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Integrated Management of *Striga hermonthica* on Sorghum

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Authors' contributions

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

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ABSTRACT

The phytoparasite, *Striga hermonthica* (Del.) Benth., is a major biotic constraint to cereals production in sub-Saharan Africa. An experiment was conducted to investigate the effects of nitrogen and the herbicides triclopyr, chlorsulfuron and their combination on Striga incidence and sorghum (cv. Wad-Ahmed) growth and yield. The present research was undertaken at the College of Agricultural Studies, Sudan University of Science and Technology. Treatments were arranged in Complete Randomized Block Design (CRBD). All treatments at 45 days after sowing (DAS), reduced Striga emergence albeit not significantly as compared to the control. At 60 DAS, untreated control (3 plants/ m2) sustained the highest Striga emergence significantly as compared to other treatments. Sorghum height, irrespective of the observation date did not show significant differences between treatments. At 60 DAS, triclopyr at 0.49 and 0.73 kg a.e ha^{-1} supplemented

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with nitrogen at 43.8 kg ha^{-1}, increased sorghum height by 11.9 and 9.4%, respectively, as compared to untreated control. Chlorsulfuron at 2.38 g a.i ha^{-1} when supplemented with nitrogen, irrespective of rate, caused considerable decrease in peduncle length by 48.7-51.3%, respectively when compared to the control. However, triclopyr at 0.73 kg a.e. ha^{-1} alone or in combination with nitrogen at 87.6 kg ha^{-1} had no effects on peduncle length when compared to the untreated control. All treatments significantly increased head length over the untreated control. Chlorsulfuron at the highest dose when combined with nitrogen at the highest rate resulted in the highest increase in head length 27.6%. All treatments increased head circumference over the untreated control albeit not significant. Triclopyr at 0.49 and 0.73 kg a.e. ha^{-1}, in supplementation with nitrogen at 87.6 kg ha^{-1} displayed the highest increase in straw weight 30.2-39.6%, respectively. Triclopyr at 0.49 kg a.e. ha^{-1}, tank mixed with chlorsulfuron at 1.19 g a.i ha^{-1} and supplemented with nitrogen at 87.6 kg ha^{-1} caused an increase in straw weight by 5.7-9.4% over the untreated control.

Conclusion: Herbicides examined when applied subsequent to nitrogen provide efficient packages for *Striga* management than when applied alone or tank mixed with each other.

Keywords: Nitrogen; chlorsulfuron; triclopyr; Striga; sorghum; emergence.

1. INTRODUCTION

The phytoparasite, *Striga hermonthica* (Del.) Benth., infests millions of hectares of cultivated fields of cereal crops in sub-Saharan Africa. Yield losses are often 70% but can be as high as 100% and farmers often abandon infested fields and move to new areas (Kim, 1995). It is an obligate parasitic plant that attaches to host roots to deplete them of nutrients. In Sub-Saharan Africa, the most destructive *Striga* species is *Striga hermonthica* which parasitizes major food crops affecting two-thirds of the arable land and over 100 million people. One potential weakness in the *Striga* infection process is the way it senses the presence of a host crop [1].

Striga hermonthica is a widespread parasitic weed in Africa, causing severe damages to the major cereal crops: millet, sorghum and maize. Considering the subsistence nature of farming in Africa, the development of resistant or tolerant varieties is the most promising cost-effective approach to overcoming the weed problem [2].

Witchweeds (*Striga* spp.) are noxious parasitic weeds that cause considerable crop damage in the semiarid tropics [3].

The witchweed *Striga hermonthica* is proving to be a nightmare for smallholder farmers in the Sahel and Savannah regions of Africa. The close and intricate biological association between this phytoparasite and the cereal host makes its management difficult [4].

Herbicides are considered to have the most potential, however, they have to be appropriate, cost-effective and affordable [5]. Damages by chemical persistence and availability are other major constraints that limit the successful usage of herbicides for parasitic weed control. In addition, in developing countries, the income of subsistence farmers is usually too low to afford to purchase inputs including herbicides [6].

