Evaluation of Tick-trefoil (*Desmodium* species) for Drought Tolerance and Control of Witchweed {*Striga hermonthica (Del.) Benth.}* in Grain Sorghum and Branched Broomrape *(Orobanche ramosa* L.) in Tomato

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Dedication

I dedicate this work to my parents, brothers, and sisters and to the soul of my brother Dr. Azzam Izzeldin Idris who always wished to see me complete my studies but never lived to see me through.

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Abbreviations

%	Perentage
°C	Degree centigrade
µL	Micro litre
µM	Micro molar
cm	Centimetre
cv	Cultivar
DMBQ	2, 6- dimethoxy-p-benzoquinone
Fig	Figure
g	Gram
GFFP	Glass fiber filter paper
GPD	Glass Petri- dish
GR 24	a Synthetic Strigol analogue
h	Hours
ha	Hectare
i.d.	Internal diameter
i.d.	Internal diameter
kg	Kilogramme
L	Litre
ml	Millilitre
mm	Millimetre
PEG	Polyethylene glycol
ppm	Part per million
RE	Root exude
t	Tonne

تقويم أنواع من نبات أبوعريضة (*Desmodium* spp.) لتحمل الجفاف ومكافحة طفيل البودا (*Striga hermonthica*) فى الذره الرفيعة وطفيل الهالوك (*Orobanche ramosa*) فى الطماطم

خوجلي عزالدين ادريس السيد
دكتوراه الفلسفة في وقاية المحاصيل (علم الحشائش) (نوفمبر 2009)
قسم وقاية المحاصيل
كلية العلوم الزراعية

الخلاصة

الحشائش الطفيلية من جنس البودا (*Striga*) والهالوك (*Orobanche*) تعتبر من المشاكل التي تعيق الزراعة وذلك لصعوبة مكافحتها وتأثيرها المدمر على المحاصيل. هدفت الدراسة إلي تقويم أنواع مختلفة من نبات ابوعريضة المحلية والمستجلبة لتحمل الجفاف والقدرة علي مكافحة طفيل البودا في محصول الذرة الرفيعة وطفيل الهالوك في محصول الطماطم. أجريت التجارب المعملية ، المشتلية والحقلية في الفترة ما بين عام 2006 إلي 2009م بمحطة بحوث الجزيرة، واد مدني، وسط السودان ومحطة بحوث القضارف، شرق السودان . شملت التجارب المعملية (1) تأثير درجات الحرارة والجفاف علي إنبات أنواع مختلفة من نبات أبو عريضة. (2) دراسة إفرازات جذور أنواع أبوعريضة علي استثارة إنبات بذور البودا والهالوك. أنواع نبات أبو عريضة شملت أنواع مستجلبة وهي *D. uncinatum* ، *D. distortum* ، *D. intortum* ، *D. tortuosum* والنوع المحلي *D. dichotomum* الذي تم جمعه من منطقتي الدمازين وكادوقلي. أظهرت الدراسة المعملية أن إنبات أنواع أبو عريضة ارتفع بزيادة درجات الحرارة وفترة الحضانة. هذا وقد كان الإنبات عند درجة حرارة 15°م بطيئاً ومتأخراً بينما كانت درجات الحرارة 25 و 30 °م هي المثلي للإنبات. التركيز المنخفض (50g/L) لـ PEG 8000 لم يكن له أثر سلبي علي الإنبات بينما أدت زيادة التركيز إلي 100g/ L إلي تأخير الإنبات . أما في حالة التركيز العالي (200g/L) لم يحدث إنبات للنوع *D. uncinatum*. انخفض المجموع الجذري لكل أنواع أبو عريضة انخفاضًا معنوياً مع زيادة تركيز PEG 8000. أظهرت الدراسة أن إفرازجذور النوع *D. distortum* أحدث أعلي نسبة إنبات (35%) للبودا مقارنة بالأنواع الأخري . بينما لم تحدث مستخلصات الجذور لأنواع أبوعريضة الاخري أي إنبات للهالوك. أظهرت النتائج المعملية أن نمو جذور *D. uncinatum* و *D. dichotomum* أدي إلي الحد من وعدم التصاق البودا بجذور محصول الذرة الرفيعة للصنف

ارفع قدمك . أظهرت تجارب المشتل أن *D tortuosum* كان اكثر تحملاً للجفاف مقارنة بـــالأنواع الأخرى. الكثافة العالية لنباتات أبو عريضة من النوع *D. uncinatum* أدت إلي الحد مـــن إنبـــات البودا معنويا عند المستوى المنخفض لبذور البودا تحت ظروف المشتل. أوضحت النتائج أن زراعة النوع المحلي قبل 60 يوماً من زراعة الذرة الرفيعة أدي إلي الحد من إنبات البودا مقارنة بالزراعة قبـــل 30 أو 90 يومـــاً أو الزراعـــة فـــي نفـــس الوقـــت. النتـــائج الحقليـــة أشـــارت إلـــي أن *D. intortum* و *D. uncinatum* أنتجا أقل عدد من النباتات مقارنة بالأنواع الأخرى. كما اظهرت النتائج عدم مقدرة الأنواع تحت الدراسة لتجدد النمو في الموسم التالي. أشارت النتائج بمحطة بحوث الجزيرة الي أن زراعة محصول الذرة الرفيعة بعـــد *D. tortuosum* و *D. dichotomum* أدي إلي زيادة غير معنوية في إنتاجية الذرة التي بلغت 77 و39% علي التوالي. كما وان زراعة الذرة الرفيعة ونبات *D. dichotomum* في نفس الزمن أدت إلي تقليل إنبات البودا، الوزن الجاف للبودا وزيادة في إنتاجية الذرة الرفيعة بنسبة 161% وذلك بمحطة بحوث الجزيرة في موســـم 2008/09. وبالنسبة للقضارف (موسم2007 /08) فقد أدي هذا النوع من الزراعة لصـــنف الـــذرة كوركولـــو ونباتات *D. dichotomum* إلي زيادة معنوية في الإنتاجية بينما أدت الأنواع الأخرى مـــن نبـــات ابوعريضة إلي زيادة غير معنوية في الإنتاجية. ثم أن زراعة أبو عريضة في موسم 2006/07 بين حفر الطماطم أو في نفس الحفرة أدت إلي انخفاض إنبات الهالوك وزيادة معنوية في إنتاجية الطماطم بينما لم تكن الزيادة في الإنتاجية معنويةً في موسم 2007/08.

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Abstract

Parasitic weeds of the genera *Striga* and *Orobanche* pose a severe problem for agriculture because they are difficult to control and are highly destructive to several crops. The present study was undertaken to evaluate local and exotic *Desmodium* species for drought tolerance and for ability to suppress *S. hermontica* on sorghum and *O. ramosa* on tomato. A series of laboratory, green house and field experiments was conducted during the period 2006 to 2009 at the Gezira Research Station Farm, Wad Medani, central Sudan and the Gedarif Research Station, eastern Sudan. Laboratory experiments studied the i) effects of temperature and drought on germination of *Desmodium* species and ii) influence of *Desmodium* species root exudates on germination of *S. hermonthica* and *O. ramosa*. Five *Desmodium* species; the exotic, *D. uncinatum, D. intortum, D. distortum, D. tortuosum,* and two collections of the local species *D. dichotomum,* obtained from Damazin and Kadugli were used. Laboratory experiments showed that germination of *Desmodium* spp. increased with increasing temperature and time. Germination was delayed at 15 °C while temperatures of 25 to 30 °C resulted in optimal germination. PEG 8000 at low concentration (50 g/L) had no adverse effect on germination. However, PEG

8000 concentration at 100 g/L it delayed germination. At 200g/*L* PEG 8000 resulted in complete or near complete suppression of germination of *D. uncinatum*. In all *Desmodium* species radical length significantly decreased with increasing PEG 8000 concentration. Undiluted root exudates of *D. distrotum* induced higher germination (35%) of *S. hermothica* than the other species. None of the *Desmodium* species root exudate induced germination of *O. ramosa*. *D. uncinatum* and *D. dichotomum* curtailed *Striga* attachment to sorghum roots. Potted *D. tortuosum*, was slightly more drought tolerant than the other species. At its lowest level of infestation (5mg/ pot), *Striga* emergence significantly declined at the highest *D. uncinatum* population density. *D. dichotomum* when planted 60 days prior to sorghum was more effective in suppressing the parasite than when planted 30, 90 days prior to sorghum or planted on the same day as sorghum. In field trials, *D. uncinatum* and *D. intortum* gave the lowest stand in comparison with other species. None of the *Desmodium* species showed regeneration in the second season. Field trials at GRSF revealed that sorghum planted in plots previously sown to *D. dichotomum* and *D. tortuosum* displayed 39 and 77% increase in grain yield, respectively. In season 2008/09 trials at GRSF, employing two sorghum genotypes, intercropping with *D. dichotomum* reduced *Striga* emergence, *Striga* biomass and increased yield by 161%. At Gedarif (2007/08), intercropping of sorghum, cv. Korokollo, with *D. dichotomum* increased grain yield significantly. Intercropping with other *Desmodium* species increased grain yield over the sole crop, albeit not significantly. Field trials on tomato undertaken in 2006/07 showed that *Desmodium* species, planted between holes or in the same hole as tomatoes, reduced *O. ramosa* emergence and increased tomato yield significantly. However, the increase in yield was not significant in season (2007/08).

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CHAPTER ONE

INTRODUCTION

Parasitic plants (3,000 - 5,000 species) occur in about 20 families of the plant kingdom (Aly, 2007). Among the parasitic angiosperms, witchweeds (*Striga* spp.) and broomrapes (*Orobanche* spp.), in the family Orobanchaceae, are root parasitic weeds of significant economic impact on agriculture in many countries across the globe (Babiker *et al*., 2007).

Striga species are restricted to the tropics and subtropics (Musselman, 1987 b). They parasitize cereals and leguminous crops mostly, in the Savannas of Africa. They are recognized as serious pests in 42 countries, negatively affecting the lives of over 100 million people in Africa (Mboob, 1986). About 21 million ha of the area under cereals in Africa is estimated to be infested by *Striga* causing an annual grain loss of about 8 million tons (Gressel *et al*., 2004). Moreover, the parasites constitute a threat to over 73 million ha of land devoted to cereals production in the continent (Sauerborn, 1991b). The monetary value of the loss due to *Striga* damage is about US$ 7 billion (Mboob, 1986). In infested areas, yield losses associated with *Striga* damage in West Africa are often significant, ranging from 40 to 90% (Lagoke *et al*., 1991; Ejeta and Butler, 1993).

Sorghum (*Sorghum bicolor* L. Moench), a principal cereal that forms an important staple diet throughout semiarid Asia and Africa, is the main host of

the parasite (Ahmed *et al*, 2000). Sorghum ranks fifth in importance as a cereal crop worldwide in terms of area, grain yield and production.

In Sudan, the area under sorghum constitutes 74% of the area under cereals and 45% of the total cultivated areas (Babiker, 2007). Furthermore, sorghum is the major staple food crop especially in rural areas. In many parts, the crop is wholly utilized. Production of the crop is seriously constrained by *S. hermonthica* and more than 10% of the area under sorghum is infested by the parasite (Babiker, 2002). Losses in yield were reported to range between 65-100 % (Ejeta *et al*., 1993; Babiker, 2002). Complete crop failure is not uncommon under heavy infestations (Hamdoun and Babiker, 1988).

Orobanche spp are considered as important pests in the Middle East, the Mediterranean Region and North Africa (Parker and Riches, 1993). Of the *Orobanche* species, *O. ramosa* L. and *O. crenata* Forsk., in particular, are major biotic factors that limit production of solanaceous crops including tomato (*Lycopersicon esculentum* Mill.) , potato (*Solanum tuberosum* L.) and eggplant (*Solanum melongena* L *)* and crops of the family fabaceae viz faba bean (*Vicia faba* L.) and chickpea *(Cicer arietinum* L.).

Tomatoes are one of the most widely produced and consumed vegetables in the world (temperate and tropical regions), for both fresh fruit market and processed food industries (Matto and Razdan, 2008).

Tomato, potato and eggplant are the major solanaceous crops in the Sudan. They are planted continuously in limited areas around major cities mainly on the alluvial fertile soils in the Nile valley. The total area under tomato, potato and eggplant is 33,000, 18,500 and 2,800 ha, respectively (Anon, 2006). *O. ramosa*, a pest of significant economic importance on solanaceous crops, was first observed as a pest in Khartoum State in the 1970s. However, by the 1990s the parasite has become widely spread in all production areas across the country and many farmers had to abandon their farms (Babiker *et al.*, 2004; 2007). Recently, *O. crenata* has become a threat to faba bean production. The infested area, as revealed by a survey undertaken in 2005, was estimated to be about 1 and 12 % of the total area under faba bean in the River Nile State and the Northern State, respectively (Babkier *et al.*, 2004). The parasite has been identified in 73 widely distributed sites within the faba beans production area. The production area (63,000 ha) is a strip of land within the Nile Valley extending from Khartoum northwards to Wadi Halfa on the Egyptian border.

Food crop losses from *Orobanche* spp. in the Middle East are conservatively estimated at a billion dollars annually (Aly, 2007). Sauerborn (1991b) estimated that over one million hactares of faba bean in the Mediterranean region and western Asia are infested or at risk from *O. crenata.* The parasite can cause losses of up to 100% on farmers fields, which they often have to abandon due to non- productivity (Kroschel and Klein, 2004). Yield

losses due to *Orobanche* spp. range from 5 to 100% depending on host susceptibility, level of infestation and environmental conditions (Abang *et al*., 2007). Major impedance to the control of *Striga* and *Orobanche* species is the production of large number of seeds, which are easily dispersed and remain viable in the soil for long periods even in the absence of the host and the high damage that they cause at the subterranean stage.

Seed germination and attachment are key phases in the life cycle of parasitic plants. Thus, the ideal solution to the problem would be inhibition of attachment to the host root without impairing germination. Such a solution results in depletion of seed reserves in soil in addition to curtailment of damage to the host by the parasite. Most of the available means of control viz resistant varieties, cultural, chemical and biological methods are either not satisfactory, have inconsistent performance, have no effects on current crop or expensive for subsistence farmers. The need for a management approach that provides a greater level of protection, does not involve a high level of skill and at the same time environmentally friendly, cost effective and sustainable is imperative. Farmers are in need for low-input solutions to the problem. In ICIPE, Khan *et al*, (2000, 2001, 2002, 2006, 2007 and 2008) demonstrated that intercropping maize or sorghum with the fodder leguminous weeds *Desmodium uncinatum* (Jacq.) DC. and *D. intortum* (Mill.) Urb, significantly reduced *S. hermonthica* infestation and increased grain yield. In Sudan, different *Desmodium* spp viz *D.*

dichotomum (Klein) DC. , *D. adsendens* (SW.) DC. , *D. iasiocarpum* (Beauv.) DC. and *D. repandum* (Vahl) DC were reported, mainly in the rain -fed areas (Andrews, 1952).

The present study was undertaken with the primary objective of developing simple, environmentally friendly methods for control of S. *hermonthica* in sorghum and *O. ramosa* in tomato focusing on intercropping with drought tolerant *Desmodium* spp. However, in Kenya in Lake Vectoria basin, where the technique of intercropping with *Desmodium* spp. is most successful, bimodal rains are predominant. The perennial *Desmodium* species survive once established. In Sudan, in the central clay plain where *Striga* predominates, the rainy season is short. It extends from July to October. Moreover, soil surface temperature, in the dry season often exceeds 40- 50 ºC. In winter, when tomatoes, the major host of *O. ramosa*, are planted, low temperature is predominant. The need for testing and selecting *Desmodium* species for drought tolerance and ability to survive, the dry hot period between rainy seasons and capacity to germinate and grow in the relatively cool winter is imperative. The secondary objectives were to i) examine the effects of temperature on germination of different *Desmodium* species, and ii) screen *Desmodium* species for drought tolerance.

Chapter two

Literature review

2.1. General:

Parasitic plants are plants that obtain their resources (assimilates, water, nutrients) partly or completely from another host plant. Today, parasitic plants from 20 families have been recognized as serious pests causing considerable economic damage (Aly, 2007). Parasitic plants are among the most destructive known weeds (Parker and Riches, 1993). They adopt different forms to invade host plants. Some invade the underground roots such as *Striga* spp. and *Orobanche* spp. (Joel *et al*., 2007), whereas, others invade the aerial parts such as dodders and mistletoes (Aly, 2007). Parasitic weeds vary widely in their degree of host dependence. Some parasites have an absolute host requirement, but retain some photosynthetic capacity (obligate hemi- parasites.) i.e., *Striga* and *Alectra*. Other parasites lack chlorophyl and are completely reliant on the host for all nutritional needs e.g *Orobanche* spp. (Parker and Riches, 1993). Although *Striga* and *Orobanche* species occur in different parts of the world, their life cycles are very similar (Bouwmeester *et al*., 2003). Hence, the two genera, *Striga* and *Orobanche*, will be reviewed together, as they are the most economically significant higher plant parasitic genera (Plate 1).

These unique organisms in the genera *Striga* and *Orobanche* are both weeds and parasites. As weeds, they show great phenotypic plasticity and wide environmental tolerance. As parasites, they depend upon another vascular plant for nutrients or water, which flow from host to parasite through haustoria. Haustoria form a morphological and physiological graft with the roots of the host.

2.2. *Striga* and *Orobanche* species:

Striga spp. (witchweeds) belong to the family Orobanchaceae (Matusova *et al*, 2005). They are an endemic problem in Africa's cereal and legume crops (Ejeta *et al*., 1993). The common name witchweed ascribed to these weeds befits the debilitating and bewitching effects they inflict on host plants even before they emerge and become visible above the ground (Joel *et al*., 2007). Three species are seriously damaging. These are *S. asiatica* and *S. hermonthica* that are almost entirely specific to grasses and are, therefore, important parasites of cereal crops like sorghum, pearl millet {*Pennisetum glaucum* (L.) R. Br.} and upland rice (*Oryza sativa* L.) (Ejeta *et al*. 1993; Kroschel, 1999; Bouwmeester *et al*., 2003 and Oswald, 2005). These crops are the major staple food for over 300 million people in Sub- Saharan Africa. *S. gesnerioides* attacks dicot hosts, mainly cowpea {*Vigna unguiculata* (L.) Walp} and tobacco

(*Nicotiana tabacum* L.) (Emechebe *et al*., 1991; Parker and Riches, 1993; Kroschel, 1999; Oswald, 2005 and Dugje *et al*, 2006).

Orobanche spp. (Broomrapes) belong to the family Orobanchaceae and are widespread in Mediterranean areas in Asia, Southern and Eastern Europe and North Africa attacking dicotyledonous crops (Parker and Riches, 1993). The Latin name *Orobanche* is derived from the Greek Orobos, a vetch, and ancho, to strangle, referring to the effect these parasites have on their hosts (Joel *et al*., 2007). The common name " broomrape" ascribed to these weeds is a translation of mediveal Latin *Rapum genistea* "broom knob", rapum being a knob (or tubercle, i.e. the young parasites) formed on the roots of broom (*Genista* sp.) that is a common host of *O. majus* in Europe (Joel *et al*., 2007). The genus *Orobanche* has more than 100 species, but the most economically important are *O. aegyptiaca* (Pers.), *O. ramosa*, *O. cernua*, *O. minor* (Sm), *O. crenata* (Forsk.) and *O. foetida* (Poir) (Parker and Riches, 1993). Unlike the *Striga* species, which are usually rather selective in their host preference, some *Orobanche* spp. are less selective and may attack a variety of host crops belonging to various families (Joel *et al*., 2007).

Striga hermonthica on sorghum *Orobanche ramosa* on tomato

Plate 1. Photographs of *Striga* and *Orobanche*.

2.3. Geographic distribution of *Striga* and *Orobanche* spp.:

About 40 *Striga* species are reported worldwide. Most of them are found in Africa (Kroschel, 2001; Kroschel and Müller- Stöver, 2004). Economically important *Striga* spp. are reported from more than 50 countries, especially from East and West Africa and Asia (Aly, 2007). *Striga* has been a problem even in the United States (Ejeta, 2007). At least 11 of these species parasitize crops and pose one of the most severe biological constraints to agriculture in low- input farming systems especially in the African Savanna (Parker and Riches, 1993). *S. hermonthica* is common throughout northern tropical Africa and extends from Ethiopia and Sudan to West Africa. It also extends from the western Arabian region southwards into Angola and Namibia (Gethi and Smith, 2004).

S. asiatica has a wider distribution and is found throughout semi-arid areas of tropical and subtropical Africa, Asia and Australia (Gethi and Smith, 2004). *Striga* is most prevalent where plants are grown under moisture stress or where soil fertility is low (Gethi and Smith, 2004). In Sudan, the parasite is widely distributed throughout the whole country causing serious crop losses to subsistence crops i.e sorghum and millet (Ismail, 1979). Dawoud *et al*. (2007) reported that the parasite is listed as one of the most harmful weeds and constitute a major threat to sorghum production.

Orobanche species are found in temperate regions of the northern hemisphere as well as in the sub-tropics and tropics, especially in arid and semi-arid regions (Kroschel, 2001). Their main centre of origin is the Mediterranean region where large areas are heavily infested (Parker and Riches, 1993; Aksoy and Bulbul, 2004). Recently, several *Orobanche* spp. have become problematic in many African countries including Sudan (Babiker *et al*, 2007).

In Sudan, three *Orobanche* species, *O. ramosa* L., *O. cernua* Loef. Var desertorum (G. Beck) Stapf and *O. minor* SM. were reported as early as 1948 as minor pests on horticultural crops, ornamental plants and common weeds (Andrews, 1956). *O. crenata* Forsk, was introduced recently as it was not reported prior to the year 2001 (Babiker *et al*., 2004). *O. ramosa* and *O. crenata*, the most noxious and pestiferous in among *Orobanche* spp., are

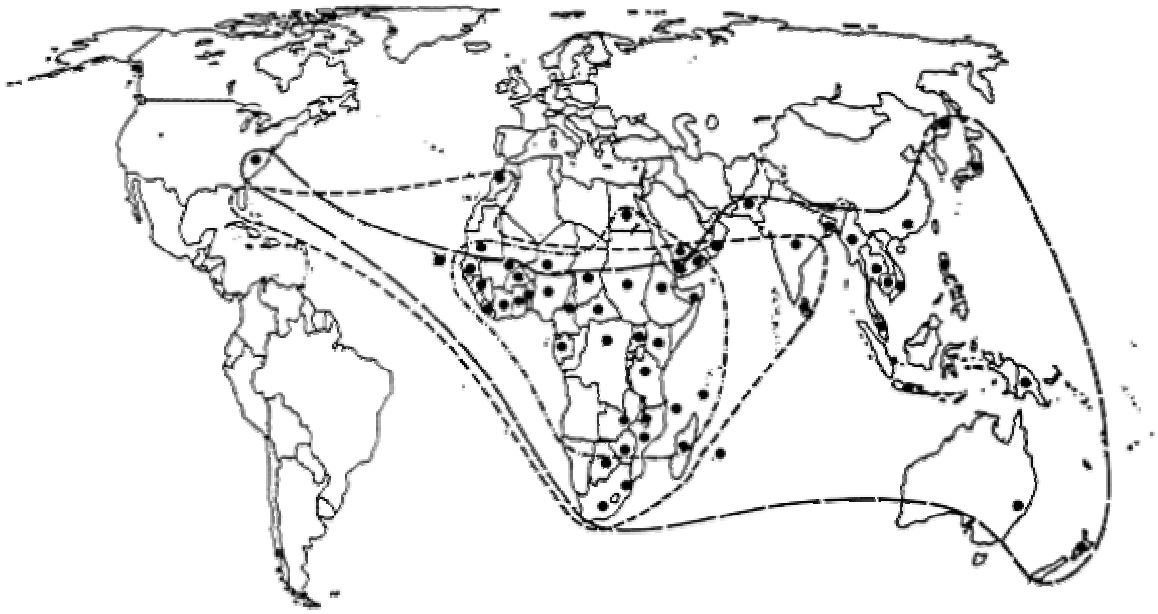
confined, mainly, to the fertile alluvial soils of the Nile Valley (Babiker *et al*., 2007). *O. ramosa* (branched broomrape) was first reported in Wadi Halfa on the southern border of Egypt and in Khartoum in 1948 (Andrews, 1956). Since the 1970s, the parasite has become a major pest on solanaceous crops. It has spread into central Sudan and has become a limiting factor to tomato production in the rich alluvial soils along the Nile banks from El Gaily in Khartoum State to the southern borders of Gezira State. Recently, infestations were reported along the Blue Nile to the South of Roseries (Babiker *et al*., 2007). Map 1 and 2 show the worldwide distribution of *Striga* and *Orobanche* species, respectively.

