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Effects of Inter-cropping and a Herbicide on Management of *Striga hermonthica* on Sorghum

Mazen Ahmed Abdalroof[1], Amani Hamad Eltayeb[1] and Rashida M. A. Abusin[2*]

[1]College of Agricultural Studies, Sudan University of Science and Technology, Sudan.
[2]Pests and Plant Health, College of Agriculture, University of Bahri, Khartoum North, Sudan.

Authors' contributions

This work was carried out in collaboration between all authors. Author MAA carried out the experimental field work. Author AHE designed the study, performed the statistical analysis wrote the protocol and the first draft of the manuscript. Author RMAA managed the analyses of the study. Authors MAA and AHE read and approved the final manuscript.

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ABSTRACT

Aims: The present work was undertaken to determine the effects of the herbicide chlorsulfuron and intercropping sorghum (cv.Wad-Ahmed) with cowpea (T100K-901-6 cv.) on *S. hermonthica* incidence and sorghum growth.
Study Design: Randomized Complete Block Design (RCBD) with four replicates.
Place and Duration of Study: A series of laboratory and greenhouse experiments was undertaken at the College of Agricultural Studies, Sudan University of Science and Technology (SUST) at Shambat, during the season 2013/2014.
Methodology: *Striga* free or infested soil was placed in plastic pots (9 cm i .d) with perforations at the bottoms. Pots filled with *Striga* free soil (0 mg) were included as control for comparison. Sorghum cultivar Wad-Ahmed was sown as sole crop or intercropped with cowpea. Chlorsulfuron at 1.3 g active ingredient (a.i)/fed was applied three weeks after sowing. Plant height and Stem diameter were measured in centimetres using a ruler and vernier caliper instrument, respectively, while weight was weighed in gram after drying using a balance.

**Corresponding author: E-mail: rashidaabusin333@gmail.com;*

Results: At 60 and 75 days after sowing (DAS), irrespective of *Striga* seed bank size, cowpea intercropped with sorghum displayed significant reduction in stem diameter (19.0-56.7%). Sorghum intercropped with cowpea at Striga seed bank size of 16 mg/pot resulted in a significant reduction in sorghum dry weight (61.6%). However, at 60 and 75 DAS displayed a significant reduction in sorghum height only at the seed bank size of 16 mg/pot. Chlorsulfuron applied to Sole sorghum at Striga seed bank size of 16 mg/pot reduced sorghum dry weight by 51.9%. Sorghum intercropped with cowpea and subsequently treated with chlorsulfuron at Striga seed bank size of 16 mg/pot decreased sorghum height significantly (20.8 – 29.5%). Sorghum intercropped with cowpea and subsequently treated with chlorsulfuron, irrespective of Striga seed bank size, reduced sorghum dry weight (28.1- 47.6%).

Conclusion: According to this study, *Striga* management requires integrated practices comprising different components. Intercropping sorghum with cowpea reduced *Striga* emergence. Chlorsulfuron effectively reduced germination and suppressed *Striga* emergence.

Keywords: Chlorsulfuron; cowpea; intercropping; sorghum; Striga.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench), is the fifth major cereal crop in terms of production, after maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), and barley (*Hordeum vulgare* L.) [1]. Ninety percent of the world's area cultivated with sorghum is in the developing countries, mainly in Africa and Asia. Major world's producers include Sudan, Nigeria, India, United States, Mexico, Ethiopia, China and Argentina [2]. Sorghum production, negatively influenced by abiotic (heat and drought) and biotic stresses (diseases, insects and weeds [3]. Of all weeds *Striga hermonthica* (Del.) Benth, an obligate root-parasite has been identified as one of the major biological threats to sorghum production in the savannah zones of sub-Saharan Africa [4]. Gressel et al. [5] and Rodenburg et al. [6], described that the parasite causes huge losses ranging from 40-90%, depending on crop variety, climatic conditions and seed infestation level of the soil and up to 75% of its overall damage to the hosts occurred during its subterranean stage of development [7]. A single *S. hermonthica* plant can produce up to 500, 000 seeds which remain viable for more than 14 years [8]. In Sudan the area under sorghum constitutes about 74% of the area under cereals and 45% of the total cultivated areas [9]. Furthermore, sorghum is the major staple food crop especially in rural areas [10]. In Sudan Sorghum production is seriously constrained by *S. hermonthica,* whereas more than 20% of the area under sorghum is infested by the parasite [11].Yield losses were reported to range between 65-100% and complete crop failure is not uncommon under heavy infestations [12]. Various control methods (e.g., hand-pulling, hoe-weeding, trap- and catch cropping) have been tried out with no conclusive and consistent results for subsistence farmer. This may partly be due to the difficulty to deplete huge amounts of seeds that have accumulated and continue to accumulate in the seed bank over the years. Prodigious seed production, prolonged viability of the seeds and the subterranean nature of the early stages of parasitism make control of the *Striga* by conventional methods difficult if not impossible [13]. *S. hermonthica* problem may be too widespread and too severe to control using a single approach. Management of the hemi-parasite needs an integrated approach that includes host plant resistance, cultural practices, and chemical treatments.