Parasitic weeds control, has proved to be extremely difficult. Unusual seed production, prolonged viability and ease of distribution of the seeds together with the subterranean nature of the early stages of parasitism make *Striga* a difficult weed to control [7]. However, several control methods have been investigated positively, but often inconsistent results across seasons and sites. These methods include biological, cultural and chemical methods and they are well reviewed by [8] and sumed up by [9,10,7,11,6].

2. MATERIALS AND METHODS

A field experiment was undertaken at the College of Agricultural Studies, (CAS), Shambat, Sudan University of Science and Technology, Sudan during the season 2011/2012. The experiment was designed to investigate the effects of nitrogen and the herbicides triclopyr, chlorsulfuron and their combinations on *Striga* incidence and sorghum (cv. Wad-Ahmed) growth and yield.

2.1 Experimental Materials

The experimental area was disc ploughed, harrowed, levelled, ridged and divided into sub-plots. Sorghum (Wad Ahmed) seeds, supplied by the Arab Seed Production Company, were treated with the fungicide Thiram. Seeds were sown in holes at a within row spacing of 20 cm. In experiments involving fertilization, nitrogen in form of urea was applied as broadcast by hand. All plots were artificially infested with *Striga hermonthica* (Del.) Benth seeds. *Striga* seeds used in this study were collected from under sorghum in Gazira, Sudan. Inoculums were prepared by thorough mixing of 1 g of clean *Striga* seeds with 1 kg of soil. Inoculums were applied to the soil at time of sowing. The crop was sown in July. Sorghum seedlings were thinned to two per hole 15 days after emergence. The herbicide triclopyr as Garlon was applied 30 DAS by knapsack sprayer as aqueous spray. Weeds were removed by hand to avoid damaging emerged *Striga* plants at biweekly intervals for the first six weeks. Irrigation was applied when necessary throughout the duration of thetrial.

2.2 Treatments and Experimental Design

Treatment effects, were assessed by determining i) number of emerged *Striga* plants per meter square 45, 60 and 90 days after sowing (DAS), ii) peduncle length in cm, iii) diameter at flag leaf in cm, iv) threshing percentage, v) *Striga* dry weight in g. Treatments were arranged in Complete Randomized Block Design (CRBD).

2.3 Effects of Nitrogen, Triclopyr, Chlorsulfuron and Their Combinations on *Striga* incidence and Sorghum Growth and Yield

Nitrogen at 43.8 and 87.6 kg ha^{-1} was applied by broadcasting. Triclopyr at 0.49 and 0.73 kg a.e. ha^{-1} implemented alone. Chlorsulfuron 2.38 g a.i ha^{-1} implemented alone. The combination triclopyr at 0.49 a.e ha^{-1} and urea at 43.8 and 87.6 kg ha^{-1}. The combination triclopyr at 0.73 kg a.e. ha^{-1} and urea at 43.8 and 87.6 kg ha^{-1}. The combinations triclopyr at 0.49 a.e ha^{-1}, Chlorsulfuron at 1.19 and urea at 43.8 and 87.6 kg ha^{-1} were applied 30 days after sowing.

2.4 Data Collection and Data Analysis

Data collected from the experiment was subjected to statistical analysis using GenStat (PC/Windows 7), VSN International Ltd., UK statistical package **(**Rothamsted Experimental Station), Means were separated for significance using Least Significant Difference (LSD).

3. RESULTS

3.1 *Striga*

3.1.1 *Striga* emergence

At 45 days after sowing (DAS), *Striga* emergence in the untreated control displayed 2 plants/ m^2. All treatments reduced *Striga* emergence albeit not significantly as compared to the control. At60 DAS, untreated control (3 plants/ m^2) sustained the highest *Striga* emergence significantly as compared to other treatments (Table 1).