2.4. Origin of *Striga* and *Orobanche* species:

The center of origin of *S. hermonthica* is thought to be the northern part of Ethiopia (Tigray) and Nuba Mountains of Sudan. These regions are also the origin of sorghum. Therefore, it can be assumed that the distribution of *S. hermonthica* was associated with sorghum seeds trade to other parts of Africa (Kroschel, 2001).

According to Sauerborn (1991a), the centre of origin of *Orobanche* species are Italy, Spain, Turkey and Morocco. Different species achieved broader distribution through international trade and commercial exchange of contaminated seeds that contributed to the worldwide spread (Abu-Irmaileh, 2004).

Map 1. World wide distribution of important *Striga* species (Source: Suerborn, 1992)

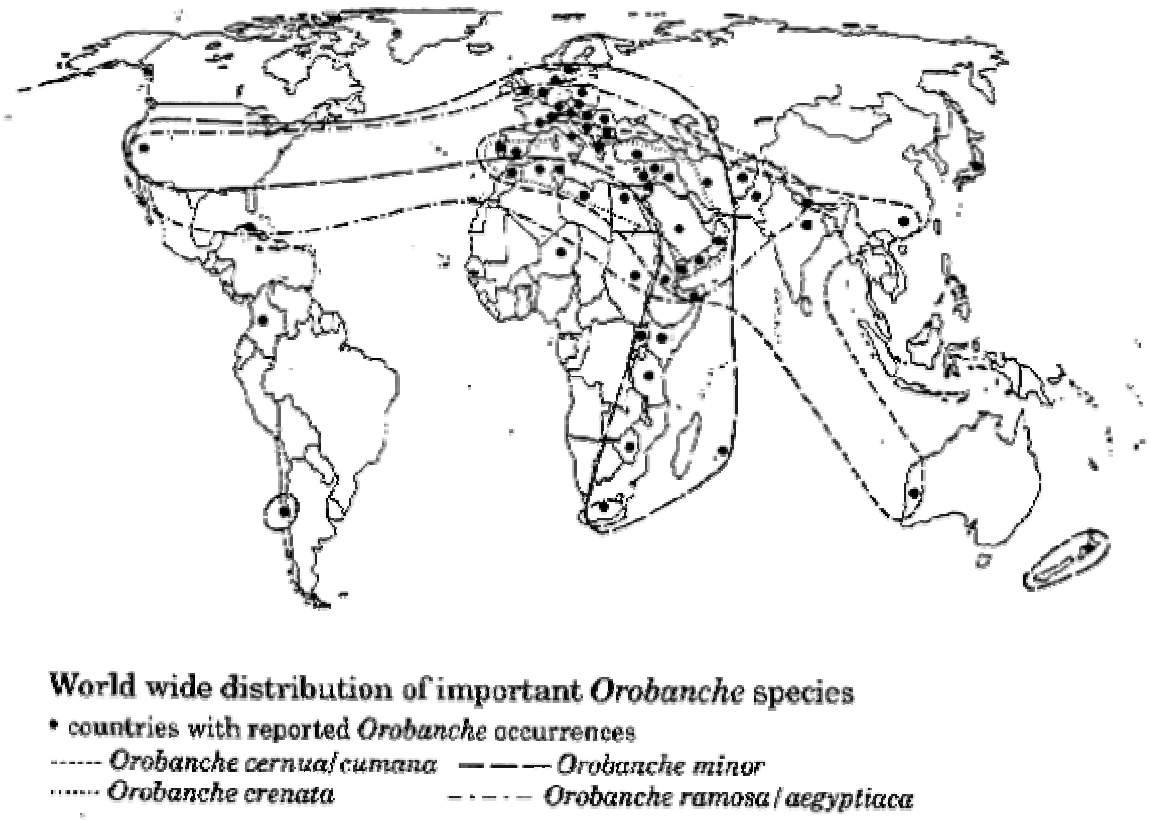


World wide distribution of important *Striga* species

• countries with reported *Striga* occurrences

— — *Striga asiatica* – – – *Striga gesnerioides* – · – · – *Striga hermonthica*

Map 2. World wide distribution of important *Orobanche* species (Source: Sauerborn, 1992)



2.5. Economic importance of *Striga* and *Orobanche* species:

Parasitic weeds develop a strong sink, which allows them to remove water, minerals and photosynthates from the crop. Thus, infection by parasitic weeds reduces the ability of the hosts to grow and yield (Joel *et al*., 2007). *Striga* and *Orobanche* cause significant yield and quality losses in many important crops and affect the livelihoods of millions of people worldwide (Parker and Riches, 1993). The root parasites *Striga* and *Orobanche* spp. exert the greatest damage prior to their emergence (Parker, 1991; Matusova *et al*., 2005 and Sauerborn *et al*, 2007), and the majority of field loss may occur before diagnosis of infection (Joel, 2000).

The economic impact of *Striga* species is greatest in cereals cultivated in Africa, e.g., sorghum, pearl millet and maize (*Zea mays* L.). The most destructive species on cereal crops are *S. hermonthica* and *S. asiatica*. Damage to crops by *Striga* is often severe (Joel *et al*., 2007). About 21 million hectares of cereal production area in Africa is estimated to be infested by *Striga* causing an annual grain loss of about 8 million tons (Gressel *et al*., 2004). *Stirga* spp. are recognized as serious pests in 42 countries, negatively affecting the lives of over 100 million people in Africa (Mboob, 1986). At present the area infested by *Striga* spp. is estimated to be 3, 1.4 and 3.5 million hectares in East and Central Africa, Southern Africa and Western Africa, respectively. These

estimates are consistent with predictions based on ecological modeling, species genetic diversity, invasiveness, plasticity and ecological profile (Mohammed *et al*., 2007). A survey conducted by Dugje *et al* (2006) in the three Savanna zones, Sudan (SS), Northern Guinea (NGS), and Southern Guinea (SGS), revealed that four common *Striga* spp. were predominant. These species were *S. hermonthica*, *S. aspera* (Willd.) Benth, *S. gesnerioides*, and *S. densiflora*, Benth. Maize and sorghum fields were mostly infested by S. *hermonthica*, whereas, rice fields were mainly infested by *S. aspera*. *S. gesnerioides* was the dominant parasitic weed species present in sole cowpea fields. *Striga* species infested 60, 68 and 74% of the fields in SGS, SS and NGS, respectively. The levels of infestation of the fields were 34% in weedy fallows, 44% in rice, 77% in maize, 80 % in cowpea, 84% in pearl millet and 94% in sorghum (Dugje *et al*., 2006).

Striga has become a poor man's problem in Africa (Joel *et al*., 2007). Crop losses due to *Striga* infestation are usually high with range of estimates varying depending on the crop cultivars and degree of infestation. In many places in Africa and India, the parasite infestation has reached epidemic proportions and is presenting a rather desperate situation to subsistence agriculture. The *Striga* problem in Africa is particularly increasing because purchase of agricultural inputs is unaffordable, and population growth has

forced alteration of traditional methods of prolonged fallows and intercroppings to meet the growing demand on farm land and food production (Joel *et al*., 2007).

Food crop losses from *Orobanche* spp. in the Middle East are conservatively estimated at billion dollars annually (Aly, 2007). Sauerborn (1991 b) estimated that over one million hectares of faba bean in the Mediterranean region and western Asia are infested or at risk from *O. crenata.* The parasites can cause losses of up to 100% on farmer's field, which they often have to abandon due to non- productivity (Kroschel and Klein, 2004). Yield losses due to *Orobanche* spp. range from 5 to 100% depending on host susceptibility, level of infestation and environmental conditions (Abang *et al*., 2007). Besides causing yield loss and reduction in cropped area, *Striga* and *Orobanche* also reduce crop quality. The presence of broomrape plant materials in a harvested crop produce may reduce the value of the latter or make it unmarketable.

2.6. Growth and development of *Striga* and *Orobanche* species:

2.6.1. Seeds of *Striga* and *Orobanche* species:

The seeds of obligate parasitic weeds are very small; approximately 0.2 to 0.35 mm long (Joel *et al*., 2007). These seeds are the main vehicle for the spread of the parasites. The seeds are easily carried by farm and construction

equipment, water, wind or animal droppings. Each plant may produce 50,000 or more seeds depending on the species and conditions for plant development (Ejeta and Butler, 1993). The seeds are long lived, some surviving in the soil for more than 10 years (Parker and Riches, 1993; Al- Khteeb *et al*., 2005), until induced to germinate by root exudates.

2.6.2. After- ripening

The seeds of *Striga* and *Orobanche* need to pass a rest period after they are mature. This period is generally called after- ripening or post- harvest ripening (Dawoud, 1995). This period is defined as the time between shedding of the seeds and their ability to respond to germination stimulants applied subsequent to conditioning (Musselman, 1979). After- ripening is influenced by temperature. In certain *Striga* species this period lasts several months, while in certain populations of *Orobanche* this period is limited to few weeks (Ejeta and Butler, 1993).

2.6.3. Conditioning:

Seeds of most of the parasitic weeds taxa remain dormant in the soil and do not germinate unless they are exposed to moist warm conditions for some days before they receive the germination stimulant (Dawoud, 1995). This process is termed conditioning (Joel *et al*., 2007), or pre- treatment (Babiker, 2007). The length and effectiveness of the pre- treament period may vary with

temperature, humidity, and other environmental factors (Musselman, 1987a). During conditioning, seed coat permeability may increase and /or changes in the levels or activities of endogenous germination promoters or inhibitors may occur (Musselman, 1987a).

2.6.4. Germination stimulation:

The seeds of parasitic plants of the genera *Striga* and *Orobanche* species will only germinate after induction by a chemical signal exuded from the roots of their hosts (Matusova *et al*, 2005). It has also been found that roots of a number of non- host (false hosts) can exude germination stimulants. Cook *et al.* (1972) were able to isolate and identify the first germination stimulant, Strigol, from the root exudates of cotton (*Gossypium hirsutum* L.), a non- host plant. So far, several of these germination stimulants have been isolated and identified in the root exudates of a series of host plants of both *Striga* and *Orobanche* species. In most cases, the compounds were shown to be isoprenoids and belong to one chemical class, collectively called the Strigolactones (Matusova *et al*., 2005).

2.6.5. Haustorial initiation:

In order to attach to their hosts, the obligate root parasites must form a special organ called the haustorium, from the latin *haurire*, to drink (Joel *et al.*, 2007). With initiation of haustorium, the apical meristem of the radicle switches

from extension in longitudinal direction to radial division resulting in swelling and proliferation of hair- like projections. The haustoria of *Striga* are generally more pronounced in their characteristics than those of *Orobanche* (Joel *et al*., 2007). As with germination transition, the parasite use host- derived signals to trigger this developmental transition. The chemical stimulants, kinetin, simple phenolic compounds, and quinones like 2, 6- dimethoxy-p-benzoquinone (DMBQ), are active haustorial initiators (Riopel and Timko, 1995).

2.6.6. Attachment and penetration:

The seeds of *Striga* and *Orobanche* spp. contain small amount of food reserves, and can only survive for a few days after germination unless they reach a host root and a xylem connection is established (Matusova *et al*., 2005). Attachment of the parasite to host root surface takes place as soon as the parasite meets host roots (Joel, 2000). This is facilitated by the secretion of an adhesive substance by the parasite (Joel and Losner-Goshen, 1994). Penetration is the first stage of intimate contact between cells of host and parasite. This is also the beginning of the true parasitic phase in which the parasites take nutrients and water from the host. Therefore, it is crucial to any further development of the parasite.

2.6.7. The mature parasite:

After the establishment of conductive connection between host and parasite, the parasite develops a tubercle that accumulates nutrients. The tubercle is a juvenile parasite. At a certain stage, it matures and forms a flowering shoot that emerges above soil surface and produces flowers and seeds. The development of both the juvenile and the mature parasites is coordinated with that of the host (Joel, 2000).

2.7. Life cycles of *Striga* and *Orobanche* species:

Although *Striga* and *Orobanche* species are parasites in different parts of the world, their life cycles are broadly similar (Bouwmeester *et al*., 2003). Figures 1 and 2 illustrate the life cycle of root parasitic weeds, *Striga* and *Orobanche*, which reflects a high dependence of the parasite on the host. The parasites depend on their hosts not only during the early developmental stages but even after the parasite emerges and develops to maturity. The important steps in the life cycle are germination, radicle growth to the host root, haustorium formation, attachment to the host root, successful establishment of a xylem connection and compatible interactions and production of seeds (Matusova *et al*., 2005). The minimal length of the life cycle of *Striga*, from germination to seed production, averages 4 months (Babiker, 2007), while that of *Orobanche* requires about 3- 7 months (Linke *et al*., 1989).

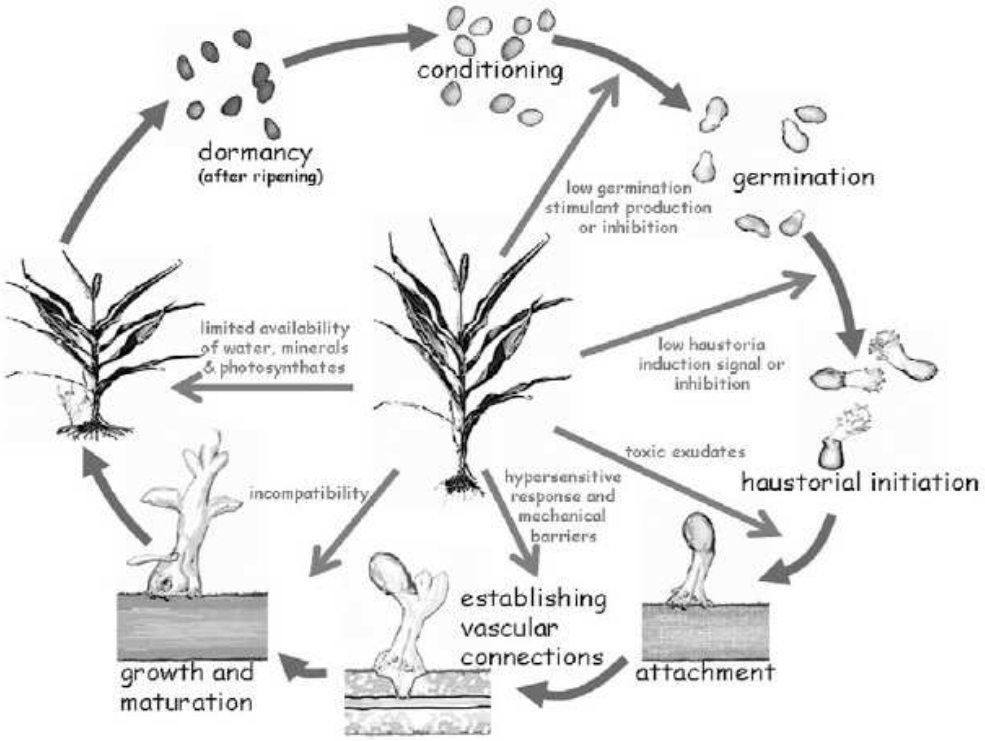


Figure1. Life cycle of *Striga* species (Source: Ejeta, 2007)

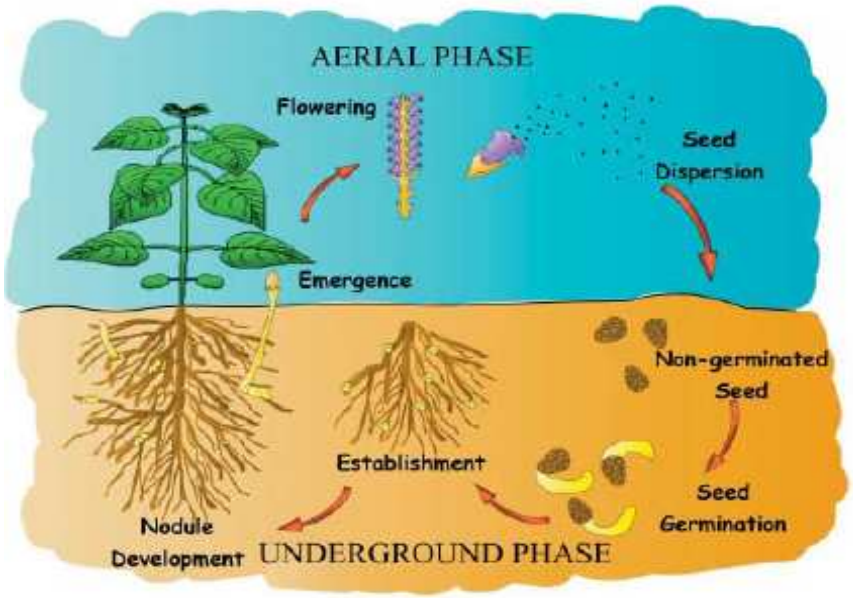


Figure 2. Life cycle of *Orobanche* species (Source: Rispail *et al*., 2007)

2.8. Management of *Striga* and *Orobanche* species:

Management of parasitic weeds is often difficult due to several reasons. These include the high amount of seed produced, viability and longitivity of seeds in the soil over years (Lagoke *et al*., 1991; Parker and Riches, 1993; Kostovik and Slavov 2007), lack of seed germination in the absence of a chemical trigger from a suitable host, vigorous growth habit after emergence and close association with the host (Joel *et al*, 2007.; Aly, 2007). A range of parasitic weed management practices have been developed that can be broadly classified under the general themes of chemical, cultural, biological and host- plant resistance (Lagoke *et al*., 1991; Parker and Riches, 1993; Babiker, 2007; Aly, 2007).

2.8.1. Cultural control:

2.8.1.1. Hand- weeding:

Hand- pulling is the simplest and certainly the most effective method to apply in small fields with low level of infestation of *Striga* or *Orobanche* species (Parker and Riches, 1993; Babiker, 2007). The practical use of hand- pulling varies according to the parasite in question. For *Striga* hand- pulling had to be delayed to flowering. Hand- pulling of young *Striga* seedling is difficult after the seedling breaks and regenerate from the broken stump. *O. minor, O. ceruna*

and *O. crenata* are easy to locate and grip, while the small, much branched *O. ramosa* can be much more difficult and time consuming to hand pull (Parker and Riches, 1993). Hand- weeding is labour intensive, tiresome, when heavy infestations develop (Lagoke *et al*., 1991). Generally, farmers are reluctant to adopt hand- weeding as it often provides no immediate benefits to the current crop (Babiker, 2007).

2.8.1.2. Crop rotation:

Rotation, with non- host crops in general, prevents annual build up of parasitic weeds seed bank. Rotating *Striga* and/or *Orobanche* susceptible crops with those that stimulate parasite germination without being parasitized (trap crops), has been advocated as an effictive measure for reducing parasite seed bank (Parker and Riches, 1993). For *Striga*, common cultivated trap crops include cotton (*Gossypium* spp.), groundnut (*Arachis hypogaea* L.), sun hemp (*Crotalaria juncea* L.), pigeon pea (*Cajanus cajan* L.), green or black- gram *(Phaseolus mungo* L.), Lucerne (*Medicago sativa* L.), sunflower (*Helianthus annuus* L.) and sesame (*Sesamum indicum* L.). Leguminous crops have been reported to decrease *Striga* seed bank and increase yield of subsequent cereal crops. In Sudan, a crop sequence of onion (*Allium cepa* L.)-alfalfa and alfalfa reduced *O. ramosa* emergence in subsequent tomato to 25 % and increased crop yield by more than 50% (Babiker *et al*., 2007). Flax (*Linum usitatissimum* L.)

has a good potential as a trap crop for *O. ramosa* infesting tomato. Planting flax for a period of 4 to 6 weeks and then planting tomato can effectively decrease infestation in tomato (Abu- Irmaileh, 1984). Planting of false or trap crops to curb *Orobanche* infestation is predominant in northern Sudan where the area under faba bean was reduced to about 50 and 60% of that prior to *O. crenata* infestation (Babiker *et al*., 2007). These false hosts include French bean (*Phaselous vulgaris* L.), berseem (*Trifolium alexandrinum* L.), onion, sorghum and wheat (*Triticum aestivum* L.). Major constraints to adoption of crop rotation include adaptation of the introduced crop to the farming system, food habit and availability of markets (Babiker, 2007).

2.8.1.3. Catch cropping:

Catch- cropping is another means of depleting *Striga* and *Orobanche* seed reserves in soil. Contrary to trap cropping, which relies on false hosts, catch cropping employs true hosts of the parasite (Babiker, 2007). The susceptible crop is planted at high density and then sacrificed 6- 8 weeks later prior to peak emergence of the parasite. Sudan grass {*Sorghum sudanense* (Piper) Stapf} grown for 5 weeks as a catch crop, before sowing of sorghum as the main crop, significantly decreased the incidence of *Striga* and increased grain yield of sorghum in Sudan (Last, 1961). However, the cropping season is rather short and may not allow for a second crop. Another technique,

"Sarwala", which combines the effects of catch cropping and at the same time preserves a crop was developed by farmers, and further improved by Yousif (2001). In this technique sorghum densely planted, is allowed to grow for 3- 6 weeks and then disc- harrowed to normal stand (Yousif, 2001). This technique significantly increased sorghum yield and decreased the number of *S. hermonthica*.

Although the use of trap and catch crops may be useful tools for depletion of *Striga* seed reserves in soil, their use is often not feasible in many areas where subsistence farming is prevalent and farmers can not leave long rotational gaps between major food crops (Adam, 1985).

