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Potential role of intercropping, bacterial strains and inorganic fertilizers in integrated *Striga hermonthica* management on sorghum

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ABSTRACT

Striga hermonthica (Del.) Benth is an obligate, root-parasitic flowering plant that limits cereal production in sub-Saharan Africa. In this study, two greenhouse experiments were carried out to screen the optimum intercropping ratio (2:1, 2:3 and 2:6) of sorghum and groundnut and to evaluate the effect of intercropping, bacterial strains (*Bradyrhizobium* spp. and *Bacillus megatherium* var. *phosphaticum* BMP) and inorganic fertilizers (nitrogen and phosphorus) on *S. hermonthica* incidence and sorghum growth. The sorghum Wad Ahmed cultivar and groundnut Sodari cultivar were used for both experiments. All experiments were laid out in a randomized complete block design (RCBD) with four replicates. In the first experiment, results showed that intercropped sorghum with groundnut at the ratios of 2:1 and 2:3 performed the best in terms of both reducing *S. hermonthica* emergence (by 44% and 41%) and increasing sorghum growth (by 24% and 52%), respectively compared to the sole sorghum crop. *S. hermonthica* numbers were decreased as the proportion of groundnut increased in the intercrop. In the second experiment, results revealed that *S. hermonthica* emergence in sole sorghum crop showed significantly higher number than the intercropping. Overall means showed that *S. hermonthica* emergence was reduced by 48% in groundnut intercrop, 78% in intercrop treated with nitrogen and92% when inoculated with *Bradyrhizobium* + BMP + nitrogen. Furthermore, sorghum/groundnut intercropping inoculated with the bacterial combination, invariably achieved the highest reductions in *S. hermonthica* emergence and the highest increase in the measured sorghum growth parameters.

KEYWORDS: *Striga*, Intercropping, *Bradyrhizobium*, BMP, inorganic fertilizers

INTRODUCTION

The improvement of soil fertility is one of the most common strategies to increase agricultural production. Biological nitrogen fixation is very important in enhancing soil fertility. In addition to biological nitrogen fixation, phosphate solubilization is equally important. Nitrogen and phosphorusare major essential macronutrients for biological growth and development [1]. The genus *Striga* (Orobanchaceae) is one of the most agriculturally important pests. Moreover these parasitic plants exhibit high rates of transpiration and consequently they obtain a large amount of water and minerals from their hosts [2]. These facts result in the parasite causing yield losses from a few percent to complete crop failure depending on crop species, crop variety and severity of infection [3]. The unique life cycle of the parasite and the close linkage between the parasite and its host make *Striga* control by conventional methods insufficient. Various cultural and chemical strategies have been used to control *Striga* on sorghum. Unfortunately, most of them alone are not effective or have insufficient success due to the longevity in soil, small size, and high fecundity of *Striga* seeds. Intercropping, particularly of cereals with cowpea (*Vigna unguiculata*), is a common practice in many parts of the semi-arid zone. Intercropping of cereals with legumes has also been proposed as a means of suppressing *Striga* in cereal crops[4].

The nitrogen-fixing bacteria *Azospirillum brasilense* has been reported to inhibit germination and radical growth of *Orobanche aegyptiaca* [5] and *S. hermonthica* [6].Also arbuscular mycorrhizal fungi have been reported to increase phosphorous uptake and to reduce infection by weedy root parasites [7]. Current means for controlling parasitic weeds are focusing on reducing the soil seed bank, preventing seed set and inhibiting seed movement from infested to non-infested areas. Intercropping is regarded as an ecological method to manage pests, diseases and weeds via natural competitive principles that allow for more efficient resource utilization [8].The aim of the present work was to evaluate the intercropping efficiency of sorghum with groundnut, bacterial strains and inorganic fertilizers on *Striga* incidence and sorghum performance.

MATERIALS AND METHODS

Two greenhouse experiments were undertaken to investigate the efficacy of groundnut intercropping, bacterial strains and inorganic fertilizers on parasitism of *S. hermonthica* on sorghum. *S. hermonthica* seeds, used in this study, were collected from parasitic plants growing under sorghum in 2014 at the Gezira Research Station Farm, Agriculture Research Corporation (ARC), Wad Medani.

Bacterial strains:

A general purpose medium [Nutrient Agar (2.8%)] was used for the growth of bacterial strains. Media were sterilized by autoclaving at 121ºC for 15 min, whereas glass- ware was sterilized using an oven set at 160ºC for 2 h. *Bradyrhizobium* spp. and Phosphorus solubilizing bacteria *Bacillus megatherium* var. *phosphaticum* (BMP) strains were obtained from Bio-pesticides and Bio-fertilizers Department, Environment, Natural Resources and Desertification Research Institute (ENDRI), National Center for Research (NCR), Khartoum, Sudan.

To prepare the inoculant, liquid yeast extract mannitol medium was inoculated with a fresh culture of bacterial strains and then incubated at 28^{O}C for 72 h. with shaking at 150 rpm. An aliquot of 15 ml of the culture was applied to each pre-germinated ground nut seed in the pot.