3.2 Plant Height

Sorghum height, irrespective of rate of observation did not show significant differences between treatments (Table 2). At 45 DAS, combination between triclopyr at 0.49 kg a.e. ha^{-1} and nitrogen at 43.8 kg ha^{-1} displayed the highest plant height, while chlorsulfuron alone at 2.38 g a.i ha^{-1}displayed the lowest (Table 2). At 60 DAS, triclopyr at 0.49 and 0.73 kg a.e ha^{-1} supplemented with nitrogen at 43.8 kg ha^{-1}, increased sorghum height by 11.9 and 4.9%, respectively, as compared to untreated control. Chlorsulfuron at 2.38 g a.i ha^{-1} in combination with nitrogen at 87.6 kg ha^{-1} and triclopyr alone at 0.49 kg a.e. ha^{-1} reduced sorghum height by 7.7-8.5%, but not significantly, as compared to the control (Table 2).

3.3 Peduncle Length

Chlorsulfuron at 2.38 g a.i ha^{-1} alone and when supplemented with nitrogen irrespective of rate, caused considerable decrease in peduncle length by 41.0-51.3% when compared to the control (Table 3). Triclopyr at 0.49 kg a.e. ha^{-1} alone and when added subsequent to nitrogen at 43.8 kg ha^{-1} decreased peduncle length by 15.4%. Triclopyr at 0.73 kg a.e. ha^{-1} when combined with nitrogen irrespective of rate increased peduncle length by 5.1-25.6%. However, triclopyr rate at the same rate when tank mixed with chlorsulfuron at1.19 g a.i ha^{-1} and nitrogen at 43.8 kg ha^{-1} increased peduncle length by 17.9% (Table 3).

3.4 Diameter at Flag

In general, all treatments had no significant effects on diameter at flag leaf when compared

Table 1. Effects of chlorsulfuron, nitrogen and their combinations on Striga emergence

Treatment	Herbicide rate ha^{-1}	*Striga* emergence (plants/m^2) (DAS)	
		45	**60**
Untreated control	-	2(2)	2(3)^a
Chlor. ^{i}	2.38	1(0)	1(0)^b
Chlor.+ 1N	2.38	1(1)	1(0)^b
Chlor.+ 2N	2.38	1(0)	1(0)^b
Tr. ^{ii}	0.49	1(0)	1(0)^b
Tr. + 1N	0.49	1(0)	1(0)^b
Tr. + 2N	0.49	1(0)	1(0)^b
Tr. + Chlor.	0.49+1.19	1(1)	1(1)^b
Tr. + Chlor.+1N	0.49+1.19	1(0)	1(0)^b
Tr. + Chlor.+2N	0.49+1.19	1(0)	1(0)^b
Tr.	0.73	1(0)	1(0)^b
Tr. + 1N	0.73	1(1)	1(0)^b
Tr. + 2N	0.73	1(0)	1(0)^b
F Pr.	**-**	**0.2**	**0.001**
LSD	**-**	**0.4**	**0.3**
CV%	**-**	**26.1**	**20.7**

*Means within a column having the same superscript letter(s) are not significantly different according to LSD test. Bracketed data are real. NS = Non significant. ***= P ≤ 0.001. ^{i} = Chlorsulfuron/ g a.i. ha^{-1}. ^{ii} = Triclopy/kg a.e ha^{-1}, 1N= Nitrogen at 43.8 kg ha^{-1} 2N= Nitrogen at 87.6 kg ha^{-1}*

Table 2. Effects of chlorsulfuron, nitrogen and their combinations on sorghum height