2.8.1.4. Intercropping:

Intercropping cereals with legumes and other crops is a traditiotional African farming practice. Parker and Riches (1993) showed that *S. hermonthica* is significantly reduced by intercropping in West Africa. Intercropping maize with cowpea and sweet potato significantly reduced emergence of *Striga* in Kenya (Oswald *et al*., 2002). Research work in Sudan showed that intercropping is a valuable, cheap and effective method for suppressing localized infestations of *Striga* on relatively small farms (Babiker, 2002; Dawoud *et al*., 2007). Intra- row planting of hyacinth bean, *Lablab purpureus* (L), 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). Parker and Riches (1993) attributed the suppressive effects of intercropping to several factors, including its action as trap- crop, interference with production of germination stimulants, exudation of germination stimulants, decreasing air temperature and increasing humidity. Research results from Kenya using silver leaf {*Desmodium uncinatum* (Jacq.) Dc} and green leaf {*D. intortum* (Mill.) Urb} by Khan *et al.*, (2002) showed that the action of intercrops may be much more complex than originally thought and indicated exudation of allelopathic compounds which induce pre- mature haustoria, curtail radicle extension and thereby decrease attachment and parasitism without influencing germination. *Desmodium* spp., apart from successful suppression of *Striga* and increasing grain yield by several fold, are repellent to the stem borers {*Busseolo fusca* (Noctuidae)} and *Chilo partellus* (Pyralidae), excellent nitrogen fixers (100-180 kg nitrogen/ ha), preserve soil moisture and are high value fodders (Khan *et al.*, 2002). Intercropping with *Desmodium* spp. represents a platform technology around which new income generation components such as livestock keeping can be built. At present, intercropping with *Desmodium* spp. to combat *Striga* and insect pests in maize is adopted by over 6 thousand farmers in western Kenya and eastern Uganda (Khan, Z.R., 2006, Personal contact).

Intercropping faba bean with some trap crops like flax and fenugreek (*Trigonella foenum- graecum* L.) significantly reduced the infestation level of *Orobanche*. Inhibition of *O. crenata* seed germination by allelochemicals released by fenugreek roots is suggested as mechanism for reduction of O. *crenata* (Fernāndez- Aparicio *et al*., 2008).

2.8.1.5. Fertilizers:

The *Striga* problem and its debilitating effects have been linked with low soil fertility, particularly nitrogen (Ejeta *et al*., 1993). Agabawi and Younis (1965) reported that nitrogen delayed *Striga* emergence, reduced infestation and increased grain yield. However, fertilizers are expensive, not always available and their use in low- rain fall areas is fraught with an element of risk (Babiker, 2007).

Orobanche tends to be associated with less fertile soil conditions. High levels of nitrogen fertilizer and chicken manure showed suppressive effects. There is no full understanding of the mechanism of such a suppressive effect. The input of nitrogenous fertilizes to the rain fed cropping system of food legumes is of low consideration due to the high cost of fertilizers (Abu-Irmaileh, 2004).

2.8.2. Chemical control:

Various chemicals including synthetic germination stimulants, fumigants, antitranspirants and herbicides have been reported as means of control of *Striga* and *Orobanche* spp. (Parker and Riches, 1993; Aly, 2007). Induction of *Striga* seed germination in absence of host plants, suicidal germination, has been the subject of numerous researchers (Parker and Riches, 1993). Ethylene is very effective against *S. hermonthica*, but not *S. gesnerioides* (Eplee and Norris, 1995). However, ethylene is a pressurized gas, flammable and requires specialized storage and application equipment for soil injection (Babiker, 2007). Soil fumigation with methyl bromide is effective for control of both *Striga* and *Orobanche* (Parker and Riches, 1993; Abu- Irmaileh, 2004). However, because of high cost, labour and equipment requirements as well as health risk the product is not considered suitable for commercial application (Aly, 2007). Some chemicals have become available for parasitic weeds control, but only few herbicides are selective enough (Gressel *et al*., 2004).

Dicamba and 2, 4- D are the most widely used herbicides against *Striga* (Aly, 2007). Dicamba is a systemic herbicide applied to the crop foliage about 35 days after crop emergence, whereas, 2, 4- D is sprayed several times directly on the parasites during the growing season. The herbicides that are currently in use for *Orobanche* control are glyphosate, inhibitor of 5- enolpyruvyl

shikimate- 3- phosphate (EPSP) synthase- a key enzyme in the biosynthesis of the aromatic amino acids and imidazolinones and sulfonylureas, inhibitors of acetolectate synthase (ALS), a key enzyme in the biosynthesis of branched-chain amino acids (Joel *et al*., 2007). Other chemicals have been tested on *Striga* and *Orobanche* spp. and some provide good control (Parker, 1991; Haidar *et al*., 2005; Ransom *et al*., 2007). However, the chemical approach poses some difficulties. In among these difficulties are lack of application technology, chemical damage to the host, continuous parasite seed germination throughout the season, marginal crop selectivity and environmental pollution. Low persistence and availability are other major constraints that limit the successful usage of herbicides for parasitic weeds control (Aly, 2007). In addition, in developing countries, the income of subsistence farmers is usually too low to afford purchasing them (Babiker, 2007; Dawoud *et al*., 2007).

2.8.3. Biological control:

Biological control of weeds started in the last century using polyphagus insects as biocontrol agents for a number of weeds. Efforts were then extended, using plant pathogens after successive achievements on arable weeds, to parasitic weeds. The base of biological control of *Striga* and *Orobanche* is the use of natural enemies (insects or pathogens) to suppress *Striga* and *Orobanche* growth and to reduce their population and seeds bank in soils.

Natural enemies of *Striga* include the insects *Smicronyx albovariegatus*, *Ophiomyia strigalis*, and *Junonia* spp. (Bashir, 1987), and *Phytomyza orobanchia* for *Orobanche* (Kroschel and Müller- Stöver, 2004).

The *Smicronyx* spp. was found feeding as larvae on fruit, flowers, ovaries and on stems of *Striga* plants. The feeding activity of the larvae caused development of galls and reduced seed production (Parker and Riches, 1993). Injudicious use of pesticides, parasitoids and the polyphagous nature of some of these insects pose serious limitations on their use under practical field conditions (Babiker, 2007).

Fungal pathogens including several *Fusarium* species proved to be very effective on both *Striga* and *Orobanche* (Idris, 1997; Abbasher and Sauerborn, 1998; Zonno and Vurro, 2002; Boari and Vurro, 2004). However, mycotoxins produced by these fungi present a considerable risk to human and animal health. In Sudan, many species of fungi were isolated from diseased *Striga* plants i.e *Alternaria* spp., *Fusarium* spp., *Dreshlera* spp., *Curvularia* spp., *Aspergillus* spp., *Rhizoctonia* spp. and *Penicillium* spp. (Idris, 1997). However, there are concerns about the use of fungi in weed control regarding user and consumer safety as well as the specificity of the fungus (Babiker, 2007).

2.8.4. Host resistance:

The best long- term strategy for limiting damage by parasitic weeds is the development of resistant varieties (Parker, 1991; Abu-Irmaileh, 2004). However, conventional breeding has yielded few varieties with stable resistance, but genetic engineering may offer the possibility of creating novel resistance mechanisms that may be introduced into many commercial crops (Abu- Irmaileh, 2004). Three *Striga* resistant sorghum cultivars were officially released for wide cultivation in *Striga* endemic regions of Ethiopia in 1999-2002 (Elzein and Kroschel, 2003). For *Orobanche*, the outstanding example has been the development of sunflower varieties resistant to *O. cernua* and *O. cumana*. Unfortunately, this resistance has often been overcomed by new virulent 'races' of *Orobanche* in many countries in the Mediterranean region, eastern Europe, and the former Soviet Union (Fernădez- Martinez *et al*., 2005).

Two cultivars of faba been with a good level of resistance to *O. crenata* have been released in middle and upper Egypt (Elzein and Kroschel, 2003). In Southern Africa, few varieties with very high level of resistance to *S. hermonthica* were identified (Parker and Riches, 1993). These varieties include ICSV 0017, IS 6961, IS 777, IS 7739 and IS 14928. However, these varieties have very low yield and can only be used as sources of resistance (Babiker, 2007). In Sudan, two sorghum cultivars, SRN 39 (ICSV 1007 BF) and IS- 9830

were identified as resistant to *S. hermonthica* and were released as Mugawim Buda 1 and Mugawim Buda 2, respectively (Parker and Riches, 1993). However, because of unacceptable grain qualities and low yield, the cultivars were not widely adopted by farmers (Babiker, 2007). Moreover, SRN 39 has a lengthy milk stage which renders it susceptible to attack by the African boll worm (*Helicoverpa armigera*) (Babiker, 2007).

2.8.5. Integrated management:

Single methods are not sufficient to control parasitic weeds effectively in one cropping season. Therefore, combinations of control methods and their yearly application are the only solution. Integrated management strategies need to combine low- cost control methods that i) enhance crop tolerance to the parasite through improvement of soil fertility, particularly nitrogen status, ii) utilize the most tolerant cultivars available and iii) curtail replenishment of the parasite seed reserves in soil (Abu- Irmaileh, 2004).

Chapter Three

Materials and Methods

3.1. General:

A series of laboratory, green house and field experiments was conducted at Wad Medani, Gezira, central Sudan and Gedarif, eastern Sudan to evaluate several *Desmodium* species for drought tolerance, capacity to germinate under different temperatures and ability to suppress *Striga* on sorghum and *Orobanche* on tomato. The experiments were conducted during seasons 2006, 2007 and 2008/09 under irrigation at the Gezira Research Station (GRS). The GRS is located in Wad Medani, central Sudan (latitude 14°2 4' N, longitude 33°9' E) and altitude 407 m. The climate is semi-arid, with a short rainy season. The rainy season strats in July reaches a peak in August and ends late September or early October. The average rainfall is 350 mm per annum. Furthermore, some field trials on evaluation of *Desmodium* for *Striga* control on sorghum were undertaken in the rain fed areas at Gedarif Research Station Farm (latitude 14°01' and longitude 35°13' E) during seasons 2007 and 2008. The soil at both experimental sites is Vertisol (heavy cracking clay), with very low organic carbon and N content (0.03 %) (Hassan and Elasha, 2008). Tomatoes, were planted in winter under irrigation at GRS.

3.2. Seeds:

Seeds of *Desmodium distortum, D. tortuosum, D. uncinatum* and *D. intortum* were kindly received from the International Livestock Research Institute (ILRI) and International Centre of Insect Physiology and Ecology (ICIPE). Seeds of the local *Desmodium* genotype, *D. dichotomum*, were collected from Damazin and Kadugli henceforth referred to as Damazin and Kadugli collections, respectively. Seeds of sorghum cultivars, Arfa Gadamak, Hakika, Korokolo and Abu Sabeen and those of tomato**,** S. *hermonthica* and *O. ramosa*, were obtained from the stock of the weed control unit at Wad Medani.

S. hermonthica and *O. ramosa* seeds were sterilized using 1% sodium hypochlorite solution (NaOCl). The seeds were immersed in NaOCl solution for 5 minutes. NaOCl was drained off and the seeds were thoroughly washed with distilled sterilized water. The seeds were air dried and kept in small closed glass vials in a dark cupboard at ambient temperature till used.

3.3. Preconditioning of *Striga* and *Orobanche* seeds:

Glass- fiber filter papers (GFFP) placed in a Perti- dish, saturated with distilled water, were cut into 5 mm discs and placed in 9 cm Perti dishes, lined with moist glass fiber filter papers. The sterilized, dried *Striga* and *Orobanche* seeds were, aseptically sprinkled on the discs (approximately 20 to 50 seeds per disc). The filter paper was then wetted with more distilled water so that the seeds,

were sufficiently moistened. The seeds were incubated at 30 º C for *Striga* and at 25 ºC for *Orobanch*e, in the dark for a period of 8 to 14 days prior to use for germination assays.

3.4. Laboratory experiments:

3.4.1. General:

Five *Desmodium* species namely *D. distortum, D. tortuosum, D. uncinatum, D. intortum* and *D. dichotomum* (Damazin collection) were used. Unless otherwise mentioned, each species was tested in a separate experiment. In all experiments, treatments were arranged in a Complete Randomized Design with 4 replicates.

3.4.1.1. Influence of temperature on germination of *Desmodium* species:

Twenty five seeds of the respective *Desmodium* species were placed on filter papers in Petri dishes 9 cm (i.d.), and moistened with 5 ml distilled water. The Petri- dishes were then sealed with para-film, wrapped in aluminum foil and incubated at constant temperatures of 15, 20, 25 and 30 ° C in the dark. Germination counts were made daily over a period of 7 days.

3.4.1.2. Seed germination of *Desmodium* species under simulated drought:

Drought was simulated by using Polyethylene glycol 8000 (PEG 8000). Twenty five seeds of *Desmodium*, placed on filter papers in Petri dishes, were

moistened with 5 ml distilled water or aqueous solution of PEG 8000 at 50, 100, 150 and 200 g/L . The Petri- dishes were then sealed with para-film, wrapped in aluminum foil and incubated at 30 º C in the dark. The seeds were examined for germination over a period of 7 days.

3.4.1.3. Effects of *Desmodium* species root exudates on *S. hermonthica* and *O. ramosa* germination:

D. distortum, D. tortuosum, D. intortum, D. dichotomum and *D. uncinatum*, seedlings (25 each) were grown for 10 days on rock-wool under light in an incubator set at 30 ° C. Root exudates were collected, under suction using a pump. Five concentrations of GR 24 were prepared by sequential dilution of a stock solution with sterilized- distilled water to give 0.001, 0.0015, 0.01, 0.015 and 0.1 ppm solutions. A control with sterilized- distilled water was included for comparison. Discs containing pre-conditioned *Striga* seeds, incubated at 30° C in the dark for 10 days, were transferred to new Petri dishes (5 discs per treatment) and placed in the prefery of each Petri- dish. Each disc was then treated with 15 µl of the respective GR 24 solution or with 40 µl of *Desmodium* root exudates. A piece 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 Petri dishes, sealed with para- film and wrapped in aluminum foil, were incubated at 30 ºC in the dark. *Striga* seeds

were examined for germination 24 h later under a binocular stereomicroscope. Seeds were considered to have germinated when the radicle penetrated the seed coat. Conditioned *O. ramosa* seeds, similarly treated with GR 24, were incubated at 25 ºC and examined for germination 5 and 7 days after treatments.

3.4.1.4. Effects of *Desmodium* species root exudates on haustorium initiation in *S. hermonthica*:

Root exudates were collected from *D. dichotomum*, *D. intortum* and *D. uncinatum* seedlings, each grown on rock-wool as in 3.4.1.3. *Striga* seeds, placed on glass fiber discs pre- conditioned in water as in 3.3., were transferred to plastic culture plates with 24 wells. *Striga* seeds were treated with DMBQ at 10µM and *D. dichotomum*, *D. intortum* and *D. uncinatum* root exudates at 40µl, each alone or in mixture with DMBQ, 24 h subsequent to GR 24 (0.1 ppm) or simultaneously with it. The plates were sealed with para-film, wrapped with aluminum foil, placed in black polyethylene bags and incubated at 30º C in the dark for 24 h. *Striga* germilings were examined for haustorium induction after treatment.

3.4.1.5. Effects of *Desmodium* spp. on *S. hermonthica* parasitism:

A 3- days old sorghum (cv. Arfa Gadamak) seedling together with D. *dichotomum* and *D. uncinatum* seedlings (0, 1, 2, 3 and 4 in number) were

transferred to rock-wool, placed in plastic Petri dishes, with lateral openings to allow for emergence of sorghum and *Desmodium* shoots. Conditioned *Striga* seeds, placed on discs of glass fiber papers (0.5 mm), treated with GR 24 at 0.1 ppm or with distilled water, were placed near the sorghum roots. The Petri dishes were sealed with para-film, wrapped with aluminum foil, placed in black polyethylene bags and incubated at 30 ºC in continuous light. Sterilized distilled water was added to each Petri dish as needed. *Striga* attachment was examined 7 days after transfer.

3.5. Greenhouse experiments:

Each species of *Desmodium* was tested in a separate experiment. Treatments were arranged in a Complete Randomized Block Design with 3 or 4 replicates.

3.5.1. Effects of timing of irrigation on regeneration of *Desmodium* species:

Experiments were undertaken at GRS to investigate drought tolerance and regeneration capacity of *Desmodium* spp. Five *Desmodium* spp., namely; *D. distortum*, *D. tortuosum*, *D. dichotomum* (Damazin collection), *D. intortum* and *D. uncinatum* were planted during the last week of July, 2007 in pots buried to their rims in the ground. However, because of poor establishment and mortality of *D. intortum* and *D. uncinatum*, the experiment was repeated on the 20th of

November, 2007. *Desmodium* seedlings, thinned to 10, were allowed to grow till maturity and then cut. First irrigation was made at 0, 30, 60, 90 and 120 days after cutting and subsequently as needed. Regeneration of *Desmodium* spp. was assessed 15 and 30 days after initial irrigation.

3.5.2. Influence of *Desmodium* spp. population density on emergence of *S. hermonthica and* sorghum growth and yield:

Three *Desmodium* species namely, *D. dichotomum*, *D. uncinatum* and *D. intortum* were used. *Striga* seeds at 0, 5 and 10 mg were added to soil and hand mixed in the top 6 cm layer of each pot. *D. dichotomum*, *D. uncinatum* and *D. intortum* seeds were planted at 0, 5, 10, 15 and 20 seeds per pot on the second week of July. Sorghum cv. Arf Gadamak (5 seeds per pot) were planted in the same day as *Desmodium* and later thinned to 2 plants per pot. The pots received water every two days. *Striga* count, sorghum plant height and shoot dry weights were recorded at harvest. Sorghum shoots were cut at ground level, dried in a forced draught oven at 70º C for 48 h and then weighed.

3.5.3. Effects of *D. dichotomum* planting time on *S. hermonthica* incidence and sorghum performance:

Plastic pots, 20 cm i.d. and 18 cm high, with drainge holes at the bottom were filled with clay soil (Gezira soil) and river sand mixed in the ratio of 2:1.

Striga seeds at 0 and 10 mg were mixed with the top 6 cm soil in each pot. The pots were either sown or not sown to *D. dichotomum* (10 plants per pot) at 0, 30, 60 and 90 days prior to sorghum (cv. Arf Gadamak) planting. At sorghum planting *D. dichotomum* was cut at ground level. The pots were irrigated regularly. *Striga* count, sorghum height and shoot dry weight were recorded at harvest. The experiment was repeated twice.

3.6. Field trials:

3.6.1. General:

Field trials were undertaken to investigate reaction of the respective *Desmodium* species to drought and their ability to suppress *Striga* on sorghum and *Orobanche* on tomato. The field trials, conducted during the period July 2007 to 2008/09, were executed under irrigated and rain fed conditions at GRS and Gedarif Research Station Farm, respectively. Treatments were laid in a Randomized Complete Block Design with 3 or 4 replicates. Sub-plots comprised 4 rows. All measurements were taken from the two middle rows.

3.6.1.2. Screening of *Desmodium* species for drought tolerance and residual effects on *S. hermonthica* on sorghum:

In the first season, *Desmodium* species namely; *D. dichotomum* (Damazin and Kadugli collections), *D. distortum*, *D. tortuosum*, *D. intortum*

and *D. uncinatum* were planted in a *Striga* sick plot. *Desmodium* seeds were hand drilled on both sides of ridges 80 cm apart at GRS or on flat in rows 80 cm apart at Gedarif at a seed rate of 1 kg per fed. Pearl millet was grown as barriers between plots. The plot size was 3.2 x 4 m. Fallow plots, similarly infested with *Striga*, were included as controls. *Desmodium* straw and seed yields were recorded at harvest.

In the second season, all the plots were planted to sorghum. Arfa Gadamak seeds were planted in 4 cm deep holes (2 seeds /hole) on ridges or rows 80 cm apart at 20 cm between holes. Sorghum stand was counted 30 days after sowing and at harvest. *Striga* count was made at 30, 60 and 90 days after sowing. *Striga* air-dry weight, sorghum height, straw and seed yields as well as regeneration of *Desmodium* were determinated at harvest.

3.6.1.3. Influence of intercropping with *Desmodium* species and sorghum genotype on *S. hermonthica* incidence and sorghum growth and yield:

Two sorghum genotypes, Hakika (*Striga* resistance) and Abu Sabeen (*Striga* susceptible) were used at GRS, while Hakika and *Striga* susceptible (Korokollo) were employed at Gedarif. Sorghum seeds were planted in holes on ridges 80 cm apart at GRS and on flat in rows 80 cm apart at Gedarif. Sorghum was planted as sole crop or intercropped with *Desmodium* spp. *Desmodium*

seeds were planted on both sides of each ridge at GRS and in rows on both sides of the sorghum row at Gedarif. Planting was accomplished on the second or third week of July, 2007 and 2008. *Striga* count, dry weight and sorghum height, straw and seed yields were recorded at harvest.

3.6.2. Trial on *Orobanche ramosa* on tomatoes:

3.6.2.1. Effects of intercropping with *Desmodium* species on *O. ramosa* parasitism and tomato growth and yield:

An experiment was conducted during the winter seasons of 2006/07 and 2007/08 at GRS. Tomato, variety Peto 86, was either direct seeded or transplanted in *O. ramosa* sick plot. Planting was done on the last week of November, 2006 and on the first week of December, 2007. The crop was planted or transplanted on beds, 120 cm apart, at a within row spacing of 50 cm. Each plot consisted of 2 beds adjoined to each other. *D. dichotomum* (Damazin collection) and *D. uncinatum* were hand- drilled i) ten cm behind the tomatoes holes, ii) in the same hole with tomato and iii) in between holes of tomato. Urea at 190 kg/ha was applied as a split dose, 95 kg each. The first dose was applied three weeks after sowing while the second dose was applied 1 month later. Plots were irrigated at 7 to 12 days intervals. Total yield was determined by summation of fruit weight of individual harvest. *Orobanche* counts were made at 60, 90 and 120 days after tomatoes planting or transplanting.

3.7. Statistical analysis:

The data were subjected to analysis of variance ANOVA. Data on percentage of germination and haustorium initiation were transformed to arcsine and subjected to analysis of variance ANOVA. Mean separation was carried out using Duncan's Multiple Range Test.

Chapter four

Results

4.1. Laboratory experiments:

4.1.1. Influence of temperature on germination of *Desmodium* species:

Germination of all *Desmodium* species increased with increasing temperature and time (Figs. 3-7). However, differential response to temperature was observed between species. At 15 °C no germination was displayed in the first 2 days after incubation for all species. However, on extension of the incubation period to 7 days germination was 43% for *D. intortum*, 30% for *D. dichotomum* (Damazin collection) and 23% for *D. uncinatum* (Figs. 3, 4 and 5).

