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Enhancing maize production in a *Striga* infested environment through weed management practices, sowing date and improved crop varieties

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A two-year investigation into the effects of weed management practices, sowing dates and maize varieties was made in a *Striga* endemic field at Minna, Nigeria. The treatment was a factorial combination of variety (SAMMAZ 15, 17, 37, 40 and SUWAN-1-SR-Y), weed management practices (weedy check, two hoe weeding (HW) at 3 + 6 weeks after sowing (WAS), pre-emergence (PE) Atrazine at 2.4 kg a.i ha^{-1} + 1 HW at 6 WAS and PE Atrazine at 2.4 kg ha^{-1} + post-emergence (POE) Nicosulfuron at 0.06 kg ha^{-1} at 6 WAS) and sowing dates: early (28th May), mid-season (18th June) and late-season (9th July) in 2018 and early-season (26th May), mid-season (16th June) and late-season (7th July) in 2019 laid in a split plot arranged in a randomized complete block with three replications. Maize variety and weed management practices were combined as the main plot and sowing dates constituted the subplot. Delayed *Striga* shoot emergence and reduced shoot density were observed in SAMMAZ 15 and 40 and higher grain yield with SAMMAZ 17 in 2018 and 2019. Application of Atrazine plus Nicosulfuron significantly delayed *Striga* shoot emergence, reduced shoot density and higher maize grain yield in both years. Sowing in May significantly delayed *Striga* shoot emergence and reduced shoot density in both years. Sowing in June significantly increased maize grain yield in 2018 and 2019. These results suggest that SAMMAZ 15 and 40 in combination with PE Atrazine at 2.4 kg a.i ha^{-1} and POE Nicosulfuron at 0.06 kg a.i ha^{-1} and sowing in May effectively reduced *Striga* infestation. SAMMAZ 17 in combination with PE Atrazine at 2.4 kg a.i ha^{-1} and POE Nicosulfuron at 0.06 kg a.i ha^{-1} and sowing in June increased maize grain yield.

Key words: Maize variety, sowing date, *Striga,* weed management.

INTRODUCTION

The witchweed (*Striga hermonthica* (Del.) Benth) is among the serious biotic constraints affecting cereal crops production in sub-Sahara Africa (Ekeleme et al., 2011). These authors also claim that about 17 million hectares representing 64% of land put to cereal production in West Africa are under *Striga* infestation. *Striga* infestation remains endemic in many maize producing belts of Nigeria and accounts for grain yield losses that vary between 30 to 70% (Kamara et al., 2014). Under these circumstances, farmers have been made to abandon their farmlands.

It is thus suggested that the use of improved cultivars

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and appropriate sowing dates can help to control *Striga* infestation (Ekeleme et al., 2011). To reduce losses in maize yield due to *Striga* infestation, the use of tolerant or resistant varieties has been suggested (Kanampiu et al., 2018). Progress has been made by researchers in maize breeding in the area of identifying genotypes that are tolerant or resistant to *Striga* (Kanampiu et al., 2018; Adesina and Akinwale, 2014). It is practicable and compatible with the low-cost input technology of the resource-poor farmer (Kamara et al., 2014). Olaniyan (2015) noted that several *Striga* infections can cause total crop loss in maize and sorghum and losses can be much higher under heavy infestation, even resulting in total crop failure.

Manipulating the sowing date of maize can be used to reduce the yield losses caused by *Striga* infestation. As noted by Ekeleme et al. (2011), sowing date can be used as an essential component of crop management to control *Striga* infestation in cereal crop production. In a previous study, in the northern and southern Guinea savanna of Nigeria, Ekeleme et al. (2011) noted a reduction in *Striga* infestation when maize was sown in mid-July compared to mid-May or mid-June. Also, Dugje et al. (2008) reported that grain yield was lower when maize was sown in mid-July compared to mid-June in the Guinea savanna of Nigeria.

Herbicide use has been reported to be more efficient than hoe-weeding in the production of various crops in Nigeria (Imoloame, 2014). Hoe weeding is a weed management method used in controlling *Striga* and increasing maize yield, but it is laborious and time-consuming. Despite the use of several management methods adopted in controlling *Striga*, no single control approach has been reported to be effective in controlling the weed, as such, the development of integrated *Striga* control is the alternative for maize production in a *Striga* infested environment (Teka, 2014).

