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Effects of Rotation with Trap Crops on Striga (*Striga hermonthica* Del. Benth) Incidence, its Seed Bank and Sorghum Growth and Yield♦

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Abstract: A trial was conducted for three consecutive seasons (2006/07, 2007/08 and 2008/09) in a field artificially infested by *Striga hermonthica* in the Experimental Farm of the Faculty of Agriculture, University of Sinnar. The effects of a two seasons' crop rotation on striga incidence, its seed bank and growth and yield of subsequent sorghum crop were investigated. The rotation comprised the trap crops, cowpea (*Vigna unguiculata*), millet (*Pennisetum glaucum*), sesame (*Sesamum indicum*), sunflower (*Helianthus annuus*) and fallows, in assorted combinations. A sorghum monoculture, for the three seasons, was included as a control. All treatments reduced striga emergence significantly in comparison to sorghum monoculture. Sunflower and sesame grown for two consecutive seasons caused the maximum reductions (80%), while a fallow followed by sorghum resulted in the least reduction (42%). Significant reduction in striga capsules (37%) was caused by two consecutive sesame crops. In the second season, all treatments significantly reduced striga seed bank,. Two consecutive fallows and two consecutive crops each of cowpea, millet and sunflower resulted in the highest reductions in striga incidence (80% - 92%), while a fallow followed by sorghum exhibited the least reduction (51-65%). None of the treatments had adverse effects on sorghum stand early in the season; however, at harvest significant reduction was observed. Sorghum monoculture resulted in the lowest stand, while sunflower planted subsequent to a fallow and two successive sunflower crops affected the highest stands. Among all treatments, sorghum

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monoculture and sorghum planted subsequent to sorghum resulted in the lowest straw and grain yield. Sorghum planted subsequent to two consecutive sunflower crops displayed the highest yield. The results clearly indicated the importance of crop rotation as an integral component in striga management.

Key words: Crop rotation; trap crops; striga; sorghum; sesame; sunflower; cowpea

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is a crop that, provides food, feed, fiber, fuel and biofuel, is of vital importance in sub-Saharan Africa, where crop choice is often limited by drought (AAFT 2011). The crop, mostly rain- fed, is often planted in monocultures on soils of low fertility. Traditional African farming, based on low inputs, was sustained through prolonged fallows. However, population pressure and market demands have led to intensification of sorghum planting and replacement of traditional low – yielding land races by improved high yielding cultivars (Parker and Riches 1993; Babiker 2007). Nevertheless, yields are, comparatively, low. The low yields are attributable to several factors among them heavy infestations by the root parasitic weed *S. hermonthica*. It was estimated that over 21 million hectares of arable land in Africa are infested by *S. hermothica* resulting in losses amounting to 4.1 million tons of grain per year (Moboob 1986). In monetary terms, the losses were estimated to exceed US$ 7 billion in value (Michael *et al.* 2012)

Copious seed production by *S. hermonthica* and prolonged seed viability lead to buildup of a huge seed bank, shortly after initiation of infestation, which when coupled with the subterranean nature of its early developmental stages make the parasite difficult to control (Babiker 2007). Lack of awareness of the parasite life cycle and low productivity arising from the damage inflicted by the parasite while subterranean, make farmers reluctant to accept and/or adopt post-emergence measures (Babiker 2007).

A potentially useful control option is the depletion of the soil seed bank by suicidal germination, which involves germination of the seeds in absence of host plants (Kgosi *et al.* 2012). Suicidal germination could be achieved by synthetic germination stimulants or by natural ones through catch and/or trap cropping. The natural germination stimulants, collectively known as strigolactones (SLs), are unique rhizosphere signaling molecules that play pivotal roles as host detection signals for arbuscular mycorrhizal (AM) fungi and root parasitic weeds in addition to their hormonal role in controlling shoot branching in plants (Lopez-Raez *et al.* 2008). A number of SLs were isolated from root exudates of several hosts and non-host plants. They emerged as a new class of plant hormones controlling plant architecture through repression of shoot branching (Prandi and Cardinale 2014). Many SLs' analogues were synthesized and proved to be highly effective in inducing germination of the parasite under laboratory and greenhouse conditions. However, their extreme instability in soil poses a serious constraint for their use under field conditions (Babiker 2007). Furthermore, cost and application technology may provide an additional hurdle against their use in Africa.

Traditional farming in sub-Saharan Africa is predominantly subsistence with limited use of purchased inputs. Accordingly, high cost inputs for control of the parasite is not likely to be a viable option. Simple methods for induction of suicidal germination to be deployed as part of an integrated striga management strategy seem to be more realistic and rotation with trap crops seems to be a plausible option.