Greenhouse experiments:

General:

Two experiments were conducted in the season 2015/2016. Treatments were arranged in a Randomized Complete Block Design with 4-replicates. Soil mix made of river silt and sand (2:1 v/v) was prepared. The soil was placed in plastic bags (19 cm diameter) with drainage holes at the bottom. *Striga* infestation was accomplished by mixing 10mg of *S. hermonthica* seeds in the top surface of the soil. Sorghum (cv Wad Ahmed) (5 seeds/pot) and groundnut seeds (7/pot) were planted at *Ca.* 2 cm soil depth. At 7 days after sowing (DAS), sorghum and groundnut seedlings were thinned depends on treatments. Sole sorghum, *Striga* infested and *Striga* free sorghum intercropped with groundnut were included as controls for comparison. Weeds other than *S. hermonthica* were removed by hand. All pots were irrigated at 3 days intervals throughout the growing period. *Striga* count and sorghum height were determined at 30, 45, 60, 75and 90 DAS. Number of leaves and leaf chlorophyll content were measured at 30, 60 and 90 DAS. At harvest sorghum shoot and root and *Striga* shoot were air-dried and weighed.

First greenhouse experiment:

Effects of sole and intercropping on Striga incidence and sorghum performance:

The objective of the present study was to assess the effect of controlling *S. hermonthica* in sorghum by intercropping with groundnut. Pots (21 cm i.d.), perforated at the bottom, and were filled with soil and mix (2:1) as described above. The soil was infested with 10mg/pot of *S. hermonthica* seeds. Sorghum (cv. Wad Ahmed) and groundnut (Sodari) seeds were planted. Sorghum and groundnut were thinned. A pot experiment was performed during the 2015 season, in which the host crop sorghum was intercropped with groundnut at various ratios in presence or absence of *Striga*. These ratios were 2:1 (66% host: 33% groundnut), 2:3 (40% host: 60% groundnut), 2:6 (25% host: 75% groundnut). Sole sorghum, *Striga* infested and *Striga* free sorghum, intercropped with groundnut were included as controls. *Striga* emergence, sorghum heights, leaves number, chlorophyll content and sorghum and *Striga* shoot dry weight were measured as described above.

Second greenhouse experiment:
Effects of intercropping with groundnut, bacterial strains and inorganic fertilizers on Striga incidence and sorghum growth:

A pot experiment was conducted to study the effect of intercropping, bacterial strains and inorganic fertilizers on controlling *Striga* in sorghum. Sorghum plants were grown individually (one per pot) or mixed with groundnut in large pots filled with 7Kg of caly:sand (2:1, v:v) mixed with 10 mg of *Striga* seeds as described above. Urea (43 kg N/ha) and super phosphate (41kgP_2O_5/ha) were placed as side dressing, directly, beneath the sorghum plants at sowing. Seeds of groundnut inoculated with *Bradyrhizobium* spp. and *Bacillus megatherium* var. *phosphaticum* (BMP) each alone and in combination, were planted. At 7DAS, sorghum and groundnut seedlings were thinned to 2 and 1 plants/pot, respectively. Emergent *S. hermonthica*, sorghum height, chlorophyll content, leaves number, sorghum and *S. hermonthica* dry weights were measured as described above.

Statistical analysis:

Data collected from all experiments were subjected to statistical analysis using Microsoft excel 2010 program. Means were separated for significance using Duncan Multiple Range Test (DMRT). Data were analyzed by analysis of variance.

Results:
Effects of sole and intercropping with groundnut on the performance of sorghum under S. hermonthica infestation:
Effects on S. hermonthica emergence:

On average, inter-cropping sorghum with groundnut resulted in reduce and delay of *S. hermonthica* infestation compared to sole sorghum (Table 1). There were variations in *Striga* emergence between the different inter-cropping ratios. At 30 and 45 DAS, sole crop sustained the highest *S. hermonthica* emergence as compared to intercropped plants. At 60 DAS, intercropping sorghum with groundnut at ratios2:1and 2:3 reduced *S. hermonthica* emergence by 38and 28%, respectively in comparison to sole sorghum. However at the ratio 2:6 *S. hermonthica* emergences induced to 7% as compared to control. At 75 DAS all intercropping ratios reduced *S. hermonthica* emergence as compared to sole crop. At90 DAS, sole sorghum displayed 14 *S. hermonthica* plants/pot. *Striga* emergence was lowest at the intercropped plant ratios 2:1 and 2:3. However, intercropping at the ratio 2:6 sustained the highest *S. hermonthica* number.

On overall mean, groundnut was more effective in reducing *S. hermonthica* emergence in all intercropping ratios especially when it was intercropped with sorghum at a ratio of 2:1 sorghum/groundnut.

Table 1: Effects of sole crop and intercropping on *S. hermonthica* emergence

Treatments	*Striga* count					Means
	Days after sowing					
	30	45	60	75	90	
Sole crop	2.55^a(7.00)	3.10^a(10.00)	3.80^a(14.00)	3.92^a(18.33)	3.59^a(14.00)	12.67
Intercropping 2:1	1.00^b(0.67)	1.55^a(3.33)	3.32^a(11.67)	3.24^a(10.33)	3.11^a(9.33)	7.07
Intercropping 2:3	0.71^b(0.00)	2.10^a(5.00)	3.15^a(10.00)	3.38^a(11.00)	3.40^a(11.33)	7.47
Intercropping 2:6	0.71^b(0.00)	2.09^a(4.00)	3.91^a(15.00)	3.66^a(13.00)	3.72^a(15.00)	9.40
SE $\pm$	0.54	0.94	0.70	1.00	0.97	

Original Data with brackets and data without brackets indicates root square transformed data. The data presented are the means of three replicates. Figures followed by the same letters in a column are not significantly different (P=0.05), using Duncan's multiple range test.

