بسم الله الرحمن الرحيم

Sudan University of Science and Technology

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Effects of Chlorsulfuron Herbicide and Sorghum Intercropping with Cowpea on *Striga hermonthica* Emergence and Sorghum Growth

تأثير مبيد الكلوروسلفرون و الزراعة المتداخلة مع اللوبيا الحلو على نمو البودا و الذرة الرفيعة

A Thesis submitted in partial fulfillment of the requirements for the Degree of Master (M.Sc.) in Agronomy

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الآية

قال تعالى :

(وَآيَةٌ لَهُمُ الْأَرْضُ الْمَيْتَةُ أَحْيَيْناها وَأَخْرَجْنا مِنْها حَبًّا فَمِنْهُ يَأْكُلُونَ (33) وَجَعَلْنا فِيها جَنَّاتٍ مِنْ نَخِيلٍ وَأَعْنابٍ وَفَجَّرْنا فِيها مِنَ الْعُيُونِ (34) لِيَأْكُلُوا مِنْ ثَمَرِهِ وَما عَمِلَتْهُ أَيْدِيهِمْ أَفَلا يَشْكُرُونَ (35)

صدق الله العظيم

سورة يس الآيات (33– 35)

Dedication

I would like to dedicate this work to:-

My dearest father

My lovely mother

My elder sister

My fiancé

Finally, to all my teaching staff of the Agronomy.

Acknowledgements

First my all thanks and praises is due are Almight Allah, the beneficent and the merciful, for giving me health and strength to accomplish this work. Further, I would like to express my special thanks and gratitude to my supervisor Dr. Amani Hamad Eltayeb who supervised the work throughout the study. The study broader my knowledge and I came to know about many techniques. Special thanks to Dr. Atif Abu Ali and Dr. Nahid Abdel Fattah and Mohamed Feisal who help a lot. I am really thankful to them. Secondly I would also like to thank my parents and friends, who helped me a lot in finishing this project within the limited time.

Table of contents

List of Abbreviations

%	Percent
ºC	Degree centigrade
µM	micro molar
cm	Centimeter
Fig.	Figure
GR24	*Striga* Synthetic germination stimulant
Ppm	Part per million
G	Gram
mg	Milligram
L	Litre
SE	Standard Error
h	Hours
ha	Hectare
CV	Coefficient of variation
GFFP	Glass fiber filter papers
et al	and others
DAS	Days after sowing
No.	Number

List of Tables

List of Figures

Abstract

Green house and laboratory experiments were conducted, during the season 2014/2015, at the College of Agricultural Studies (CAS), Sudan University of Science and Technology (SUST) at Shambat, Khartoum North during season 2014. The green house experiment was undertaken to determine the effects of the herbicide chlorsulfuron and intercropping sorghum (cv. Wad-Ahmed) with cowpea (T100K-901-6 cv.) on *S. hermontica* incidence and sorghum growth. Treatments were arranged in a Randomized Complete Block Design (RCBD) with four replicates. The laboratory experiment was undertaken to study the effects of the herbicide chlorsulfuron on *S. hermonthica* seed germination. The results of green house showed that *Striga* emergence increased with increasing size of the seed bank. At 30 DAS, intercropping sorghum with cowpea did not reduced *Striga* emergence. However, at 45 DAS, intercropping sorghum with cowpea reduced *Striga* emergence by 16.3%, albeit not significantly. At 30 and 45 DAS, sorghum treated with chlorsulfuron at 3.1 g a.i ha^{-1}, irrespective of *Striga* seed bank size suppressed the *Striga* emergence by 96.6 – 100 and 49.0 – 63.6%, respectively. Intercropping sorghum with cowpea and a subsequent treatment with chlorsulfuron reduced *Striga* emergence (33–37%), but not significantly. Sorghum intercropping with cowpea, irrespective of *Striga* seed bank size, decreased *Striga* dry weight by 44.3-50.5%. Chlorsulfuron alone, reduced *Striga* dry weight by 10-44.3%, but not significantly. Intercropping sorghum with cowpea and a subsequent treatment with chlorsulfuron, decreased *Striga* dry weight by 22.8 – 70.7%. At 45 DAS, *Striga* at seed bank size of 16 mg/pot reduced sorghum height significantly (37.8%). At 60 and 75 DAS, *S. hermonthica* irrespective of seed bank size reduced sorghum height and stem diameter. At 60 DAS, *S. hermonthica* reduced chlorophyll content and the observed reductions increased progressively with increasing *Striga* seed bank size. *Striga* at seed bank size of 8 and 16 mg/pot, reduced significantly sorghum dry weight by 64.8 and 53.5%, respectively. At *Striga* seed bank of 16 mg/pot, cowpea intercropped sorghum exhibited significant reduction in sorghum height. 60 DAS, *Striga* at seed bank size of 4 and 8 mg/pot reduced the chlorophyll content in sorghum intercropped with cowpea significantly by 27.4 - 28.5 %. At 60 and 75 DAS, irrespective of *Striga* seed bank size, cowpea intercropped with sorghum

displayed significant reductions in stem diameter (19.0-56.7%).Sorghum intercropped with cowpea at *Striga* seed bank size of 16 mg/pot resulted in significant reduction in sorghum dry weight (61.6%). At 30 and 45 DAS, chlorsulfuron treated sole sorghum, displayed a significant reduction in sorghum height. However, at 60 and 75 DAS displayed a significant reduction in sorghum height only at the highest *Striga* seed bank size (16 mg/pot). At 60 DAS, *Striga* at a seed bank size of 16 mg/pot reduced chlorophyll content in chlorsulfuron treated sole sorghum by (24.7%). Chlorsulfuron applied to Sole sorghum at *Striga* seed bank size of 16 mg/pot reduced sorghum dry weight by 51.9%. Sorghum intercropped with cowpea and subsequently treated with chlorsulfuron at *Striga* seed bank size of 16 mg/pot decreased sorghum height significantly (20.8 – 29.5%). 60 DAS, *Striga* at seed bank size of 8 mg/pot, decreased chlorophyll content significantly in sorghum intercropped with cowpea and treated with chlorsulfuron. 60 and 75 DAS, sorghum intercropped with cowpea and subsequently treated with chlorsulfuron displayed significant reductions in stem diameter (28-33.3%). Sorghum intercropped with cowpea and subsequently treated with chlorsulfuron, irrespective of *Striga* seed bank size, reduced sorghum dry weight (28.1-47.6%).The results of laboratory experiment showed that *Striga* seeds conditioned in water and subsequently treated with GR24 at 0.01 and 0.1 ppm displayed 65.2 and 76.8% germination, respectively. Chlorsulfuron applied during conditioning reduced *Striga* seed germination significantly in response to subsequent treatments with GR24.

الملخص

أجريت تجارب مشتلية ومعملية، بجامعة السودان للعلوم والتكنولوجيا، كلية الدراسات الزراعية بشمبات– شمال الخرطوم خلال موسم(2015/2014م). أجريت التجربة المشتلية هو لمعرفة أثر مبيد الكلوروسلفيرون والزراعة المتداخلة ما بين محصولي الذرة الرفيعة (صنف وداحمد) واللوبيا الحلو (صنف.T100K-901-6) على إنبثاق البودا ونمو محصول الذرة (صنف وداحمد). تم إستخدام تصميم القطاعات العشوائية الكاملة بأربعة مكررات. الهدف من التجربة المعملية لمعرفة أثر مبيد الكلوروسلفيرون على إنبات بذور البودا. أظهرت نتائج التجربة المشتلية بأن إنبثاق البودا يزداد بزيادة مخزون البذور. بعد 30 يوم من الزراعة، لم تؤدي الزراعة المتداخلة ما بين محصولي الذرة الرفيعة واللوبيا الحلو إلى خفض إنبثاق البودا، بينما بعد 45 يوم من الزراعة أدت إلى تقليل إنبثاق البودا بنسبة16.3%، ولكن بصورة غير معنوية. أدي إستخدام مبيد الكلوروسلفيرون بمعدل 1.3 جم / هكتار مادة فعالة، بعد 30 و 45 يوم من الزراعة إلى خفض إنبثاق البودا بنسبة (100%–96.6) و(49–63.6%)، علي التوالي.أدت الزراعة المتداخلة ما بين محصولي الذرة الرفيعة واللوبيا الحلو والتي أعقبها المعاملة بمبيد الكلوروسلفيرون إلى تقليل إنبثاق طفيل البودا بنسبة (37%–33)، ولكن بصورة معنوية. أدت الزراعة المتداخلة ما بين محصولي الذرة الرفيعة واللوبيا الحلو، بغض النظر عن مخزون بذور البودا إلى خفض الوزن الجاف للبودا بنسبة –50.5 44.3%. أدي إستخدام مبيد الكلوروسلفيرون منفرداً إلى تقليل الوزن الجاف للبودا بنسبة 10–44.3% ولكن ليس بفرق معنوى. الزراعة المتداخلة ما بين محصولي الذرة الرفيعة واللوبيا الحلو والتي أعقبها المعاملة بمبيد الكلوروسلفيرون أدت إلى تقليل الوزن الجاف للبودا بنسبة 22.8–70.7%. بعد 45 يوم من الزراعة أدي مخزون بذور البودا 16ملجرام/ اصيص، إلى تقليل نمو طول الذرة بفرق معنوى بنسبة (37.8 %). بعد 60 و 70 يوم من الزراعة، أدت البودا، وبغض النظر عن مخزون البذور إلى تقليل طول النبات وقطر الساق. بعد 60 يوم من الزراعة أدت البودا إلى إنخفاض محتوى الكلورفيل وإزداد الإنخفاض بزيادة مخزون بذور البودا. أدي مخزون بذور البودا 8 و 16 ملجرام/ اصيص إلى خفض الوزن الجاف للذرة الرفيعة بصورة معنوية بنسبة 64.8 و53.5%، على التوالى .أدت الزراعة المتداخلة ما بين محصولي الذرة الرفيعة واللوبيا الحلو عند مخزون بذور البودا 16 ملجرام/الاصيص، إلى تقليل طول الذرة معنوياً. بعد 60 يوم من الزراعة، أدي مخزون بذور البودا 4 و 8 ملجرام/