The present investigation was therefore set to study the effects of rotation with trap crops on striga incidence, its seed bank and growth and yield of a subsequent sorghum crop.

MATERIALS AND METHODS

A field trial was conducted for three consecutive seasons (2006/07, 2007/08 and 2008/09) to study the effects of a two seasons' crop rotation on striga incidence, its seed bank and on a subsequent sorghum crop growth and yield. Four trap crops and a fallow were used in the rotation. The experimental area was disc ploughed, disc harrowed and leveled. The soil was inoculated with striga seeds once, at the initiation of the experiment. The trap crops: cowpea (*Vigna unguiculata* Walp), millet [*Pennisetum glaucum* (L.) R.Br.], sesame (*Sesamum indicum* L.) cv. kenana 2 and sunflower, (*Helianthus annuus* L.) cv. Hyssun 33 were planted in randomly selected, marked and fixed sub-plots (4 x 7m each). Sorghum cv. 'Arfaa Gadamak' was included as a control. In the third season (2008/2009), all sub-plots were sown with sorghum cv. 'Arfaa Gadamak'. In all seasons, the crops were sown, on the first week of July. Sowing methods and seed rate, for each crop, were as recommended by the Agricultural Research Corporation.

Treatment effects were assessed by counting emergent striga plants at 60 and 90 days after sowing (DAS), henceforth referred to as early and late season emergence and by determining number of capsules produced by the striga plant, striga seed bank, sorghum stand and straw and grain yields. Striga seed bank was assessed by collecting soil samples at 0 – 15 cm depth using an augur. Samples from similar treatments were pooled and further sub-sampled. Striga seeds were extracted as described by Berner *et al.* (1997).

Briefly soil sub-samples (200 g each) were crushed and subsequently washed through a series of sieves of mesh sizes of 250, 212, and 90 µm, placed under running tap water for 20 minutes. The contents of the lower sieve (90 µm) were transferred to a sucrose solution with specific gravity of 1.2, stirred for 5 minutes and allowed to settle for two hours. The floating materials, including striga seeds, were retrieved, collected in a 90 µm sieve and washed gently under tap water. The water was removed by filtration and the seeds were captured on filter papers. The filter papers were allowed to dry and the seeds, brushed into Petri dishes each divided radially with lines 2 mm apart, were counted under a stereomicroscope using a Tally hand counter.

Statistical analysis

Data were analyzed using analysis of variance, and means were further tested for significance using the Duncan Multiple Range Test (DMRT) at $P \leq 0.05\%$.

RESULTS AND DISCUSSION

Early (60 DAS) and late (90 DAS) emergence of striga and production of capsules per plant were significantly different among the crop sequences (Table 1). At 60 DAS, sorghum planted in sub-plots, previously sown to sorghum for two consecutive seasons, resulted in the highest striga emergence. A fallow/sorghum sequence (FA/SO) reduced early and late striga emergence in subsequent sorghum by 41.8% and 33.6% of the SO/SO, respectively. The sequences fallow/fallow (FA/FA), fallow/ cowpea (FA/CP) and fallow/sesame (FA/SE) were more suppressive to the parasite than the sequence FA/SO as they reduced early and late season striga emergence by 71.8%-66.7%, 72.5%-64.5% and 68.5%-71.8%, respectively, in comparison to sorghum monocropping. The sequence fallow/ sunflower (FA/SF), fallow/ millet (FA/MI), sesame/ sesame (SE/SE) and sunflower/ sunflower (SF/SF) reduced early and late season striga emergence by 75.5%-73.8%, 77.3%-78.3%, 79.9%-79.6% and 80.2% -70.6%%, respectively. The above data were consistent with several reports (Parker and Riches 1993; Babiker 2007) which indicated that continuous planting of a host plant is conducive to heavy striga infestation. The data also showed that leaving land as a fallow or rotating cereals with non-host trap crops reduced striga infestation on subsequent crops. Reduction of striga infestation through planting non-host crops is in line with previous reports on trap cropping as a simple mean for reducing striga infestation on subsequent susceptible cereals. It could be attributed to reduction in the size of the parasite seed bank through induction of suicidal germination by root exudates. However, the substantial reduction in striga infestation which resulted from a single fallow on the subsequent sorghum substantiated by the results obtained from two consecutive fallows (Table 1) is at variance with the previously reported prolonged viability of striga seeds (Parker and Riches1993; Babiker 2007).