Effects on S. hermonthica dry weight (SDW):

In the sole sorghum crop SDW was 15.33 g/pot. *S. hermonthica* infested sorghum intercropped with groundnut at ratio of 2:1, 2:3 and 2:6 displayed 11.6, 13 and 9 g/pot, respectively (Fig.1). Furthermore, dry matter production was insignificantly influenced by planting pattern. *S. hermonthica* dry matter production was highest in sole crop and lowest when intercropped with groundnut. *S. hermonthica* dry matter decreased as the proportion of groundnut increased in the intercrop except 2:3 ratio. Intercropping sorghum with groundnut at a ratio of 2:6 resulted into the lowest average dry weight as compared to the control.

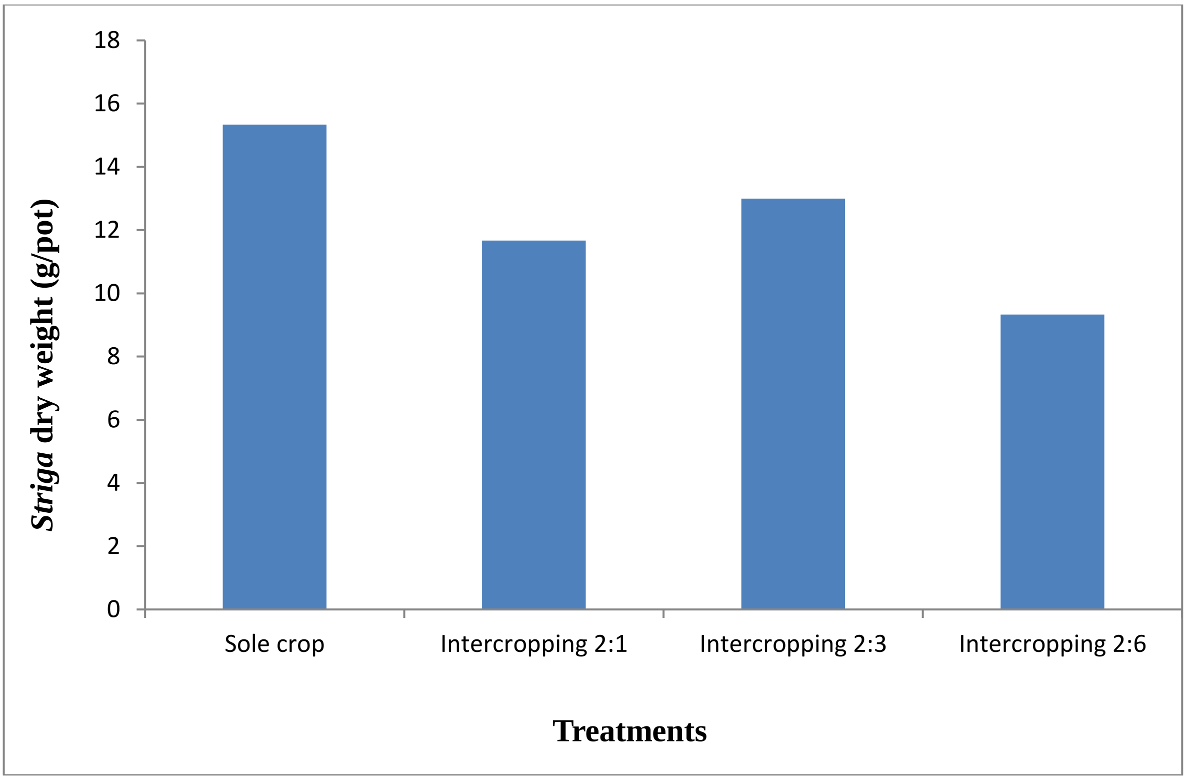

Fig. 1: Effects of sole crop and intercropping on *S. hermonthica* dry weight. (SE= ±0.73)

Effects on sorghum height:

Sorghum performance, in terms of plant height was influenced by the various inter-cropping treatments in presence or absence of *Striga* (Table 2). At 30 and 45 DAS, intercropping at different ratios had no significant effects on the sorghum height. At 60 DAS, intercropping at ratios of2:1, 2:3 and 2:6 increased sorghum heights albeit not significant as compare to the sole crop. They increased sorghum height by 36, 22and 15% respectively in presence of *S. hermonthica*. At 90 DAS, *Striga* free sorghum, irrespective to planting ratio, showed no significant differences in height. Unrestricted *Striga* growth, irrespective of plant ratio, insignificantly increased sorghum height as compared to the sole crop. Considering sorghum growth and *Striga* suppression, the best intercropping ratio between sorghum and groundnut was 2:1. Based on overall means, inter-cropping sorghum with groundnut had the average tallest sorghum plants in presence or absence of *Striga* infestation as compared to the sole crop.