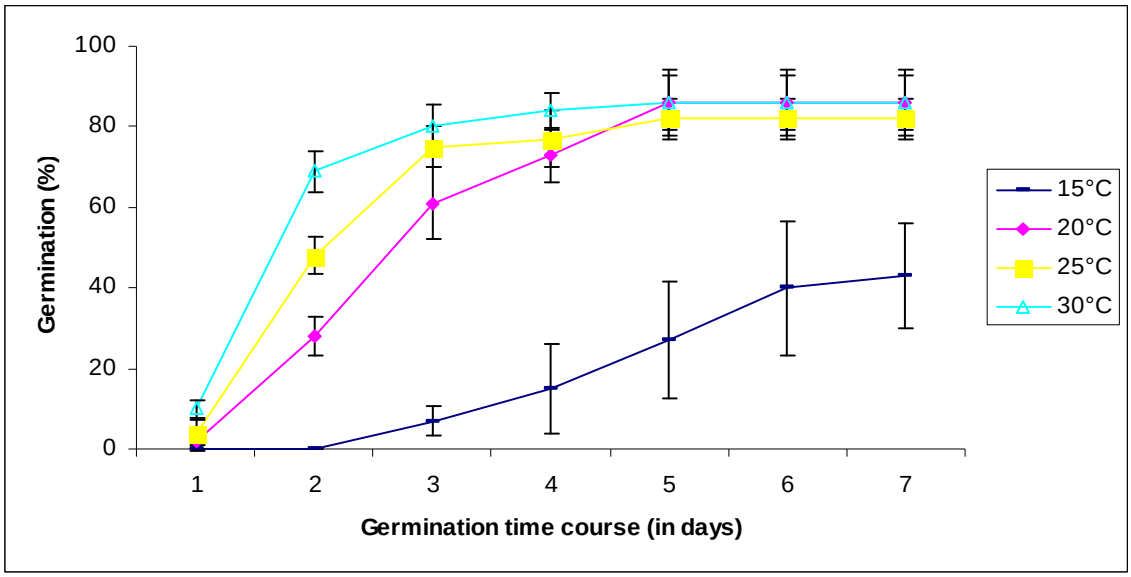


Figure 3. Influence of temperature on *D. intortum* germination. Bars = Standard deviation

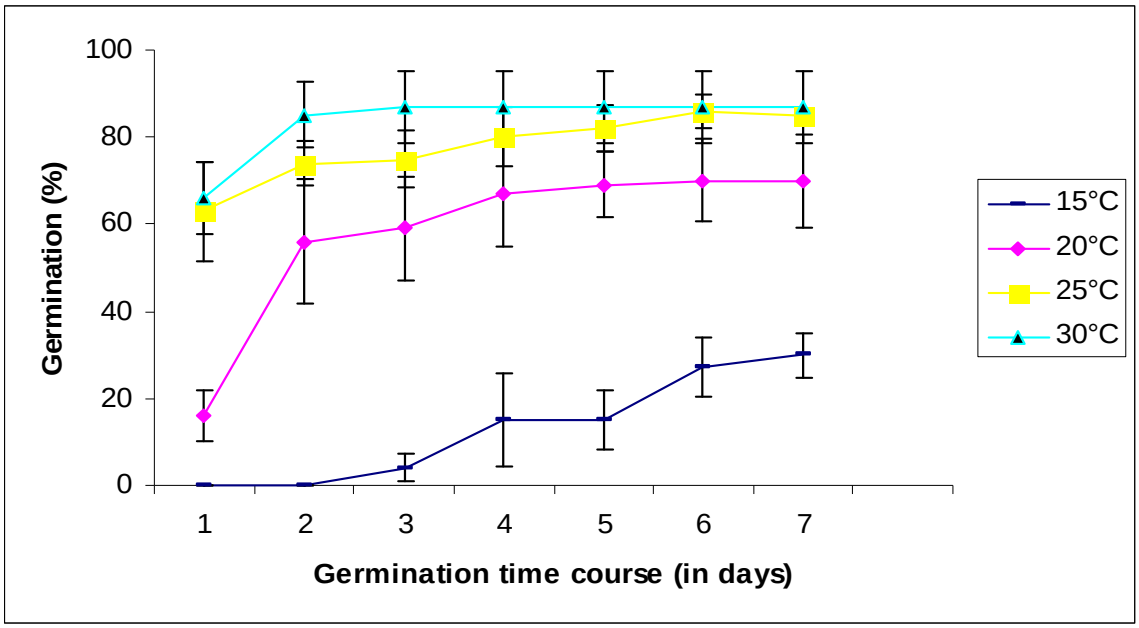


Figure 4. Influence of temperature on *D. dichotomum* germination. Bars = Standard deviation

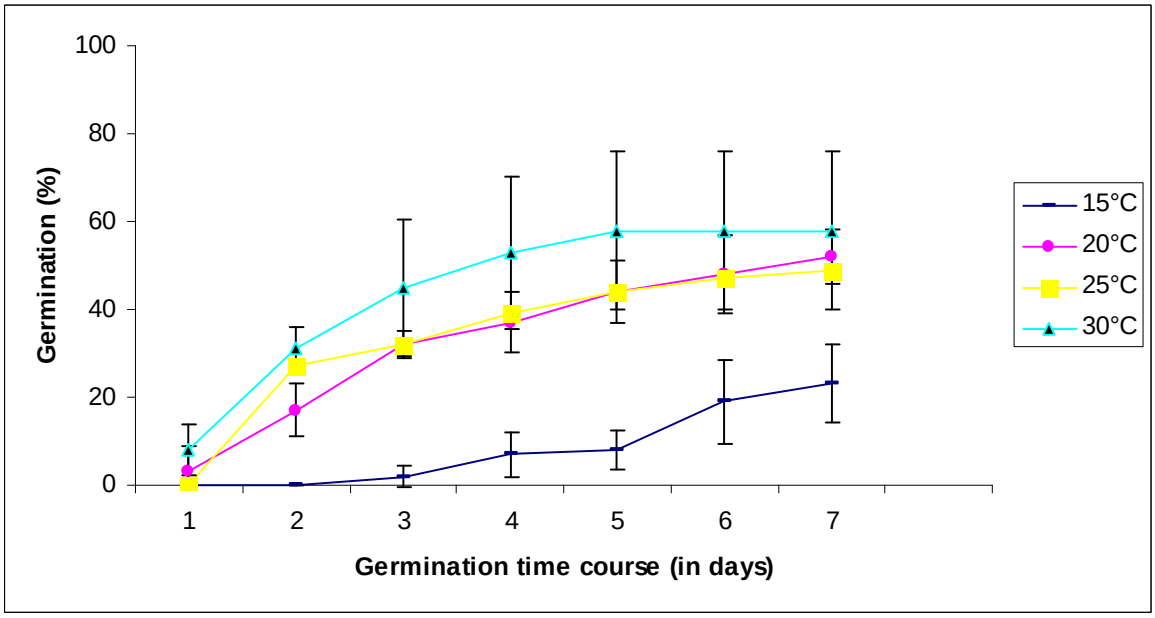


Figure 5. Influence of temperature on *D. uncinatum* germination. Bars = Standard deviation

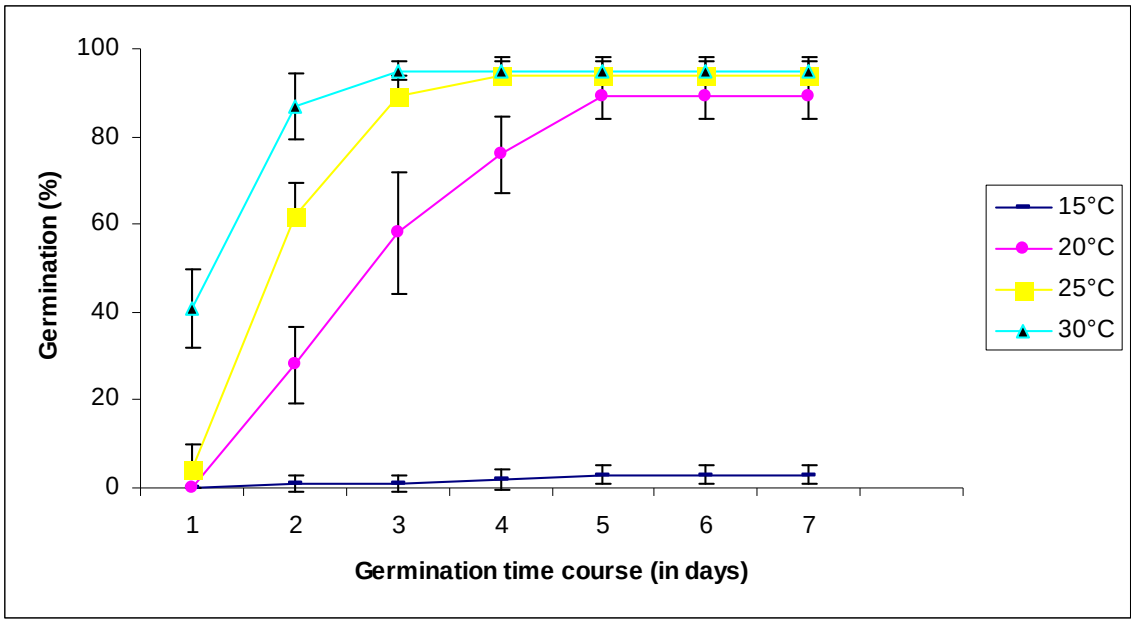


Figure 6. Influence of temperature on *D. distortum* germination. Bars = Standard deviation

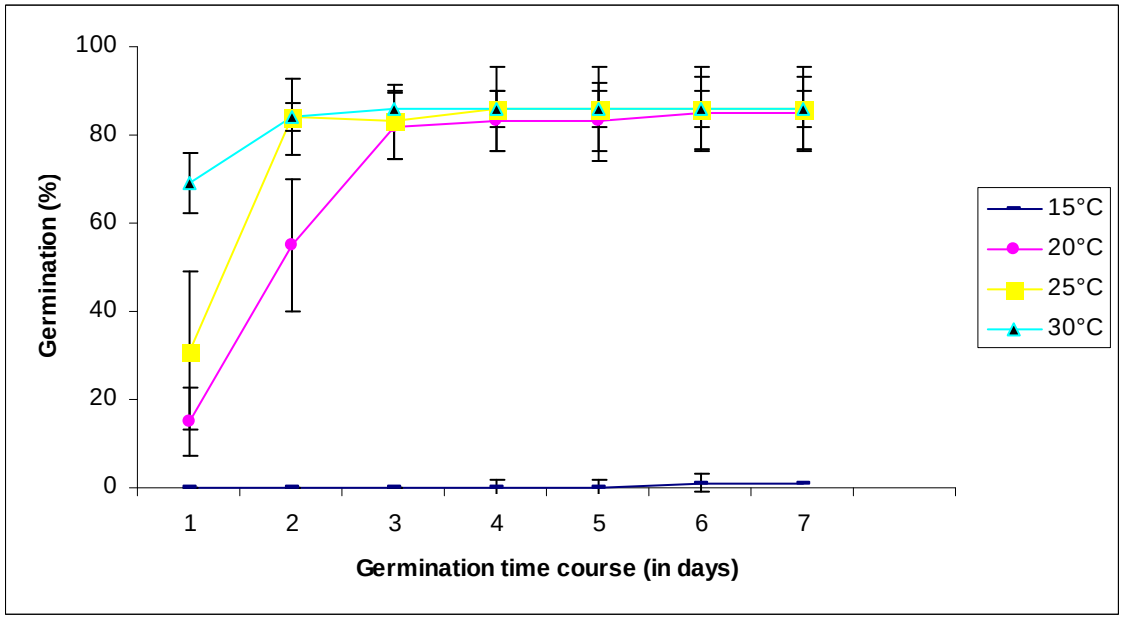


Figure 7. Influence of temperature on *D. tortuosum* germination. Bars = Standard deviation

D. distortum and *D. tortuosum* showed negligible (1 to 3%) germination (Figs. 6 and 7). At 20 °C, *D. intortum*, *D. dichotomum*, *D. uncinatum* and *D. tortuosum* showed 2, 16, 3 and 15% germination, respectively, one day after incubation (Figs. 3, 4, 5, and 7). Increasing the incubation period to 7 days increased germination to 86, 70, 52, 89 and 85% for *D. intortum, D. dichotomum, D. uncinatum*, *D. distortum* and *D. tortuosum*, respectively. Increasing temperature to 25°C increased germination substantially in all species. One day after incubation germination was 4, 63, 0, 4 and 31% for *D. intortum, D. dichotomum*, D. *uncinatum D. distortum* and *D. tortuosum,* respectively. At 7 days after incubation germination was 82, 85, 49, 94 and 86% for *D. intortum*, *D. dichotomum, D. uncinatum*, *D. distortum* and *D. tortuosum,* respectively. At 30 °C germination, at one day after incubation, was 8, 66, 10, 41 and 69% for *D. intortum*, *D. dichotomum, D. uncinatum D. distortum* and *D. tortuosum,* respectively. The highest germination displayed 7 days after incubation at 30 °C was 87% and 95% for *D. dichotomum* and *D. distortum,* respecively (Figs. 4 and 6). *D. intortum* and *D. tortuosum* displayed 86% germination (Figs. 3 and 7). *D. uncinatum*, on the other hand, showed 58% germination (Fig. 5).

4.1.2. Germination of *Desmodium* species under simulated drought:

D. dichotomum (Damazin collection) seeds imbibed in distilled water and incubated at 30 °C, displayed 49, 75 and 80% germination 1, 2 and 3 days after incubation, respectively. Germination did not increase on further extension of the incubation period to 7 days (Fig. 8). PEG 8000 at 50 g/L had no adverse effect on germination in comparison to the aqueous control. PEG 8000 at 100 g/L, reduced germination to 9% on the first day of incubation. However, germination increased to 43 and 71% on the second and third day of incubation. A further increase of the incubation period to 7 days did not increase germination. At 150 g/L, PEG 8000 completely suppressed germination one day after incubation. Germination increased to 14, 29 43 and 50% 2, 3, 4 and 5 days after incubation, respectively, and no further significant increase in germination was displayed on extension of the incubation period to 7 days. At 200 g/L, PEG 8000 delayed germination up to third day of incubation. Germination increased to 7, 16 and 24% 4, 5 and 6 days after incubation, respectively (Fig. 8). *D. uncinatum* showed the lowest germination in comparison to the other *Desmodium* species, irrespective of treatment. PEG 8000 at 100g/L was more suppressive to germination of *D. uncinatum* than the other species. PEG at 200 g/ L resulted in complete suppression of germination of *D. uncinatum* up to 7 days after incubation.

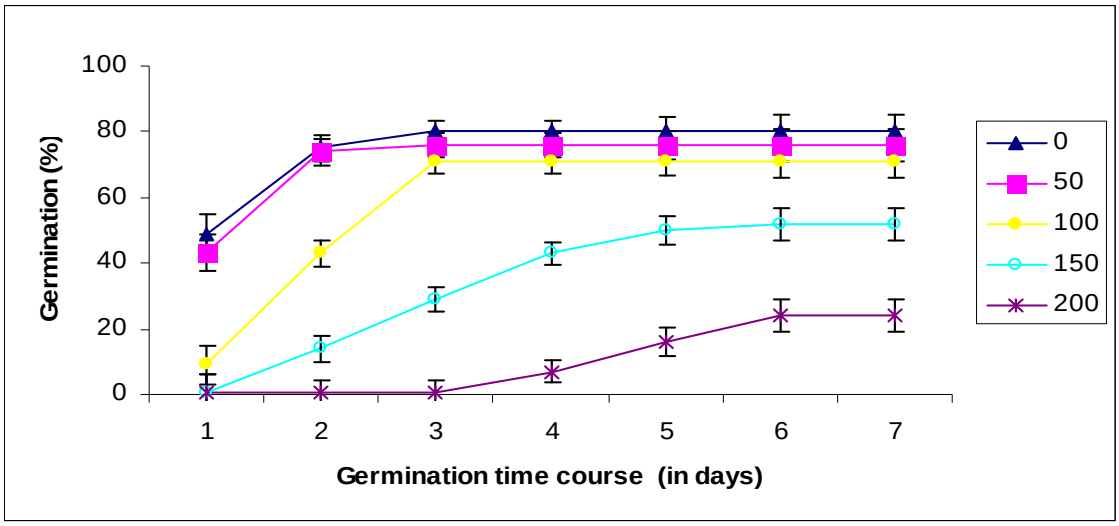


Figure 8. Influence of PEG 8000 concentration on germination of *D. dichotomum*. Bars= Standard error.

Response of germination of *D. intortum*, *D. distortum* and *D. tortuosum* to PEG 8000 concentration was more or less similar to that of *D. dichotomum* (Figs. 9, 10 and 11).

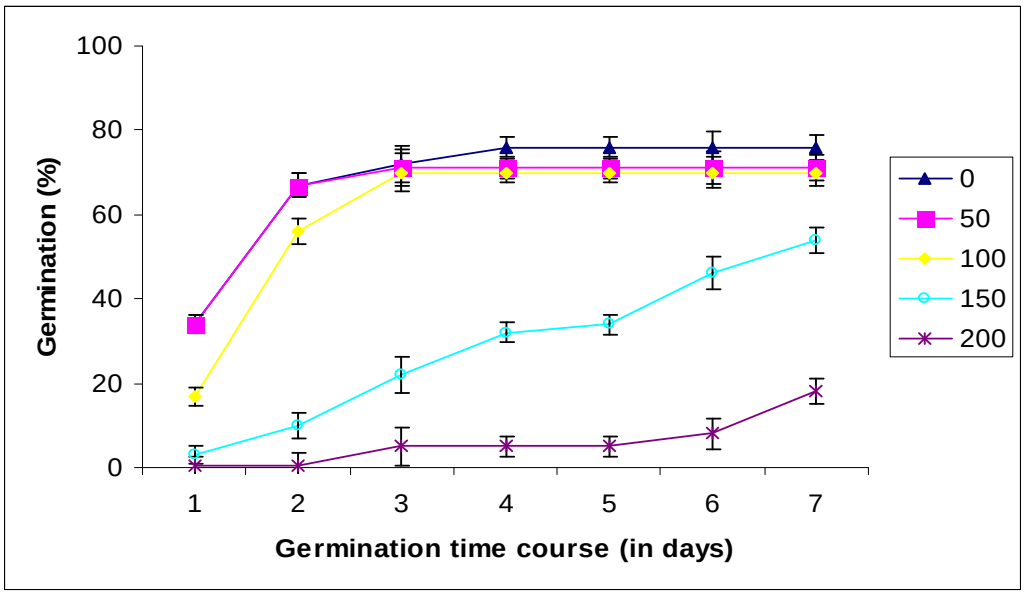


Figure 9. Influence of PEG 8000 concentration on germination of *D. intortum*. Bars = Standard error.

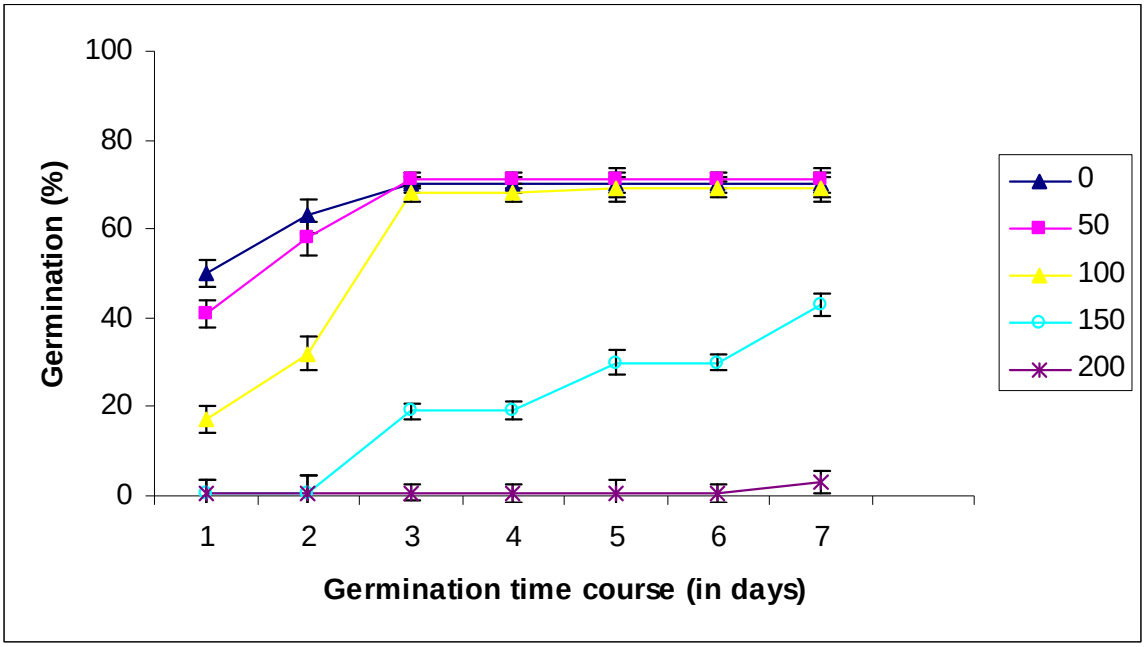


Figure 10. Influence of PEG 8000 concentration on germination of *D. distortum*. Bars = Standard error.

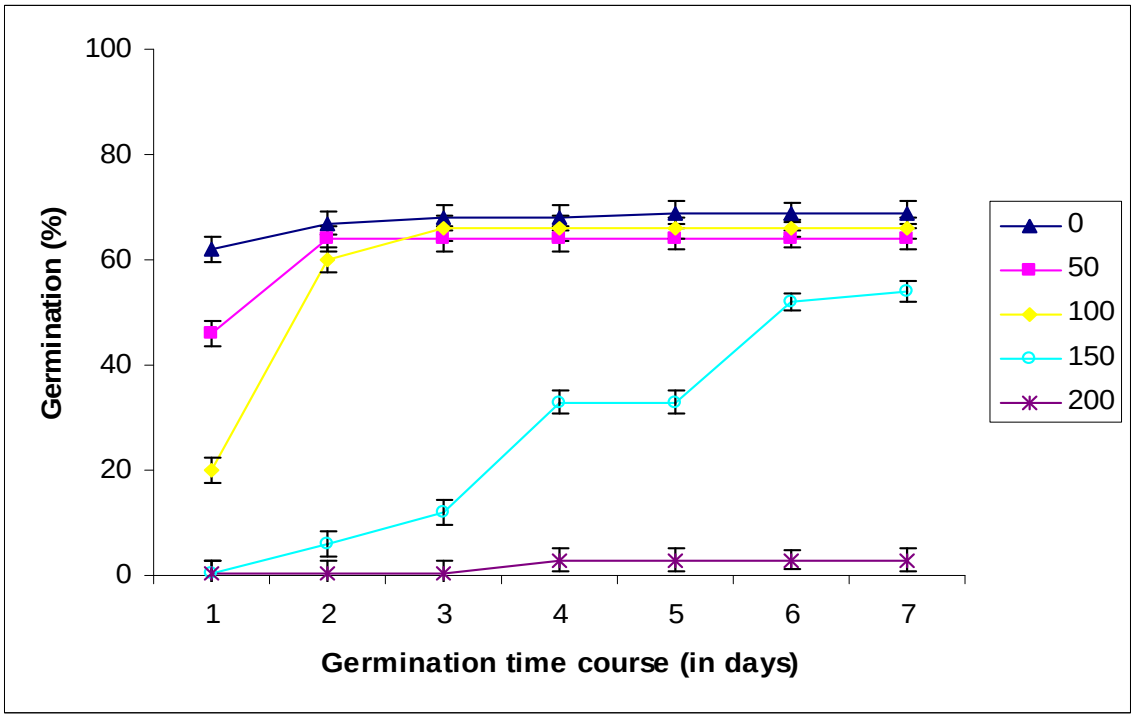


Figure 11. Influence of PEG 8000 concentration on germination of *D. tortuosum*. Bars = Standard error.