Table 1. Effect of rotation sequence on striga emergence (Plant/m^2) and capsules/plant

Crop sequence	Emergent striga (plant/m^2) Days after crop sowing (DAS)				No. of capsules/plant	
	60 DAS	% reduction	90 DAS	% reduction	No of capsules	% reduction
SO/SO/SO	99.33^{a}	0.00	117.50^{a}	0.00	51.33^{a}	0.00
FA/FA/SO	28.00^{bcd}	71.8	39.17^{c}	66.7	43.33^{ab}	15.6
FA/SO/SO	57.83^{b}	41.8	78.00^{b}	33.6	45.67^{ab}	11.0
FA/SE/SO	31.33^{bcd}	68.5	33.17^{c}	71.8	43.67^{ab}	14.9
FA/CP/SO	27.33^{bcd}	72.5	41.67^{c}	64.5	40.67^{ab}	20.8
FA/SF/SO	24.33^{cd}	75.5	30.83^{c}	73.8	40.17^{ab}	21.7
FA/MI/SO	22.50^{cd}	77.3	25.50^{c}	78.3	39.50^{ab}	23.0
CP/CP/SO	52.50^{bc}	47.1	50.00^{c}	57.4	39.83^{ab}	22.4
MI/MI/SO	29.83^{bcd}	70.0	40.67^{c}	65.4	44.33^{ab}	13.6
SE/SE/SO	20.00^{d}	79.9	24.00^{c}	79.6	32.33^{b}	37.0
SF/SF/SO	19.67^{d}	80.2	34.50^{c}	70.6	38.00^{ab}	26.0
CV%	42.68	-	31.30	-	17.62	-

Means in the same column followed by the same letter(s) are not significantly different at P <0.05, according to DMRT; DAS = days after sowing; SO = sorghum; FA = Fallow; CP = cowpea; SE = sesame; MI = millet; SF = sunflower; CV = coefficient of variation

Striga parasitizing sorghum sown in the same sub-plots for 3 consecutive seasons produced the highest production of capsules (Table 1). All rotational sequences reduced production of capsules by 11%-37%, with SE/SE being the highest and FA/SO the lowest. The observed reduction in capsule production together with reduction in striga emergence suggest a considerable reduction in seed replenishment and is in line with a report by Ahonsi *et al.* (2004) in West Africa who indicated a decrease in capsule production and striga seed bank following rotating striga susceptible cereals with leguminous crops.

Striga seed bank was significantly different among crop sequences after the second and third seasons (Table 2). Soil samples collected at the end of the second season showed that the rotational sequence SO/SO had the highest seed bank size and that a single fallow preceding sorghum (FA/SO) reduced striga seed bank size by 65.4% compared to the concurrent SO/SO sequence. The crop sequences FA/FA, FA/CP, FA/SE, FA/MI and FA/SF reduced striga seed bank by 91.8%, 87.8%, 88.11%, 88.9% and 90.4% respectively, in the second season. The crop sequences SE/SE, CP/CP, MI/MI, SF/SF reduced the seed bank size by 89.1%, 90.7%, 92.7% and 92.8%, respectively in the second season.

Soil samples collected in the third season showed that all crop sequences significantly reduced striga seed bank in comparison to the continuous sorghum (Table 2). A single fallow at the start of the rotation reduced striga seed bank in the third season by 50.9%. Two consecutive fallows (FA/FA) prior to planting sorghum in the third season (FA/FA/SO) reduced striga seed bank by 81.59%. The crop sequences FA/SE, FA/CP, FA/MI and FA/SF reduced striga seed bank by 82.4%, 83.9%, 76.5%, and 85.4%, respectively.

Striga seed bank in sub-plots sown to millet, sesame, cowpea or sunflower for two consecutive seasons prior to planting sorghum in the third season resulted in 73.8%-85.7% reduction. Depletion of the striga seed reserves by the trap crops could be attributed to induction of suicidal germination by trap crops' root exudates which concomitantly reduced striga emergence on sorghum planted in the third season. However, the high reductions of the parasite seed bank indicated in fallows are at variance with the general consensus that striga seeds are endowed with prolonged viability which may extend for over 10 years (Parker and Riches 1993). The results corroborate with the findings of Pieterse *et al*. (1996) in Kenya, Gbehounou (1998) in Benin and Murdoch and Kebreab (2013) in Gambia; who reported the importance of the influence of other factors, including, possibly, natural attrition in demise of striga seeds and reduction of seed production as a consequence of reduced striga emergence and capsules production (Table 1). However, the possibility of increased soil fertility and consequently diminished stimulant production (Parker and Riches 1993) cannot be ruled out at this stage.