Research on performance of *Striga* tolerant maize varieties with different weed management practices and sown at different dates under naturally *Striga* infested condition are scarce in this agro-ecology of Nigeria. Therefore, the objective of this study was to assess the combined effects of weed management practices and time of sowing on *Striga* infestation, growth, yield and yield attributes of some *Striga* tolerant maize varieties.

MATERIALS AND METHODS

Experimental site

A field study was conducted at the Teaching and Research Farm of the Federal University of Technology, Gidan Kwano (latitude 09° 31′N, longitude 06° 27′E, 212 m above sea level) during the rainy seasons (May – October) of 2018 and 2019. The experimental site is located in the southern Guinea savanna of Niger State, Nigeria. The soil at Gidan Kwano, prior to field establishment was loamy sand, with organic carbon of 3.6 g kg^{-1}, N 0.014 g kg^{-1}, P 11.5 mg kg^{-1}, K 0.08 cmol kg^{-1} and pH ($CaCl_2$) 5.5 in 2018. Prior to trial establishment in 2019, the soil was loamy sand, with organic carbon of 2.3 g kg^{-1}, N 0.012 g kg^{-1}, P 10.3 mg kg^{-1}, K 0.09 cmol kg^{-1} and pH ($CaCl_2$) 5.2. The area has an average annual rainfall of 1247 mm, a maximum and minimum temperatures of 33.54 and 22.55°C respectively (Olayemi et al., 2014). The field used was chosen based on verified history of notable build-up of *Striga* infection due to continuous cultivation of maize and sorghum over the years.

Experimental treatments and design

Five maize varieties (SAMMAZ 15, 17, 37, 40) and SUWAN-1-SR-Y were evaluated. The SAMMAZ varieties are medium maturing, open-pollinated, tolerant to *Striga*, non-tillering, and have high yield potential and are adapted specifically for the savanna zones of Nigeria; and SUWAN-1-SR-Y is a *Striga* susceptible variety). The treatments were a factorial combination of variety (SAMMAZ 15, 17, 37, 40 and SUWAN-1-SR-Y) and weed management practices [weedy check, two hoe weeding (HW) at 3 + 6 weeks after sowing (WAS)], pre-emergence (PE) Atrazine at 2.4 kg a.i ha^{-1} + 1 HW at 6 WAS and PE Atrazine at 2.4 kg ha^{-1} + post-emergence (POE) Nicosulfuron at 0.06 kg ha^{-1} at 6 WAS) and sowing dates: early (28th May), mid-season (18th June) and late-season (9th July) in 2018 and early-season (26th May), mid-season (16th June) and late-season (7th July) in 2019. Sowing dates were determined based on the establishment of rainfall in the experimental area. Main plot treatments were variety and weed management practices, and sowing date was assigned to the subplot. The experiment was a split-plot arranged in a randomized complete block design and replicated three times. Gross plot size was 4 x 3 m of four ridges 4 m long each.

Cultural practices

Before sowing, the land was manually cleared and ridged with a handheld hoe at 75 cm apart. Each maize variety was treated with Apron Star® 42 WS (thiamethoxam 200 g kg^{-1}, metalaxyl-M 200 g kg^{-1} and Difenoconazole 20 g kg^{-1}) at 10 g per 4 kg of seed. Three seeds of maize were sown per hole on ridges at an intra-row spacing of 50 cm and later thinned to two plants per stand at 2 WAS. Weed management was done as per the treatment combinations of the study. Fertilizer NPK 15:15:15 was applied at the rate of 120 kg N, 60 kg P_2O_5 and 60 kg K_2O. A basal dose rate of 60 kg N, 60 kg P_2O_5 and 60 kg K_2O was applied at 3 WAS by side placement, 5 cm from the plant stand. The remnant dose of nitrogen at 60 kg N from urea was side dressed at 6 WAS.

Data collection

Days to first *Striga* shoot emergence was determined as the number of days from sowing to when the emergence of *Striga* was observed in each plot. *Striga* shoot density was taken by counting the number of *Striga* shoots within a plot at 8 and 10 WAS and converted to per meter square. Maize plant height was measured in centimetres, from five randomly tagged plants from the soil level to the collar of the uppermost leaf at 6 and 9 WAS. For yield determination, all the ears were harvested from each treatment net plot at mass maturity, dehusked, and further sun-dried to constant weight. Cob length was measured in centimetre from the base of the cob to the tip from five randomly selected cobs and the mean used for analysis. Grain yield was determined by shelling and winnowing the cobs harvested in each treatment net plot to obtain clean grains. The grains were weighed and expressed in kg ha^{-1}.