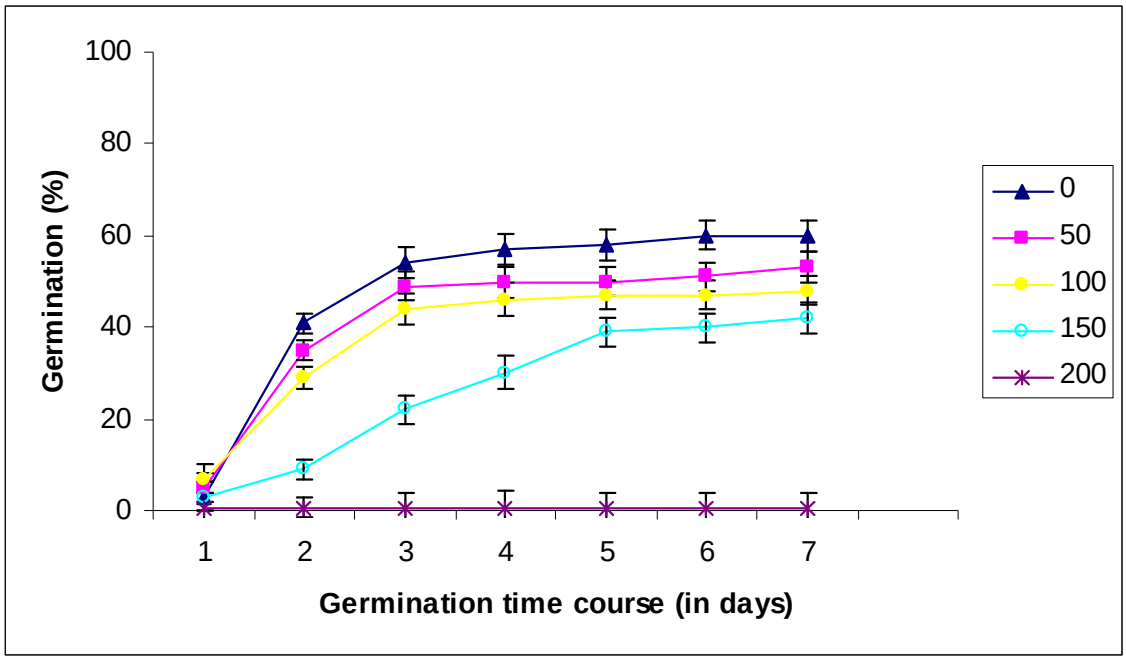


Figure 12. Influence of PEG 8000 concentration on germination of *D. uncinatum*. Bars = Standard error.

In all *Desmodium* species radical length significantly decreased with increasing PEG 8000 concentration (Table 1). PEG 8000 at 50 g/L did not reduce root length of *D. dichotomum*, *D. distortum* and *D. tortuosum*. However, *D. intortum* and *D. uncinatum* root length was reduced by 11 and 19%, respectively (Table 1). At 100, 150 and 200 g/L PEG 8000 reduction in radical length was 50, 92 and 100% and 19, 59 and 95% for *D. uncinatum* and *D. intortum*, respectively. The corresponding figures for *D. dichotomum*, *D. distortum* and *D. tortuosum* were 46, 75 and 91%, 35, 84 and 100% and 13, 74 and 100%, respectively (Table 1).

Table 1. Influence of PEG 8000 concentrations on radical length of five *Desmodium* species

Treatment*	Root length (cm)				
	Desmodium species				
PEG 8000(g/L)	*D. dichotomum*	*D. intortum*	*D. distortum*	*D. uncinatum*	*D. tortuosum*
0	10.6	7.3	9.3	6.2	10.3
50	10.9	6.5	9.2	5.0	10.4
100	5.7	5.9	6.0	3.1	9.0
150	2.6	3.0	1.5	0.5	2.7
200	1.0	0.4	0.02	0.0	0.1
SE±	0.78	0.34	0.35	0.32	0.37

*Each species of *Desmodium* was tested in a separate experiment.

4.1.3. Effects of *Desmodium* species root exudates on *S. hermonthica* and *O. ramosa* germination:

GR 24 induced *Striga* germination which increased with increasing concentration (Figs. 13- 17). The stimulant at it lowest concentration induced 0 to 48 % germination. However, at it highest concentration (0.1 ppm) germination was 57- 76%. Undiluted root exudates of *D. uncinatum, D. intortum, D. tortuosum* and *D. dichotomum* induced negligible germination (3 to 9%) of S. *hermomthica* seeds (Figs. 13- 16).

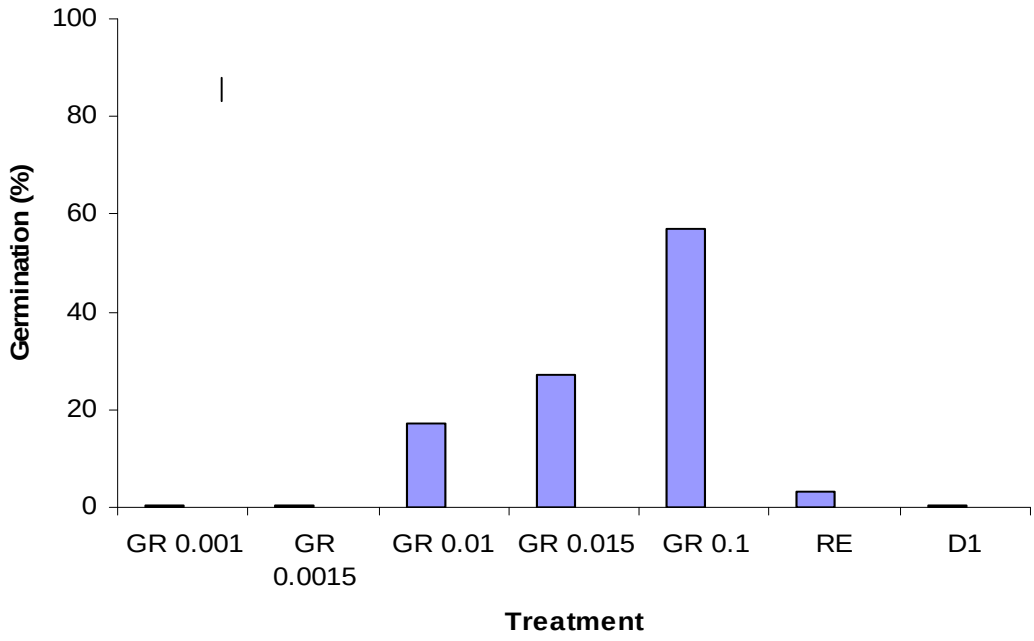


Figure 13. Influence of *D. uncinatum* and GR 24 on germination of *S. hermonthica*. Bars = Standard error. RE= Undiluted root exudate, D1= Distilled water.

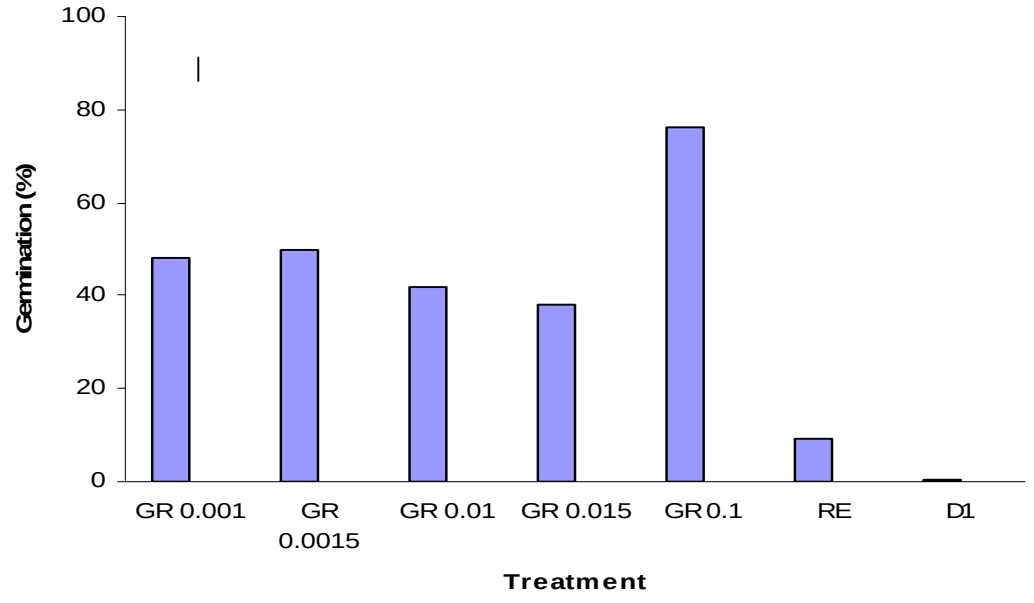


Figure 14. Influence of *D. intortum* and GR 24 on germination of *S. hermonthica.* Bars = Standard error. RE= Undiluted root exudate, Distilled water.

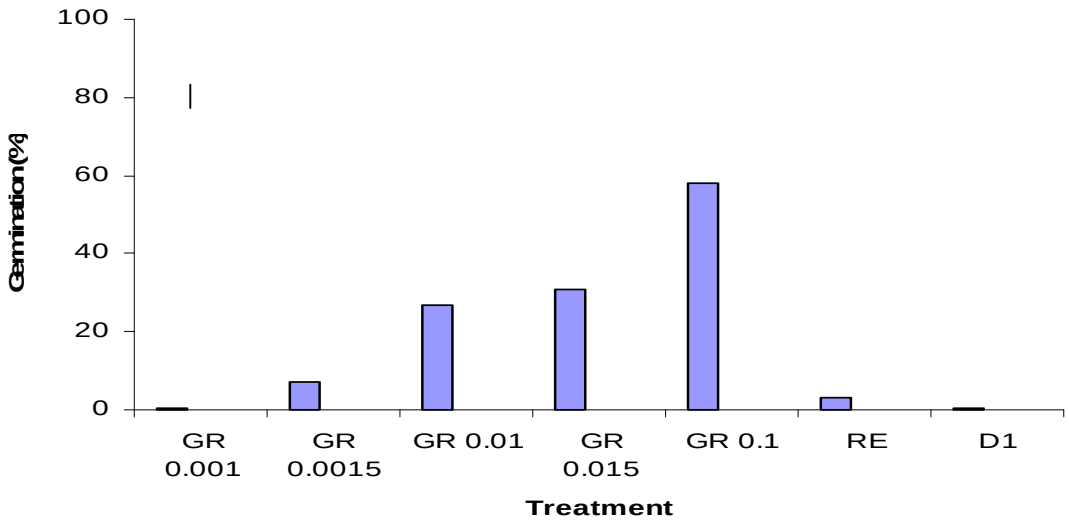


Figure 15. Influence of *D. tortuosum* and GR 24 on germination of *S. hermonthica*. Bars = Standard error. RE= Undiluted root exudate, D1= Distilled water.

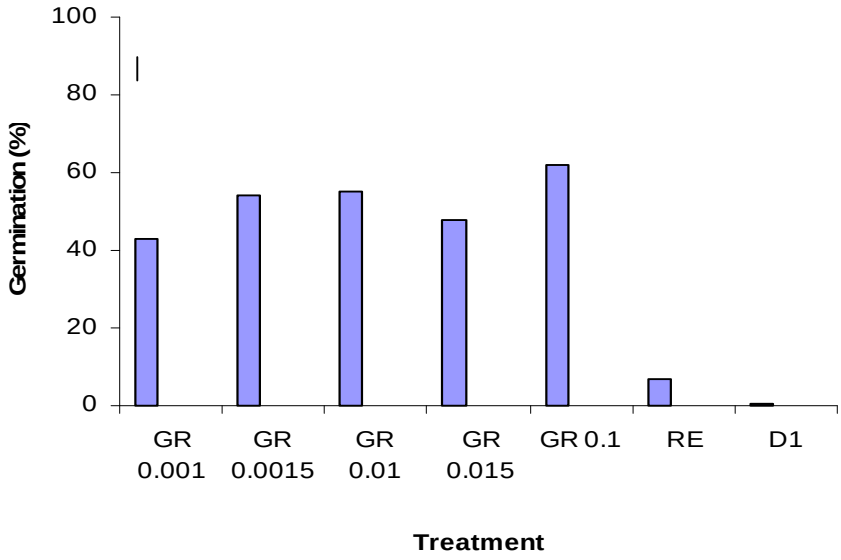


Figure 16. Influence of *D. dichotomum* and GR 24 on germination of *S. hermonthica*. Bars = Standard error. RE= Undiluted root exudate, D1= Distilled water.

However, undiluted root exudate of *D. distortum* induced high germination (35%) (Fig. 17). The exudate from *D. distortum* stimulated more germination than the synthetic germination stimulant GR 24 at 0.01 and 0.015 ppm.

GR 24 at 0.001 to 0.1ppm induced 2 to 48% germination of *O. ramosa.* None of the *Desmodium* species induced germination of *O. ramosa* (Figs. 18-22).

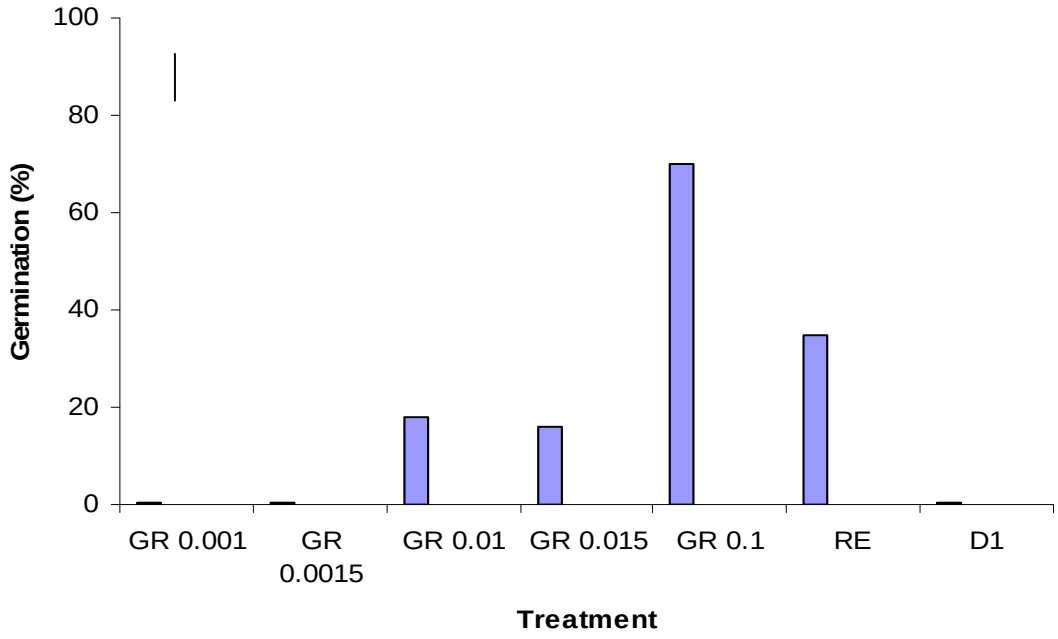


Figure 17. Influence of *D. distortum* and GR 24 on germination of *S. hermonthica.* Bars = Standard error. RE= Undiluted root exudate, D1= Distilled water.

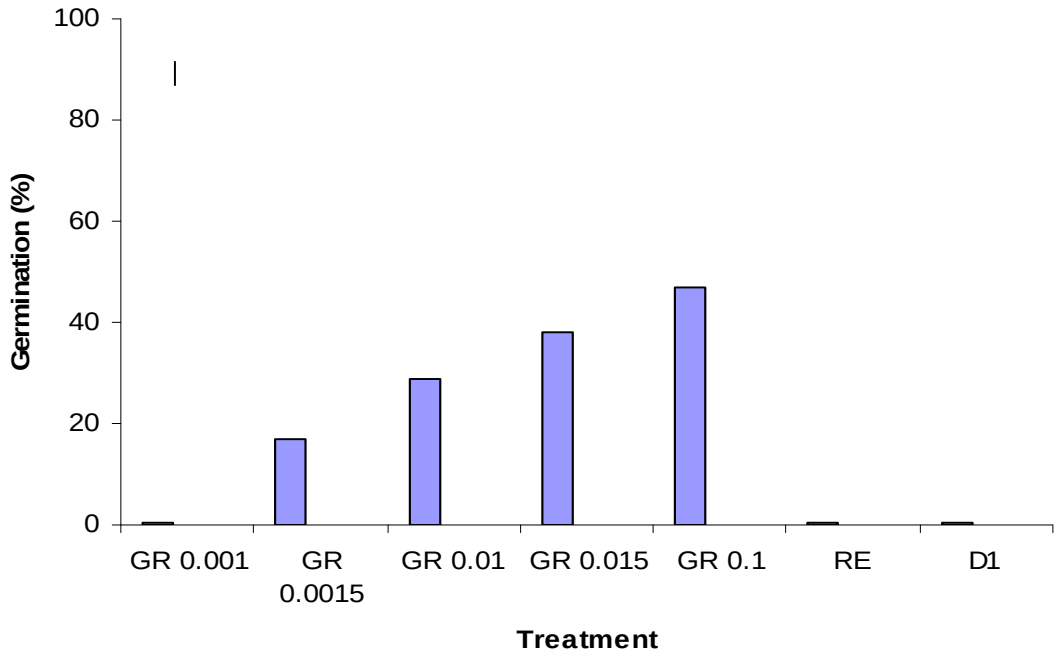


Figure 18. Influence of *D. uncinatum* and GR 24 on germination of *O. ramosa*. Bar= Standard error. RE= Undiluted root exudate, D1= Distilled water.

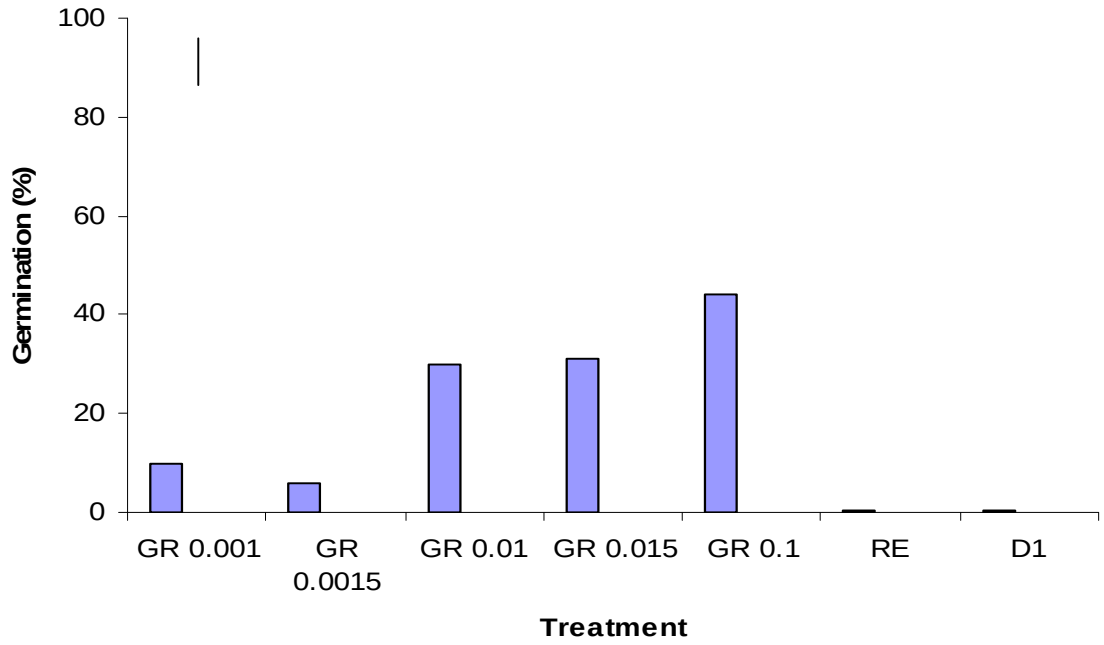


Figure 19. Influence of *D. distortum* and GR 24 on germination of *O. ramosa*. Bar= Standard error. RE= Undiluted root exudate, D1= Distilled water.

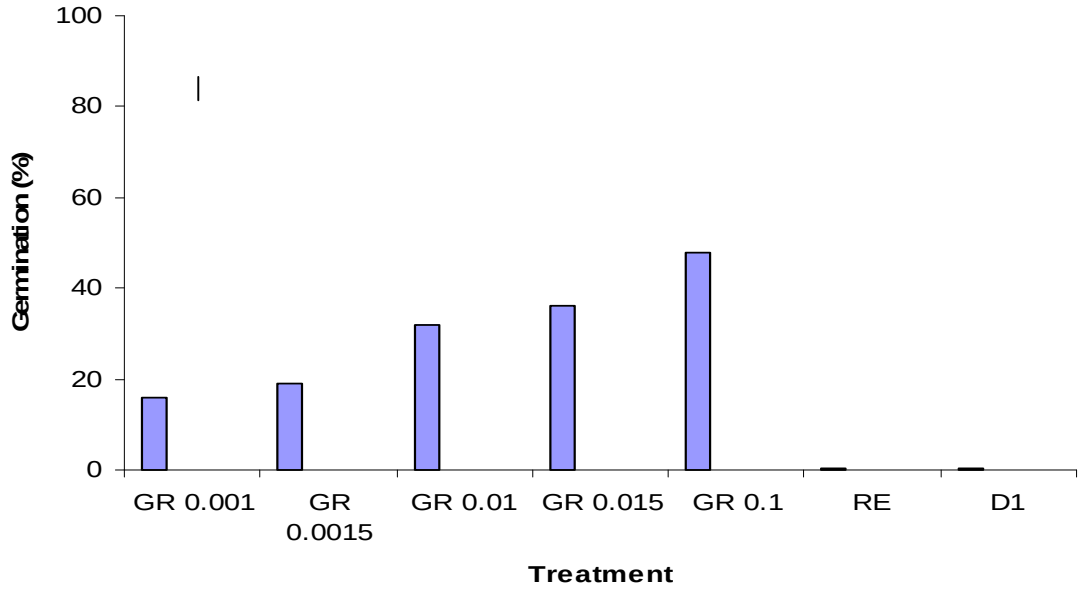


Figure 20. Influence of *D. dichotomum* and GR 24 on germination of *O. ramosa*. Bar= Standard error. RE= Undiluted root exudate, D1= Distilled water.

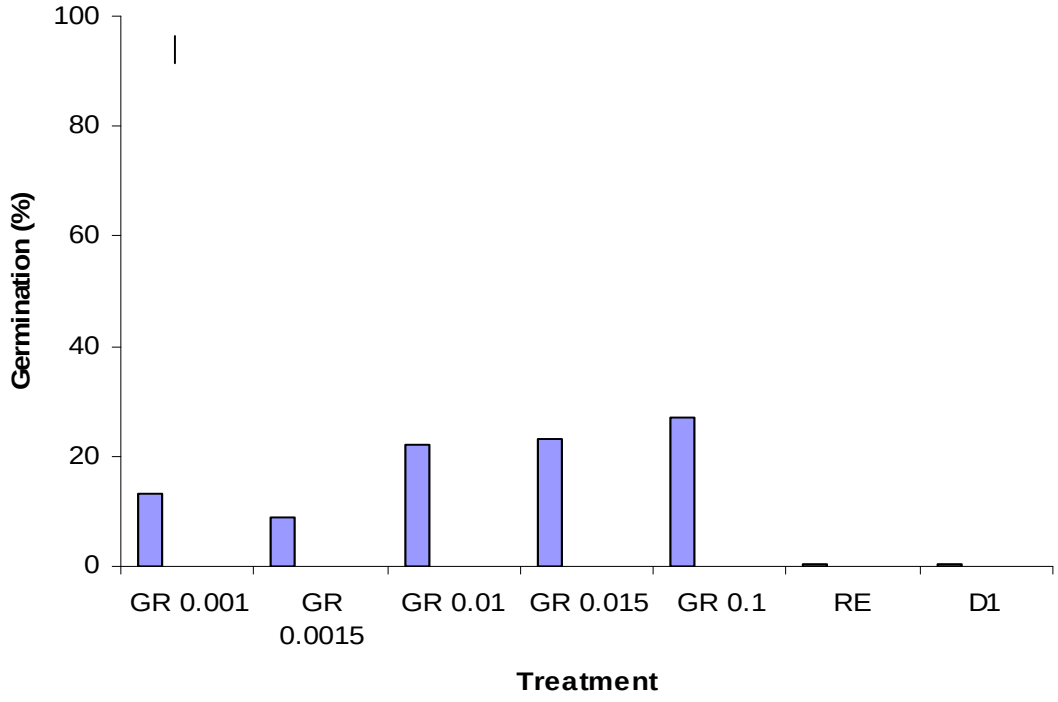


Figure 21. Influence of *D. tortuosum* and GR 24 on germination of *O. ramosa*. Bar= Standard error. RE= Undiluted root exudate, D1= Distilled water.