الأصيص إلي خفض محتوي الكلوروفيل معنوياً في محصول الذرة وذلك عند الزراعة المتداخلة ما بين محصولي الذرة الرفيعة واللوبيا الحلو بنسبة 27.4–28.5%. عند 60 و75 يوم من الزراعة، وبغض النظر عن مخزون البذور، أدت الزراعة المتداخلة ما بين اللوبيا الحلو والذرة إلي تقليل قطر الساق معنوياً (19–56.7%). إنخفض الوزن الجاف لمحصول الذرة والتي تمت زراعته متداخلاً مع اللوبيا حلو بصورة معنوية عندما كان مخزون بذور البودا 16 ملجرام/ الأصيص (61.6 %). بعد 30 و 45 يوم من الزراعة، معاملة الذرة منفرداً مبيد الكلوروسليفرون أدى إلي خفض طول الذرة معنوياً. بينما بعد 60 و75 من الزراعة أدي إلي خفض طول النبات فقط عندما كان مخزون بذور البودا 16 ملجرام/ الاصيص. إنخفض محتوي الكلوروفيل في الذرة بعد 60 يوم من الزراعة وذلك عند معاملة محصول الذرة بمبيد الكلوروسليفرون عندما كان مخزون بذور البودا 16 ملجرام/ الأصيص بنسبة 24.7%. إنخفض الوزن الجاف للذرة عندما كان مخزون بذور البودا 16 ملجرام/ الأصيص وذلك بعد معاملة الذرة بمبيد الكلوروسليفرون بنسبة 51.9%. الزراعة المتداخلة ما بين الذرة الرفيعة واللوبيا الحلو والتي أعقبها المعاملة بمبيد الكلوروسلفيرون عندما كان مخزون بذور البودا 16 ملجرام/ الأصيص، أدت إلي تقليل طول الذرة معنوياً (20.8–29.5%). بعد 60 يوم من الزراعة وعندما كان مخزون بذور البودا 8 ملجرام /اصيص، إنخفض محتوي الكلوروفيل في الذرة معنوياً، وذلك في الزراعة المتداخلة ما بين الذرة الرفيعة واللوبيا الحلو والتي أعقبها المعاملة بمبيد الكلوروسلفيرن. بعد 60 و 75 يوم من الزراعة المتداخلة ما بين الذرة الرفيعة واللوبيا الحلو والتي أعقبها المعاملة مبيد الكلوروسلفيرون إنخفض قطر الساق معنوياً (28–33.3%). أظهرت الزراعة المتداخلة مابين الذرة الرفيعة واللوبيا الحلو والتي أعقبها المعاملة بمبيد الكلوروسلفيرن، وبغض النظر عن مخزون بذور البودا، خفض في الوزن الجاف للذرة (28.1– 47.6%). أظهرت نتائج التجارب المعملية بأن بذور البودا المهيأة فى الماء والتي تم معاملتها بمحفز الإنبات الإصطناعي GR24 بمعدل 0.01 و 0.1 جزء من المليون أعطت نسبة 65.2 و 76.8% إنبات، علي التوالى. مبيد الكلوروسلفيرون والذي تم تطبيقه أثناء فترة التهيأة أدي إلي خفض نسبة إنبات بذور البودا معنوياً وذلك بعد إستجابتها للمعاملة بمحفز الانبات GR24.

CHAPTER ONE

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench), a Poaceae, is native to Africa. It is widespread throughout the inter-tropical zone and its cultivation now extends well into the temperate regions (Lendzemo, 2004). Sorghum, the staple food crop in Africa, South Asia and Central America particularly in rural areas. Sorghum is the fifth major cereal crop in terms of production, after maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), and barley (*Hordeum vulgare* L.) (Awika and Rooney, 2004). Ninety percent of the world's area cultivated by sorghum is in the developing countries, mainly in Africa and Asia. Major world's producers include Sudan, Nigeria, India, United States, Mexico, Ethiopia, China and Argentina (FAO, 2013). Sorghum provides grain for consumption in the form of stiff or thin porridges, steam-cooked products such as couscous, or beverage for the resource-poor farmers. The leaves and stems are also used as forage for livestock, building materials and fuel for cooking. In the industrialized countries, sorghum grains are generally used as animal feed (Lendzemo, 2004).

Sorghum production is however, negatively influenced by a biotic (heat, drought and low fertility) and biotic stresses (diseases, insects and weeds). Of all weeds *Striga hermonthica* (Del.) Benth., an obligate root-parasite has been identified as one of the major biological threats to sorghum production in the savannah zones of sub-Saharan Africa. The parasite causes huge losses ranging from 40-90% (Gressel *et al.*, 2004), depending on crop variety, climatic conditions and seed infestation level of the soil (Rodenburg *et al*., 2005), and up to 75% of its overall damage to the hosts occurred during its subterranean stage of development (Parker and Riches,

1993). A single *S. hermonthica* plant can produce up to 500,000 seeds which remain viable for more than 14 years (Bebawi *et al.*, 1984). In Sudan the area under sorghum constitutes about 74% of the area under cereals and 45% of the total cultivated areas (Babiker, 2007a). Furthermore, sorghum is the major staple food crop especially in rural areas. Sorghum production is seriously constrained by *S. hermonthica*, whereas more than 20% of the area under sorghum is infested by the parasite (Babiker, 2007b). Yield losses were reported to range between 65-100% and complete crop failure is not uncommon under heavy infestations (Hamdoun and Babiker, 1988). *S. hermonthica* has been recognized as a problem of national importance since the 1940 (Babiker, 2007b).

Various control methods (e.g., hand-pulling, hoe-weeding, trap- and catch cropping) have been tried out with no conclusive and consistent results for subsistence farmer. This may partly be due to the difficulty to deplete huge amounts of seeds that have accumulated and continue to accumulate in the seed bank over the years. Prodigious seed production, prolonged viability of the seeds and the subterranean nature of the early stages of parasitism make control of the *Striga* by conventional methods difficult if not impossible (Babiker *et al*., 2007). *S. hermonthica* problem may be too widespread and too severe to control using a single approach. Management of the hemi-parasite needs an integrated approach that includes host plant resistance, cultural practices, and chemical treatments.

The present study comprising laboratory and greenhouse experiments was designed to determine the effects of the herbicide chlorsulfuron, intercropping with cowpea (*Vigna unguiculata* L.) and combination on *S. hermontica* incidence and Sorghum growth. The laboratory experiment was undertaken to study the effects of the chlorsulfuron herbicide on *Striga* germination.

CHAPTER TWO

LITEATURE REVIEW

2.1. Sorghum

Sorghum belongs to family Poaceae, It is a self pollinated crop cultivated for its edible grains, commonly called sorghum and also known as durra in Sudan. Sorghum genetically is considered as a drought tolerant crop and has evolved various eco types that withstand an array of biotic factor. It is considered more tolerant to many stresses, including heat, drought, salinity and flooding as compared to other cereal crops (Ali *et al*., 2011). However, the crop grown in rain-fed areas is highly affected by drought stress (Kebede *et al*., 2001). The crop is crucially important to food security in Africa as it is exclusively drought resistant and can withstand periods of high temperature (Taylor, 2006).

In Sudan the amount and rainfall patterns of and length of rainy seasons as in Sub-Sahara Africa is fluctuating. These climatic changes adversely affect traditionally sorghum growing areas of North Gdaref, Gezira, Sennar, White Nile State and North Kordofan. The dominant varieties grown are the traditional Feterita types e.g. *Arfa Gadmek*, *Abdalla Mustafa* and *Korolo*. *Tetron* and *Dabar* are grown on a limited scale. Some pioneer farmers in south Gadarif grow the improved varieties, Wad *Ahmed* and *Tabat.* Sorghum grown in this region is used for commercialization purposes and is sold mainly in the local markets, with some of it for export (Babiker, 2002).

2.2. Parasitic Plants

A parasitic plant is one that derives some or all of its nutritional requirements from another living plant. All parasitic plants have special organs, named haustoria (singular: haustorium), which connect them to the conductive

system of their host and provide them with the ability to extract water and nutrient from the hosts. Approximately 4,500 species of flowering plants (more than 1% of all angiosperms) are parasitic, obtaining some or all of their water and nutrients from other plants. A small percentage of these parasitic species infest agricultural crops and cause serious problems for farmers in many parts of the world (Parker and Riches, 1993; Musselman *et al*., 2001). They can be classified into two main types depending on the presence or absence of chlorophyll. Holoparasites do not contain chlorophyll and depend completely on their host for the supply of assimilates. Hemiparasites do contain (some) chlorophyll and can perform photosynthesis to some extent. Some of these hemiparasites can live either as a parasite or on their own roots, and these are called facultative parasites (Joel *et al*., 1995). Parasitic plants can attach to their host on several different organs (shoots, roots or branches). Root parasites are parasitic plants that attach to the roots of their host. They belong to a number of families and can be non-photosynthetic or photosynthetic. The most damaging root parasites belong to the family Orobanchaceae (Joel *et al*., 2007). The most economically important families are the Orobanchaceae (Broomrapes). This family includes the largest number of genera (85) and species (ca. 1650) of all the families of parasitic flowering plants (Nickrent and Musselman, 2004). The genus *Striga*, recently placed in the Orobanchaceae (Olmstead *et al*., 2001) contains about 41 species that are found on the African continent and parts of Asia; Africa is the presumed region of origin (Wolfe *et al*., 2005). Mohamed *et al*. (2001) described 28 species and six subspecies from Africa. Of these 22 species of *Striga* are endemic. The most important of 11 species that attack crops are *Striga asiatica* (L.) Kuntze and *Striga hermonthica* (Del.) Benth. parasitising cereals and *Striga gesnerioides* (Willd.) Vatke parasitizing cowpea and other wild legumes.

2.2.1. *Striga*

Striga (witchweed) is one of the most important pests that affect food production in the tropics. *Striga* are generally native to semi-arid, tropical areas of Africa, but have been recorded in more than 40 countries (Ejeta, 2007). *Striga* possibly originates from a region between the semien Mountains of Ethiopia and the Nubian Hills of Sudan (Atera and Itoh, 2011). It is also widespread in eastern and northern Uganda on sorghum and finger millet (Ebiyau *et al*., 2000).