Treatment	Herbicide rate ha^{-1}	Sorghum height (cm) (DAS)	
		45	**60**
Untreated control	-	77.6	107.5
Chlor.^{i}	2.38	56.3	102.7
Chlor.+1N	2.38	77.1	107.1
Chlor.+ 2N	2.38	67.7	98.4
Tr.^{ii}	0.49	67.4	99.2
Tr. + 1N	0.49	83.3	120.3
Tr. + 2N	0.49	79.0	110.5
Tr. + Chlor.	0.49+1.19	74.4	111.6
Tr. + Chlor.+1N	0.49+1.19	79.5	113.6
Tr. + Chlor.+2N	0.49+1.19	68.3	109.0
Tr.	0.73	67.2	107.2
Tr. + 1N	0.73	74.9	117.6
Tr. + 2N	0.73	67.1	108.0
F Pr.	-	**0.2**	**0.3**
LSD	-	**17.7**	**16.3**
CV%	**-**	**17.1**	**10.5**

NS= non- significant. ^{i} = Chlorsulfuron/ g a.i. ha^{-1}. ^{ii} = Triclopy/kg, 1N= Nitrogen at 43.8 kg ha^{-1}, 2N= Nitrogen at 87.6 kg ha^{-1}

to the untreated control (Table 3). Chlorsulfuron at 2.38 g a.i ha $^{-1}$ alone and when supplemented with nitrogen irrespective of rate, caused an increase in diameter at flag leaf by 5.0-6.6%. Triclopyr at 0.49 kg a.e. ha^{-1} alone and when combined with nitrogen at 87.6 kg ha^{-1} displayed an increase in diameter at flag leaf by 5.2-7.0%. Triclopyr at the lower dose when combined with nitrogen at the lower rate and Triclopyr at the higher dose in combination with nitrogen at the lower rate resulted in an increase of 2.5-.8%, respectively (Table 3).

3.5 Head Length

All treatments significantly increased head length over the untreated control. Chlorsulfuron at the highest dose when combined with nitrogen at the highest rate resulted in the highest increase in head length 27.6% (Table 4). Chlorsulfuron at 2.38 g a.i ha^{-1} when supplemented with nitrogen at the lower rate, and triclopyr at 0.73 kg a.e. ha^{-1} when supplemented with nitrogen at the lower rate, displayed head length increase by 18.7%. Triclopyr at 0.49 kg a.e. ha^{-1}, alone and when supplemented with nitrogen irrespective of nitrogen rate, caused an increase in sorghum head length by 8.1-15.4%. However, triclopyr at 0.73 kg a.e. ha^{-1} alone or in combination with nitrogen at 87.6 kg ha^{-1} displayed the least sorghum head length of 6.5% (Table 4).

3.6 Head Circumference

All treatments increased head circumference over the untreated control albeit not significant (Table 4). Chlorsulfuron at 2.3 8 g a.i ha $^{-1}$ in supplementation with nitrogen at 87.6 kg ha^{-1} and triclopyr at 0.49 kg a.e. ha^{-1}, tank mixed with chlorsulfuron at 1.19 g a.i ha^{-1} in supplementation with nitrogen at 43.8 kg ha^{-1} displayed the heist increase in head circumference 31.3%. Chlorsulfuron at 2.3 8 g a.i ha^{-1} in supplementation with nitrogen at 43.8 kg ha^{-1} gave an increase in head circumference by 28.9%. Triclopyr at the lower rate alone and triclopyr at the highest dose when applied subsequent to nitrogen at 87.6 kg ha^{-1} showed an increase in head circumference by 18.1% (Table 4).

Triclopyr at 0.49 kg a.e. ha^{-1} alone, or when added subsequent to nitrogen irrespective of rate, displayed an increase in sorghum head circumference by 8.4-21.7%. However, triclopyr at 0.73 kg a.e. ha^{-1} alone or in combination with nitrogen at 43.8 kg ha^{-1} caused the lowest head circumference effect 8.4-26.5%, respectively (Table 4).