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

2. MATERIALS AND METHODS

A series of laboratory and greenhouse experiments was undertaken at the College of Agricultural Studies, Sudan University of Science and Technology (SUST) at Shambat.

2.1 Green House Experiment

Pot experiments were conducted in the greenhouse at the College of Agriculture Studies, (CAS), at Shambat during the season 2013/2014. Sorghum (cv. Wad-Ahmed) seeds were obtained from Agricultural Research Corporation, Gedarif. However, cowpea (T100K-

901-6 cv.), was obtained from the International Institute of Tropical Agriculture, Ibadan- Nigeria (IITA). A soil mix prepared by mixing Shambat soil with sand (2:1 v/v). The experiment was conducted under artificial *S. hermonthica* infestation. Artificial infestation of soil was achieved by mixing 2 g of *Striga* seeds with 1 kg soil, followed by subsequent dilution with *Striga* free soil to give the required infestation level (4, 8 and 16 mg/pot). *Striga* seed soil mix was added to *S. hermonthica* free soil and thoroughly mixed by hand. *Striga* free or infested soil was placed in plastic pots (9 cm i .d) with perforations at the bottoms. Pots filled with *Striga* free soil (0 mg) were included as control for comparison. Sorghum cultivar Wad-Ahmed was sown as sole crop or intercropped with cowpea. Sorghum and cowpea seeds (5/pot) were sown at 2 cm soil depth. The pots were immediately irrigated. Subsequent irrigations were carried out every two days. Sorghum and cowpea seedlings were thinned to three plants per pot two weeks after sowing. Chlorsulfuron as Glean at 1.3 g a.i /fed was applied three weeks after sowing (WAS) by knapsack sprayer as aqueous spray at a rate of 100 L per feddan (10 ml/pot). An untreated *Striga* infested control was included for comparison.

Plant height and Stem diameter were measured in centimetres using a ruler and vernier caliper instrument, respectively, while weight was weighed in gram after drying using a balance.

Treatments were arranged in a Randomized Complete Block Design (RCBD) with four replicates.

2.2 Laboratory Experiments

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

2.2.1 Strigol analogue (GR24) stock solution

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

2.2.2 Preparation of chlorsulfuron stock solution

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

2.3 Effects of Chlorsulfuron on *Striga*

Glass fiber filter papers (GFFP) discs (8 mm diameter) were cut, wetted thoroughly with water and placed in an oven set at 104ºC for one hour to be sterilized before use. For pre-conditioning the sterilized discs, placed in 9 cm Petri dishes lined with a single sheet of glass fiber filter papers, were moistened with 5 ml of the suspension of the respective herbicide at 20, 40 and 80 µM. The control, in which seeds were conditioned in distilled water, was included for comparison. Subsequently, about 25-50, surface sterilized *Striga* seeds were sprinkled on each of the glass fiber discs. The Petri dishes, sealed with Parafilm and wrapped with aluminum foil were incubated in the dark at 30ºC, for 14 days. For germination glass fiber filter discs containing *S. hermonthica* seeds conditioned in water or test solution, were, dapped on a filter paper to remove excess water and transferred to sterile Petri dishes. Each disc was treated with a 20 µl aliquot, of GR24 at 0, 0.01 and 0.1ppm. Apiece of filter paper moisturized with sterilized distilled water was placed in the centre of each Petri dish to maintain moist conditions during the test period. Seeds were reincubated in the dark at 30ºC for 24 hours, and examined for germination 24 hours later using a binocular stereomicroscope. Treatments were arranged in a Complete Randomized Design (CRD) with six replicates.