Striga has been a serious problem of cereal and legume crops among farmers in sub-Saharan Africa. Its effects on crops range from stunted growth, through wilting, yellowing, and scorching of leaves, to lowered yields and death of many affected plants. Farmers have reported losses between 20% and 80%, and are eventually forced to abandon highly infested fields (Atera and Itoh, 2011). Grain yield losses even can reach 100% in susceptible cultivars under a high infestation level and drought conditions (Haussmann *et al.,* 2000). According to estimated by Gressel *et al*., (2004), 17.2 million hectares (64% of the total area) of sorghum and pearl millet production in West African are infested with *Striga*. Most of the yield loss (about 75%) occurs before *Striga* emergence (Parker and Riches, 1993).

2.2.2. *Striga* Life cycle

Striga spp. are obligate hemi-parasitic plants that attach to the roots of their host to obtain water, nutrients and carbohydrates (Parker and Riches, 1993). They have a very complex life cycle, which is intimately tied to that of its host and that follows a series of developmental stages from seed to seed producing plants. After dispersal, the seeds are in a state of primary dormancy for up to six months (Kuiper *et al.*, 1996). Following after-ripening, a second prerequisite for germination is the preconditioning of the seeds, which requires an imbibition period of several weeks under humid and

warm (25-35 ° C) conditions (Kebreab and Murdoch, 1999). After reaching maximum sensitivity, prolonged preconditioning induces secondary dormancy (Matusova *et al.*, 2004). Pre-conditioned ***Striga*** seeds require various secondary metabolites (xenognosins) derived from the host roots and some non-host plants to induce germination and to develop (Yoder, 2001). These chemical compounds have been identified as sesquiterpene lactones, released in trace amounts in the root exudates (Bouwmeester *et al.*, 2003). After the conditioning period, the parasite seeds will germinate only if exposed to sufficiently high concentrations of germination stimulants hence assuring that germination only occurs in close vicinity of the host root. The adaptation of parasites to respond to these germination stimulants is of evolutionary significance: their tiny seeds contain limited reserves and the seedlings will die within a number of days after germination unless a host root is invaded (Butler, 1995).When the seeds have germinated, the radicle must grow towards the host root and this process is possibly directed by the concentration gradients of germination stimulants (Dube and Olivier, 2001). The host root has also been reported to produce other secondary metabolites, for example, as yet unidentified compounds that inhibit germination or the elongation of the radicle (Joel *et al*., 1995; Khan *et al*., 2002). When the radicle reaches the host root, the attachment and penetration of the host root are achieved by the formation of a special organ called haustorium. The haustorium penetrates the host and connects the vascular system of the host with that of the parasite. The formation of this organ requires other host-derived chemical signals to initiate and guide this developmental transition. Following the establishment of the connection with the host, the parasite will develop a so-called tubercle that helps to accumulate nutrients. At a certain stage it forms a shoot, emerges above the soil, flowers and produces seeds after which the lifecycle can start again (Sun,

2008). *Striga* seeds are minute (0.20-0.50 mm long), weighing only approximately 3.7-12.4 μg each and are produced in very large numbers. Estimates of numbers of seeds produced per reproductive *Striga* plant can vary from several thousands to over 85,000 depending on species and growing conditions (Parker and Riches, 1993; Rodenburg *et al.*, 2006).

2.3.3. Control Methods

Control of *S. hermonthica* in cereals has so far proven elusive. Economically feasible and effective technologies are still to be developed for the cash strapped subsistence farmers in most of the *Striga*-stricken areas (Debrah, 1994). The control of *S. hermonthica* has also been made very difficult due to the biology of this weed. It is very prodigious as far as seed production is concerned.

Several control methods against *Striga* species have been recommended such as crop rotation, land fallowing, trap cropping, weeding and use of fertilizers. Others include the use of germination stimulants (Ariga and Berner, 1993), herbicides, host resistance (Radi, 2007), and biological control. Moreover, used alone, none of these methods has given a satisfactory suppression of the parasite.

2.3.3.1. Cultural Methods

These comprise of many of the traditional methods, including hand-pulling, intercropping, crop rotation, trap and catch cropping, and nitrogen fertilizers.

2.3.3.1. 1. Hand-weeding

Hand-weeding is the most widely practiced used control method against *Striga* and it is recommended to prevent seed set and seed dispersal. It is necessary to prevent seed production and reinfestation of the soil (Teka, 2014). Due to high labour costs in repeated hand-pulling of *Striga*, it is

recommended that hand-pulling should not begin until 2-3 weeks after *S. hermonthica* begins to flower to prevent seeding (Parker and Riches, 1993). Hand-pulling will usually need to be continued for 3-4 years and is most economical on the least infested fields. It is always recommended as a supportive treatment (Parker and Riches, 1993).

2.3.3.1.2. Intercropping

Intercropping is a potentially viable, low cost technology, which would enable to address the two important and interrelated problems of low soil fertility and *Striga* (Fasil, 2002). Intercropping with a false host crop that stimulates *Striga* seed germination without being itself attacked or parasitized, has been thought as a method for depletion of *Striga* seed reserves in soil (Parker and Riches, 1993). Intercropping cereals with legumes and other crops is a common practice in most area of Africa, and has been reported as influencing *Striga* infestation (Teka, 2014). According to Khan *et a*l. (2007), intercropping different legumes with maize and sorghum helps reduce *Striga* but not eliminate the weed. Intercropping sorghum and groundnuts (*Arachis hypoguaea* L.), sorghum and cowpea (*Vigna unguiculata*), and sorghum and dolichos beans (*Lablab purpurous* L.) reduced population density of *S. hermonthica* (Babiker *et al.*, 1996). Growing in sorghum association with cowpea and haricot bean was effective against *S. hermonthica* and produced significantly improved yield per unit area in Ethiopia (Fasil, 2002). Intercropping maize with cowpea and sweet potato significantly reduce the emergence of *Striga* in Kenya (Oswald *et al*., 2002). Work in Sudan showed that intercropping is a valuable cheap and effective method for suppressing localized infestations of the parasite on relatively small farms (Babiker, 2002). Intra-row planting of hyacinth bean (*Lablab purpureus*) with sorghum, reduced *S. hermonthica* emergence by 48-93%, dry weight by 83-97%, number of seed capsules by 52-100% and increased sorghum grain yield by several fold in comparison with the sole crop (Babiker, 2002).

Intercropped fodder legumes (*Desmodium uncinatum* and *D. intortum*) with maize reduced *Striga* infestation in Kenya (Khan *et al*., 2000). The effect was

significantly greater than that on other legumes such as cowpeas, as were the concomitant yield increases. The mechanism by which *D. Uncinatum* reduce *Striga* infestation in intercropping was found to be the allelopathic effect inhibiting the development of haustoria of *Striga* (Khan *et al*., 2001). Identification of the compounds released from *D. Uncinatum* involved in the suppression of the parasite may give more exploitation for developing reliable intercropping strategies, as well as new approaches for molecular biology in *S. hermonthica* (Gressel, 2000).

Parker and Riches (1993) attributed the suppressive effects of intercropping to several factors, including its action as a trap-crop, interference with production of germination stimulants, exudation of germination inhibitors and/or reduction of the parasite transpiration, through decreasing air temperature and increasing humidity. In common with most parasitic weeds *Striga* species have high transpiration rate, associated with stomata which remain open under most if not all conditions (Shah *et al*., 1987).

2.3.3.1.3. Crop rotation

Crop rotation of infested land with non-susceptible crops or fallowing is theoretically the simplest solution. Rotation with non-host crops interrupts further production of *Striga* seed and leads to decline in the seed population in the soil. The practical limitation of this technique is required more than three years for *rotation* (Teka, 2014). The choice of rotational crop should therefore be based 1st on its suitability to the local conditions and only secondarily on its potential as a trap crop (Parker and Riches, 1993).

Rotating the infested maize or sorghum areas to wheat, barley, pluses or groundnuts are viable and effective options in Ethiopia (Teka, 2014). In Ethiopia two years of cropping to a non-host was reported to reduce *Striga* infestation by 50% (Shank, 2002). In West Africa rotating *Striga* susceptible cereals with leguminous crops has been reported to decrease *Striga* seedbank and increase yield of subsequent cereal crops (Ahonsi *et al*., 2002). The increase in yield due to millet-cowpea rotation was 37% as compared to three

or five year's continuous millet cropping (Samak, 2003). De-Groote *et al*. (2010) found that soybean triggers suicidal germination of *Striga* and reduces the *Striga* seed bank in the soil when intercropped with maize. Practical control measures are effective when a combined program of crop rotation, weeding, sanitation and resistant varieties is included (Teka, 2014).

2.3.3.1.4. Trap and Catch Crops

The use of trap and catch crops that induce the germination of *Striga* but are not themselves parasitized is currently one of the best methods to control agricultural root parasites.

Trap crops cause suicidal germination of the weed, which reduces the seed bank in the soil (Teka, 2014). Common cultivated trap crops include cotton (*Gossypium barbadense*), groundnut (*Arachis hypogaea*), soybean, pigeonpea (*Glycine max*), green or black gram (*Vigna mungo*), lucerne (*Medicago sativa*), sunflower (*Helianthus annuus*) and sesame (*Sesamum indicum*) (Babiker, 2007). Weerasuriya *et al.* (1993) reported that production of *Striga* germination stimulants and concomitantly the efficiency of the false host may be influenced by edaphic and climatic conditions.

Catch crops are planted to stimulate a high percentage of the parasite seeds to germinate but are destroyed or harvested before the parasite can reproduce (Teka, 2014). It is another mean of depleting *Striga* seed reserves in soils. Contrary to trap cropping, which relies on false hosts, catch cropping employs true hosts of the parasite. A thick planting of Sudan grass at 20-25 kg seed per hectare should be sown and either ploughed in or harvested for forage at 6-8 weeks before *Striga* seeds. The main crop could then be planted during the main rains (Parker and Riches, 1993). The catch crop, when ploughed under is equivalent to green manuring it is restorative effects on soil fertility (Bebawi, 1987). Catch crops are considered to be less economically favoured than trap crops because of the lack of direct financial returns.