3.7 Straw Weight

Triclopyr at 0.49 and 0.73 kg a.e. ha^{-1}, in supplementation with nitrogen at 87.6 kg ha^{-1} Displayed the highest increase in straw weight 23.2-28.4%, respectively when compared to the control (Table 5). Triclopyr at 0.49 kg a.e. ha^{-1} and 0.73 kg a.e. ha^{-1}, in supplementation with nitrogen at 43.8 kg ha^{-1} displayed 15.2-39.2% decrease in straw weight. Chlorsulfuron at 2.3 8 g a.i ha^{-1} alone or in supplementation with nitrogen irrespective of rate displayed an increase in sorghum straw weight by 3.6, 7.0 - 8.6%, respectively. Triclopyr at 0.49 kg a.e. ha^{-1}, tank mixed with chlorsulfuron at1.19 g a.i ha^{-1} and in supplemented with nitrogen at 87.6 kg ha^{-1} caused straw weight increase by 5.4-8.6% over the untreated control (Table 5).

Table 3. Effects of chlorsulfuron, nitrogen and their combinations on sorghum exertion

Treatment	Herbicide rate ha^{-1}	Head attributes	
		Peduncle length /cm	Diameter at flag Leaf/cm
Untreated control	-	1.9(3.9)	5.15
Chlor. [i]	2.38	1.5(2.3)	4.70
Chlor.+ 1N	2.38	1.3(1.9)	5.41
Chlor.+ 2N	2.38	1.4(2.0)	5.49
Tr. [ii]	0.49	1.8(3.3)	5.51
Tr. + 1N	0.49	1.8(3.3)	4.41
Tr. + 2N	0.49	1.6(2.7)	5.42
Tr. + Chlor.	0.49+1.19	1.7(3.1)	5.14
Tr. + Chlor.+1N	0.49+1.19	2.1(4.6)	5.28
Tr. + Chlor.+2N	0.49+1.19	1.5(3.0)	5.33
Tr.	0.73	1.9(3.8)	4.92
Tr. + 1N	0.73	2.2(4.9)	5.19
Tr. + 2N	0.73	1.9(4.1)	4.33
F Pr.	**-**	**0.5**	**0.4**
LSD	**-**	**0.8**	**10.5**
CV%	**-**	**31.2**	**17.7**

*Bracketed data are real. NS = Non significant. ***= P ≤ 0.001. [i] = Chlorsulfuron/ g a.i. ha^{-1}. [ii] = Triclopy/kg a.e ha^{-1}, 1N= Nitrogen at 43.8 kg ha^{-1} 2N= Nitrogen at 87.6 kg ha^{-1}*

Table 4. Effects of chlorsulfuron, triclopyr, nitrogen and their combinations on sorghum head length and circumference

Treatment	Herbicide rate ha^{-1}	Head attributes	
		Length/cm	Circumference/cm
Untreated control	-	12.3	8.3
Chlor. [i]	2.38	13.2^{bcd}	9.4
Chlor.+ 1N	2.38	14.6^{b}	10.7
Chlor.+ 2N	2.38	15.7^{a}	10.9
Tr. [ii]	0.49	14.2^{bc}	9.8
Tr. + 1N	0.49	13.3^{bcd}	10.1
Tr. + 2N	0.49	13.4^{bcd}	9.0
Tr. + Chlor.	0.49+1.19	13.8^{bc}	9.8
Tr. + Chlor.+1N	0.49+1.19	13.6^{bcd}	10.9
Tr. + Chlor.+2N	0.49+1.19	14.5^{ab}	9.5
Tr.	0.73	13.1^{cd}	9.0
Tr. + 1N	0.73	14.6^{ab}	10.5
Tr. + 2N	0.73	13.1^{cd}	9.8
F Pr.	**-**	**0.003**	**0.2**
LSD	**-**	**1.4**	**1.9**
CV%	**-**	**7.1**	**13.6**

*Means within a column having the same superscript letter(s) are not significantly different according to LSD test. NS = Non significant. **= P ≤ 0.01. [i] = Chlorsulfuron/ g a.i. ha^{-1} . [ii] = Triclopy/kg a.e ha^{-1}, 1N= Nitrogen at43.8 kg ha^{-1} 2N= Nitrogen at 87.6 kg ha^{-1}*