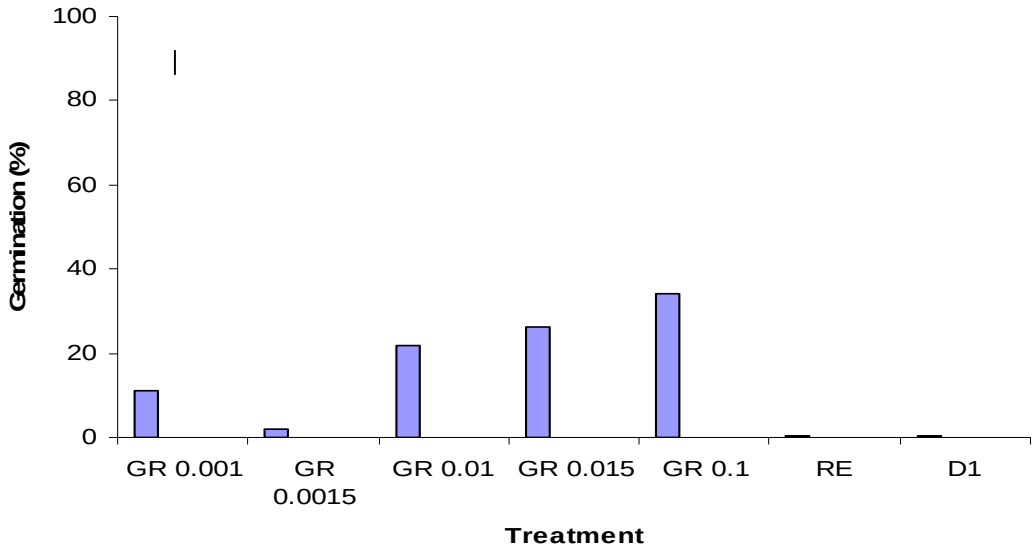


Figure 22. Influence of *D. intortum* and GR 24 on germination of *O. ramosa*. Bar= Standard error. RE= Undiluted root exudate, D1= Distilled water.

4.1.4. Effects of *Desmodium* species root exudates on *S. hermonthica* germination and haustorium initiation:

DMBQ at 10µM applied 24 h subsequent to GR 24 at 0.1 ppm or in mixture with it induced 56 and 86% haustorium initiation, respectively (Table 2). DMBQ in mixture with *D. dichotomum* root exudate applied 24 h subsequent to GR 24 reduced haustorium initiation to 50%. However, simultaneous application of GR 24, *D. dichotomum* root exudate and DMBQ resulted in 44% haustorium initiation (Table 2). *D. dichotomum* root exudate applied 24 h subsequent to GR 24 or simultaneously with the stimulant inhibited haustorium initiation (Table 2).

Table 2. Influence of *D. dichotomum* root exudates on haustorium induction by DMBQ

Treatment	Haustorium initiation (%)
GR 24 + DMBQ (a)	(56) 48
GR 24 +DMBQ (b)	(86) 73
GR 24 + RE +DMBQ (c)	(50) 45
GR 24 + RE+ DMBQ (d)	(44) 41
GR 24 + RE (e)	(0) 0.41
GR 24 + RE (f)	(0) 0.41
SE±	4.95

a = GR 24 applied 24 hour prior to DMBQ, b= GR 24 applied simultaneously with DMBQ, c = GR 24 applied 24 hour prior to *D. dichotomum* root exudates and DMBQ mixture, d=GR 24 applied simultaneously with *D. dichotomum* root exudates and DMBQ mixture, e= GR 24 applied 24 hour prior to *D. dichotomum* root exudate, f= GR 24 applied simultaneously with *D. dichotomum* root exudate. Data are arcsin transformed. Figures in parenthesis are actual data.

In the second experiment, DMBQ applied 24 h subsequent to GR 24 or in mixture with it induced 47 and 38% haustorium initiation, respectively (Table 3). DMBQ in mixture with *D. uncinatum* root exudate applied 24 h subsequent to GR 24 induced 38% haustorium initiation. However, simultaneous application of GR 24 and *D uncinatum* root exudate and DMBQ resulted in 23% haustorium initiation. *D. uncinatum* root exudate applied 24 h subsequent to GR 24 or simultaneously with it completely inhibit haustorium initiation (Table 3).

Table 3. Influence of *D. uncinatum* root exudates on haustorium induction by DMBQ

Treatment	Haustorium initiation (%)
GR 24 + DMBQ (a)	(47) 43
GR 24 +DMBQ (b)	(38) 37
GR 24 + RE +DMBQ (c)	(38) 38
GR 24 + RE+ DMBQ (d)	(23) 28
GR 24 + RE (e)	(0) 0.41
GR 24 + RE (f)	(0) 0.41
SE±	3.90

Data are arcsin transformed. Figures in parenthesis are actual data. Legend as in table (2).

In the third experiment, DMBQ applied 24 h subsequent to GR 24 or in mixture with it induced 90 and 45% haustorium initiation, respectively (Table 4). DMBQ in mixture with *D. intortum* root exudate applied 24 h subsequent to GR 24 induced 56% haustorium initiation. However, simultaneous application of GR 24 and *D. intortum* root exudate and DMBQ resulted in 16% haustorium initiation. *D. intortum* root exudate applied 24 h subsequent to GR 24 or simultaneously with it resulted in 2 and 0% haustorium initation, respectively (Table 4).

Table 4. Influence of *D. intortum* root exudates on haustorium induction by DMBQ

Treatment	Haustorium inatiation (%)
GR 24 + DMBQ (a)	(90) 77
GR 24 +DMBQ (b)	(45) 41
GR 24 + RE +DMBQ (e)	(56) 49
GR 24 + RE+ DMBQ (f)	(16) 16
GR 24 + RE (e)	(2) 4
GR 24 + RE (f)	(0) 0.41
SE±	8.45

Data are arcsin transformed. Figures in parenthesis are actual data. Legend as in table (2).

4.1.5. Effects of *Desmodium* spp. on *S. hermonthica* parasitism:

Striga seeds, conditioned in water and placed near sorghum roots, displayed 6% attachment within 7 days after incubation. *Striga* germilings resulting from seeds conditioned in distilled water, treated with GR24 and placed in the vicinity of sorghum roots displayed 2% attachment after placement in proximity of sorghum roots (Table 5). In presence of *D. uncinatum* roots *Striga* germilings displayed no attachment (Table 5).

In the second experiment, *Striga* germilings resulting from seeds conditioned in water, treated with GR 24 and placed near sorghum roots displayed 37% attachment 7 days after transfer. *Striga* germilings resulting from seeds conditioned in water and placed in the vicinity of sorghum roots displayed 11% attachment (Table 6). The observed attachment decreased with

increasing number of *D. dichotomum* plants. *D. dichotomum* plants at 1, 2, 3 and 4 per Petri dish reduced attachment of *Striga* germilings induced by GR 24 by 41, 30, 43 and 57%, respectively. *Striga* germilings resulting from seeds conditioned in water and not treated with GR 24, invariably, showed no attachment to sorghum roots in presence of *D. dichotomum* (Table 6).

Table 5. Effect of *D. uncinatum* root exudates on *S. hermonthica* attachment 7days after incubation

***Desmodium* density**	**Attachment (%)**	
	GR 24	**Distilled water**
0	(2) 7	(6) 14
1	(0) 0.41	(0) 0.41
2	(0) 0.41	(0) 0.41
3	(0) 0.41	(0) 0.41
4	(0) 0.41	(0) 0.41
SE±	1.13	

Data are arcsin transformed. Figures in parenthesis are actual data.

Table 6. Effect of *D. dichotomum* root exudates on *S. hermonthica* attachment 7 days after incubation

***Desmodium* density**	**Attachment (%)**	
	GR 24	**Distilled water**
0	(37) 37	(11) 12
1	(22) 28	(0) 0.41
2	(26) 30	(0) 0.41
3	(21) 27	(0) 0.41
4	(16) 23	(0) 0.41
SE±	4.31	

Data are arcsin transformed. Figures in parenthesis are actual data.

4.2. Green house experiments:

4.2.1. Effects of timing of irrigation on regeneration of *Desmodium* species:

D. dichotomum displayed 92 and 80% regeneration in the first and second seasons, respectively, when irrigated immediately after cutting. However, regeneration was reduced to 6 and 13% when irrigation was delayed to 30 days after cutting in the first and second seasons, respectively. On further delay of irrigation to 60 days or more no regeneration was displayed (Tables 7 and 8). Regenerative response of *D. distortum* to timing of irrigation was more or less similar to that displayed by *D. dichotomum* (Tables 7 and 9). *D. tortuosum*, on the other hand, showed 96 and 88% regeneration when irrigation was delayed to 30 and 60 days after cutting (Table 10). Regeneration was, however, reduced to 6% when irrigation was delayed to 90 days after cutting, and no regeneration was displayed when irrigation was delayed to 120 days.

Table 7. Effects of timing of irrigation on regeneration of *D. dichotomum* (First season)

Time of irrigation (days after cutting)	Regeneration (%)	
	15 days after irrigation	30 days after irrigation
0	(92) 75	(92) 75
30	(6) 10	(6) 10
60	(0) 0.41	(0) 0.41
90	(0) 0.41	(0) 0.41
120	(0) 0.41	(0) 0.41
SE±	1.85	1.85

Data are arcsin transformed. Figures in parenthesis are actual data.

Table 8. Effects of timing of irrigation on regeneration of *D. dichotomum* (Second season)

Time of irrigation (days after cutting)	Regeneration (%)	
	15 days after irrigation	30 days after irrigation
0	(80) 67	(80) 67
30	(13) 21	(13) 21
60	(0) 0.41	(0)0.41
90	(0) 0.41	(0) 0.41
120	(0) 0.41	(0) 0.41
SE±	3.48	3.48

Data are arcsin transformed**.** Figures in parenthesis are actual data.

Table 9. Effects of timing of irrigation on regeneration of *D. distortum*

Time of irrigation (days after cutting)	Regeneration (%)	
	15 days after irrigation	30 days after irrigation
0	(80) 66	(80) 66
30	(2) 4	(7) 13
60	(0) 0.41	(0) 0.41
90	(0) 0.41	(0) 0.41
120	(0) 0.41	(0) 0.41
SE±	3.46	3.57

Data are arcsin transformed. Figures in parenthesis are actual data.

Table 10. Effects of timing of irrigation on regeneration of *D. tortuosum*

Time of irrigation (days after cutting)	Regeneration (%)	
	15 days after irrigation	30 days after irrigation
0	(97) 85	(97) 85
30	(96) 81	(96) 81
60	(88) 72	(88) 72
90	(0) 0.41	(6) 8
120	(0) 0.41	(0) 0.41
SE±	2.53	3.77

Data are arcsin transformed**.** Figures in parenthesis are actual data

4.2.4. Influence of *Desmodium* spp. population density on emergence of *S. hermonthica* and sorghum growth and yield:

At the lowest level of infestation (5 mg/pot), *Striga* emergence significantly declined at 15 plants/ pot *D. uncinatum* population density (Table 11). The observed decline in *Striga* emergence was 67 % in comparison to corresponding control. However, at the highest *Striga* infestation level (10 mg seeds/ pot) emergence of the parasite showed no consistent trend with *D. uncinatum* population density.

At 5 and 10 mg levels of *Striga* seeds height of sorghum, when not intercropped with *Desmodium*, was reduced by 50 and 70%, respectively in comparison to the corresponding *Striga* free crop (Table 12). *D. uncinatum* decreased height of *Striga* free sorghum by 12 to 29%. The obsereved reductions did not show obvious trends with *D. uncinatum* population density (Table 12). However the tallest plants were invariably achieved in pots free of *D. uncinatum* and *Striga* seeds (Table 12). At *Striga* level (10 mg seeds/pot) *D. uncinatum* at 5 plants per pot increased sorghum height significantly ($P > 0.05$). However, at higher *D. uncinatum* population density the observed increments in sorghum height were not significant.

Table 11. Effects of *D. uncinatum* population density on emergence of *S. hermonthica* on sorghum at harvest

Level of *Striga* infestation (mg / pot)	*Striga* emergence (plants / pot)				
	Desmodium population density (Plants/pot)				
	0	5	10	15	20
5	6	5	6	2	3
10	6	6	8	6	7
SE±			1.53		

Striga level = 0.68 *Desmodium* density = 1.08

Table 12. Effects of *D. uncinatum* population density on sorghum plant height at harvest

Level of *Striga* infestation (mg / pot)	Sorghum height (cm)				
	Desmodium population density (plants/pot)				
	0	5	10	15	20
0	45.0	34.9	37.4	32.0	39.5
5	22.5	28.9	30.6	26.9	28.5
10	13.5	25.2	20.6	19.9	20.0
SE±			3.59		

At 5 and 10 mg infestation level *Striga* parasitism reduced, shoot dry weight by 67 and 93%, respectively, in comparison with the *Striga* free crop (Table 13). Intercropping with *D. uncinatum* did not improve sorghum biomass in comparison to the corresponding *Striga* infested crop.

Table 13. Effects of *D. uncinatum* population density on sorghum shoots dry weight at harvest

Level of *Striga* infestation (mg / pot)	Sorghum shoot dry weight (g)				
	Desmodium population density				
	0	**5**	**10**	**15**	**20**
0	4.5	3.2	2.9	3.5	2.5
5	1.5	1.1	1. 8	1.0	1.9
10	0.3	0.7	0.4	0.4	0.4
SE±			0.53		

In the second experiment, presence of *D. dichotomum* had no effects on *Striga* emergence (Table 14).

Table 14. Effects of *D. dichotomum* population density on emergence of *S. hermonthica* on sorghum at harvest

Level of *Striga* infestation (mg / pot)	*Striga* emergence (plants / pot)				
	Desmodium population density (Plants/pot)				
	0	**5**	**10**	**15**	**20**
5	2	3	2	2	3
10	4	7	5	6	4
SE±			0.94		

At 5 and 10 mg levels of *Striga* seeds sorghum height was reduced by 35 and 54%, respectively in comparison to the *Striga* free crop (Table 15). At the lowest *Striga* level, *D. dichotomum* at 15 plants per pot increased sorghum

height significantly. However, at higher *D. dichotomum* population the observed increments in sorghum height were not significant (Table 15).

At the highest *Striga* level, *D. dichotomum* at 15and 20 plants per pot improved sorghum height significantly.

Table 15. Effects of *D. dichotomum* population density on sorghum plant height at harvest

Level of *Striga* infestation (mg / pot)	Sorghum height (cm)				
	D. dichotomum population density (plants/pot)				
	0	**5**	**10**	**15**	**20**
0	36.4	35.6	34.6	33.3	30.9
5	23.8	29.3	24.5	30.7	27.0
10	16.8	19.8	21.2	22.7	24.9
SE±			2.27		

At 5 and 10 mg level of infestation, *Striga* parasitism reduced shoot dry of sorghum by 71 and 90%, respectively in comparison with the *Striga* free crop (Table 16).

The highest dry weight was obtained in pots free of *D. dichotomum* and *Striga* infestation. At the highest *Striga* level (10 mg/ pot) *D. dichotomum* at 15 and 20 plants per pot increased sorghum dry weight, albeit not significantly (Table 16).

Table 16. Effects of *D. dichotomum* population density on sorghum shoots dry weight at harvest

Level of *Striga* infestation (mg / pot)	Sorghum shoot dry weight (g)				
	Desmodium population density				
	0	**5**	**10**	**15**	**20**
0	4.2	2.4	2.7	3.5	1.1
5	1.2	1.4	0.8	0.9	1.0
10	0.4	0.4	0.3	0.6	0.9
SE±			0.35		

In the third experiment, *Striga* emergence increased with *Striga* level. The presence of *D. intortum* had no effects on *Striga* emergence (Table 17).

Table 17. Effects of *D. intortum* population density on emergence of *S. hermonthica* on sorghum at harvest

Level of *Striga* infestation (mg / pot)	*Striga* emergence (plants / pot)				
	Desmodium population density				
	0	**5**	**10**	**15**	**20**
5	2	3	3	4	3
10	6	11	8	6	6
SE±			1.15		

At 5 and 10 mg levels of *Striga* seeds sorghum height was reduced by 19 and 34%, respectively in comparison to *Striga* free crop (Table 18). At the lowest *Striga* infestation, *D. intortum* at 10, 15 and 20 plants per pot increased sorghum height, albeit not significantly (Table 18). However, at the highest *Striga* level, *D. intortum* had no effects on sorghum height (Table 18).

Table 18. Effects of *D. intortum* population density on sorghum plant height at harvest

Level of *Striga* infestation (mg / pot)	Sorghum height (cm)				
	Desmodium population density				
	0	**5**	**10**	**15**	**20**
0	34.0	29.6	32.4	32.3	37.5
5	27. 7	26.5	28.8	31.5	29.2
10	22.6	20.5	21.4	22.1	21. 5
SE±			3.48		

At 5 and 10 mg/pot *Striga* parasitism reduced shoot dry weight of sorghum by 87 and 83%, respectively in comparison with the *Striga* free crop (Table 19). At the lowest *Striga* level, *D. intortum* at 10 plants per pot significantly increased sorghum dry weight (Table 19). However, at the highest infestation level slight non- significant increase in sorghum dry weight was observed at higher density (20 plants/pot).

Table 19. Effects of *D. intortum* population density on sorghum shoots dry weight at harvest

Level of *Striga* infestation (mg / pot)	Sorghum shoot dry weight (g)				
	Desmodium population density				
	0	**5**	**10**	**15**	**20**
0	3.0	1.2	3.0	2.7	2.5
5	0.4	1.1	1.8	0.5	1.6
10	0.5	0.4	0.4	0.5	0.6
SE±			0.43		

4.2.4. Influence of *D. dichotomum* planting time on *S. hermonthica* incidence and sorghum growth and yield:

In the first season, *Striga* emergence was low, irrespective of *D. dichotomum* population density and planting time (Table 20). Under *Striga* infestation *D. dichotomum* planted 30 days prior to sorghum or planted on the same day as sorghum had no effects on sorghum height and dry weight. However, *D. dichotomum* planted 60 days prior to sorghum significantly increased sorghum plant height and dry weight (Table 20). *D. dichotomum* planted 90 days prior to sorghum had no significant effects on sorghum height and dry weight. In absence of *Striga*, *D. dichotomum* planted in the same day as sorghum had no effects on sorghum plant height. However, sorghum dry weight was reduced by 49% (Table 20). *D. dichotomum* planted 30, 60 and 90 days prior to sorghum had no effects on sorghum height and dry weight.

In the second season, *D. dichotomum* planted 30 and 60 days prior to sorghum reduced *Striga* emergence, albeit not significantly (Table 21).

Under *Striga* infestation *D. dichotomum* planted 30 and 90 days prior to sorghum, resulted in non- significant increase in sorghum height and dry weight. However, *D. dichotomum* planted 60 days prior to sorghum substantially increased sorghum height and dry weight (Table 21).

Table 20. Influence of *D. dichotomum* planting time on *S. hermonthica* incidence and sorghum growth and yield (season, 2006/07)

Time of *Desmodium* planting prior to sorghum planting	*Striga* infested		*Striga* free	
	+ *Desmodium*	- *Desmodium*	+ *Desmodium*	- *Desmodium*
a/ *Striga* population density (plants/pot)				
0	1	1	-	-
30	1	2	-	-
60	1	2	-	-
90	1	1	-	-
SE±		0.21		
b/ Sorghum height (cm):				
0	20.7	26.3	34.5	38.0
30	26.7	31.3	46.8	43.5
60	44.3	27.3	43.0	37.6
90	36.4	38.1	33.2	44.4
SE±		5.11		
c/ Sorghum dry weight (g):				
0	0.55	0.53	0.83	1.62
30	0.34	0.53	1.50	1.85
60	3.34	0.81	2.50	2.50
90	1.49	1.5	0.94	2.76
SE±		0.46		

+ and – with and without *Desmodium* planting.

Table 21. Influence of *D. dichotomum* planting time on *S. hermonthica* incidence and sorghum growth and yield (season, 2007/08)

Time of *Desmodium* planting prior to sorghum planting	***Striga* infested**		***Striga* free**	
	+ *Desmodium*	– *Desmodium*	+ *Desmodium*	– *Desmodium*
a/ *Striga* population density(plants/pot)				
0	3	3	-	-
30	1	3	-	-
60	1	2	-	-
90	1	2	-	-
SE±		0.29		
b/ Sorghum height (cm):				
0	22.8	24.2	45.5	40.6
30	30.3	21.9	32.4	26.7
60	37.1	19.3	44.1	33.8
90	36.4	23.5	33.3	30.9
SE±		4.9		
c/ Sorghum dry weight (g):				
0	0.36	0.54	4.70	5.69
30	1.48	0.55	1.91	1.85
60	4.7	0.40	4.82	2.98
90	4.04	0.82	4.07	3.08
SE±		1.19		

+ and – with and without *Desmodium* planting

4.3. Field trials:

4.3.1. Trials on *S. hermonthica*:

4.3.1.1. Screening of *Desmodium* species for drought tolerance and residual effects on *S. hermonthica* on sorghum at Gezira Research Station:

In the first season (2007/08), only *D. dichotomum* from Damazin and Kadugli, *D. tortuosum* and *D. distortum* were able to establish. However, *D. intortum* and *D. uncinatum* displayed significantly the lower stands in comparison with the other species (Table 22). In among the *Desmodium* species, *D. dichotomum* collected from Kadugli gave the highest straw yield (5039 kg/ha) followed by *D. dichotomum* collected from Damazin (3583 kg/ ha) (Table 22). Exotic species gave significantly lower straw yield. Straw yield from *D. tortuosum* and *D. distortum* was 1581 and 720 kg/ ha, respectively. *D. intortum* and *D. uncinatum* failed to produce any straw yield. The local *Desmodium* species gave the highest grain yield of 718 and 827 kg/ha for Kadugli and Damazin collection, respectively. Grain yield from *D. tortuosum* was 105 kg/ha, while *D. distortum* gave very low grain yield (41 kg/ha). *D. intortum* and *D. uncinatum*, on the other hand, gave no grain yield (Table 22).