2.3.3.1.5. Nitrogen fertilization

Nitrogen and phosphorus deficiency as well as water stress accentuate the severity of *Striga* damage to the hosts (Teka, 2014). *Striga* is particularly a pest of low fertile soil and usually the infection decreases if mineral nutrients, especially nitrogen and phosphorus, are applied in sufficient quantities (Adagba *et al*., 2002). Nitrogen is believed to reduce stimulant production. The use of nitrogen to suppress *Striga* has been demonstrated in the East and Central African highlands (Esilaba *et al*., 2000; Gacheru and Rao, 2001). Mumera (1983) recorded a 64% reduction in *S. hermonthica* emergence in maize using 39 kg N/ ha^{-1} as calcium ammonium nitrate (CAN). Studies in western Kenya show that CAN at 0-140 kg N /ha-1 had no significant effect on maize yield but reduced *Striga* populations. Farmyard manure trials indicated that 100 t/ha^{-1} reduced *Striga* counts and increased maize yield. Mumera and Below (1993) found that although *Striga* infection generally declined with increasing N availability, the impact was partially dependent on the severity of infestation. Application of high dosage of nitrogen fertilizer is generally beneficial in delaying *Striga* emergence and obtaining stronger crop growth (Dugie *et al*., 2008). Also other advantageous effects of fertilizers include increasing soil nitrogen and other nutrients, replenishing the organic matter of the soil and increasing soil moisture holding capacity (Ikie *et al*., 2006). However, results of field trials across countries and locations have not been consistent in term of host crop yield or *Striga* numbers (Parker and Riches, 1993). These variations, which may be associated with intrinsic soil or crop variety characteristics, make recommendation of nitrogen as a sole treatment for *Striga* control difficult.

2.3.3.1.6. Host plant resistance

Resistance is the process by which host withstand the parasite attack in a manner that prevent parasite establishment and growth, whereas tolerance involves the ability to endure damage inflicted by the parasite (Eizenberg *et al*., 2013). Host plant resistance would probably be the most feasible and potential method for parasitic weed control(Teka, 2014).Using biotechnological approaches (including biochemistry, tissue culture, plant genetics and breeding, and molecular biology)

significant progress has been made in developing screening methodologies and new laboratory assays, leading to the identification of better sources of parasitic weed host resistance (Omanya, 2001). It is potentially an acceptable *Striga* control option to resource poor farmers (Gurney *et al*., 2003). However, reliance on host resistance alone is not ideal because so far complete resistance against cannot be attained through breeding (Gurney *et al*., 2002), and usually the newly developed varieties may not fulfill farmers preference traits (Adugna, 2007). Full immunity of host plants to *Striga* or *Orobanche* has not yet been found. However, several resistant crop varieties are used nowadays in various parts of Africa, Europe and Asia. As the reported resistant or tolerant cultivars are often not accepted by farmers because of their low yield, low seed and storing quality, poor adaptation to a wide range of agro-ecological zones and their sensitivity to pest and diseases, the newly developed techniques significantly contribute to overcoming these problems by permitting transfer of resistance genes into adapted cultivars with high-yielding potential. This will lead to a lower parasite infestation and to a higher crop yield (Elzein and Krosche, 2003).

2.3.3.2. Chemical Control

Various chemicals including herbicides, fumigants, and synthetic germination stimulants were reported as means of *Striga* control.

2.3.3.2.1. Herbicides

Chemical herbicides have been applied to reduce *S. hermonthica* and can reduce infestation to some degree in maize and sorghum (Babiker *et al*., 1996), and were more cost-effective than other methods.

Many herbicides are useful in preventing the build-up of *Striga* seeds in the soil but may not prevent the damage done by *Striga* plants before emergence. Research efforts should therefore be directed towards identifying herbicides that persist in the soil, allowing the germination of *Striga* seeds but killing the seedlings before attachment to the host. Several herbicides have been recommended for control of *Striga* on sorghum and maize (Langston *et al*., 1991). Aly (2007) reported Dicamba and 2, 4-D are the most widely used

herbicides against *Striga*. Recent on-farm trials in Kenya and Tanzania indicate that seed dressing with Imazapyr and Pyrithiobac offers good *Striga* control and increased maize yields (Kanampiu *et al*., 2004). Work in India and Sudan (Korwar and Friesen, 1984) showed that 2,4-D and MCPA, applied as soil directed sprays 3 to 4 weeks after crop emergence, reduced *Striga* incidence and increased crop yield. Similar results were reported with oxyfluorfen, triclopyr and chlorsulfuron (Langston and English, 1990). These products kill the parasite during the early developmental stages and thus make evasion of crop damage possible. Furthermore, most of these herbicides are either none selective to sorghum (oxyfluorfen) or has a narrow safety margin (chlorsulfuron).

Chlorsulfuron, triasulfuron and imazaquin herbicides significantly reduced the broomrape parasitizing tomato plants (Ghannam *et al*., 2012). Chlorsulfuron and its tank mix with dicamba, when used against *Striga* on Sorghum, effected excellent and persistent control of the parasite on both tolerant and resistant cultivars and increased yield and yield components (Babiker, 2002). Applying herbicides through soil for management of root-parasitic weeds targets the seedlings and its early development stages. The success of this mode of herbicide application depends on the aviability of herbicide in the soil layer where the host roots are parasitized (Eizenberg *et al*., 2013). Chlorsulfuron at 2.38 and 2.98 g a.i. ha^{-1} resulted in satisfactory to excellent suppression of the *Striga* emergence early in the season (Rashida, 2014).

3.3.2. 1.1. Chlorsulfuron

Chlorsulfurona sulphonylurea, 2-Chloro-N-[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)aminocarbonyl] benzenesulfonamide, is selective herbicide for pre- and post- emergence control of annual and perennial broadleaved weeds on cereal grains, pastures and rangeland, indusrial sites, and lawns.

Chlorsulfuron enters plants through the root zone and foliage. The herbicide is an acetolactate synthases (ALS) inhibitor that inhibits the synthesis of the

amino acid L-leucine, L-isoleucine and L-valine and subsequently protein synthesis (Dastgheib and Field, 1998).

2.3.3.2. 2. Fumigants

Fumigants are chemicals that have the ability to kill most soil borne organisms including bacteria, fungi, nematodes, and weed seeds. The seeds must be physiologically active to be killed (Nandulla, 1998**).** Soil fumigation is one of the methods of control which was used in USA for eradication of the parasite. Three fumigants were reported to provide effective control of parasitic weeds. Bromomethane (methyl bromide) and Basamid (3, 5-dimethyl-2h-1, 3, 5-thiadazine-2-thione) were reported to be highly effective on *S. asiatica* (Eplee and Langston, 1971; Parker and Riches, 1993). However, high cost, high toxicity and requirement of special skills in handling limit the use of Bromomethane to experimental plots. The product is easy to handle. However, its potential for controlling *Striga* in farmer`s fields remains to be determined. All fumigants are used at very high rate, expensive, labour intensive, and extremely environmentally hazardous (Aly, 2007).

2.3.3.2. 3. Germination Stimulants

Striga seed will not germinate in the absence of a chemical germination stimulant. These stimulants can be classified as host root exudates, non-host root exudates, natural leachates/compounds, and synthetic germination stimulants. A large number of investigators have attempted to isolate, characterize and /or identify the stimulant from many host and non-host (Awad *et al*., 2006). The natural stimulants are highly active, but are present in root exudates in such an extremely low levels that their isolation, purification and identification have been difficult (Musselman, 1987). A number of different classes of secondary metabolites have been described to have germination stimulant activity including dihydrosorgoleone, the strigolactones and the sesquiterpene lactones (Sun, 2008). Several strigolactone, were found in the root exudates of various plant species (Yasuda *et al.,* 2003), and proved to stimulate the germination of both *Orobanche* and *Striga*. Strigol was the first *Striga* germination stimulate to be

identified, and was first isolated from root exudates of cotton (*Gossypium hirsutum* L.) (Cook *et al.,* 1972) and was also isolated at later stages from the root exudates of a variety of other plants including maize, millet and sorghum (Sato *et al.,* 2005). In addition to these compounds, at least 10 additional strigolactones have been detected in root exudates of different plant species include sorgolactone from sorghum, orobanchol and alectrol from red clover, and 5-deoxystrigol from *Lotus japonicus* (Hauck *et al*., 1992; Yokota *et al*., 1998; Akiyama *et al*., 2005; Yoneyama *et al*., 2006).

2.4.4. Integrated Management

Various control methods (e.g., hand-pulling, hoe-weeding, trap- and catch cropping) have been tried out with no conclusive and consistent results for the subsistence farmer. This may partly be due to the difficulty to deplete huge amounts of seeds that have accumulated and continue to accumulate in the seedbank over the years. *S. hermonthica* problem may be too widespread and too severe to control using a single approach. Management of the hemi-parasite needs an integrated approach that includes host plant resistance, cultural practices, and chemical treatments. With integrated management, it is important to understand the interaction of the host plant, sorghum, with the biotic and a biotic environment (Lendzemo, 2004).

Several integrated techniques for the control of *Striga* have been developed and tested. Mumera (1983) investigated the efficacy of three herbicides with N fertilizer on maize and sorghum cultivars. Odhambo and Ransom (1994) recommended that maintenance of soil fertility (fertiliser and crop residues) and the removal of *Striga* before seed set would restore the productivity of lands infested with *Striga*. However, the best solution in the control of *Striga* is an integrated approach that includes a combination of methods that are affordable and acceptable by farmers.

CHAPTER THREE

MATERIALS AND METHODS

3.1. General

A series of laboratory and greenhouse experiment was undertaken at the College of Agricultural Studies, Sudan University of Science and Technology (SUST) at Shambat, to determine the effects of the herbicide chlorsulfuron and intercropping with cowpea on *S. hermontica* incidence on Sorghum.