2.4 Statistical Analysis

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

3. RESULTS

3.1 Green House Experiment

3.1.1 Effects of chlorsulfuron and cowpea on striga and sorghum growth

3.1.1.1 Effects on Striga

3.1.1.1.1 Striga emergence

Striga count made 45 and 60 days after sowing (DAS) showed that *Striga* emergence increased with increasing size of the seed bank (Table1). Sorghum intercropping with cowpea at *Striga* seed bank size of 4, 8 and 16 mg/pot displayed 5, 4 and 18.5 *Striga* plants/pot, respectively. However, sorghum treated with chlorsulfuron, irrespective of *Striga* seed bank size displayed negligible *Striga* emergence (Table 1). Sorghum intercropped with cowpea and subsequently treated with chlorsulfuron sustained an average of 1.8 - 11 *Striga* plants/pot (Table 1).

Table 1. Effects of chlorsulfuron and cowpea on *Striga* emergence

	Number of *Striga* emergence/pot	
	Days after sowing (DAS)	
Treatments	**45**	**60**
Un-treated control	0.0 c	0.0 d
S4	5.8 c	10.8 bcd
S8	7.3 bc	20.3 b
S16	20.5 a	22.0 b
S4+C	5.0 c	9.0 cd
S8+C	4.0 c	13.0 bc
S16+C	18.5 ab	37.0 a
S4+H	0.3 c	5.5 cd
S8+H	0.0 c	8.8 cd
S16+H	0.8 c	8.0 cd
S4+C+H	2.0 c	6.8 cd
S8+C+H	1.8 c	14.8 bc
S16+C+H	11.0 abc	14.8 bc
LSD	11.8	11.2
F- Value	2.8*	5.2***

**S_X = Striga seed bank size (mg/pot), C = Cowpea, H = Herbicide. Means within a column followed by the same letter(s) are not significantly different according to LSD-Test. *P≤0.05, *** = P≤0.001*

At 60 DAS, the parasite displayed an average of 10.8 plants /pot at the lowest seed bank size (4 mg/pot). Increasing seed bank size to 8 and 16 mg/pot increased *Striga* emergence to 20 and 22 plants /pot, respectively (Table 1). At *Striga* seed bank size of 4 mg/pot intercropping sorghum with cowpea reduced *Striga* emergence by 16.3%, albeit not significantly. However, at seed bank size of 8 mg/pot, intercropping sorghum with cowpea reduced *Striga* emergence significantly and the observed reduction was considerable (35.8%) (Table 1).

Chlorsulfuron alone, irrespective of *Striga* seed bank size, reduced the parasite emergence by 49.0–63.6% in comparison with the untreated control (Table 1). Intercropping sorghum with cowpea and a subsequent treatment with chlorsulfuron, reduced *Striga* emergence considerably (33–37%), but not significantly, in comparison with the untreated control (Table 1).

3.1.1.1.1.1 Striga dry weight

Statistical analysis showed no significant differences in *Striga* dry weight between the treatments (Table 2). At the lowest seed bank size (4 mg/pot) the parasite displayed 4.2 g dry weight g/pot. Increasing *Striga* seed bank size to 8 and 16 mg/pot increased *Striga* dry weight to 9.7 and 5.4 g/pot, respectively, but not significantly (Table 2).

Table 2. Effects of chlorsulfuron and cowpea on *Striga* dry weight

Treatments	***Striga* dry weight (g)/pot**
Un-treated control	0.0 b
S4	4.2 ab
S8	9.9 a
S16	5.4 ab
S4+C	2.1 b
S8+C	5.6 ab
S16+C	3.0 b
S4+H	3.8 b
S8+H	5.6 ab
S16+H	3.0 b
S4+C+H	1.4 b
S8+C+H	3.0 b
S16+C+H	4.1 ab
LSD	6.0
F- Value	1.2 Ns

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

Sorghum intercropping with cowpea, irrespective of *Striga* seed bank size, reduced *Striga* dry weight by 44.3-50.5%, in comparison with the untreated control. Chlorsulfuron alone, irrespective of *Striga* seed bank size, reduced *Striga* dry weight by 10-44.3%, albeit not significantly (Table 2). At seed bank size of 4 and 16 mg/ pot, intercropping sorghum with cowpea and a subsequent treatment with chlorsulfuron, decreased *Striga* dry weight by 22.8 and 67.9%, respectively. However, the reduction was not significant (Table 2). At a seed bank size of 8 mg/ pot, intercropping sorghum with cowpea followed by chlorsulfuron reduced *Striga* dry weight significantly (70.7%).