Table 2. Effect of crop sequence on striga seed bank and reduction percentage in the second and third seasons

Crop sequence	Number of striga seeds/200 g soil				
	2nd season			3rd season	
	Seed count	Reduction%	Crop sequence	Seed count	Reduction%
SO/SO	378.33[a]	00	SO/SO/SO	360.33[a]	00
FA/FA	31.00[c]	91.81	FA/FA/SO	66.33[c]	81.59
FA/SO	131.67[b]	65.20	FA/SO/SO	176.67[b]	50.97
FA/CP	46.00[c]	87.84	FA/SE/SO	63.33[c]	82.42
FA/SE	45.00[c]	88.11	FA/CP/SO	58.00[c]	83.90
FA/Ml	42.00[c]	88.90	FA/SF/SO	52.67[c]	85.38
FA/SF	36.33[c]	90.40	FA/MI/SO	84.67[c]	76.50
SE/SE	41.33[c]	89.08	CP/CP/SO	53.67[c]	85.11
CP/CP	35.33[c]	90.66	MI/MI/SO	94.33[c]	73.82
MI/MI	27.67[c]	92.69	SE/SE/SO	72.00[c]	80.02
SF/SF	27.33[c]	92.78	SF/SF/SO	51.33[c]	85.75
CV%	31.03			27.76	

Means in the same column followed by the same letter(s) are not significantly different at P< 0.05 according to DMRT.

FA = Fallow; CP = cowpea; SE = sesame; MI = millet; SF = sunflower; CV = coefficient of variation

Sorghum planted in the third season showed no stand reduction at 30 DAS (Table 3). However, stand counts made at harvest showed significantly different reductions in crop stand among sequences. Rotational sequences of FA/MI, FA/SE and SO/SO resulted in significant reductions in crop stand. The sequences FA/FA, FA/SO, CP/CP, MI/MI and SE/SE had insignificant reductions. Of all sequences, sorghum monocropping resulted in the lowest crop stand, whereas the sequences FA/CP, SF/SF resulted in the lowest loss in crop stand (Table 3).

Table 3. Effect of crop sequence on sorghum stand 30 DAS and at harvest

Crop sequence	No. of plants/1 m of row	
	30 DAS	At harvest
SO/SO/SO	11.08[a]	5.17[b]
FA/FA/SO	12.00[a]	7.00[ab]
FA/SO/SO	11.83[a]	6.67[ab]
FA/SE/SO	12.00[a]	6.00[b]
FA/CP/SO	11.92[a]	9.33[a]
FA/SF/SO	12.50[a]	8.17[ab]
FA/MI/SO	11.42[a]	5.83[b]
CP/CP/SO	13.00[a]	8.17[ab]
MI/MI/SO	11.92[a]	7.50[ab]
SE/SE/SO	12.83[a]	8.00[ab]
SF/SF/SO	12.92[a]	9.50[a]
CV%	8.53	21.56

Means in the same column followed by the same letter(s) are not significantly different at $P< 0.05$ according to DMRT.
FA = Fallow; CP = cowpea; SE = sesame; MI = millet; SF = sunflower.

Continuous planting of sorghum, for two or three consecutive seasons, gave the lowest straw yield (Table 4). Sorghum following the sequences FA/SE, FA/MI, CP/CP, MI/MI, FA/FA, FA/CP, FA/SF, SE/SE and SF/SF showed significantly higher straw yields than continuous sorghum. Of all cropping sequences, SF/SF resulted in the highest straw yield. Sorghum monocropping for three consecutive seasons resulted in the lowest grain yield. The sequence FA/SO, FA/MI increased grain yield of subsequent sorghum, albeit not significantly. The rotational sequences FA/FA, FA/SE, FA/CP, CP/CP, FA/SF, MI/MI, SF/SF and SE/SE increased grain yield significantly over the corresponding SO/SO sequence. The low yield and poor crop growth and considerable loss of stand attained from sub-plots planted to sorghum for the three consecutive seasons could be attributed to heavy striga infestation. However, the possibility of accumulation of allelochemicals in soil, due to the repeated planting could not be ruled out as autotoxicity, is reported in sorghum (Rice 1984). Sorghum following the rotational sequence SF/ SF resulted in the highest grain yield. The increase in sorghum straw and grain yield affected by the rotational sequences could be attributed to the decrease in the striga seed bank and the concomitant reduction in parasitism (Tables 1 and 2).

