low rice dry matter accumulation. Evans (1983) and Seeman *et al.* (1987) found that there is a positive correlation between the amount of leaf nitrogen and the photosynthetic activity of the plant. Further studies on chlorophyll content showed that SPAD–50/2 measurements in rice (Takebe and Yoneyama, 1989), *Zea mays* (Wood *et al.*, 1992) and wheat (*Triticum sativum*) (Follet *et al.*, 1992) had been precise in estimating the amount of Nitrogen and

chlorophyll present in plants. Chlorophyll is an important plant pigment for absorption of solar radiation. Hence, any abnormal physiological disorder which interferes or reduces the amount of plant chlorophyll, reduces the ability of plant to capture light and therefore affects significantly the rate of photosynthesis hence reduced rate of carbon production and assimilation.

Stomatal conductance reflecting the rate of exchange of carbon dioxide and water vapour between the plants and the atmosphere is a very important physiological process as both (CO_2 and water) are important raw materials for photosynthesis. Results from this study have showed that there was a general decrease in stomatal conductance with increase in *S. asiatica* as well as *R. fistulosa* infestation densities. However, this study has also pointed out that the effect of *S. asiatica* to the host plants is not only weed density dependent but also on how successful the parasite has been able to establish relationship with host plant. This has been observed in values of stomatal conductance where by the stomatal conductance of rice plants infested with 5990 *S. asiatica* seeds/pot was higher than that of the rice plants infested with 2990 *S. asiatica* seeds/pot.

Earlier studies on the effects of *Striga* spp. on maize plants (*www.invasive.org*, 2006) came up with results which showed that *Striga* spp. affected maize photosynthetic process through impairment of stomatal conductance. According to Nickrent (2002), pathogenicity by parasitic plants is subject to several aspects including the number of parasites attached to an individual host plant. In this study for the case of *S. asiatica* experiment, it can therefore be concluded that, the reduced stomatal conductance in

rice plants was attributed to the number of parasites attached to the individual rice plants.

This led to reduced rate of photosynthesis and therefore contributed to the observed significant reduction of rice biomass. Whenever the rate of exchange of CO_2 and water between the plant and the atmosphere is interfered it always affect photosynthetic rate of the plants. So the observed reduction of stomatal conductance from the rice plants in this study could therefore account for the low yields obtained due to reduced carbon assimilation.

Results from this study showed that there was no significant difference in chlorophyll fluorescence between plants in different *S. asiatica* infestation densities at 60 DAS. It has been reported (*http://www.optisci.com/cf.htm,* 2013) that CO_2 assimilation, plant health and condition can be affected by several factors such as light levels, light quality, water availability, nutrient availability, heat, cold, herbicides, pesticides, pollution, heavy metals, disease, and genetic makeup. These factors are also reflected in the fluorescence signal in PSII (*http://www.optisci.com/cf.htm,* 2013).

Since it is known that *Striga* spp. competes with host plants for water and nutrients through direct syphoning, this could have caused the observed slight decrease in chlorophyll fluorescence and hence affecting the photosynthetic ability. However, in the case of *R. fistulosa* experiment results showed that rice chlorophyll fluorescence was significantly reduced in infested pots compared to control. However, contrary to

the expectations as it was for the case of rice leaf area, chlorophyll fluorescence was higher in rice plants infested with 250 and 500 seeds/pot compared to the pots infested with lower densities (31 and 62 *R. fistulosa* seeds/pot) and this was because of earlier attachment of the parasites in the host plants in the lower infestation densities. Earlier research (*http://www.optisci.com/cf.htm*, 2013) showed that, there is correlation between carbon dioxide fixation and chlorophyll fluorescence whereby changes in the plant that affect stoma opening and gas exchange with the atmosphere are manifested by fluctuations in the fluorescence characteristics of a leaf.

5.3 Effects of *Striga asiatica* and *Rhamphicarpa fistulosa* Seed Densities on Rice Yield and Yield Components

At 120 DAS results indicated significant reduction in average rice biomass with increase in *S. asiatica* infestation densities. However *S. asiatica* biomass accumulation could not account for the observed rice biomass loss with increase in *S. asiatica* infestation densities. Earlier studies by Cochrane and Malcolm (1997) showed that *Striga* spp. not only affect host plants through diversion of host photosynthesis but because of other reasons like phytotoxic effects. Results from the current study proves this as though rice plants in the highest *S. asiatica* infestation densities had the lowest biomass accumulation but the corresponding biomass gain by *S. asiatica* was not that much pronounced.

The observed significant decrease in rice biomass and yields in terms of panicle dry weight (g/pot), total grain number, weight of grains (g/pot), number of filled grains and total rice biomass (g/pot) were similar to other studies by Press and Sterwat (1987) and Logan and Stewart (1991).