3.2. Green house experiment

A pot experiments was conducted in a greenhouse at the College of Agriculture Studies, (CAS), at Shambat during the season 2013/2014. Sorghum (cv. Wad-Ahmed) was obtained from Agriculture Research Corporation, Gadarif. However, cowpea (T100K-901-6 cv.), was obtained from the International Institute of Tropical Agriculture, Ibadan- Nigeria (IITA). Chlorsulfuron as glean was obtained from Striga Research Laboratory, CAS. A soil mix prepared by mixing Shambat soil with sand (2:1

v/v). The experiment was conducted under artificial *S. hermonthica* infestation. Artificial infestation of soil was achieved by mixing 2g of *Striga* seeds with 1kg soil, followed by subsequent dilution with *Striga* free soil to give the required infestation level (4, 8 and 16 mg/pot). *Striga* seed soil mix was added to *S. hermonthica* free soil and thoroughly mixed by hand. *Striga* free or infested soil was placed in plastic pots (9 cm i .d) with perforations at the bottoms. Pots filled with *Striga* free soil (0 mg) were included as control for comparison. Sorghum cultivar Wad-Ahmed was sown as sole crop or intercropped with cowpea. Sorghum and cowpea seeds (5/pot) were sown early August at 2 cm soil depth. The pots were immediately irrigated. Subsequent irrigations were carried out every two days. Sorghum and cowpea seedlings were thinned to three plants per pot two weeks after sowing. Chlorsulfuron as Glean at 1.3g a.i /fed was applied three weeks after sowing (WAS) by knapsack sprayer as aqueous spray at rate of 100 L per feddan (10 ml/pot). An untreated *Striga* infested control was included for comparison. Treatments were arranged in a Randomized Complete Block Design (RCBD) with four replicates.

Data collected on Sorghum growth comprised of i) Plant heights (cm), ii) number of leaves, iii) chlorophyll content (SPAD readings) , iv) stem diameter, vi) sorghum dry weight (g). Data collected on *S. hermonthica* included i) *Striga* emergence and ii) *Striga* dry weight (g).

Average of SPAD readings at 3 points using a chlorophyll meter (SPAD-502, Konica Minolta Sensing, Japan) was recorded for each leaf

3.3. Laboratory experiments

A series of experiments was conducted at the *Striga* research laboratory, at the College of Agricultural Studies, Sudan University of Science and Technology, to study the effects of the herbicide chlorsulfuron on early developmental stages of the *S. hermonthica* germination.

3.3.1. Strigol analogue (GR24) stock solution

A stock solution of the synthetic germination stimulants GR24 was prepared by dissolving 1mg in 1ml of acetone and completion to volume (100 ml) with sterilized distilled water to obtain the desired concentration (10 ppm).

3.3.2. Preparation of chlorsulfuron stock solution

A stock suspension (100µM) of chlorsulfuron was prepared by shaking 4.8 mg with 10 ml of sterilized distilled water and subsequently completing to volume (100 ml).

3.3.3. Effects of chlorsulfuron on *Striga*

Glass fiber filter papers (GFFP) discs (8mm diameter) were cut, wetted thoroughly with water and placed in an oven set at 104 ºC for one hour to be sterilized before use. For pre-conditioning the sterilized discs, placed in 9 cm Petri dishes lined with a single sheet of glass fiber filter papers, were moistened with 5 ml of the suspension of the respective herbicide at 20, 40 and 80 µM. A control in which the seeds were conditioned in distilled water was included for comparison. Subsequently, about 25-50, surface sterilized *Striga* seeds were sprinkled on each of the glass fiber discs. The Petri dishes, sealed with Parafilm and wrapped with aluminum foil were incubated in the dark at 30 ºC, for 14 days.

For germination glass fiber filter discs containing *S. hermonthica* seeds conditioned in water or test solution, were, dapped on a filter paper to remove excess water and transferred to sterile Petri dishes. Each disc was treated with a 20µl aliquot, of GR2 at 0, 0.01 and 0.1ppm. Apiece of filter paper moistened with sterilized distilled water was placed in the centre of each Petri dish to maintain moist conditions during the test period. The seeds, reincubated in the dark at 30 ºC for 24 hour. The seeds were examined for germination 24 hour later using a binocular stereomicroscope. Treatments were arranged in a Complete Randomized Design (CRD) with six replicates.

3.4. Statistical analysis

Data on Sorghum growth attributes and *S. hermonthica* were subjected to analysis of variance (ANOVA) and means were separated for significance by the Least significance Differences (LSD) at 5% level using Statistix 8 statistical software, Version 2.0 (UK).

CHAPTER FOUR

Results

4.1. Field experiment

4.1.1. Effects of chlorsulfuron and cowpea on *Striga* and sorghum growth

4.1.1.1. Effects on *Striga*

4.1.1.1.1. *Striga* emergence

Striga count made 30 and 45 days after sowing (DAS) showed that *Striga* emergence increased with increasing size of the seed bank (Table 4.1). Statistical analysis showed significant differences between treatments (Table

4.1). At 30 DAS, *Striga* emergence at the lowest seed bank size was 5.8 plants /pot. Increasing seed bank size to 1mg/pot increased *Striga* emergence to 7.3 plants /pot. A Further increase in *Striga* seed bank size to 16 mg/pot increased *Striga* emergence significantly to 20.5 plants/pot (Table 4.1). Sorghum intercropping with cowpea at *Striga* seed bank size of 4, 8 and 16 mg/pot displayed 4, 5 and 18.5 *Striga* plants /pot, respectively. However, sorghum treated with chlorsulfuron, irrespective of *Striga* seed bank size displayed negligible *Striga* emergence (Table 4.1). Sorghum intercropped with cowpea and subsequently treated with chlorsulfuron sustained an average of 1.8 - 11 *Striga* plants/pot (Table 4.1).

At 45 DAS, the parasite displayed an average of 10.8 plants /pot at the lowest seed bank size (4 mg/pot). Increasing seed bank size to 8 and 16 mg/pot increased *Striga* emergence to 20 and 22 plants /pot, respectively (Table 4.1). At *Striga* seed bank size of 4 mg/pot intercropping sorghum with cowpea reduced *Striga* emergence by 16.3%, albeit not significantly. However, at seed bank size of 8 mg/pot, intercropping sorghum with cowpea reduced *Striga* emergence significantly and the observed reduction was considerable (35.8%) (Table 4.1).

Chlorsulfuron alone, irrespective of *Striga* seed bank size, reduced the parasite emergence by 49.0–63.6% in comparison with the untreated control (Table 4.1). Intercropping sorghum with cowpea and a subsequent treatment with chlorsulfuron, reduced *Striga* emergence considerably (33–37%), but not significantly, in comparison to untreated control (Table 4.1).

Table4.1:Effects of chlorsulfuron and cowpea on *striga* emergence

Number of *Striga* emergence/pot		
	Days After Sowing (DAS)	
Treatments	**30**	**45**
S4	5.8 c	10.8 cd
S8	7.3 bc	20.3 bc
S16	20.5 a	22.0 b
S4+C	5.0 c	9.0 d
S8+C	4.3 c	13.0 bcd
S16+C	18.5 ab	37.0 a

S4+H	0.3 c	5.5 d
S8+H	0.0 c	8.8 d
S16+H	0.8 c	8.0 d
S4+C+H	2.0 c	6.8 d
S8+C+H	1.8 c	14.8 bcd
S16+C+H	11.0 abc	14.8 bcd
LSD	11.8	11.2
F- Value	2.8*	5.2***

*S_X=*Striga* seed bank size (mg/pot), C=Cowpea, H=Herbicide

Means within a column followed by the same letter(s) are not significantly different according to LSD-Test. *P≤0.05, ***= P≤0.001

4.1.1.1.2. *Striga* dry weight

Statistical analysis showed no significant differences in *Striga* dry weight between the treatments (Table 4.2). At the lowest seed bank size (4mg/pot) the parasite displayed a dry weight of 4.2 g/pot. Increasing *Striga* seed bank size to 8 and 16 mg/pot increased *Striga* dry weight to 9.7 and 5.4 g/pot, respectively, but not significantly (Table 4.2).

Sorghum intercropping with cowpea, irrespective of *Striga* seed bank size, reduced *Striga* dry weight by 44.3-50.5%, in comparison with the untreated control. Chlorsulfuron alone, irrespective of *Striga* seed bank size, reduced *Striga* dry weight by 10-44.3%, albeit not significantly (Table 4.2). At seed bank size of 4 and 16 mg/ pot, intercropping sorghum with cowpea and a subsequent treatment with chlorsulfuron, decreased *Striga* dry weight by 22.8 and 67.9%, respectively. However, the reduction was not significant (Table 4.2) , At a seed bank size of 8 mg/ pot, intercropping sorghum with cowpea followed by chlorsulfuron reduced *Striga* dry weight significantly (70.7%).

Table 4 .2: Effects of chlorsulfuron and cowpea on *striga* dry weight

Treatments	***Striga* dry weight (g)/pot**
S4	4.2 ab
S8	9.9 a
S16	5.4 ab
S4+C	2.1 b
S8+C	5.6 ab
S16+C	3.0 b

S4+H	3.8 b
S8+H	5.6 ab
S16+H	3.0 b
S4+C+H	1.4 b
S8+C+H	3.0 b
S16+C+H	4.1 ab
LSD	6.0
F- Value	1.2 Ns

*****S_X=*Striga* seed bank size (mg/pot), C=Cowpea, H=Herbicide
Means within a column followed by the same letter(s) are not significantly different according to LSD-Test. Ns= non- significant

4.1.1.2. Effects on Sorghum

4.1.1.2.1. Plant height

At 30 DAS significant differential were observed between the treatments in plant height (Table 4.3). *Striga* at a seed bank size of 16 mg/pot reduced sorghum height by 17.9%, albeit not significantly. Intercropping sorghum with cowpea, irrespective of *Striga* seed bank size had no significant effect on sorghum height. At *Striga* seed bank size of 4, 8 and 16 mg/pot chlorsulfuron treated sole sorghum displayed a significant reduction in sorghum height by 24.2, 26.1 and 20.5%, respectively in comparison with the *Striga* free control (Table 4.3). At seed bank size of 16 mg/pot, sorghum intercropped with cowpea and treated with chlorsulfuron displayed a significant reduction in height and the observed reduction was considerable (22.1%).