Table 5. Effects of chlorsulfuron, nitrogen and their combinations on sorghum straw dry weight

Treatment	Herbicide rate ha^{-1}	Straw weight g/m^{2}
Untreated control	-	53
Chlor.[i]	2.38	55
Chlor.+ 1N	2.38	58
Chlor.+ 2N	2.38	57
Tr. [ii]	0.49	38
Tr. + 1N	0.49	56
Tr. + 2N	0.49	69
Tr. + Chlor.	0.49+1.19	58
Tr. + Chlor.+1N	0.49+1.19	48
Tr. + Chlor.+2N	0.49+1.19	56
Tr.	0.73	52
Tr. + 1N	0.73	46
Tr. + 2N	0.73	74
F Pr.	**-**	**0.3**
LSD	**-**	**230.0**
CV%	**-**	**28.9**

NS = Non significant. [i] = Chlorsulfuron/ g a.i. ha^{-1}. [ii] = Triclopy/kg a.e ha^{-1}, 1N= Nitrogen at43.8 kg ha^{-1} 2N= Nitrogen at 87.6 kg ha^{-1}.

4. DISCUSSION

The herbicides triclopyr and chlorsulfuron irrespective of doses, effected sizeable to significant decrease in Striga hermonthica infestation. In general the herbicides triclopyr and chlorsulfuron when applied subsequent to nitrogen as urea, at 43.8 (1N) and 87.6 (2N) kg ha^{-1}, or combined with their tank mixtures were more exploitive to the parasite than when each was applied alone.

At 45 DAS *Striga* emergence was inconsistent and maximum emergence was 1 plant m^{-2}. At 60 DAS the parasite displayed maximum emergence (3 plants m^{-2}) in the untreated control sub-plots, followed by sub-plot treated with triclopyr at 0.49 kg a.e. ha^{-1} tank mixed with chlorsulfuron at 1.19 g a.i. ha^{-1}.

Chlorsulfuron is acetolactate synthase (ALS) inhibitor [12,13]. 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 [14]. These findings indicate clearly that chlorsulfuron alone delayed *Striga* emergence early in the season these findings are in agreement with those previously reported by [15,16,17,18,19].

Chlorsulfuron at 2.38 g a.i ha^{-1} alone and when supplemented with nitrogen irrespective of rate, caused considerable decrease in peduncle length by 41.0-51.3% when compared to the control (Table 3). Triclopyr at 0.49 kg a.e. ha^{-1} alone and when added subsequent to nitrogen at 43.8 kg ha^{-1} decreased peduncle length by 15.4%. In general, all treatments had no significant effects on diameter at flag leaf when compared to the untreated control. All treatments significantly increased head length over the untreated control. Chlorsulfuron at the highest dose when combined with nitrogen at the highest rate resulted in the highest increase in head length 27.6% (Table 4). All treatments increased head circumference over the untreated control albeit not significant.

The general trend in growth of the chlorsulfuron treated sorghum compared to the untreated Sorghum height, irrespective of rate of observation did not show significant differences between treatments (Table 2). At 60 DAS triclopyr, alone, at the two rates (0.49 and 0.73 kg a.e.ha^{-1}) and when applied subsequent to nitrogen irrespective of rate suppressed *Striga* emergence completely.

Furthermore, the results, in addition to the improved performance, indicate that nitrogen allows the use of low herbicide rates, which beside economic benefits, safeguard against phytotoxicity and prolonged persistence, which may be expected from high rates and/or variations in edaphic and environmental conditions.

5. CONCLUSION AND RECOMMENDATION

- *Striga* is a difficult weed to control.
- *Striga* management requires integrated practices comprising different components.
- Sorghum (cv. Wad Ahmed), *Striga* tolerant, the herbicides triclopyr or chlorsulfuron when applied subsequent to nitrogen provide efficient packages for *Striga* management than when applied alone or tank mixed with each other.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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