Table 2: Effects of sole crop and intercropping on sorghum plant height

Treatments	Plant height (cm) Days after sowing					Means
	30	45	60	75	90	
Sole crop	18.83[a]	59.47[a]	56.80[b]	78.17[a]	84.42[a]	59.54
Sole crop+ *Striga*	21.20[a]	51.77[a]	55.47[b]	38.80[b]	21.87[b]	37.82
Intercropping 2:1	21.00[a]	68.17[a]	81.97[ab]	87.47[a]	93.50[a]	70.42
Intercropping 2:1 + *Striga*	18.83[a]	40.33[a]	75.17[ab]	61.42[ab]	38.67[ab]	46.88
Intercropping 2:3	22.83[a]	68.33[a]	73.10[ab]	73.50[ab]	67.33[ab]	61.02
Intercropping 2:3 + *Striga*	25.00[a]	59.58[a]	67.78[b]	70.75[ab]	63.42[ab]	57.31
Intercropping 2:6	22.33[a]	63.37[a]	100.07[a]	91.08[a]	92.58[a]	73.89
Intercropping 2:6+ *Striga*	17.50[a]	48.83[a]	64.07[b]	61.17[ab]	61.75[ab]	50.66
SE ±	3.52	13.01	10.28	13.63	21.36	

The data presented are the means of three replicates. Figures followed by the same letters in a column are not significantly different (P=0.05), using Duncan's multiple range test.

Effects on sorghum leave chlorophyll content:

At 30 DAS, chlorophyll content irrespective to planting ratio and presence of *S. hermonthica* showed no significant differences in chlorophyll content (Table 3). At 60 DAS, intercropping at ratio 2:1 and in absence of *S. hermonthica* infestation, sustained the highest chlorophyll content (42.8) as compared to sole sorghum crop. However, at 90 DAS, chlorophyll content declined in all treatments compared to sole crop.

Table 3: Effects of sole crop and intercropping on sorghum leaf chlorophyll content

Treatments	Chlorophyll content			Means
	Days after sowing			
	30	60	90	
Sole crop	27.90^{a}	35.10^{a}	30.40^{a}	31.13
Control + *Striga*	21.70^{a}	25.10^{a}	25.17^{a}	23.99
Intercropping 2:1	27.23^{a}	42.87^{a}	30.07^{a}	33.39
Intercropping 2:1 + *Striga*	21.27^{a}	24.30^{a}	9.23^{a}	18.27
Intercropping 2:3	25.07^{a}	26.53^{a}	17.60^{a}	23.07
Intercropping 2:3 + *Striga*	22.70^{a}	22.83^{a}	10.43^{a}	18.65
Intercropping 2:6	28.10^{a}	34.63^{a}	25.50^{a}	29.41
Intercropping 2:6+ *Striga*	26.37^{a}	25.83^{a}	15.73^{a}	22.64
SE ±	3.30	8.20	10.81	

The data presented are the means of three replicates. Figures followed by the same letters in a column are not significantly different (P=0.05), using Duncan's multiple range test.

Effects on sorghum number of leaves:

Sorghum performance, in terms of plant number of leaves, was influenced by the various intercropping treatments in presence or absence of *S. hermonthica* (Table 4). Based on overall means, results revealed that intercropping sorghum with groundnut had the highest leaves numbers in presence or absence of the parasite as compared to sole crop. On average, leaves number was increased with the increase of plant ratio.

Table 4: Effects of sole crop and intercropping on sorghum leaves number

Treatments	Leaves number			Means
	Days after sowing			
	30	60	90	
Sole crop	2.49^{a} (5.83)	2.87^{ab} (7.73)	2.53^{ab} (5.93)	6.50
Sole crop + *Striga*	2.65^{a} (6.53)	2.27^{c} (4.70)	1.51^{b} (2.10)	4.44
Intercropping 2:1	2.73^{a} (7.00)	3.08^{a} (9.00)	2.40^{ab} (5.83)	7.28
Intercropping 2:1 + *Striga*	2.45^{a} (5.50)	2.44^{bc} (5.50)	1.54^{b} (2.33)	4.44
Intercropping 2:3	2.57^{a} (6.17)	2.52^{bc} (6.00)	2.76^{a} (7.67)	6.61
Intercropping 2:3 + *Striga*	2.68^{a} (6.67)	2.83^{abc} (7.50)	2.19^{ab} (4.50)	6.22
Intercropping 2:6	2.55^{a} (6.00)	2.59^{abc} (6.33)	3.09^{a} (9.17)	7.17
Intercropping 2:6+ *Striga*	2.52^{a} (5.90)	2.77^{abc} (7.20)	2.45^{ab} (5.50)	6.20
SE ±	0.19	0.23	0.51	

Origin Data with brackets and data without brackets indicates root square transformed data. The data presented are the means of three replicates. Figures followed by the same letters in a column are not significantly different (P=0.05), using Duncan's multiple range test.

Effects on sorghum dry weight:

Intercropping with groundnut at ratio 2:1 and infestation with *S. hermonthica*, increased sorghum total biomass as compared to infested sole crop (Table 5). In the absence of *S. hermonthica,* intercropping increased sorghum total dry weight by 25% in comparison to the corresponding *Striga* free control. Among ratios, ratio 2:3 sustained the highest dry weight in presence of *S. hermonthica*.