The authors reported that *Striga* spp. not only reduced plant growth through interference of photosynthesis but also competed with crop plants for carbon. Further, Press *et al.* 1996 found that about 35% of *Striga* spp. carbon is derived from its host photosynthesis products. The decrease in crop yields with increase in *Striga* infestation densities in this study could be attributed to increased number of *Striga* as sinks of host carbon. However, the observed loss in rice yield in parasite infested rice plants cannot simply be concluded to be the result of source- sink relationship. This was because the variations of rice total biomass i.e. (2.5) and (0.3 g/pot) for non-infested and infested plants respectively exceeded the biomass accumulated by the parasites (0.16 g/pot). Similar results were also reported by Cechin and Press, (1993a). Furthermore, since *Striga* spp. has got phytotoxic effects to the host plants (Cochrane and Malcolm, 1997), the toxic effects could have resulted into reduced rates of photosynthesis and thus reduced yields.

In the current study, *R. fistulosa* infestation significantly contributed to biomass reduction in rice plants. Similar results were reported by Rodenburg *et al.* (2011). In the rice plants infested with 125, and 1000 *R. fistulosa* seeds/pot had almost similar effect on rice biomass loss and *R. fistulosa* biomass accumulation. However the trend of *R. fistulosa* biomass accumulation was not very much clear. This was ascribed to different times of attachment of *R. fistulosa* to the host as earlier attachment leads to higher *R. fistulosa* biomass accumulation.

Similarly, the observed reduction in rice total biomass and yield with increase in *R. fistulosa* infestation densities could be explained by the source sink relationship in which case *R. fistulosa* was an additional sink of rice carbon. This reduction can also

be explained as a result of interspecific competition between weeds and rice as was also reported by Rodenburg *et al.* (2011). Cechin and Press (1994) and Johnson *et al.* (1997) reported similar observations on their studies that, parasitic weeds *Striga asiatica* and *Striga hermonthica* significantly reduced rice yield and biomass. Furthermore, in this study the average number of panicles in rice plants infested with 250 *R.fistulosa* seeds per pot was higher than those infested with 125 seeds/pot. This was due to different times of attachment of *R. fistulosa* to host plants as it was for the case of average leaf area and chlorophyll fluorescence.

5.4 Growth Characteristics of *Rhamphicarpa* Plants with and without Host

Results from this study showed no significant differences between treatment means with regards to *R. fistulosa* plant height when grown without a host. Plant height of *R. fistulosa* measured at 60 DAS revealed that the height of plants in all *R. fistulosa* infestation densities were not significantly different. Since the *R. fistulosa* plants were not in parasitic relationship with host, their growth rate was almost the same and the highest average plant height was (0.8 cm) which was recorded from the pots infested with 62 *R. fistulosa* seeds/pot and the lowest average height (0.6 cm) was obtained in the highest *R. fistulosa* infestation density equivalent to 1000 *R. fistulosa* seeds/pot. These results are in agreement with studies by Quedraogo *et al.* (1999) who reported that when not parasitizing *R. fistulosa* plants remained stunted and did not develop branches. In the absence of host, at 60 DAS *R. fistulosa* plants accumulated low total maximum biomass of (0.03 g/pot) compared to the parasitizing plants which were able to accumulate a maximum of 0.7 g/pot. There was no significant difference between the treatment means (*R. fistulosa* infestation

densities) with regards to biomass accumulation for non–parasitizing *R. fistulosa* plants. The quantity of biomass accumulated by non-parasitizing *R. fistulosa* plants was low compared to biomass accumulated by parasitizing *R. fistulosa* plants under the same infestation level. These findings are in agreement with results by Rodenburg (2011) who found that host parasite association had a significant effect on *R. fistulosa* biomass accumulation.

Generally, the current study has indicated that in the absence of host, *R. fistulosa* behaves differently from the other plants. In other plant species like beans, under low plant density, plants have low intraspecific competition for resources and therefore higher biomass accumulation. On the other hand, under high plant density plants exhibit more intraspecific competition for resources including light and hence less biomass accumulation and increased plant height. All these have been different in *R. fistulosa*. This shows that, even in the presence of sunlight, without a suitable host, *R. fistulosa* growth is limited and photosynthesis is very minimal and this justifies the maximum reliance of *R. fistulosa* on its host for its survival.