3.1.1.1.2 Effects on sorghum

3.1.1.1.2.1 Plant height

At 45 DAS, *Striga* at seed bank of 4 and 8 mg/pot decreased sorghum height, but not significantly in comparison with the parasite free control (Table 3). On the other hand, increasing seed bank size to 16 mg/pot reduced height significantly (37.8%). At seed bank size of 4 and 8 mg/pot intercropping sorghum with cowpea had no significant effect on sorghum height. At *Striga* seed bank size of 16 mg/pot, intercropping sorghum with cowpea reduced sorghum height significantly and the observed reduction was 24.6% (Table 3). At seed bank size of 4 and 8 mg/pot chlorsulfuron treated sole sorghum displayed a reduction height of sorghum by 20.5 and 25.4%, respectively. At *Striga* seed bank size of 16 mg/pot height of sorghum intercropped with cowpea and treated with chlorsulfuron displayed a significant reduction in height (28.7%), in comparison to the *Striga* free control (Table 3).

Table 3. Effects of chlorsulfuron and cowpea on plant height

	Plant height (cm)		
	Days after sowing (DAS)		
Treatments	**45**	**60**	**75**
Un-treated control	60.6 a	96.2 a	111.8 a
S4	53.3 abc	75.1 bcd	83.1 bc
S8	51.8 abc	67.8 bcd	75.3 bc
S16	37.7 d	57.0 d	63.8 c
S4+C	49.8 abcd	76.9 bc	93.7 ab
S8+C	56.4 ab	81.2 abc	92.9 ab
S16+C	45.7 bcd	63.4 cd	78.7 bc
S4+H	45.2 bcd	85.3 ab	90.8 ab
S8+H	48.2 bcd	78.0 abc	72.8 bc
S16+H	51.1 abc	76.4 bc	75.5 bc
S4+C+H	54.7 abc	81.9 abc	93.0 ab
S8+C+H	48.3 abcd	78.2 abc	88.1ab
S16+C+H	43.2 cd	76.2 bc	78.7 bc
LSD	12.2	18.5	23.8
CV%	17.2	16.9	19.6
F- Value	2.0*	2.3*	2.3*

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

At 60 DAS statistical analysis showed significant differences between treatments (Table 3). *S. hermonthica* reduced sorghum height and the observed reductions increased with increasing seed bank size. *Striga* at seed bank size of 4, 8 and 16 mg/pot reduced sorghum height significantly and the observed reductions were 21.9, 29.5 and 40.7%, respectively. At *Striga* seed bank size of 4 and 16 mg/pot sorghum intercropped with cowpea displayed 20.1 and 34.1% reduction in height, respectively in comparison with the parasite free control (Table 3). At seed bank size of 4 and 8 mg/pot, sole sorghum treated with chlorsulfuron showed no significant reduction in height. However, at a seed bank size of 16 mg/pot, chlorsulfuron treated sole sorghum displayed a significant reduction in height. At seed bank size of 16 mg/pot, sorghum intercropped with cowpea and treated with chlorsulfuron displayed a significant reduction in height and the observed reduction was considerable (20.8%).

At 75 DAS, *Striga* free sorghum displayed the highest height (111.8 cm). At the lowest *Striga* seed bank size (4 mg/pot) sorghum height was reduced by 25.8%. Increasing seed bank size to 8 and 16 mg/pot reduced sorghum height significantly and the observed reductions were 32.7 and 42.9%, respectively (Table 3). At *Striga* seed bank size of 16 mg/pot, cowpea intercropped sorghum exhibited significant reduction in height (29.6%). At seed bank size of 8 and 16 mg/pot sole sorghum treated with chlorsulfuron displayed significant reduction in height and the observed reduction was considerable 32.5 and 34.9%, respectively. At *Striga* seed bank size of 16 mg/pot sorghum intercropped with cowpea and treated with chlorsulfuron displayed 29.5% reduction in height (Table 3).