Table 5: Effects of sole crop and intercropping on sorghum dry weight

Treatments	Dry weight (g)		
	Shoot	Root	Total biomass
Sole crop	59.67^{ab}	132.00^{a}	95.84
Sole crop + *Striga*	9.00^{b}	23.33^{a}	16.17
Intercropping 2:1	54.00^{ab}	46.67^{a}	50.34
Intercropping 2:1 + *Striga*	4.00^{b}	23.33^{a}	13.67
Intercropping 2:3	40.00^{ab}	58.67^{a}	49.34
Intercropping 2:3 + *Striga*	11.67^{b}	40.00^{a}	25.84
Intercropping 2:6	105.67^{a}	124.67^{a}	115.17
Intercropping 2:6+ *Striga*	5.33^{b}	18.33^{a}	11.83
SE ±	26.70	44.10	

The data presented are the means of three replicates. Figures followed by the same letters in a column are not significantly different (P=0.05), using Duncan's multiple range test

Second experiment:

Effects of intercropping with groundnut and bacterial strains on Striga hermonthica and sorghum growth:

Effects of intercropping and bacterial strains on S. hermonthica emergence:

All treatments decreased *S. hermonthica* emergence considerably in comparison to the sole crop (Table 6). Furthermore, *S. hermonthica* emergence progressively increased with time. At 30 DAS, *S. hermonthica* emergence was observed in all treatments except *Bradyrhizobium* alone or in combination with BMP + Nitrogen. Sole sorghum produced the highest *S. hermonthica* emergence compared to intercropping. At 45 DAS, *S. hermonthica* emergence was increased as compared to 30 DAS. The combination of *Bradyrhizobium* +

BMP + Nitrogen significantly (P≤0.05) delayed and reduced *S. hermonthica* emergence completely at 30, 45 and 60 DAS. At 60 DAS, *S. hermonthica* emergence was maximal on sole sorghum (10.76plants/pot). Intercropping with groundnut treated with nitrogen at (43 kg/ha) was effective in reducing *S. hermonthica* emergence by more than 81% in comparison to the sole sorghum crop. At 75 and 90 DAS, intercropping with groundnut inoculated with *Bradyrhizobium* plus BMP plus nitrogen significantly (P≤0.05) reduced *S. hermonthica* emergence by 89 and 81%, respectively as compared to sole crop. At 90 DAS, intercropping with groundnut treated with nitrogen plus phosphorus significantly (P≤0.05) reduced *S. hermonthica* emergence by 71% compared to the sole crop. Based on overall means, *S. hermonthica* emergence was reduced by up to 78% in groundnut intercrop treated with nitrogen and92% in groundnut inoculated with *Bradyrhizobium*+ BMP + nitrogen as compared to the sole crop.

Table 6: Effects of intercropping and bacterial strains on *S. hermonthica* emergence

Treatments	*Striga* count					Means
	Days after sowing					
	30	45	60	75	90	
Sole crop	2.26^{a} (6.33)	3.10^{a} (10.00)	3.20^{a} (10.67)	3.92^{a} (18.33)	3.59^{a} (14.00)	11.87
Intercropping	1.05^{a} (0.67)	2.17^{ab} (4.67)	3.07^{a} (10.00)	2.76^{ab} (8.33)	2.69^{abc} (7.33)	6.20
Bradyrhizobium	0.71^{a} (0.00)	1.47^{ab} (2.00)	1.99^{ab} (4.33)	2.47^{ab} (5.67)	2.11^{abc} (4.00)	3.20
BMP	1.17^{a} (1.00)	2.79^{a} (7.33)	3.17^{a} (9.67)	3.18^{ab} (9.67)	2.58^{abc} (6.33)	6.80
Nitrogen	0.88^{a} (0.33)	1.17^{ab} (1.00)	1.56^{ab} (2.00)	2.36^{ab} (5.33)	2.18^{abc} (4.33)	2.60
Phosphorus	2.04^{a} (4.67)	2.51^{ab} (6.33)	2.88^{a} (8.33)	2.97^{ab} (8.67)	2.58^{abc} (6.67)	6.93
Bradyrhizobium + BMP	1.39^{a} (1.67)	1.18^{ab} (1.33)	2.20^{ab} (4.33)	2.46^{ab} (5.67)	2.20^{abc} (4.33)	3.47
Nitrogen + Phosphorus	1.78^{a} (5.00)	2.02^{ab} (7.00)	2.41^{ab} (7.67)	2.79^{ab} (9.00)	1.89^{bc} (4.00)	6.53
Bradyrhizobium + Phosphorus	1.17^{a} (1.00)	1.49^{ab} (2.33)	1.77^{ab} (3.33)	2.38^{ab} (6.33)	2.39^{abc} (6.00)	3.80
BMP + Nitrogen	1.47^{a} (2.00)	1.27^{ab} (1.33)	3.18^{a} (9.67)	3.47^{ab} (12.00)	2.54^{abc} (6.00)	6.20
BMP + Phosphorus	1.60^{a} (3.67)	2.26^{ab} (6.33)	2.59^{ab} (8.00)	3.44^{ab} (11.33)	3.32^{ab} (10.67)	8.00
Bradyrhizobium + BMP + Nitrogen	0.71^{a} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	1.47^{b} (2.00)	1.76^{c} (2.67)	0.93
Bradyrhizobium + Nitrogen + Phosphorus	1.10^{a} (1.00)	2.04^{ab} (4.00)	3.02^{a} (8.67)	3.43^{ab} (11.33)	3.24^{abc} (10.00)	7.00
SE ±	0.78	0.84	0.81	0.84	0.62	

Original Data with brackets and data without brackets indicates root square transformed data. The data presented are the means of three replicates. Figures followed by the same letters in a column are not significantly different (P=0.05), using Duncan's multiple range test.

Effects on S. hermonthica biomass:

The effects of intercropping with groundnut and fertilization treatments on *S. hermonthica* biomass were consistent with their effects on *S. hermonthica* emergence. Intercropping with groundnut reduced *S. hermonthica* dry weight as compared to the sole crop(Fig. 2). Moreover, intercropping with groundnut inoculated with *Bradyrhizobium* alone or in combination with BMP plus nitrogen significantly (P≤0.05) reduced *S. hermonthica* dry weight by 96 and 93%, respectively in comparison to sole sorghum.