Table 4. Effect of crop sequence on sorghum grain and straw yield

Crop sequence	Sorghum yield (t/fed.)	
	Grain	Straw
SO/SO/SO	0.71[d]	1.16[c]
FA/FA/SO	1.60[abc]	2.03[ab]
FA/SO/SO	0.94[cd]	1.37[c]
FA/SE/SO	1.69[abc]	1.79[b]
FA/CP/SO	1.69[abc]	2.01[ab]
FA/SF/SO	1.77[ab]	2.03[ab]
FA/MI/SO	1.22[bcd]	1.96[b]
CP/CP/SO	1.65[abc]	1.97[b]
MI/MI/SO	1.84[ab]	1.96[b]
SE/SE/SO	1.73[abc]	2.14[ab]
SF/SF/SO	2.11[a]	2.38[a]
CV%	10.70	27.27

Means in the same column followed by the same letter(s) are not significantly different $P < 0.05$ according to DMRT;
FA = Fallow; CP = cowpea; SE = sesame; MI = millet; SF = sunflower; C.V = coefficient of variation

CONCLUSIONS

Rotation with trap crops and the fallowing reduce striga seed bank and increase sorghum growth and yield. That is:

1. Sorghum monoculture is conducive to the buildup of striga seed bank and causes the highest striga infestation and the least sorghum straw and grain yields.
2. A single fallow or a rotational cropping sequence, even for one season, delays striga infestation and significantly reduces the seed bank. Among the trap crops, sunflower is the best as indicated by the reductions in striga emergence, seed bank, stability of stand and growth and yield of the subsequent sorghum crop.
3. Crop rotation depletes striga seeds' reserves in the soil. However, subsequent planting of susceptible crops leads to replenishment of seeds' reserves in the soil. Accordingly, an integrated management of striga in which crop rotation is an integral part is a necessity.

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تأثير الدورة الزراعية بالمحاصيل الصائدة على انتشار البودا ومخزون بذورها بالتربة ونمو وإنتاجية الذرة الرفيعة

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المستخلص: أجريت تجربة حقلية لثلاثة مواسم متتالية (2007/2006، 2008/2007 و 2009/2008 بالمزرعة التجريبية لكلية الزراعة جامعة سنار، لمعرفة تأثير دورة زراعية لموسمين متتاليين بالمحاصيل الصائدة (اللوبيا البيضاء ، الدخن ، السمسم وزهرة الشمس) والتبوير في تتابع محدد على ظاهرة إنتشار البودا ومخزون بذورها في التربة ونمو وإنتاجية الذرة الرفيعة التالية لها. استخدمت الذرة الرفيعة في دورة أحادية لثلاثة مواسم متتالية كشاهد . أدت كل المعاملات بلا استثناء إلى انخفاض معنوي في إنبثاق البودا مقارنة بالزراعة الأحادية للذرة في الموسم الثالث . أدت زهرة الشمس متبوعة بالسمسم لموسمين متتاليين إلى أعلى نسبة إنخفاض في انبثاق البودا (80.2%) . بينما أعطى التبوير متبوعاً بالذرة الرفيعة أقل نسبة انبثاق (41.8%) . أدت جميع المعاملات (التتابع المحصولي والتبوير) إلى خفض إنتاج طفيل البودا من الكبسولات ولكن كان الانخفاض أعلى (37%) في التتابع المحصولي بالسمسم لموسمين متتاليين. أدت جميع المعاملات إلى خفض معنوي في مخزون بذور البودا في التربة في الموسم الثاني والثالث من التجربة . أدى التبوير لموسمين متتاليين والتتابع المحصولي لموسمين متتاليين لكل من اللوبيا البيضاء والدخن وزهرة الشمس إلى أعلى نسبة في خفض مخزون البذور بالتربة (80%–92%) . بينما أعطى التبوير متبوعاً بالذرة الرفيعة أقل نسبة انخفاض في مخزون البذور (51%-65%) . لم يلاحظ أي تأثير معنوي للتتابع المحصولي على الكثافة النباتية للذرة الرفيعة في بداية الموسم ولكن حدث انخفاض معنوي في الكثافة النباتية عند الحصاد . أعطت

الزراعة الأحادية للذرة الرفيعة لثلاثة مواسم متتالية أقل كثافة نباتية في الموسم الثالث ، بينما أعطت زهرة الشمس المزروعة لموسمين متتاليين متبوعة بالذرة الرفيعة في الموسم الثالث أعلى كثافة نباتية. أعطت الزراعة الأحادية للذرة الرفيعة لثلاثة مواسم متتالية أقل إنتاجية من الحبوب والقصب. بينما أعطت الذرة الرفيعة المزروعة بعد محصولين متتاليين من زهرة الشمس زيادة معنوية وثابتة في إنتاجية الحبوب والقصب. أكدت هذه النتائج بوضوح أهمية الدورة الزراعة كمكون رئيس في إدارة طفيل البودا .