None of the *Desmodium* species showed regeneration, in the second season.

Table 22. Mean stand, straw yield and seed yield of *Desmodium* species (Gezira, 2007/08)

***Desmodium* species**	**Number of plants/ m row**	**Straw yield (kg/ha)**	**Seed yield (kg/ha)**
D. dichotomum(Damazin)	37	(3583) 59.85	(827) 28.73
D. dichotomum(Kadugli)	46	(5039) 70.97	(718) 26.50
D. intortum	1	(0) 0.707	(0) 0.707
D. distortum	49	(720) 26.77	(41) 6.36
D. uncinatum	2	(0) 0.707	(0) 0.707
D. tortuosum	49	(1581) 39.13	(105) 9.74
SE±	2.657	2.308	1.512

Data are √ + 0.5 transformed. Figures in parenthesis are actual data.

Striga emergences in plots without *Desmodium* were 34 and 22 plants/ m^2, 30 and 60 days after sowing, respectively (Table 23).

At 30 days after sowing, *Striga* displayed considerable emergence. Sorghum cv. Arfa Gadamak subsequently planted in plots previously sown to *D. dichotomum* (Damazin collection), *D. tortuosum, D. intortum* and *D. uncinatum* showed considerable (26 to 78%) reduction in *Striga* emergence. However, differences were not significant. Sorghum planted in plots previously sown to *D. distortum* and *D. dichotomum* (Kadugli collection) showed the highest *Striga* emergence (Table 23). At 60 days after crop emergence, *Striga* showed the lowest incidence in the control plots. However, a considerable increase in *Striga* emergence occurred in plots previously sown to *Desmodium*

species. Plots previously sown to *Desmodium* species invariably sustained more *Striga* emergence than the control plots. The highest *Striga* emergence was sustained in plots previously sown to *D. distortum*. At 90 days after crop emergence *Striga* population density considerably declined. However, *Striga* emergence was invariably higher in plots previously sown to *Desmodium* species. The highest *Striga* emergence was sustained in plots previously sown to *D. distortum*. Nevertheless, differences between treatments were not significant (Table 23). At harvest *Striga* air dry weight was lowest in plots previously sown to *D. dichotomum* (Damazin) and *D. intortum* and highest in plots previously sown to *D. distortum* (Table 23).

Table 23. Effects of *Desmodium* species sown in 2007/08 season on *S. hermonthica* incidence on subsequent sorghum

Previous season treatment	***Striga* population density (plants/ m^2)**			***Striga* air dry weight (kg/ha)**
	30 days after sowing	**60 days after sowing**	**90 days after sowing**	
D. dichotomum (Damazin)	(11) 3.2	(29) 4.9	(17) 3.9	(251.0) 13.7
D. intortum	(21) 4.2	(33) 5.2	(18) 3.7	(487.5) 19.4
D. distortum	(68) 7.4	(83) 8.4	(61) 7.0	(1156.3) 29.5
D. uncinatum	(25) 4.8	(43) 6.4	(19) 3.7	(582.3) 21.1
D. tortuosum	(20) 4.1	(37) 5.1	(16) 3.5	(581.3) 20.7
D dichotomum(Kadugli)	(39) 6.3	(51) 7.0	(38) 5.9	(833.3) 28.5
Control without *Desmodium*	(34) 5.7	(22) 4.6	(14) 3.4	(524.0) 19.2
SE±	1.419	1.823	1.578	8.479

Data are $\sqrt{}$ + 0.5 transformed**.** Figures in parenthesis are actual data

Sorghum stand, height and days to 50 % flowering were not affected by previous planting of plots with *Desmodium* species (Table 24).

Sorghum planted in plots previously sown to *D. dichotomum* (Damazin collection) and *D. intortum* produced the highest number of heads and heading was increased by 14 and 20 % over the control. However, differences were not significant (Table 24).

Sorghum planted in plots previously sown to *D. dichotomum* (Damazin collection) and *D. tortuosum*, displayed 39 and 77% increase in grain yield, over the control, respectively. However, the observed differences were not statistically significant (Table 24).

Table 24. Effects of previously sown *Desmodium* species on subsequent sorghum growth and yield (2008/09)

Previous season treatment	Number of sorghum plants /m row	Plant height (cm)	Days to 50 % flowering	Number of heads/ m row	Seed yield (kg/ha)
D. dichotomum (Damazin)	9.9	110.2	52	10.6	2390
D dichotomum(Kadugli)	9.8	93.9	53	6.2	936
D. intortum	10.0	106.4	55	10.0	1839
D. distortum	9.7	89.9	58	5.3	1230
D. uncinatum	9.8	105.3	52	8.0	1234
D. tortuosum	9.9	109.1	54	8.3	3049
Control without *Desmodium*	9.8	109.2	55	8.8	1724
SE±	0.288	11.048	1.957	1.783	665.99

4.3.1.2. Screening of *Desmodium* species for drought tolerance and residual effects on *S. hermonthica* on sorghum at Gedarif (rainfed):

Monthly seasonal rainfall for 2007/08 and 2008/09 seasons was recorded (Table 25). Total rainfall in season 2007/08 (446 mm) was more than 2- fold that of season 2008/09 (210 mm).

Table 25. Monthly and seasonal rainfall during 2007 and 2008 growing seasons at Gedarif

Monthly	season	July	August	September	October	Total
Rainfall	2007/08	114	238	82	12	446
(mm)	2008/09	25	70	115	0	210

In the first season, exotic *Desmodium* spp. displayed low establishment (6-16 plants/ m row) (Table 26). The local species, irrespective of collection site, showed the highest establishment. The highest straw yield (5397 kg/ha) was obtained by *D. dichotomum* (Damazin collection) followed in descending order by *D. dichotomum*, (Kadugli collection), *D. tortuosum* and *D. distortum*. *D. uncinatum* and *D. intortum* on the other hand died prior to harvest and no straw yield was produced (Table 26).

D. dichotomum (Damazin collection) gave the highest grain yield followed by *D. dichotomum* (Kadugali collection), *D. distortum* and *D. tortuosum*. *D. uncinatum* and *D. intortum* failed to obtain any grain yield (Table 26).

Table 26. Mean stand, straw yield and seed yield of *Desmodium* species (Gedarif 2007/08)

***Desmodium* species**	**Number of plants/ m row**	**Straw yield (kg/ha)**	**Seed yield (kg/ha) ***
D.dichotomum(Damazin)	29	(5397) 73.47	(989) 31.43
D.dichotomum(Kadugli)	38	(5136) 71.56	(940) 30.56
D. intortum	6	(0) 0.707	(0) 0.71
D. distortum	16	(1186) 34.26	(63) (7.68)
D. uncinatum	11	(0) 0.707	(0) 0.71
D. tortuosum	15	(2002) 44.75	(47) 6.83
SE±	2.754	1.747	0.767

Data are √ + 0.5 transformed. Figures in parenthesis are actual data.

In the second season, none of the *Desmodium* species showed regeneration. No data on growth and yield of sorghum were collected due to poor rainfall. The only, data obtained were on *Striga* emergence for the first two months (Table 27). *Striga* emergence was invariably low. At 30 days from sowing, *Striga* emergence (4 plants/m^2) was highest in plots previously sown to *D. intortum*. *Striga* emergence in the control plot was 2 and 5 plants/ m^2 at 30 and 60 days after sowing, respectively (Table 27). Furthermore, no significant difference in *Striga* emergence was observed between treatments.

Table 27. Effects of *Desmodium* species sown in 2007/08 season on *S. hermonthica* incidence on subsequent sorghum (2008/09)

Previous season treatment	*Striga* population density (plants/ m^2)	
	30 days after sowing	60 days after sowing
D. dichotomum (Damazin)	(1) 1.2	(3) 1.8
D. intortum	(4) 1.7	(4) 2.0
D. distortum	(2) 1.4	(2) 1.5
D. uncinatum	(2) 1.6	(3) 1.9
D. tortuosum	(3) 1.6	(4) 1.8
D. dichotomum (Kadugli)	(1) 1.1	(2) 1.3
Control without *Desmodium*	(2) 1.6	(5) 2.2
SE±	0.508	0.532

Data are $\sqrt{}$ + 0.5 transformed. Figures in parenthesis are actual data.

4.3.2. Influence of intercropping with *Desmodium* species on *S. hermonthica* incidence and performance of two sorghum genotypes at Gezira:

In the first season, *Striga* emergence was low (Table 28). At 60 and 90 days after sowing, emergence of the parasite on Abu Sabeen, in absence of intercropping was 3 and 1 plants/m^2, respectively. Intercropping with *Desmodium* resulted in non-significant reduction in *Striga* population (Table 28).

On Hakika, in absence of *Desmodium*, *Striga* emergence was very low and amounted to 2 and 1 plant/ m^2, at 60 and 90 days after sowing, respectively. In presence of *Desmodium* species no significant *Striga* emergence was realized as the number of emerging *Striga* plants per /m^2 was very low (Table 28).

Table 28. *Striga* incidence as influenced by *Desmodium* species and sorghum genotype (Gezira, 2007/08)

***Desmodium* species**	***Striga* incidence (plants/m^2) Sorghum genotype**	
	Abu Sabeen	**Hakika**
(a) 60 days after sowing:		
D. tortuosum	(2) 1.5	(0)0.8
D. intortum	(4) 1.8	(0) 0.9
D. dichotomum (Damazin)	(5) 2.3	(1) 1.0
D. uncinatum	(2) 1.4	(0) 0.71
D. distortum	(2)1.4	(0)0.8
Control without *Desmodium*	(3) 1.8	(2) 1.3
SE±	0.34 ns	
(b) 90 days after sowing:		
D. tortuosum	(1)1.3	(0) 0.71
D. intortum	(2) 1.3	(0) 0.83
D. dichotomum (Damazin)	(3) 1.7	(0) 0.83
D. uncinatum	(2) 1.3	(0) 0.71
D. distortum	(0) 0.9	(0) 0.71
Control without *Desmodium*	(1) 1.1	(1) 1.10
SE±	0.24 ns	ns

Data are $\sqrt{}$ + 0.5 transformed. Figures in parenthesis are actual data. ns= Not significant.

Desmodium stand determined 30 days after sowing showed considerable variations with species. *D. dichotomum* (Damazin collection), showed the highest stand establishment followed by *D. distortum* and *D. tortuosum*. *D. intortum* and *D. uncinatum*, on the other hand, failed to establish (Table 29).

At 90 days after sowing, biological yield of Abu Sabeen without *Desmodium* was 3890 kg/ha. Intercropping with each of the *Desmodium* species did not a significantly effect in biological yield (Table 30).

Table 29. Population density of *Desmodium* as influenced by species and companion crop genotype at 30 days after sowing (Gezira, 2007/08)

***Desmodium* species**	**Population density (m/row)**	
	Abu Sabeen	**Hakika**
D. tortuosum	14 ab	9 ab
D. intortum	0 b	5 ab
D. dichotomum (Damazin)	18 a	20 a
D. uncinatum	0 b	0 b
D. distortum	14 ab	19 a
Control without *Desmodium*	0	0
SE±	5.123	

Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test.

Hakika, without *Desmodium* species gave a biological yield of 3119 kg/ ha. Intercropping with *D. dichotomum* increased biological yield by 41%. In among all treatments the highest biological yield was obtained on intercropping with *D. dichotomum* collected from Damazin (Table 30).

Table 30. Influence of intercropping with *Desmodium* species on biological yield of sorghum (Gezira, 2007/08)

***Desmodium* species**	**Sorghum biological yield (kg/ha)**	
	Abu Sabeen	**Hakika**
D. tortuosum	2124	2393* ns
D. intortum	2568	3818
D. dichotomum	3568	4390
D. uncinatum	1763	3156
D. distortum	2993	2923
Control without *Desmodium*	3890	3119
SE±	710.1 ns	

ns= Not significant.

In the second season (2008/09), Abu Sabeen, as sole crop, sustained the highest *Striga* emergence (93 plants/m^2), at 60 days after sowing (Table 31). Intercropping with *Desmodium* species reduced the parasite population by 16-33%. Maximum reduction in *Striga* emergence was realized on intercropping with *D. dichotomum* (Damazin collection). However, differences between treatments were not significant. At 90 days after sowing, Abu Sabeen sustained the highest *Striga* emergence (74 plants /m^2). Intercropping with *Desmodium* reduced *Striga* population by 34- 51% (Table 31). The highest reduction was obtained when intercropping with *D. distortum* was practical.

On Hakika (sole sorghum) *Striga* emergence, was 6 plants /m^2, at 60 days after sowing. Intercropping with *D. tortuosum* and *D. uncinatum*, increased *Striga* population density by 67 and 33%. However, the observed increments were not significant (Table 31).

At 90 days after sowing, *Striga* emergence on Hakika, as sole crop, was 7 plants /m^2. Intercropping with *D. dichotomum* (Damazin collection) and *D. distortum* reduced the parasite emergence in comparison with the sole crop, albeit not significantly (Table 31). Intercropping with *D. tortuosum* and *D.*

Table 31. *Striga* incidence as influenced by *Desmodium* species and sorghum genotype (Gezira, 2008/09)

***Desmodium* species**	***Striga* incidence (plants/m^2)**	
	Sorghum genotype	
	Abu Sabeen	**Hakika**
(a) 60 days after sowing:		
D. tortuosum	(64) 8.0 a	(10) 3.1 b
D. dichotomum (Damazin)	(62) 7.8 a	(5) 2.4 b
D. uncinatum	(76) 8.6 a	(8) 2.8 b
D. distortum	(66) 8.1 a	(2) 1.5 b
D. dichotomum (Kadugli)	(78) 8.7 a	(5) 2.4 b
Control without *Desmodium*	(93) 9.6 a	(6) 2.4 b
SE±	0.59	
(b) 90 days after sowing:		
D. tortuosum	(41) 6.4 b	(7)2.6 c
D. dichotomum (Damazin)	(49) 7.0 ab	(3) 2.0 c
D. uncinatum	(47) 6.9 ab	(7) 2.7 c
D. distortum	(36) 6.0 b	(3) 1.7 c
D. dichotomum (Kadugli)	(46) 6.8 b	(8) 2.7 c
Control without *Desmodium*	(74) 8.5 a	(7) 2.5 c
SE±	0.56	

Data are $\sqrt{}$ + 0.5 transformed. Figures in parenthesis are actual data. Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test.

uncinatum resulted in *Striga* emergence similar to that on sole sorghum. Intercropping with *D. dichotomum* (Kadugli collection) increased slightly *Striga* emergence.

At harvest, *Striga* biomass was highest in sub- plots planted to Abu Sabeen as sole crop (Table 32). Intercropping with *Desmodium* reduced *Striga* biomass by 9- 36%. The highest reduction was realized on intercropping with *D. distortum*, albeit not significantly (Table 32).

Striga biomass on Hakika as sole crop was very low in comparison to the corresponding Abu Sabeen treatment (Table 32). All *Desmodium* species except *D. distortum* increased *Striga* biomass. However, differences between treatments were not significant.

Table 32. *Striga* biomass as influenced by *Desmodium* species and sorghum genotypes (Gezira, 2007/08)

***Desmodium* species**	***Striga* biomass (kg/ha) Sorghum genotype**	
	Abu Sabeen	**Hakika**
D. tortuosum	(1198) 34.5 a	(101) 9.5 b
D. dichotomum (Damazin)	(1302) 36.0 a	(214) 12.1 b
D. uncinatum	(1563) 39.4 a	(95) 9.7 b
D. distortum	(1094) 32.9 a	(51) 5.3 b
D. dichotomum (Kadugali)	(1302) 35.6 a	(93) 8.8 b
Control without *Desmodium*	(1719) 40.9 a	(69) 7.7 b
SE±	3.30	

Data are $\sqrt{}$ + 0.5 transformed. Figures in parenthesis are actual data. Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test.

Days to 50% flowering of sorghum were influenced by both genotype and intercropping with *Desmodium* (Table 33). In Abu Sabeen, intercropping

with *D. distortum* delayed flowering significantly, while intercropping with *D. dichotomum* (Damazin collection) advanced flowering date, albeit not significantly. Intercropping with other *Desmodium* species, on the other hand, had no significant effect on flowering. Hakika reached 50% flowering earlier than Abu Sabeen and intercropping with *Desmodium* species had no effects (Table 33).

Table 33. Influence of intercropping with *Desmodium* species on days to 50 % flowering of sorghum under *Striga* infestation (Gezira, 2008/09)

***Desmodium* species**	**Days to 50% flowering**	
	Abu Sabeen	**Hakika**
D. tortuosum	76 bc	68 cd
D. dichotomum (Damazin)	68 cd	66 d
D. uncinatum	76 bc	69 cd
D. distortum	86 a	68 cd
D. dichotomum (Kadugli)	78 ab	68 cd
Control without *Desmodium*	75 bcd	67 cd
SE±	2.82	

Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test.

Intercropping sorghum Abu Sabeen with *D. dichotomum* (Damazin collection) increased plant height, albeit not significantly (Table 34). Intercropping with *D. distortum*, on the other hand, reduced sorghum height significantly. Intercropping with other *Desmodium* species had no effects. On Hakika, intercropping with *D. dichotomum* (Kadugli collection), *D.*

dichotomum (Damazin collection) and *D. distortum* had no effect on plant height. Intercropping with *D. tortuosum* and *D. uncinatum*, on the other hand, reduced plant height, albeit not significantly (Table 34).

Table 34. Influence of intercropping with *Desmodium* species on height of sorghum under *Striga* infestation (Gezira, 2008/09)

***Desmodium* species**	**Sorghum height (cm)**	
	Abu Sabeen	**Hakika**
D. tortuosum	131.5 abc	116.2 d
D. dichotomum (Damazin)	143.7 a	127.8 bcd
D. uncinatum	135.3 abc	120.3 cd
D. distortum	115.5 d	126.2 bcd
D. dichotomum (Kadugali)	131.8 abc	132.4 abc
Control without *Desmodium*	137.3 ab	130.1 abcd
SE±	4.46	

Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test.

Abu Sabeen, intercropping with *D. dichotomum* (Damazin collection) significantly increased sorghum population. Intercropping with *D. tortuosum* and *D. dichotomum* (Kadugli collection) increased crop stand, albeit not significantly (Table 35). Hakika population density in the control plot was about 2- fold that of Abu Sabeen. Moreover, intercropping with *Desmodium* species had no effect on Hakika stand (Table 35).

Table 35. Influence of intercropping with *Desmodium* species on population of sorghum under *Striga* infestation (Gezira, 2008/09)

***Desmodium* species**	**Sorghum stand (per m row)**	
	Abu Sabeen	**Hakika**
D. tortuosum	6.8 bc	9.8 a
D. dichotomum (Damazin)	8.3 ab	10.0 a
D. uncinatum	6.2 bc	10.0 a
D. distortum	4.8 c	10.0 a
D. dichotomum (Kadugli)	6.8 bc	10.0 a
Control without *Desmodium*	5.3 c	10.0 a
SE±	0.7	

Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test.

Abu Sabeen when not intercropped with *Desmodium* species gave low yield. Intercropping with *D. dichotomum*, (Damazin collection) increased grain yield, albeit not significantly (Table 36). Intercropping with other *Desmodium* spp. reduced grain yield, albeit not significantly. Hakika without intercropping outyielded Abu Sabeen by more than 10- fold. Intercropping with *D. uncinatum* depressed yield significantly. However, intercropping with other *Desmodium* species had no significant effect on grain yield (Table 36).

Table 36. Influence of intercropping with *Desmodium* species on grain yield of sorghum under *Striga* infestation (Gezira, 2008/09)

***Desmodium* species**	**Sorghum grain yield (kg/ha)**	
	Abu Sabeen	**Hakika**
D. tortuosum	150 d	1816 ab
D. dichotomum (Damazin)	548 cd	2695 a
D. uncinatum	96 d	1365 bc
D. distortum	122 d	2373 ab
D. dichotomum (Kadugli)	79 d	2281 ab
Control without *Desmodium*	210 d	2744 a
SE±	317.42	

Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test.

4.3.3. Influence of intercropping with *Desmodium* species on *S. hermonthica* incidence and performance of two sorghum genotypes at Gedarif:

In season 2007/08, *Striga* emergence on sole sorghum land race "Korokollo" was 12 and 13 plants /m^2, at 60 and 90 days after sowing, respectively (Table 37). At 60 and 90 days after sowing, intercropping with *D. distortum* reduced *Striga* population density by 50 and 54%, respectively (Table 37). Intercropping with *D. uncinatum*, on the other hand increased *Striga* emergence by 42 and 54 %, respectively. However, differences between treatments were not significant.

On Hakika, *Striga* emergence was 5 and 8 plants /m^2 on the sole crop 60 and 90 days after sowing, respectively (Table 37). Intercropping with *D. dichotomum* (Damazin collection) reduced *Striga* emergence by 60 and 38%, respectively. Intercropping with *D. intortum* and *D. distortum* increased *Striga* emergence by 13 to 60%. However, differences between treatments were not significant. In both counts Hakika, supported less *Striga* emeregence than "Korokollo" by 38 to 58% (Table 37).

Table 37. *Striga* incidence as influenced by *Desmodium* species and sorghum genotype at Gedarif (2007/08)

***Desmodium* species**	***Striga* incidence (plants/m^2) Sorghum genotype**	
	Korokollo	Hakika
(a) 60 days after sowing:		
D. intortum	(10) 3.1	(7) 2.6
D. dichotomum (Damazin)	(12) 3.2	(2) 1.5
D. uncinatum	(17) 4.1	(5) 2.1
D. distortum	(6) 2.5	(7)2.5
Control without *Desmodium*	(12) 3.5	(5) 2.3
SE±	0.59 ns	
(b) 90 days after sowing:		
D. intortum	(14) 3.7	(9)2.9
D. dichotomum (Damazin)	(14) 3.6	(5) 2.3
D. uncinatum	(20) 4.5	(8) 2.9
D. disotrtum	(6) 2.5	(12) 3.4
Control without *Desmodium*	(13) 3.7	(8) 2.8
SE±	0.55 ns	

Data are $\sqrt{}$ + 0.5 transformed. Figures in parenthesis are actual data. ns= not significant.

Desmodium stand determined 30 days after sowing showed considerable variation with species. *D. dichotomum* (Damazin collection), showed the

highest stand establishment followed in desending order by *D. distortum*, *D. uncinatum* and *D. intortum* (Table 38).

Table 38. Population density of *Desmodium* as influenced by species and companion crop genotype at 30 days after sowing (Gedarif, 2007/08)

***Desmodium* species**	**Population density (m/ row)**	
	Korokollo	**Hakika**
D. intortum	5 cd	2 d
D. dichotomum (Damazin)	30 a	27 ab
D. uncinatum	7 bcd	7 abcd
D. distortum	24 abc	21abcd
Control without *Desmodium*	-	-
SE±	6.0	

Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test.

Intercropping with *Desmodium* species and sorghum genotype had no effects on days to 50% flowering of sorghum (Table 39).

Table 39. Influence of intercropping with *Desmodium* species on days to 50 % flowering of sorghum under *Striga* infestation at Gedarif (2007/08)

***Desmodium* species**	**Days to 50% flowering**	
	Korokollo	**Hakika**
D. intortum	88	86* ns
D. dichotomum	87	83
D. uncinatum	87	86
D. distortum	83	85
Control without *Desmodium*	89	88
SE±	2.0 ns	

ns= not significant.