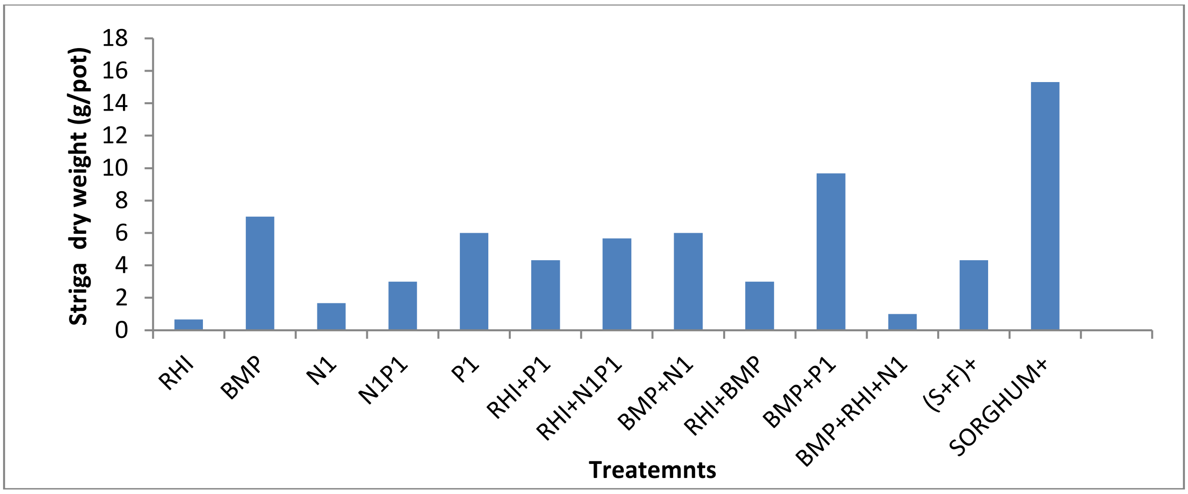

Fig. 2: Effects of intercropping and bacterial strains on *S. hermonthica* dry weight (SE = +3.05)

Sorghum plant height:

Sorghum performance, in terms of plant height was influenced by intercropping, bacterial and inorganic fertilizers treatments (Table 7). Sorghum height, irrespective to treatments, showed progressive increase with time. Unrestricted *S. hermonthica* parasitism resulted in drastic reduction in sorghum growth.

At 30 DAS, intercropping treated with nitrogen or inoculated with *Bradyrhizobium* alone or in combinations with (phosphorus or nitrogen + phosphorus) sustained the highest sorghum height compared to infested sole sorghum. At 45 DAS, intercropping treated with nitrogen, phosphorus and BMP +phosphorus increased sorghum plant height as compared to infested sole crop.

At 60 DAS, intercropping with groundnut treated with BMP + nitrogen followed by nitrogen alone was more effective in increasing sorghum growth. At 75 DAS, the highest sorghum heights were observed by nitrogen alone or in combinations with *Bradyrhizobium* + BMP or *Bradyrhizobium* + phosphorus.

At 90 DAS, unrestricted *S. hermonthica* growth reduced sorghum height by 74%. Intercropping with groundnut treated with nitrogen + phosphorus followed by phosphorus and the combination of *Bradyrhizobium* + BMP + nitrogen were more effective in increasing sorghum growth compared to infested sole crop.Based on overall means, all treatments showed stimulatory effect, in terms of plant heightas compared to infested sole sorghum.

Table 7: Effects of intercropping and bacterial strains on sorghum growth

Treatments	Plant height (cm)					Means
	Days after sowing					
	30	45	60	75	90	
Sole crop	20.00[bc]	59.47[a]	56.80[a]	78.15[b]	84.42[ab]	59.77
Control + *Striga*	21.20[bc]	51.77[a]	55.47[a]	38.80[c]	21.83[c]	37.81
Intercropping	21.00[bc]	68.17[a]	81.97[a]	87.40[a]	93.50[a]	70.41
Intercropping +*Striga*	18.17[bc]	51.83[a]	56.23[a]	61.03[c]	57.40[c]	48.93
Bradyrhizobium	29.50[ab]	65.67[a]	67.17[a]	71.83[c]	62.17[c]	59.27
BMP	22.83[abc]	61.13[a]	58.47[a]	58.57[c]	52.83[c]	50.77
Nitrogen	34.33[a]	77.13[a]	72.40[a]	76.97[b]	53.67[c]	62.90
Phosphorus	29.50[ab]	70.93[a]	67.83[a]	73.00[c]	75.47[bc]	63.35
Bradyrhizobium + BMP	19.17[bc]	56.93[a]	70.00[a]	71.97[c]	64.57[c]	56.53
Nitrogen + Phosphorus	25.50[abc]	65.83[a]	65.33[a]	69.67[c]	79.00[b]	61.07
Bradyrhizobium + Phosphorus	29.50[ab]	70.17[a]	70.17[a]	73.73[c]	68.07[c]	62.33
BMP + Nitrogen	19.50[bc]	56.47[a]	73.00[a]	71.67[c]	56.67[c]	55.46
BMP + Phosphorus	21.00[bc]	59.73[a]	65.23[a]	65.47[c]	47.33[c]	51.75
Bradyrhizobium + BMP + Nitrogen	15.00[c]	55.23[a]	67.73[a]	74.93[c]	74.63[bc]	57.50
Bradyrhizobium + Nitrogen + Phosphorus	26.50[abc]	66.30[a]	66.17[a]	74.07[c]	52.53[c]	57.11
SE +	4.64	9.43	10.57	13.39	19.38	

The data presented are the means of three replicates. Figures followed by the same letters in a column are not significantly different (P=0.05), using Duncan's multiple range test.