3.1.1.1.2.2 Stem diameter

Statistical analysis showed that differences between treatments in stem diameter were not significant at 45 DAS. However, at 60 DAS significant differences were observed between the treatments (Table 4). At 60 DAS, *Striga* free control displayed the highest stem diameter (17.5 cm). *Striga* at the lowest seed bank size reduced stem diameter by 43.4%. Increasing seed bank size to 8 and 16 mg/pot, reduced stem diameter significantly and the observed reductions were 39.4 and 50.3%, respectively. At *Striga* seed bank size of 4 and 8 mg/pot, cowpea intercropped sorghum displayed insignificant reduction in stem diameter by 19.0 and 26.4%, respectively. However, increasing seed bank size to 16 mg/pot decreased stem diameter significantly (49.1%). Sole sorghum treated with chlorsulfuron, irrespective of *Striga* seed bank size displayed considerable reductions (28.6-34.9%) in stem diameter. At *Striga* seed bank size of 4, 8 and 16mg/pot sorghum intercropped with cowpea and subsequently treated with chlorsulfuron displayed significant reductions in stem diameter (28 -32%).

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

Table 4. Effects of chlorsulfuron and cowpea on stem diameter

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

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

3.1.1.1.2.3 Sorghum dry weight

Statistical analysis showed that differences between treatments in sorghum dry weight were not significant (Table 5). *Striga* free control displayed a dry weight of 46.3 g. At the lowest *Striga* seed bank size (4 mg/pot) sole sorghum displayed slight non-significant (5.9%) increase in dry weight. A further increase in *Striga* seed bank size to 8 and 16 mg/pot, decreased sorghum dry weight significantly and the observed reductions were 64.8 and 53.5%, respectively in comparison to the *Striga* free control (Table 5).

Sorghum intercropped with cowpea at seed bank size of 4 and 8 mg/pot, displayed a considerable, but not significant loss (21.6 – 33.5%) in dry weight, in comparison to the *Striga* free control (Table 5). Increasing seed bank size to 16 mg /pot resulted in significant reduction in sorghum dry weight and the observed reduction was 61.6%. At *Striga* seed bank size of 4 and 8 mg/pot chlorsulfuron treated sole sorghum showed no significant reductions in dry weight and the observed reductions was 17.3 - 42.7%. Increasing *Striga* seed bank size to 16 mg/pot chlorsulfuron treated sorghum sole displayed further reduction 51.9% (Table 5).

Sorghum intercropped with cowpea and subsequently treated with chlorsulfuron, irrespective of *Striga* seed bank size, showed considerable reduced sorghum dry weight, but not significant. The observed reductions were 28.1- 47.6% (Table 5).

Table 5. Effects of chlorsulfuron and cowpea on sorghum dry weight

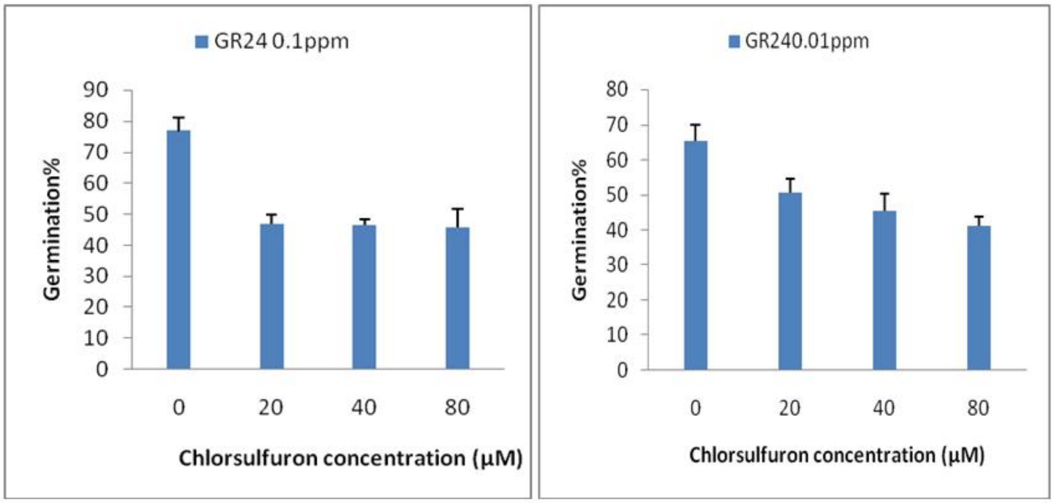
Treatments	Sorghum dry weight (g)/pot
Un-treated control	46.3 ab
S4	49.0 a
S8	16.3 c
S16	21.5 bc
S4+C	36.3 abc
S8+C	30.8 abc
S16+C	17.8 c
S4+H	38.3 abc
S8+H	26.5 abc
S16+H	22.3bc
S4+C+H	33.3 abc
S8+C+H	24.3abc
S16+C+H	24.5 abc
LSD	26.0
F- Value	1.3 Ns