Korokollo was taller than Hakika, albeit not significantly. Intercropping with *D. intortum* and *D. dichotomum* (Damazin collection), increased Korokollo height significantly. Intercropping with other *Desmodium* spp. increased height, albeit not significantly (Table 40). On Hakika intercropping with *Desmodium* species had no significant effects on crop height (Table 40).

Table 40. Influence of intercropping with *Desmodium* species on height of sorghum under *Striga* infestation at Gedarif (2007/08)

***Desmodium* species**	**Sorghum height (cm)**	
	Korokollo	**Hakika**
D. intortum	126.9 a	69.1 c
D. dichotomum (Damazin)	132.1 a	84.3 c
D. uncinatum	115.9 ab	83.0 c
D. distortum	123.4 ab	69.3 c
Control without *Desmodium*	91.43 bc	83.6 c
SE±	8.779	

Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test.

Sole Korokollo and Hakika crops gave grain yield of 211 and 180 kg per ha, respectively. Intercropping of Korokollo with *D. dichotomum* (Damazin) increased grain yield significantly. Intercropping with other *Desmodium* species increased grain yield over the sole crop, albeit not significantly (Table 41). Intercropping with *D. uncinatum* increased grain yield of Hakika, albeit not significant. However, other *Desmodium* species had no effect on grain yield (Table 41).

Table 41. Influence of intercropping with *Desmodium* species on grain yield of sorghum under *Striga* infestation (Gedarif, 2007/08)

***Desmodium* species**	**Sorghum grain yield (kg/ha)**	
	Korokollo	**Hakika**
D. intortum	381 b	142 b
D. dichotomum (Damazin)	850 a	165 b
D. uncinatum	301 b	279 b
D. distortum	228 b	179 b
Control without *Desmodium*	211 b	180 b
SE±	109.3	

Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test.

In the second season (2008/09), *Striga* emergence on sole Korokollo was 9 plants/m^2, at 60 days after sowing. Intercropping with *D. uncinatum* and *D. dichotomum* (Damazin and Kadugli collections) reduced *Striga* emergence, albeit not significantly (Table 42). Other *Desmodium* species had negligible effects.

Hakika, as sole crop, supported 2 *Striga* plants/ m^2. Intercropping with *D. uncinatum* increased *Striga* emergence in comparison to the sole crop. Intercropping with other *Desmodium* species had no significant effects on *Striga* emergence. Drought and the concomitant loss of crop preculded further collection of data on *Striga* emergence and sorghum performance.

Table 42. *Striga* incidence as influenced by *Desmodium* species and sorghum genotypes at 60 days after sowing (Gedarif, 2008/09)

Desmodium species	Sorghum genotype	
	Korokollo	**Hakika**
D. tortuosum	(6) 2.40 ab	(1) 0.98 b
D. dichotomum (Damazin)	(6) 2.1 ab	(1) 1.00 b
D. uncinatum	(1) 1.04 ab	(4) 2.00 ab
D. distortum	(7) 2.73 ab	(1) 1.33 ab
D. dichotomum (Kadugali)	(2) 1.37 ab	(2) 1.48 ab
Control without *Desmodium*	(9) 3.02 a	(2)1.36 ab
SE±	0.3882	

Data are √ + 0.5 transformed. Figures in parenthesis are actual data. Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test.

4.4. Trials on *O. ramosa* on tomatoes:

4.4.1. Effects of intercropping of *Desmodium* species on *O. ramosa* parasitism and tomato yield:

In season 2006/07, *Desmodium* spp., irrespective of placement and observation date tended to reduce *O. ramosa* infestation in comparison to the control (Table 43). *O. ramosa* infestation irrespective of observation date or *Desmodium* species was invariably the lowest when *Desmodium* was drilled 10 cm from tomato rows and highest when *Desmodium* was planted between tomato holes and/or when planted in the same hole with tomato (Table 43).

At 60 and 90 days after sowing, *O. ramosa* population density was low, irrespective of treatment. However, at 120 days after sowing *O. ramosa* population density was 36 plants/m^2 in the control plot. Intercropping with *Desmodium* species, at 120 days after sowing reduced *O. ramosa* emergence

by 28- 78 %. Emergence of the parasite was invariably the lowest when *Desmodium*, irrespective of the species, was drilled 10 cm from tomato rows. *Desmodium* species when planted between tomato holes resulted in considerable reduction 44 to 67% in *O. ramosa* emergence. However, the observed reduction was only significant in case of *D. uncinatum*. Placement of *Desmodium* species in the same hole as tomato plants resulted in the least reductions. The observed reductions were 33 and 28% for *D. dichotomum* and *D. uncinatum*, respectively (Table 43).

Table 43. Influence of intercropping with *Desmodium* spp. on *O. ramosa* parasitism on tomato (2006/07)

Treatment	*O. ramosa* population density (plants/ m^2)		
	60 DAS*	**90 DAS**	**120 DAS**
D. dichotomum hand- drilled at 10 cm from tomato row	(1) 0.96	(2) 1.45	(8) 2.27
D. dichotomum intercropped with tomato in the same hole	(1) 1.14	(4) 2.08	(24) 4.89
D. dichotomum intercropped with tomato between holes	(3) 1.69	(6) 2.35	(20) 4.29
D. uncinatum hand- drilled at 10 cm from tomato row	(1) 1.02	(2) 1.49	(9) 2.83
D. uncinatum intercropped with tomato in the same hole	(2) 1.49	(6) 2.35	(26) 4.73
D. uncinatum intercropped with tomato between holes	(1) 1.07	(4) 1.82	(12) 3.23
Orobanche infested control	(3) 1.89	(8) 2.84	(36) 5.81
SE±	0.2785	0.3708	0.6545

Data are √ + 0.5 transformed. Figures in parenthesis are actual data. DAS*= days after sowing.

Intercropping with *Desmodium*, invariably, increased tomato yield. Increaments in tomato yield were the lowest (2 and 16%) and not significant when *Desmodium* species were drilled at 10 cm from tomato rows. However, high and significant increaments (61- 82%) in tomato yield were obtained when

Desmodium species were planted in between holes or in the same hole as tomato plants (Table 42). Intercropping with *D. dichotomum* tended to increase yield more than *D. uncinatum* (Table 44).

Table 44. Influence of intercropping with *Desmodium* spp. on yield of tomato under *Orobanche* infested field (2006/07)

Treatment	Yield (t/ha)	Increase in yield (%)
D. dichotomum hand- drilled at 10 cm from tomato row	8.07	16
D. dichotomum intercropped with tomato in the same hole	12.62	82
D. dichotomum intercropped with tomato between holes	11.76	70
D. uncinatum hand- drilled at 10 cm from tomato row	7.10	2
D. uncinatum intercropped with tomato in the same hole	11.16	61
D. uncinatum intercropped with tomato between holes	11.31	63
Orobanche infested control (Sole crop)	6.93	
SE±	1.216	

In 2007/08 season, *O. ramosa* emergence was higher and earlier than that of the first season (Table 45). At 60 days after sowing, emergence of *O. ramosa* was generally low (1 to 5 plants/ m^2). The number of *O. ramosa* spikes in the control plots was 37 and 66 plants per m^2 at 90 and 120 days after sowing, respectively.

D. dichotomum and *D. uncinatum* when drilled at 10 cm from tomato row or planted in the same hole as tomato plants reduced *Orobanche* emergence substantially, albeit not significantly. The observed reductions, irrespective of *Desmodium* species were invariably higher when the latters were planted at 10 cm from the tomato rows.

At 120 days after sowing *Desmodium*, irrespective of species, planted at 10 cm from tomato rows or in the same hole as tomato plants reduced *O. ramosa* emergence considerably, albeit not significantly. In among treatments, planting in between tomato holes resulted in the lowest reductions of *O. ramosa* emergence (Table 45).

Table 45. Influence of intercropping with *Desmodium* spp. on *O. ramosa* parasitism on tomato (2007/08)

Treatment	*O. ramosa* population density(plants/ m^2)		
	60 DAS*	90 DAS	120 DAS
D. dichotomum hand- drilled at 10 cm from tomato row	(1) 1.30	(22) 4.26	(38) 6.08
D. dichotomum intercropped with tomato in the same hole	(1) 1.11	(30) 5.48	(56) 7.43
D. dichotomum intercropped with tomato between holes	(3) 1.75	(38) 6.20	(68) 8.29
D. uncinatum hand- drilled at 10 cm from tomato row	(1) 1.03	(19) 4.17	(31) 5.28
D. uncinatum intercropped with tomato in the same hole	(0) 0.89	(24) 4.71	(46) 6.66
D. uncinatum intercropped with tomato between holes	(5) 1.98	(40) 6.25	(72) 8.43
Orobanche infested control	(1) 0.96	(37) 5.70	(66) 7.96
SE±	0.277	1.1245	0.8158

Data are √ + 0.5 transformed. Figures in parenthesis are actual data. DAS*= days after sowing.

Tomato yield irrespective of treatment was low (Table 46). *D. dichotomum* drilled 10 cm from tomato rows and *D. uncinatum* planted between tomato holes resulted in yield less than the control, albeit not significantly (Table 46*). D. dichotomum* planted in the same hole as tomato plants or planted between holes and *D. uncinatum* drilled 10 cm from tomato rows or in the same hole as the tomato plants improved yield considerably, but not significantly in

comparison to the control. *D. dichotomum* intercropped with tomato between holes obtained the highest yield (Table 46).

Table 46. Influence of intercropping with *Desmodium* spp. on yield of tomato under *Orobanche* infested field (2007/08)

Treatment	Yield (t/ha)	Increase in yield (%)
D. dichotomum hand- drilled at 10 cm from tomato row	3.40	-
D. dichotomum intercropped with tomato in the same hole	3.73	4
D. dichotomum intercropped with tomato between holes	6.03	68
D. uncinatum hand- drilled at 10 cm from tomato row	4.66	29
D. uncinatum intercropped with tomato in the same hole	3.81	6
D. uncinatum intercropped with tomato between holes	3.21	-
Orobanche infested control (Sole crop)	3.60	
SE±	0.960	

Chapter five

Discussion

Parasitic weeds of the genera *Striga* and *Orobanche* pose a severe problem for agriculture. They are difficult to control and are highly destructive to several crops. The effects of parasitic weeds are greater than those of other weeds. The root parasitic weeds *Striga* spp. and *Orobanche* spp. appear late in the growing season so they escape from normal weeding practices or control measures. As parasites they live at the expense of their hosts. They rob water and nutrients. Moreover, for root parasitic weeds most of the damage is inflicted before they emerge on the soil surface. Control after emergence of parasitic weeds often is of no benefit to the current crop, albeit it reduces the seed bank (Goldwasser and Kleifeld, 2004 and Sauerborn *et al*, 2007). The close association between the parasites and their hosts, the complexity of the life cycle of the parasite, the underground nature of early developmental stages, copious seed production, germination requirements, variability between parasitic weed population and existence of host specific populations and physiological variants make the parasites difficult weeds to control (Goldwasser and Kleifeld, 2004; Babiker, 2007). Developmental stages of *Striga* and *Orobanche* comprise a number of mechanisms that ensure close coordination of the parasites life cycle and that of the hosts (Bowmeester *et al*, 2003). The life

cycles of the parasites could be suitable targets for their control especially the chemical signals involved in their regulation. Therefore, control methods should focus on reduction of the soil seed bank and interference with the parasites early developmental stages. It is also agreed that researchers should focus on the developement of integrated control measures that are based on modifications of the cultural practices without much increase in the cost of production so as to be acceptable to subsistence farmers who are faced with a shortage of resources. Improved cultural methods such as intercropping could be integrated in a control programme with other non- expensive technologies, such as tolerant varieties, that suit the production system in vouge. In this study, indigenous *Desmodium* species and some selected exotic species from the world collection were screened for drought tolerance and suppressive effects on *S. hermonthica* on sorghum and *O. ramosa* on tomato.

In this study, temperatures of 25 to 30 °C were found to be most favourable for *Desmodium* species seed germination. This finding is in agreement with the results obtained by Veasey and Martins (1991) who found that scarified seed of four *Desmodium* species germinated at high percentages at 20 to 40 °C and germination at 15°C was low. Accordingly, temperature during the rainy season will be suitable for their germination and establishment.

However, in winter when temperatures range between 18 and 24 °C they may be at a disadvantage.

Laboratory experiments revealed that the initial effect of simulated drought was a delay in seed germination. In general, the germination of five *Desmodium* species decreased with increasing PEG 8000 concentration.

PEG 8000 at low concentration (50 g/L) had no adverse effect on germination of *D. dichotomum* (Fig. 8). Increasing PEG 8000 concentration to 100 g/L delayed germination. At higher concentration of PEG 8000 no germination was displayed up to 3 days (Figs. 8, 10, 11 and 12). The response of *D. tortuosum*, *D. distortum* and *D. intortum* to PEG 8000 was more or less similar to that of *D. dichotomum* (Figs. 9, 10 and 11). On the other hand, *D. uncinatum* showed lower germination in comparison to other *Desmodium* species. These experiments have demonstrated that PEG 8000 is able to mimic the effect of drought stress, confirming results previously reported by Michael and Kaufmann (1937). In addition, pot experiments showed that *D. tortuosum* is slightly more drought tolerant under green house conditions than the other species (Table 10). *D. tortuosum* showed 88% regeneration on receiving the second irrigation 60 days after cutting, while *D. dichotomum* and *D. distortum* showed no regeneration.

Laboratory experiments (Figs. 13- 16) showed that all *Desmodium* species tested induced little to moderate *S. hermonthica* seed germination. This is at variance with the results of Khan *et al*. (2002) who found that *D. uncinatum* root exudates induced germination of *S. hermonthica* as effectively as maize root exudates. In among the *Desmodium* species, *D. distortum* root exudates induced the highest germination (35%). Furthermore, none of the *Desmodium* species induced germination of *O. ramosa*. The results suggest that *Desmodium* species under the set of experimental conditions adopted in this study may have a limited capacity as trap crops. Dawoud (1995) reported that the leguminous plants, hyacinth bean (*Lablab purpureous* L.) stimulates high (40%) *Striga* seed germination.

D. uncinatum, D. dichotomum and *D. intortum* root exudates applied 24 h subsequent to or simultaneously with GR 24 did not induce haustoria (Tables 2, 3 and 4). Similar findings have been reported by Khan *et al* (2002) who found that chemical components of *D. uncinatum* root exudates gave a significant inhibition of haustorial growth. Moreover, Khan *et al* (2008) reported that root exudates of *D. uncinatum* contain novel flavonoid compounds, some of which stimulate germination of *Striga* and others dramatically inhibit its subsequent development, including radicle growth. Other legumes also produce *Striga* germination stimulants, but demonstrate no significant post-germination

allelopathic effects. This suggests close similarity between the two groups of legumes differentiated by a lack of specific tailoring enzymes, e.g. *C*- glycosyl transferase, that convert common precursors, i.e. a pigenin to highly active post-germination inhibitors (Pickett *et al*, 2007). The initiation of haustorium takes place after *Striga* seeds germinate. As a result, the germinated seed either receives the signal to attach to the host or shrivels and die.

Allelopathy has been reported to be the cause for the reduction of *S. hermonthica* infection in intercropping with *D. uncinatum* by inhibition of the development of *Striga* haustoria although not of seed germination (Khan *et al*, 2002).

The allelopathic effect of chemicals exuded from the roots that interfere with haustorial development, combined with the potent chemical stimulants causing suicidal germination, provide not only direct witchweed control, but also a significant depletion of viable seeds in the soil (Khan *et al*, 2002).

Laboratory experiments showed that the presence of *D. uncinatum* and *D. dichotomum* reduced attachment of *Striga* into sorghum roots. This finding suggests the presence of haustorium and/ or radicle elongation inhibitors in the root exudates of D. *uncinatum* and *D. dichotomum.* The similar effects of *D. dichotomum* and *D. uncinatum* which may indicate comparable phytochemical

and physiological attributes. Furthermore, *Striga* plants which are able to survive can be easily controlled or destroyed before seeds setting.

Pot experiments revealed that the *D. dichotomum* planted 60 days prior to sorghum was more effective in suppressing the parasite. This result could be attributed to the fact that as leguminous plants, *Desmodium* spp. may fix nitrogen and thus improve soil fertility. Nitrogen fixed by legumes has been pointed as an important factor contributing to *Striga* control. The means by which levels of nitrogen suppress *Striga* are not clearly understood. However, the main effects of nitrogen fertilization could be via reduction of stimulant exudation, direct damage to *Striga* seeds and seedling in the soil, reduced osmotic pressure in the parasite relative to the host and increased shading by the crop (Parker and Riches, 1993).

Under field conditions at Wad Medani and Gedarif locations, only three *Desmodium* species namely *D. dichotomum*, *D. distortum* and *D. tortuosum* were able to establish, while the other two species, *D. uncinatum* and *D. intortum* were unable to establish particularly in July which is the time for planting sorghum in Sudan. Their stand was invariably low (Tables 22 and 26). Field observations showed that all *Desmodium* species tested did not regenerate in the next season. The ability of *Desmodium* species to regenerate or survive

after harvest was greatly affected by poor or low rainfall. The bulk of Sudan has a short rainy season. Annual rainfall in Sudan usually starts in June and ends in October. Climatic factors play an important role in determining the type of economic activities, especially in arid tropical areas where rainfall is vital to human and animal existence and determines the scale of agricultural production (Himedan and Hamid, 2006).

The field trial of intercropping of *Desmodium* with two sorghum genotypes at Wad Medani in the first season was attacked by diseases and termites which highly affected the growth of sorghum. Moreover, the number of *Striga* emergence was very low. However, the influence of intercropping of *Desmodium* appeared in the second season where *Striga* incidence was low (Table 31). Intercropping with *Desmodium* reduced the parasite population and biomass. In addition, an increase in sorghum yield amounting to 161% over that of the sole crop was realized (Tables 31, 32 and 36).

Similar results were obtained at Gedarif location in the first season where the intercropping with *Desmodium* increased yield of sorghum by 8- 303% in comparison with that of sole sorghum (Tables 37 and 41). However, in the second season low rainfall damaged the crop and precluded collection of reliable data. Total rainfall in the first season (2007/08) was 446 mm (Table 25). Most of the rainfall (26 and 53%) was in July and August and only 18 and

3% occurred in September and October. In the second season, rainfall was very low (210 mm). Very little rainfall occurred in July and August. The bulk of rainfall (115 mm) was in September and no rainfall occurred in October.

The field trials on tomato showed that *Orobanche ramosa* infestation was highest in the control plot (Tables 43 and 45). Both *D. dichotomum* and *D. uncinatum* reduced the number of emergent parasite and increased the total yield of tomato in the first and second season. This is consistant with the findings of Fernández- Aparicio *et al (*2008) who found consistent control of *O. crenata* infection in faba bean, pea and lentil when intercropped with fenugreek. They also found that, allelopathy was a major component for the reduction of *Orobanche* seed germination.

Intercropping with *Desmodium* offered satisfactory control of *O. ramosa*. Control of the parasite was reflected in noteable increase in tomato yield. The increase in yield without substantial inputs by farmers fits well into the subsistence African traditional culture of mixed cropping. The net result is an overall enhancement of the quality of life of peasant farmers and their families. *Desmodium* species provide fodder and meet the need for a reliable source of forage. However, the effects of intercropping with *Desmodium* species in *Strig*a on sorghum was less than expected based on reports from Kenya (Khan *et al*., 2000, 2001, 2002, 2006 2007 and 2008).

Despite induction of low and negligible germination of *S. hermothica* and lack of induction of germination of *O. ramosa* seeds by *Desmodium* species in the laboratory possible stimulation of germination in the field can not be ruled out. Furthermore, a reduction in debilitating effects of the parasites through smothering by *Desmodium* due to its spreading habit of growth is also a viable possibility. Parker and Riches (1993) proposed that suppression of *S. hermonthica* by leafy intercrops may be due, at least in part, to shading effects. Shading may reduce temperature and raise humidity over the emerging witchweed plants, thus reducing transpiration and supply of nutrition from the host plant.

Control of *Striga* and *O. ramosa* by intercropping with *Desmodium*, though positive results were obtained, showed less promise than reported elsewhere (Khan *et al*., 2001, 2002, 2006 and 2007). The decrease in performance of the species may be attributed to differences in climatic conditions. The bimodal rainfall in Lake Vectoria region enables the *Desmodium* species to survive and regenerate after cutting. However, in Sudan the lengthy dry period lead to death and preclude regeneration of even the perennial species *D. uncinatum* and *D. intortum*. However, the perennial species may offer promise in Southern Sudan where the rainy season is longer

and when bimodal rains occur. Further, studies on mode of action, for which a number of possible mechanisms have been considered, need to be undertaken.

An integrated *Striga* and *Orobanche* control is the key to success. Components of an integrated package for control of parasitic weeds need to be adaptable to the environment and tuned to farmers needs and capabilities. Moreover, farmers or those that advise and educate farmers need a high level of knowledge about parasitic weeds and the control options that are available. An effective integrated programme should combine tactics that are complimentary and should include a component that protects or enhances yield. Host plant resistance, intercropping with *Desmodium* or other leguminous species are examples of currently available technologies that protect yield potential (Ransom *et al*, 2007). Rotation is a practice that should be encouraged, even in the absence of high levels of *Striga* and *Orobanche* infestation. Resources are needed to identify productive and profitable rotation crops (Ransom *et al*, 2007).

Conclusions

In this study:

1. Germination of *Desmodium* species was delayed by low temperature and drought. Temperatures of 25 and 30 ºC were optimum for germination. Furthermore, of all *Desmodium* spp., *D. uncinatum* was the most sensitive to drought, while *D. tortuosum* was the most tolerant. Moreover, local *Desmodium* species displayed higher establishment. None of the *Desmodium* species showed regeneration in the next season.
2. Root exudate of *D. distortum* low germination of *S. hermonthica.* Other *Desmodium* species induced negligible germination. None of the root exudates of all *Desmodium* species, studied, induced *O. ramosa* germination.
3. *D. uncinatum and D. dichotomum* roots co- planted on rock- wool with sorghum curtailed *Striga* attachment to sorghum. Furthermore, *D. uncinatum* at higher population density reduced *Striga* emergence significantly. Other *Desmodium* species were less effective. Sorghum planted in plots previously sown to Desmodium species showed reduced *Striga* infestation.
4. *D. dichotomum* and *D. uncinatum* species were more suppressive to *O. ramosa* when planted in rows at 10 cm from tomato rows. Moreover,

intercropping with Desmodium species increased tomato yield, albeit not significantly.

5. Performance of *Desmodium* species on *Striga* and sorghum was by far less than reported by Khan *et al*. (2001, 2002, 2006 2007 and 2008). The reduced efficiency in suppression of the parasite may be attributed to climatic conditions. The bimodal rains in Lake Vectoria region sustain growth of *Desmodium* species across seasons. However, the extreme drought in central and northern Sudan precludes regeneration of even the perennial species (*D. uncinatum* and *D. intortum*). Accordingly, *Desmodium* spp., particularly the perennials (*D. uncinatum* and *D. intortum*), may be useful in combating *Striga* in southern Sudan in places where bimodal rains occur.
6. Research on ability of leguminous plants to suppress *Striga* and *Orobanche* species should continue. Mixed cropping is a traditional African practice and it may be deployed as a component of an integrated package for control of parasitic weeds.

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