Chlorophyll content:

At 30 DAS, *S. hermonthica* free and infested sole sorghum crop displayed 27.9and 25.4, chlorophyll content, respectively (Table 8). Intercropping treated with nitrogen or phosphorus each alone, nvariably resulted in the highest significant (P≤0.05)increments in sorghum chlorophyll contents as compared to the corresponding control. At 60 and 90 DAS, intercropped plants treated with BMP + nitrogen sustained the highest chlorophyll content compared to the infested sole crop. Based on overall means, phosphorus followed by BMP + nitrogen treatments displayed the highest leaf chlorophyll content as compared to the infested sole crop.

Table8: Effects of intercropping and bacterial strains on sorghum leaf chlorophyll content

Treatments	Chlorophyll content			Means
	Days after sowing			
	30	60	90	
Sole crop	27.90^{b}	44.90^{a}	30.40^{a}	34.40
Control + Striga	25.43^{b}	25.10^{cde}	22.47^{a}	24.33
Intercropping	27.23^{b}	42.87^{ab}	30.07^{a}	33.39
Intercropping +*Striga*	20.00^{b}	21.80^{cde}	19.47^{a}	20.42
Bradyrhizobium	26.53^{b}	22.33^{cde}	30.23^{a}	26.36
BMP	21.20^{b}	22.57^{cde}	30.80^{a}	24.86
Nitrogen	33.27^{a}	39.77^{ab}	36.87^{a}	36.64
Phosphorus	33.23^{a}	42.77^{ab}	49.40^{a}	41.80
Bradyrhizobium + BMP	18.80^{b}	19.20^{de}	16.77^{a}	18.26
Nitrogen + Phosphorus	26.40^{b}	15.30^{e}	25.00^{a}	22.23
Bradyrhizobium + Phosphorus	25.83^{b}	34.13^{abc}	27.63^{a}	29.20
BMP + Nitrogen	23.17^{b}	44.13^{a}	51.80^{a}	39.70
BMP + Phosphorus	21.50^{b}	29.60^{bcd}	18.67^{a}	23.26
Bradyrhizobium + BMP + Nitrogen	25.10^{b}	23.67^{cde}	26.97^{a}	25.25
Bradyrhizobium + Nitrogen + Phosphorus	25.37^{b}	39.00^{ab}	28.10^{a}	30.82
SE $\pm$	4.50	4.50	4.50	

The data presented are the means of three replicates. Figures followed by the same letters in a column are not significantly different (P=0.05), using Duncan's multiple range test.

Sorghum number of leaves:

Sorghum leaves numbers was affected by *S. hermonthica* infestation (Table 9). In overall means intercropped plants treated with the combination of *Bradyrhizobium* + BMP + nitrogen followed by phosphorus sustain the highest leaves number compared to infested sole plant.

Table 9: Effects of intercropping and bacterial strains on sorghum leaves number

Treatments	Leaves number			Means
	Days after sowing			
	30	60	90	
Sole crop	2.49^{a}(5.83)	2.69^{abc}(6.77)	2.47^{ab}(5.63)	6.08
Control + Striga	2.65^{a}(6.53)	2.27^{abcd}(4.70)	1.51^{bc}(2.10)	4.44
Intercropping	2.70^{a}(6.83)	2.23^{bcd}(4.50)	2.53^{ab}(6.17)	5.83
Intercropping +*Striga*	2.71^{a}(6.87)	2.30^{abcd}(4.83)	2.17^{abc}(4.30)	5.33
Bradyrhizobium	2.77^{a}(7.17)	2.60^{abcd}(6.33)	2.03^{abc}(4.00)	5.83
BMP	2.74^{a}(7.00)	2.75^{ab}(7.17)	1.14^{c}(1.17)	5.11
Nitrogen	2.86^{a}(7.67)	2.70^{abc}(6.83)	2.19^{abc}(4.67)	6.39
Phosphorus	2.88^{a}(7.83)	2.64^{abcd}(6.50)	2.45^{ab}(5.50)	6.61
Bradyrhizobium + BMP	2.63^{a}(6.43)	2.16^{d}(4.17)	2.32^{ab}(5.00)	5.20
Nitrogen + Phosphorus	2.79^{a}(7.33)	2.63^{abcd}(6.50)	2.00^{abc}(4.50)	6.11
Bradyrhizobium + Phosphorus	2.74^{a}(7.00)	2.64^{abcd}(6.50)	2.47^{ab}(5.83)	6.44
BMP + Nitrogen	2.46^{a}(5.60)	2.18^{cd}(4.30)	2.60^{ab}(6.33)	5.41
BMP + Phosphorus	2.74^{a}(7.00)	2.78^{a}(7.33)	1.95^{abc}(3.50)	5.94
Bradyrhizobium + BMP + Nitrogen	2.66^{a}(6.67)	2.64^{abcd}(6.50)	2.79^{a}(7.33)	6.83
Bradyrhizobium + Nitrogen + Phosphorus	2.86^{a}(7.67)	2.64^{abcd}(6.50)	2.05^{abc}(3.83)	6.00
SE $\pm$	0.18	0.22	0.49	

Original Data with brackets and data without brackets indicates root square transformed data. The data presented are the means of three replicates. Figures followed by the same letters in a column are not significantly different (P=0.05), using Duncan's multiple range test.