At 45 DAS, *Striga* at seed bank of 4 and 8 mg/pot decreased sorghum height, but not significantly in comparison with the parasite free control (Table 4.3). On the other hand, increasing seed bank size to 16 mg/pot reduced height significantly (37.8%). At seed bank size of 4 and 8 mg/pot intercropping sorghum with cowpea had no significant effect on sorghum height. At *Striga* seed bank size of 16 mg/pot, intercropping sorghum with cowpea reduced sorghum height significantly and the observed reduction was 24.6% (Table 4.3). At seed bank size of 4 and 8 mg/pot chlorsulfuron treated sole sorghum displayed a reduction height of sorghum by 20.5 and 25.4%, respectively. At

Striga seed bank size of 16 mg/pot height of sorghum intercropped with cowpea and treated with chlorsulfuron displayed a significant reduction in height (28.7%), in comparison to the *Striga* free control (Table 4 .3).

At 60 DAS statistical analysis showed significant differences between treatments (Table 4.3). *S. hermonthica* reduced sorghum height and the observed reductions increased with increasing seed bank size. *Striga* at seed bank size of 4, 8 and 16 mg/pot reduced sorghum height significantly and the observed reductions were 21.9, 29.5 and 40.7%, respectively. At *Striga* seed bank size of 4 and 16 mg/pot sorghum intercropped with cowpea displayed 20.1 and 34.1% reduction in height, respectively in comparison with the parasite free control (Table 4.3). At seed bank size of 4 and 8 mg/pot, sole sorghum treated with chlorsulfuron showed no significant reduction in height. However, at a seed bank size of 16 mg/pot, chlorsulfuron treated sole sorghum displayed a significantly reduction in height. At seed bank size of 16 mg/pot, sorghum intercropped with cowpea and treated with chlorsulfuron displayed a significant reduction in height and the observed reduction was considerable (20.8%).

At 75 DAS, *Striga* free sorghum displayed the highest height (111.8 cm). At the lowest *Striga* seed bank size (4 mg /pot) sorghum height was reduced by 25.8%. Increasing seed bank size to 8 and 16 mg/pot reduced sorghum height significantly and the observed reductions were 32.7 and 42.9%, respectively (Table 4.3). At *Striga* seed bank size of 16 mg/pot, cowpea intercropped sorghum exhibited significant reduction in height (29.6%). At seed bank size of 8 and 16 mg/pot sole sorghum treated with chlorsulfuron displayed significant reduction in height and the observed reduction was considerable 32.5 and 34.9%, respectively. At *Striga* seed bank size of 16 mg/pot sorghum intercropped with cowpea and treated with chlorsulfuron displayed 29.5% reduction in height (Table 4.3).

Table 4. 3: Effects of chlorsulfuron and cowpea on sorghum height

Sorghum height (cm)
Days After Sowing (DAS)

Treatments	30	45	60	75
Untreated control	42.5 ab	60.6 a	96.2 a	111.8 a
S4	45.3 a	53.3 abc	75.1 bcd	83.1 bc
S8	45.8 a	51.8 abc	67.8 bcd	75.3 bc
S16	34.9 bcd	37.7 d	57.0 d	63.8 c
S4+C	40.3 abc	49.8 abcd	76.9 bc	93.7 ab
S8+C	41.6 ab	56.4 ab	81.2 abc	92.9 ab
S16+C	41.5 ab	45.7 bcd	63.4 cd	78.7 bc
S4+H	32.2 d	45.2 bcd	85.3 ab	90.8 ab
S8+H	31.4 d	48.2 bcd	78.0 abc	72.8 bc
S16+H	33.8 cd	51.1 abc	76.4 bc	75.5 bc
S4+C+H	38.1 abcd	54.7 abc	81.9 abc	93.0 ab
S8+C+H	35.8 bcd	48.3 abcd	78.2 abc	88.1ab
S16+C+H	33.1 cd	43.2 cd	76.2 bc	78.7 bc
LSD	7.6	12.2	18.5	23.8
CV%	13.9	17.2	16.9	19.6
F- Value	3.5**	2.0*	2.3*	2.3*

*S_X=*Striga* seed bank size (mg/pot), C=Cowpea, H=Herbicide
Means within a column followed by the same letter(s) are not significantly different according to LSD-Test. *P≤0.05, **=P≤0.01.

4.1.1.2.2. Number of leaves

At 30 DAS, number of leaves ranged from 6 - 7 leaves /plant and increased at 75 DAS to 9 -10 leaves/plant (Table 4.4). At 30, 60 and 75 DAS differences between treatments were not significant. However, at 45 DAS significant differential were observed in number of leaves between the treatments.

At 45 DAS, *S. hermonthica*, irrespective of seed bank size had no significant effect on number of leaves of sorghum, in comparison with the *Striga* free control. *Striga* at seed bank size of 16 mg/pot reduced number of leaves, but not significantly and the observed reduction was 17.8% (Table 4.4). Intercropping sorghum with cowpea, irrespective of *Striga* seed bank size had no significant effect on number of leaves per plant. At *Striga* seed bank size of 8 mg/pot chlorsulfuron treated sole sorghum caused a slight non-significant

increase (17.8%) in number of leaves. However, at seed bank size of 16 mg/pot sorghum treated with chlorsulfuron displayed a significant increase in number of leaves by 23.3%, in comparison with the *Striga* free control (Table 4.4). Sorghum intercropped with cowpea and treated with chlorsulfuron, irrespective of *Striga* seed bank size showed no significant reduction in number of leaves (Table 4.4).

Table 4. 4: Effects of chlorsulfuron and cowpea on sorghum leaves

	Number of leaves/ plant			
	Days After Sowing (DAS)			
Treatments	**30**	**45**	**60**	**75**
Untreated control	6.4 b	7.3 bcd	9.8 a	10.3 a
S4	6.8 ab	7.1 cd	8.4 ab	8.7 ab
S8	7.3 ab	7.0 cd	9.7 a	9.0 ab
S16	7.0 ab	6.0 d	8.4 ab	8.6 ab
S4+C	6.4 b	6.8 cd	9.6 a	9.5 ab
S8+C	6.5 b	7.5 bc	10.2 a	10.0 ab
S16+C	7.0 ab	6.8 cd	7.4 b	7.9 b
S4+H	7.3 ab	7.5 bc	10.1 a	9.3 ab
S8+H	7.8 a	8.6 ab	8.9 ab	9.2 ab
S16+H	7.0 ab	9.0 a	9.8 a	9.3 ab
S4+C+H	7.3 ab	7.0 cd	9.3 ab	9.7 ab
S8+C+H	7.2 ab	7.4 bc	9.7 a	8.5 ab
S16+C+H	6.8 ab	7.8 abc	8.7 ab	9.1 ab
LSD	1.3	1.4	2.1	2.3
CV %	12.8	13.4	16.0	17.2
F- Value	0.8 Ns	2.4*	1.2 Ns	0.7 Ns

*****S_X=*Striga* seed bank size (mg/pot), C=Cowpea, H=Herbicide
Means within a column followed by the same letter(s) are not significantly different according to LSD-Test. Ns= non- significant, *P≤0.05.

4.1.1.2.3. Chlorophyll content

At 30, 45 and 75 DAS, differences between treatments in chlorophyll content were not significant (Table 4.5). However, at 60 DAS significant differential were observed in chlorophyll content between treatments. *S. hermonthica* reduced chlorophyll and the observed reductions increased progressively with increasing *Striga* seed bank size. *Striga* at a seed bank size of 4 mg/pot reduced chlorophyll content in sorghum by 16.6%, albeit not significantly. Increasing seed bank size to 8 and 16 mg/pot reduced chlorophyll content significantly, in comparison to the *Striga* free control. The observed reductions were 29.6 and 46.5%, respectively. *Striga* at seed bank size of 4 and 8 mg/pot reduced the chlorophyll content in sorghum intercropped with cowpea significantly by 27.4 -28.5 % (Table 4.5). *Striga* at a seed bank size of 16 mg/pot reduced chlorophyll content in chlorsulfuron treated sole sorghum

by 24.7%. *Striga* at a seed bank size of 8 mg/pot, decreased chlorophyll content significantly in sorghum intercropped with cowpea and treated with chlorsulfuron (Table 4.5).

Table 4. 5: Effects of chlorsulfuron and cowpea on chlorophyll content

Chlorophyll content /plant				
	Days After Sowing (DAS)			
Treatments	**30**	**45**	**60**	**75**
Untreated control	22.8 abcd	30.2 a	37.2 a	37.7 ab
S4	20.2 bcd	27.4 a	31.0 ab	29.7 b
S8	19.7 cd	27.4 a	26.2 bc	42.0 a
S16	19.3 d	26.1 a	19.9 c	29.0 b
S4+C	27.7 ab	27.0 a	26.6 bc	26.8 b
S8+C	20.6 abcd	32.2 a	33.2 ab	32.1 ab
S16+C	18.7 d	26.3 a	27.0 bc	31.4 ab
S4+H	22.9 abcd	28.0 a	34.1 ab	35.4 ab
S8+H	23.1 abcd	30.0 a	29.6 ab	31.9 ab
S16+H	20.9 abcd	28.4 a	28.0 bc	29.8 b
S4+C+H	28.2 a	33.9 a	29.2 ab	33.8 ab
S8+C+H	26.8 abc	31.7 a	28.1 bc	30.9 b
S16+C+H	25.8 abcd	29.6 a	29.2 ab	28.1 b
LSD	7.5	8.4	8.7	11.1
CV%	22.9	20.1	20.7	24.0
F- Value	1.6 Ns	0.7 Ns	1.9*	1.2 Ns

*S_X=*Striga* seed bank size (mg/pot), C=Cowpea, H=Herbicide
Means within a column followed by the same letter(s) are not significantly different according to LSD-Test. Ns= non- significant, *P≤0.05.