5.5 *Striga asiatica* and *Rhamphicarpa fistulosa* Growth Variables

Contrary to expectations, the highest *S. asiatica* weedcounts were not observed in the pots with the highest *S. asiatica* infestation densities i.e. 23 920 and 47 840 *S. asiatica* seeds/pot. Observations on the rice plants in the screen house indicated that, rice plants in the higher *S. asiatica* infestation densities (23 920 and 47 840 *S. asiatica* seeds/pot) began to exhibit wilting symptoms (8 DAS) in all replications with the same *S. asiatica* infestation densities though there were no emerged *S. asiatica* plants, where also some of the rice plants completely died. This could be

attributed to competition for attachment sites by stimulated *S. asiatica* seeds to the roots of rice which led to serious damage to the rice plants. Similar results were reported by Cochrane and Malcolm (1997) earlier that most of the crop damage by *Striga* spp. occurs before *Striga* spp. emergence. The death of the plants could be attributed to massive competition of *S. asiatica* seedlings for host root attachment that could not be supported by the roots of young rice plants hence death of both parasites and hosts. However, since there was no emerged *S. asiatica,* only swollen parts of the rice roots could be observed after root washing. The late emergence of *S. asiatica* seedlings from the recovered rice plants which also remained stunted in the higher *S. asiatica* infestation densities, accounts for the observed low *S. asiatica* dry matter accumulation. Since most of the rice plants suffered earlier damage, this accounts for the adverse effects on yield components and the reduced average rice yield. Rodenburg *et al.* (2011) reported that there was almost linear relationship between number of sown and emerged *R. fistulosa* plants. In this study there was an increase in number of emerged *R. fistulosa* with increase in infestation densities. Though there was a clear relationship between the number of sown *R. fistulosa* and the number of emerged *R. fistulosa,* the extent of damage to plants with respect to rice yielding ability was not that much clear e.g. rice total biomass . This could be due to differences in times of attachment. This study has shown that the extent of damage to host plant is not only parasite density dependent but also on how successfully the parasite is attached to the host plant.

5.6 Relationship between *Striga asiatica* and *Rhamphicarpa fistulosa* Biomass Accumulation and Rice Biomass Loss

At 120 DAS results indicated significant reduction in average rice biomass with increase in *S. asiatica* infestation densities. However *S. asiatica* biomass accumulation could not account for the observed rice biomass loss with increase in *S asiatica* infestation densities. Earlier studies by Cochrane and Malcolm, 1997 reported that *Striga* spp. not only affect host plants through diversion of host carbon but because of other reasons like phytotoxic effects. Results from the current study proves this as though rice plants in the highest *S. asiatica* infestation densities had the lowest biomass accumulation but the corresponding biomass gain by *S. asiatica* was not that much pronounced. On the other hand, *R. fistulosa* infestation significantly contributed to biomass reduction in rice plants. Similar results were reported by Rodenburg *et al.* (2011). In the rice plants infested with 125, and 1000 *R. fistulosa* seeds/pot had almost similar effect on rice biomass loss and *R. fistulosa* biomass accumulation. However, the trend of *R. fistulosa* biomass accumulation was not very much clear. This was ascribed to different times of attachment of *R. fistulosa* to the host as earlier attachment leads to higher *R. fistulosa* biomass accumulation.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the results from this study the following conclusions were drawn:

- *Striga asiatica* and *Rhamphicarpa fistulosa* affects rice plant physiological processes through reduction of stomatal conductance, chlorophyll fluorescence and reduction in chlorophyll content; hence affect rice physiology and yielding ability.
- The extent of parasite damage increases with increase in *S. asiatica* seed infestation densities.
- The extent of host damage by *R. fistulosa* depends on *R. fistulosa* density and how successfully the parasite has established connection with host.
- In the absence of host, *R. fistulosa* show stunted growth and is able to accumulate very low dry matter (0.0 to 0.02 g/plant). However, when growing with host (rice) *R. fistulosa* plants grow taller and accumulate higher dry matter (e.g. an increase of 72% in this study).

6.2 Recommendations

6.2.1 General recommendations

Based on the results from this study, the importance of *Striga asiatica* and *Rhamphicarpa fistulosa* as weeds in rice production systems will continue to increase as the two weeds prefers mostly poor fertile soils; hence

- *Striga asiatica* and *Rhamphicarpa fistulosa* management strategies should aim at reducing the amount of seeds in the soil weed seed bank.

- Quarantine measures should be taken to ensure there is zero tolerance level of *Rhamphicarpa* seeds in any given seed lot. As results from this study revealed, compared to *S. asiatica,* a very relatively lower number of *R. fistulosa* seeds lead into complete crop loss.

6.2.2 Recommendation for further study

Advance study is needed to find out the reasons for the early death of rice plants in higher *Striga* infestation densities e.g. use of root rhizotrons (Gurney *et al.*, 2006) as the number of above ground *Striga asiatica* seedlings could not account for this observation.

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