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

3.2 Laboratory Experiment

3.2.1 Effects of Chlorsulfuron on Striga Germination

S. hermonthica seeds conditioned in water and subsequently treated with GR24 at 0.01 ppm displayed 65.2% germination. Increasing GR24 concentration to 0.1 ppm increased germination



A B

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

to 76.8% (Fig. 1 A and B). Chlorsulfuron applied during conditioning reduced seed germination significantly in response to subsequent treatments with GR24. However, differences between herbicide concentrations were not significant. Seeds conditioned in chlorsulfuron at 20 µM and subsequently treated with GR24 at 0.1ppm reduced germination to 46.9%. A further increase in herbicide concentration to 40 and 80 µM did not cause further significant reductions (Fig. 1A).

Seeds conditioned in chlorsulfuron at 20 µM and treated with GR24 at 0.01 ppm displayed 50.6% germination. Increasing concentration to 40 and 80 µM decreased germination by 30.3 and 37%, respectively, in comparison to seeds conditioned in water (Fig. 1B).

4. DISCUSSION

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

Striga count made 45 and 60 days after sowing (DAS) showed that *Striga* emergence increased with increasing size of the seed bank. The observed increase in *Striga* emergence with seed bank size indicates the importance of the seed bank in determining the level of infestation and damage. At 60 DAS, intercropping sorghum with cowpea at *Striga* seed bank size of 8 mg/pot reduced *Striga* emergence significantly (35.8%). These findings are consistent with those obtained by Babiker et al. [14] who reported that intercropping sorghum and cowpea reduced population density of *S. hermonthica*. Chivinge et al. [15] reported that cowpea cultivars reduced *Striga* emergence by 40%. That reduction might either be due to shading effects from the cowpea canopy Kureh et al. [16], or attributed to the soil cover of cowpea that created unfavorable conditions for *Striga* germination. The roots of several legumes are known to induce suicidal germination of *Striga* seeds, and this feature has become incorporated into *Striga* suppression strategies involving cereal-legume rotation or intercropping [17]. The effectiveness of cereal/legume intercropping to influence *Striga* germination depends on the effectiveness of the produced stimulant/inhibitors, root development, fertility improvement, shading effect and its compatibility to *Striga* species because the response of *Striga* to management options is specific [18]. Parker et al. [7] attributed the suppressive effects of intercropping to several factors, including its action as a trap-crop, interference with production of germination stimulants, exudation of germination inhibitors and/or reduction of the parasite transpiration, through decreasing air temperature and increasing humidity.

At 45 DAS, sorghum treated with chlorsulfuron, irrespective of *Striga* seed bank size displayed negligible *Striga* emergence. At 60 DAS, chlorsulfuron alone, irrespective of *Striga* seed bank size, reduced the parasite emergence by 49.0– 63.6% in comparison with the untreated control (Table 1). Similar results were obtained by Abusin [19] who found that chlorsulfuron at 2.38 and 2.98 g a.i ha^{-1} effected excellent suppression of the parasite (83.3%). Ayman *et al.* [20] reported that all chlorsulfuron formulation significantly reduced *Striga* infestation. Chlorsulfuron in form of Glean reduce damage caused by *Striga* and effectively control the parasite. This could be attributed to the mode of action of chlorsulfuron one of amino acid inhibitors belongs to sulfonylurea's group, the mode of action in this group is the tendency of poorly developing roots and the secondary roots are shortened. Chlorsulfuron is acetolactate synthase (ALS) inhibitor [21]. The herbicide inhibits synthesis of the branched amino acids L-leucine, L-isoleucine and L-valine, and thus may interfere with protein synthesis and cell division [22].