4.1.1.2.4. Stem diameter

Statistical analysis showed that differences between treatments in stem diameter were not significant at 30 and 45 DAS. However, at 60 DAS significant differences were observed between the treatments (Table 4.6). At 60 DAS, *Striga* free control displayed the highest stem diameter (17.5 cm). *Striga* at the lowest seed bank size reduced stem diameter by 43.4%. Increasing seed bank size to 8 and 16 mg/pot, reduced stem diameter significantly and the observed reductions were 39.4 and 50.3, respectively. At *Striga* seed bank size of 4 and 8 mg/pot, cowpea intercropped sorghum displayed insignificant reduction in stem diameter by 19.0 and 26.4%,

respectively. However, increasing seed bank size to 16 mg/pot decreased stem diameter significantly (49.1%). Sole sorghum treated with chlorsulfuron, irrespective of *Striga* seed bank size displayed considerable reductions (28.6-34.9%) in stem diameter. At *Striga* seed bank size of 4, 8 and 16mg/pot sorghum intercropped with cowpea and subsequently treated with chlorsulfuron displayed significant reductions in stem diameter (28 -32%).

At 75 DAS, highly significant differences between the treatments were observed in stem diameter (Table 4.6). At *Striga* seed bank size of 4, 8 and 16 mg/pot stem diameter was reduced by 33.3, 40 and 51.7%, respectively. *Striga* at seed bank size of 4 and 16 mg/pot cowpea, intercropped with sorghum displayed significant reductions in stem diameter and the observed reductions were 36.7-56.7%. At *Striga* seed bank size of 4, 8 and 16 mg/pot chlorsulfuron treated sole sorghum displayed significant reductions in stem diameter. Sorghum intercropped with cowpea and subsequently treated with chlorsulfuron, irrespective of *Striga* seed bank size, displayed 28.9–33.3% reduction in stem diameter (Table 4.6).

Table 4. 6: Effects of chlorsulfuron and cowpea on stem diameter

Sorghum stem diameter (cm)				
Days After Sowing (DAS)				
Treatments	**30**	**45**	**60**	**75**
Untreated control	6.1 bc	5.6 abcd	17.5 a	18.0 a
S4	6.9 ab	5.2 abcd	9.9 bc	12.0 bc
S8	6.6 abc	5.2 abcd	10.6 bc	10.8 bcd
S16	5.3 bc	3.7 d	8.7 c	8.7 cd
S4+C	4.2 c	4.9 bcd	12.8 abc	11.4 bcd
S8+C	5.2 bc	5.5 abcd	14.2 ab	14.3 ab
S16+C	5.9 bc	4.7 bcd	8.9 c	7.8 d
S4+H	9.1 a	6.1 abcd	12.5 bc	11.9 bc
S8+H	6.5 bc	7.6 a	11.4 bc	12.4 bc
S16+H	6.1 bc	7.2 ab	12.4 bc	11.4 bcd
S4+C+H	6.3 bc	7.0 abc	12.6 bc	12.6 bc
S8+C+H	5.5 bc	4.8 bcd	119 bc	12.8 b
S16+C+H	5.2 bc	4.5 cd	11.7 bc	12.0 bc
LSD	2.6	2.6	4.7	4.0
CV%	30.3	32.1	27.7	23.1
F- Value	1.6 Ns	1.7 Ns	1.9*	3.2**

*S_X=*Striga* seed bank size (mg/pot), C=Cowpea, H=Herbicide
Means within a column followed by the same letter(s) are not significantly different according to LSD-Test. Ns= non- significant, *P≤0.05, **=P≤0.01.

4.1.1.2.5. Sorghum dry weight

Statistical analysis showed that differences between treatments in sorghum dry weight were not significant (Table 4.7). *Striga* free control displayed a dry weight of 46.3 g. At the lowest *Striga* seed bank size (4 mg/pot) sole sorghum displayed slight non-significant (5.9%) increase in dry weight. A further increase in *Striga* seed bank size to 8 and 16 mg/pot decreased sorghum dry weight significantly and the observed reductions were 64.8 and 53.5%, respectively in comparison to the *Striga* free control (Table 4.7).

Sorghum intercropped with cowpea at seed bank size of 4 and 8 mg/pot, displayed a considerable, but not significant loss (21.6 – 33.5%) in dry weight, in comparison to the *Striga* free control (Table 4.7). Increasing seed bank size to 16 mg /pot resulted in significant reduction in sorghum dry weight and the observed reduction was 61.6%. At *Striga* seed bank size of 4

and 8 mg/pot chlorsulfuron treated sorghum sole showed no significant reductions in dry weight and the observed reductions were 17.3 - 42.7%. Increasing *Striga* seed bank size to 16 mg/pot chlorsulfuron treated sorghum sole displayed further reduction 51.9% (Table 4.7).

Sorghum intercropped with cowpea and subsequently treated with chlorsulfuron, irrespective of *Striga* seed bank size, showed reduced sorghum dry weight considerable, but not significant reduction in dry weight. The observed reductions were 28.1- 47.6% (Table 4.7).

Table 4. 7: Effects of chlorsulfuron and cowpea on sorghum dry weight

Treatments	Sorghum dry weight (g)/pot
Untreated control	46.3 ab
S4	49.0 a
S8	16.3 c
S16	21.5 bc
S4+C	36.3 abc
S8+C	30.8 abc
S16+C	17.8 c
S4+H	38.3 abc
S8+H	26.5 abc
S16+H	22.3bc
S4+C+H	33.3 abc
S8+C+H	24.3abc
S16+C+H	24.5 abc
LSD	26.0
F- Value	1.3 Ns

*****S_X=*Striga* seed bank size (mg/pot), C=Cowpea, H=Herbicide
Means within a column followed by the same letter(s) are not significantly different according to LSD-Test Ns= non- significant.

4.2. Laboratory experiment

4.2.1. Effects of chlorsulfuron on *Striga* germination

S. hermonthica seeds conditioned in water and subsequently treated with GR24 at 0.01ppm displayed 65.2% germination. Increasing GR24 concentration to 0.1 ppm increased germination to 76.8% (Fig 4.1 A and B). Chlorsulfuron applied during conditioning reduced seed germination significantly in response to subsequent treatments with GR24. However,

differences between herbicide concentrations were not significant. Seeds conditioned in chlorsulfuron at 20 µM and subsequently treated with GR24 at 0.1ppm reduced germination to 46.9%. A further increase in herbicide concentration to 40 and 80 µM did not cause further significant reductions (Fig 4.1 A).

Seeds conditioned in chlorsulfuron at 20 µM and treated with GR24 at 0.01 ppm displayed 50.6% germination. Increasing concentration to 40 and 80 µM decreased germination by 30.3 and 37%, respectively, in comparison to seeds conditioned in water (Fig 4.1 B).

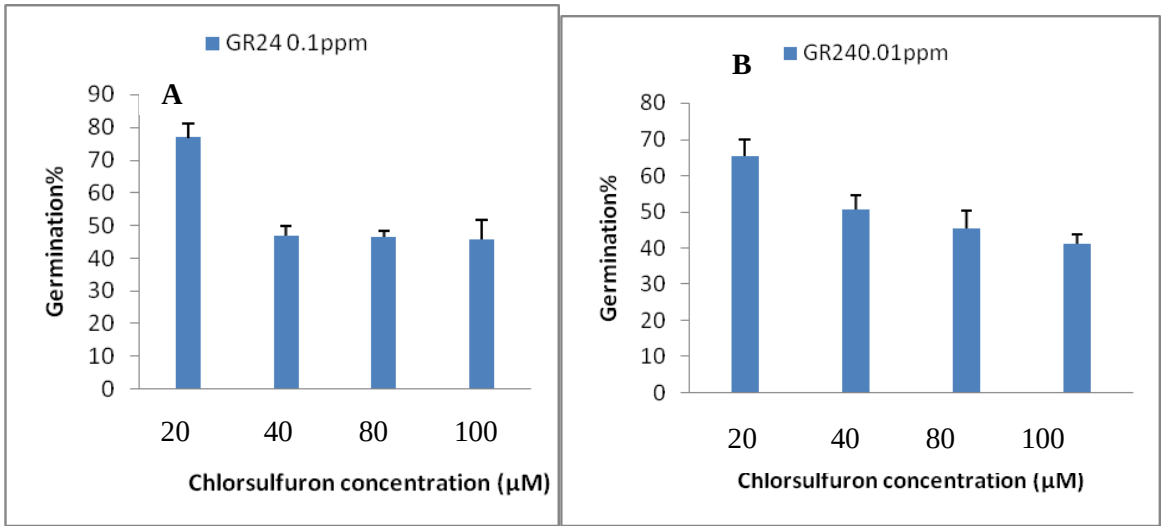

Fig 4. 1. Effects of chlorsulfuron on *S. hermonthica* seeds germination in response to GR24 at A) 0.1ppm and B) 0.01ppm. Vertical bar represents SE±

CHAPTER FIVE

Discussion

Obligate parasitic plant witchweed (*Striga spp*) infects major cereal crops such as sorghum, maize and millet and is the most devastating weed pest. An understanding of the nature of its parasitism would contribute to the development of more sophisticated management methods. *Striga* research in Africa has a long history and a range of effective component control technologies has been identified (Parker and Riches, 1993). Examples of control options for *S. hermonthica* range from the use of leguminous trap-crops to stimulate suicidal germination of *Striga* seeds and therefore reduce the seed bank and improve soil fertility, to the use of resistant host-crop cultivars.