Sorghum dry weight (SDW):

Results revealed that SDW in infested sole sorghum and intercropping were 24.3 and 9.5 g/pot (Table 10). Sorghum intercropping with groundnut treated with nitrogen alone or in combination with *Bradyrhizobium* + BMP increased SDW by 195.5 and 259.5% respectively as compared to the infested sole sorghum. Despite the enhanced growth parameters of shoots and roots by *Bradyrhizobium* + BMP + nitrogen, BMP+ nitrogen, BMP, phosphorus and nitrogen the stimulatory effect of fertilizers on root dry weight was higher than shoot dry weight.

Table 10: Effects of intercropping and bacterial strains on sorghum dry weight

Treatments	Dry weight (g)		
	Shoot	Root	Total biomass
Sole crop	59.67[ab]	132.00[a]	95.84
Control + Striga	13.50[bc]	35.00[b]	24.25
Intercropping	54.00[abc]	46.70[b]	50.35
Intercropping +*Striga*	6.50[c]	12.50[b]	9.50
Bradyrhizobium	35.50[bc]	38.50[b]	37.00
BMP	9.33[c]	62.50[b]	35.92
Nitrogen	38.67[abc]	105.00[b]	71.84
Phosphorus	16.67[bc]	105.50[b]	61.09
Bradyrhizobium + BMP	34.00[bc]	24.00[b]	29.00
Nitrogen + Phosphorus	44.50[abc]	45.50[b]	45.00
Bradyrhizobium + Phosphorus	25.00[bc]	51.00[b]	38.00
BMP + Nitrogen	18.67[bc]	36.33[b]	27.50
BMP + Phosphorus	23.50[bc]	103.00[b]	63.25
Bradyrhizobium + BMP + Nitrogen	82.70[a]	92.00[b]	87.35
Bradyrhizobium + Nitrogen + Phosphorus	22.50[bc]	35.00[b]	28.75
SE ±	17.75	34.35	

The data presented are the means of three replicates. Figures followed by the same letters in a column are not significantly different (P=0.05), using Duncan's multiple range test

Discussion:

Generally, results revealed that unrestricted *S. hermonthica* negatively affected sorghum growth, in terms of number of leaves, chlorophyll content and total dry mass. This could be attributed to perturbation of the hormonal balance of the host plant. Groundnut intercropping significantly reduced *S. hermonthica* emergence compared to the sole sorghum crop. The number of *S. hermonthica* plants decreased as the proportion of groundnut increased in the intercropping. Groundnut was more effective in reducing *S. hermonthica* emergence by 44% when it was intercropped at a ratio of 2:1 sorghum/ groundnut. The decreased number of *S. hermonthica* that emerged in the intercrop can be attributed to the suicidal germination caused by the germination stimulant produced by the groundnut roots. One of the proposed mechanisms by which legumes suppress *Striga* is through stimulation of germination of *Striga* without acting as a host [9]. Intercropping sorghum with groundnut at a ratio of 2:6 resulted in the lowest average of *S. hermonthica* dry weight. Moreover, Carson [10] reported that intercropping with cowpea significantly reduced *Striga* dry weight.

Intercropping sorghum with groundnut had the average tallest sorghum plants and chlorophyll content, in presence or absence of *S. hermonthica* infestation. Considering sorghum and *S. hermonthica* growth suppression, intercropping at 2:1ratio gave the best result. One of the key factors of successful intercropping is proper plant density, which depends on the plant species as well as the particular varieties used [11].Result revealed that, increasing groundnut planting density significantly reduced sorghum dry weight. Morgado and Willey [12] reported that dry matter yield accumulation of individual maize plant decreased with increase in bean plant population.

In the second experiment, results displayed that inoculation with *Bradyrhizobium*+ BMP + nitrogen applied to sole sorghum reduced *S. hermonthica* population number and biomass by 92 and 93%, respectively. Incidence of *Striga* is known to negatively correlate with soil fertility, particularly nitrogen availability. These findings are consistent with previous reports on suppressive effects of urea and bacteria on the parasite and improvement of sorghum growth and yield under *Striga* infestation [13, 14]. Jamil *et al*. [15] explained that host plants reduce the secretion of underground signaling molecules in response to the quick supply of mineral nutrients, and consequently resulting in lower *Striga* seed germination and infection. For instance, the nitrogen-fixing bacteria *A. brasilense* has been reported to inhibit germination and radical growth of *S. hermonthica*[6, 14].In the present study, intercropping sorghum with groundnut, improved growth of sorghum with the observed reduction in *S. hermonthica* emergence. Parker and Riches [3] attributed the suppressive effects of intercropping on the parasite to several factors, including its action as a trap crop, interference with production of germination stimulants, exudation of germination inhibitors or stimulants and/or reduction of the parasite transpiration. The increasing of chlorophyll in the symbiotic plants probably resulted in higher photosynthetic rates and thus improved plant biomass. Furthermore, sorghum/groundnut intercropping inoculated with bacterial strains increased growth parameter. These significant increments in sorghum growth attributes are consistent with the concurrent increase in sorghum total biomass, irrespective of *S. hermonthica* infestation. These results are in agreement with those reported by Lendzemo *et al*. [16].

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