Sorghum intercropping with cowpea, irrespective of *Striga* seed bank size, reduced *Striga* dry weight by 44.3-50.5%, in comparison with the untreated control. Chlorsulfuron alone, irrespective of *Striga* seed bank size, reduced *Striga* dry weight by 10-44.3%, albeit not significantly (Table 2). At *Striga* seed bank size of 8 mg/pot, intercropping sorghum with cowpea followed by chlorsulfuron reduced *Striga* dry weight significantly (70.7%). The reduction in *Striga* dry weight is consistent with the reductions in emergence caused by intercropping with cowpea and treated with chlorsulfuron. This result confirmed the observations of Yonli *et al.* 2012 [23] who reported integrated *Striga* management controls based on intercropping system, Fusarium-inoculum or both in combination significantly reduced *Striga* dry biomass. Indeed, a creeping trap crop suffocated juvenile *Striga* plants that succeeded in emerging and then, they were killed by the competition effect between trap crop and *Striga* seedlings. In addition, when the cowpea plants covered the soil, the temperature decreased while the air humidity increased under cowpea leaves and stalks. The interaction of these environmental factors may create a micro-climate that would affect the emergence and the growth of *Striga* plants and then *Striga* biomass should be significantly reduced [23].

At 45 DAS, sole sorghum showed significant reductions in height, only, at the highest *Striga* seed bank size. However, at 60 and 75 DAS, *S. hermonthica* reduced sorghum height and the observed reductions increased with increasing seed bank size. At 60 and 75 DAS, *Striga* irrespective of seed bank size reduced stem diameter. *Striga* at seed bank size of 8 and 16 mg/pot decreased sorghum dry weight significantly and the observed reductions were 64.8 and 53.5%, respectively in comparison to the *Striga* free control (Table 5). These findings are consistent with those obtained by Yonli et al. [24] who reported that *Striga* infection resulted in significant reduction in number of tillers and in growth and biomass of wheat. This is a common effect of *Striga* infection on other cereals, such as maize. The parasites remove water, minerals and Photosynthase from the host and thus reduce the latter ability to grow and compete for nutrients, light, water and space [25]. Crops that are parasitized usually grow more slowly and depending on severity of infestation, biomass production is lowered and the host may be killed. In general, *S. hermonthica* can affect its host in different ways. Only part of the reduction in growth of the host results from competition for carbon assimilates, water, mineral nutrients and amino acids [26].

At 45, 60 and 75 DAS, cowpea intercropped sorghum exhibited significant reduction in height (Table 3). At 75 DAS, irrespective of *Striga* seed bank size, cowpea intercropped with sorghum displayed significant reductions in stem diameter (Table 4). Sorghum intercropped with cowpea at seed bank size of 16 mg/pot resulted in significant reduction in sorghum dry weight and the observed reduction was 61.6% (Table 5). This finding is at consistent with that of Hamad Elneel [27], who reported a decline in dry weight of cowpea intercropped sorghum, irrespective of *Striga* infestation.

At 45 DAS, chlorsulfuron treated sole sorghum, displayed a significant reduction in sorghum height. However, at 60 and 75 DAS chlorsulfuron treated sole sorghum at *Striga* seed bank size of 16 mg/pot displayed a significant reduction in height. Similar results were obtained by Abusin [19] who found that chlorsulfuron alone and in mixture with 2, 4-D reduced sorghum height.

At seed bank size of 16 mg/pot, sorghum intercropped with cowpea and treated with chlorsulfuron displayed a significant reduction in height. At 60 DAS, at *Striga* seed bank size of 4, 8 and 16 mg/pot sorghum intercropped with cowpea and subsequently treated with chlorsulfuron displayed significant reductions in stem diameter (28-32%). Sorghum intercropped with cowpea and subsequently treated with chlorsulfuron, irrespective of *Striga* seed bank size, showed considerable reduction in sorghum dry weight, but not significantly (Table 5). The decreases may be attributed to combined effects on *Striga* and competition between sorghum and cowpea.

5. CONCLUSIONS

It can be concluded from the study that *Striga* management requires integrated practices comprising different components. Intercropping sorghum with cowpea reduced *Striga* emergence. Chlorsulfuron effectively reduced germination and suppressed *Striga* emergence.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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