Striga count made 30 and 45 days after sowing (DAS) showed that *Striga* emergence increased with increasing size of the seed bank (Table 4.1). At 30 DAS, *Striga* emergence at the lowest seed bank size was 5.8 plants/pot. However, increasing seed bank size to 16 mg/pot increased *Striga* emergence to 20.5 plants/pot. At 45 DAS, the parasite displayed an average of 10.8 plants/pot at the lowest seed bank size (4 mg/pot). Increasing seed bank size to 8 and 16 mg/pot increased *Striga* emergence to 20 and 22 plants/pot, respectively (Table 4.1). Similar findings were reported by Eltayeb (2013). The observed increase in *Striga* emergence with seed bank size indicates the importance of the seed bank in determining the level of infestation and damage. At 30 DAS, Sorghum intercropping with cowpea, irrespective of *Striga* seed bank size did not reduce *Striga* emergence significantly. However, at 45 DAS, intercropping sorghum with cowpea at *Striga* seed bank size of 4 mg/pot, reduced *Striga* emergence by 16.3%, albeit not significantly. However, at seed bank size of 8 mg/pot, intercropping sorghum with cowpea reduced *Striga* emergence significantly and the observed reduction was considerable (35.8%) (Table 4.1). These findings are

consistent with those obtained by Babiker *et al.* (1996) who reported that intercropping sorghum and cowpea reduced population density of *S. hermonthica*. Chivinge *et al*. (2001) reported that cowpea cultivars reduced *Striga* emergence by 40%. This reduction may be due to shading effects from the cowpea canopy (Kureh *et al*., 2006). This was attributed to the soil cover of cowpea that created unfavorable conditions for *Striga* germination. The roots of several legumes are known to induce suicidal germination of *Striga* seeds, and this feature has become incorporated into *Striga* suppression strategies involving cereal-legume rotation or intercropping (Einallah, 2013). The effectiveness of cereal/legume intercropping to influence *Striga* germination depends on the effectiveness of the produced stimulant/inhibitors, root development, fertility improvement, shading effect and its compatibility to *Striga* species because the response of *Striga* to management options is specific (Mbwaga *et al*., 2001). Parker and Riches (1993) attributed the suppressive effects of intercropping to several factors, including its action as a trap-crop, interference with production of germination stimulants, exudation of germination inhibitors and/or reduction of the parasite transpiration, through decreasing air temperature and increasing humidity. In common with most parasitic weeds *Striga* species have high transpiration rate, associated with stomata which remain open under most if not all conditions (Shah *et al*., 1987).

Chemical control of *Striga* is an alternative, easy, effective and non-costive method that could be used in an integrated *Striga* management approach to reduce damage inflicted by the parasite. At 30 DAS, sorghum treated with chlorsulfuron, irrespective of *Striga* seed bank size displayed negligible *Striga* emergence. At 45 DAS, chlorsulfuron alone, irrespective of *Striga* seed bank size, reduced the parasite emergence by 49.0– 63.6% in comparison with the untreated control (Table 4.1). Similar results were obtained by Abusin (2014) who found that chlorsulfuron at 2.38 and 2.98 g a.i ha^{-1} effected excellent suppression of the parasite (83.3%). Ayman *et al*. (2014) reported that all

chlorsulfuron formulation significantly reduced *Striga* infestation. Chlorsulfuron in form of Glean reduce damage caused by *Striga* and effectively control the parasite. However, presence of the herbicide from more than one source of production will enhance availability and reduce the cost of control (Ayman *et al*., 2014). This could be attributed to the mode of action of chlorsulfuron one of amino acid inhibitors belongs to sulfonylurea's group, the mode of action in this group is the tendency of poorly developing roots and the secondary roots are shortened. Chlorsulfuron is acetolactate synthase (ALS) inhibitor (Dastgheib and Field, 1998). The herbicide inhibits synthesis of the branches amino acids L-leucine, L-isoleucine and L-valine, and thus may interfere with protein synthesis and cell division (Ray, 1984).

Sorghum intercropping with cowpea, irrespective of *Striga* seed bank size, reduced *Striga* dry weight by 44.3-50.5%, in comparison with the untreated control. Chlorsulfuron alone, irrespective of *Striga* seed bank size, reduced *Striga* dry weight by 10-44.3%, albeit not significantly (Table 4.2). At *Striga* seed bank size of 8 mg/ pot, intercropping sorghum with cowpea followed by chlorsulfuron reduced *Striga* dry weight significantly (70.7%). The reduction in *Striga* dry weight is consistent with the reductions in emergence caused by intercropping with cowpea and treated with chlorsulfuron. This study results confirmed the observations of Yonli *et al.* (2012) who reported integrated *Striga* management controls based on intercropping system, Fusarium-inoculum or both in combination significantly reduced *Striga* dry biomass. Indeed, a creeping trap crop suffocated juvenile *Striga* plants that succeeded in emerging and then, they were killed by the competition effect between trap crop and *Striga* seedlings. In addition, when the cowpea plants covered the soil, the temperature decreased while the air humidity increased under cowpea leaves and stalks. The interaction of these environmental factors may create a micro-climate that would affect the emergence and the growth of *Striga* plants and then *Striga* biomass should be significantly reduced (Yonli *et al.*, 2012).

At 45 DAS, sole sorghum showed significant reductions in height, only, at the highest *Striga* seed bank size. However, at 60 and 75 DAS, *S. hermonthica* reduced sorghum height and the observed reductions increased with increasing seed bank size. At 60 DAS, *S. hermonthica* reduced chlorophyll and the observed reductions increased progressively with increasing *Striga* seed bank size. At 60 and 75 DAS, *Striga* irrespective of seed bank size reduced stem diameter. *Striga* at seed bank size of 8 and 16 mg/pot decreased sorghum dry weight significantly and the observed reductions were 64.8 and 53.5%, respectively in comparison to the *Striga* free control (Table 4.7). These findings are consistent with those obtained by Vasey *et al* (2005) who reported that *Striga* infection resulted in significant reduction in number of tillers and in growth and biomass of wheat. Similar findings were reported by Rana (2013) with *S. hermonthica* on sorghum and by Shms-Eldin (2014) on wheat. This is a common effect of *Striga* infection on other cereals, such as maize. The parasites remove water, minerals and Photosynthase from the host and thus reduce the latter ability to grow and compete for nutrients, light, water and space (Joel *et al*., 2007). Crops that are parasitized usually grow more slowly and depending on severity of infestation, biomass production is lowered and the host may be killed. In general, *S. hermonthica* can affect its host in different ways. Only part of the reduction in growth of the host results from competition for carbon assimilates, water, mineral nutrients and amino acids (Graves *et al*., 1990). However, *Striga* does not only act as an additional sink but the parasite also has a strong 'toxic' or 'pathological' effect on the host (Press and Gurney, 2000). Parts of these effects are caused by the disturbed hormonal balance in *Striga*-infected host plants, characterized by increased levels of abscisic acid and decreased levels of cytokinins and gibberellins (Frost *et al*., 1997). By altering the host's hormonal balance *Striga* affects host biomass allocation, resulting in the root systems of infected plants being greatly stimulated, while the shoot is stunted and reduced (Parker and Riches, 1993). The parasite also negatively affects

host photosynthesis. Parasite induced reduction in host photosynthesis has been reported as the most important mechanism of growth reduction. Graves *et al*. (1989) estimated that 80% of the decrease in host growth rate can be attributed to the impact *Striga* has on host photosynthesis.

At 45, 60 and 75 DAS, cowpea intercropped sorghum exhibited significant reduction in height (Table 4.3). 60 DAS, *Striga* at seed bank size of 4 and 8 mg/pot reduced the chlorophyll content in sorghum intercropped with cowpea significantly by 27.4-28.5% (Table 4.5). At 75 DAS, irrespective of *Striga* seed bank size, cowpea intercropped with sorghum displayed significant reductions in stem diameter (Table 4.6). Sorghum intercropped with cowpea at seed bank size of 16 mg/pot resulted in significant reduction in sorghum dry weight and the observed reduction was 61.6% (Table 4.7). This finding is at consistent with that of Hmad-Elneel (2012), who reported a decline in dry weight of cowpea intercropped sorghum, irrespective of *Striga* infestation.

At 30 and 45 DAS, chlorsulfuron treated sole sorghum, displayed a significant reduction in sorghum height. However, at 60 and 75 DAS chlorsulfuron treated sole sorghum at *Striga* seed bank size of 16 mg/pot displayed a significantly reduction in height. Similar results were obtained by Abusin (2014) who found that chlorsulfuron alone and mixtures with 2, 4-D reduced sorghum height. 60 DAS, *Striga* at a seed bank size of 16 mg/pot reduced chlorophyll content in chlorsulfuron treated sole sorghum by 24.7% (Table 4.5). 60 DAS, Sole sorghum treated with chlorsulfuron, irrespective of *Striga* seed bank size displayed considerable reductions (28.6-34.9%) in stem diameter At *Striga* seed bank size of 4 and 8 mg/pot chlorsulfuron treated sorghum sole showed no significant reductions in dry weight. Increasing *Striga* seed bank size to 16 mg/pot chlorsulfuron treated sorghum sole displayed further reduction 51.9% (Table 4.7).

At seed bank size of 16 mg/pot, sorghum intercropped with cowpea and treated with chlorsulfuron displayed a significant reduction in height. 60 DAS, *Striga* at a seed bank size of 8 mg/pot, decreased chlorophyll content

significantly in sorghum intercropped with cowpea and treated with chlorsulfuron (Table 4.5). 60 DAS, at *Striga* seed bank size of 4, 8 and 16 mg/pot sorghum intercropped with cowpea and subsequently treated with chlorsulfuron displayed significant reductions in stem diameter (28-32%). Sorghum intercropped with cowpea and subsequently treated with chlorsulfuron, irrespective of *Striga* seed bank size, showed reduced sorghum dry weight considerable, but not significant reduction (Table 4.7). The decreases may be attributed to combined effects on *Striga* and competition between sorghum and cowpea.

The results of laboratory experiment showed that chlorsulfuron applied during conditioning reduced seed germination significantly in response to subsequent treatments with GR24. Similar results was obtained by Abusin (2014) who found that chlorsulfuron, 2, 4-D and triclopyr each at 10 – 80 µM applied during conditioning reduced *Striga* germination in response to GR24.

Conclusions and Recommendations

Conclusions

- Intercropping sorghum with cowpea reduced *Striga* emergence.
- Chlorosulfuron effectively reduced germination and suppressed *Striga* emergence.
- *Striga* management requires integrated practices comprising different components.

Recommendations

- The experiment should be repeated for another year with additional treatments (nitrogen fertilizer) to confirm the results.

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