Data analysis

Data on *Striga* count was square root transformed to improve the

Table 1. Effect of maize variety, weed management practices and sowing date on number of days to first *Striga* shoot emergence in 2018 and 2019 rainy seasons.

Treatment	Number of days to *Striga* shoot emergence	
	2018	2019
Variety (V)		
SAMMAZ 15	43.0	50.0
SAMMAZ 17	42.0	47.0
SAMMAZ 37	41.0	46.0
SAMMAZ 40	44.0	51.0
SUWAN-1-SR-Y	39.0	42.0
LSD (0.05)	1.67	2.92
Weed management (M)		
Weedy check	37.0	35.0
2 HW	43.0	48.0
PE Atrazine + 1 HW	44.0	48.0
PE Atrazine + POE Nicosulfuron	43.0	56.0
LSD (0.05)	1.50	2.61
Sowing date (S)		
Early	44.0	58.0
Mid	41.0	47.0
Late	40.0	36.0
LSD (0.05)	1.30	2.63
Interaction		
V x M	NS	NS
S x V	*	*
S x M	NS	NS
S x V x M	NS	NS

LSD, least significant difference; NS, not significant; * - significant at 5 % level of probability.

normality prior to statistical analysis. All the data obtained from the experiment were subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS) version 9.0 (SAS Institute, 2009). Treatments were compared using the least significant difference (LSD) at 5 % level of probability.

RESULTS

Days to first *Striga* shoot emergence

The results show that SAMMAZ 15 and SAMMAZ 40 recorded significantly longer days to *Striga* shoot emergence than the other varieties in the two years of study (Table 1). Plots with two hoe weeding at 3 and 6 WAS, application of PE Atrazine + hoe weeding at 6 WAS and PE Atrazine + POE Nicosulfuron at 6 WAS similarly delayed *Striga* shoot emergence than weedy check plot in 2018 (Table 1). In 2019, the application of PE Atrazine + POE Nicosulfuron significantly delayed *Striga* shoot emergence than the other weed management practices. In terms of sowing date, early-season sowing consistently and significantly delayed days to first *Striga* shoot emergence compared to other sowing dates (Table 1).

The interaction between sowing date and variety on days to first *Striga* shoot emergence in 2018 and 2019 is shown in Table 2. In 2018, under SAMMAZ 17, SAMMAZ 40 and SUWAN-1, there was no significant response on days to first *Striga* shoot emergence as sowing date was delayed. However, under SAMMAZ 15 and SAMMAZ 37, early season sowing delayed days to first *Striga* shoot emergence in this study. In 2019, irrespective of the varieties, there was a greater delay in days to first *Striga* shoot emergence with early-season sowing of maize.

Striga shoot density

The number of *Striga* shoot density m^{-2} was lowest in SAMMAZ 15 at 8 and 10 WAS in both years of study and similar with SAMMAZ 17, 37 and 40 at 8 and 10 WAS in

Table 2. Interaction effects between sowing date and variety on number of days to first *Striga* shoot emergence in 2018 and 2019 rainy seasons.

Sowing date	Variety				
	SAMMAZ 15	SAMMAZ 17	SAMMAZ 37	SAMMAZ 40	SUWAN-1
Days to first *Striga* shoot emergence in 2018					
Early	47.0	44.0	46.0	43.0	40.0
Mid	42.0	41.0	39.0	45.0	39.0
Late	41.0	41.0	37.0	43.0	37.0
LSD (0.05)			3.01		
Days to first *Striga* shoot emergence in 2019					
Early	58.0	59.0	57.0	64.0	52.0
Mid	54.0	45.0	45.0	52.0	41.0
Late	37.0	36.0	35.0	37.0	33.0
LSD (0.05)			5.25		

LSD, least significant difference.

Table 3. Effects of maize variety, weed management practices and sowing date on *Striga* shoot density m^{-2} at 8 and 10 WAS in 2018 and 2019.

Treatment	*Striga* shoot density m^{-2}			
	2018		2019	
	8 WAS	10 WAS	8 WAS	10 WAS
Variety (V)				
SAMMAZ 15	2.0	2.0	1.0	2.0
SAMMAZ 17	2.0	3.0	1.0	2.0
SAMMAZ 37	2.0	3.0	1.0	2.0
SAMMAZ 40	2.0	3.0	1.0	2.0
SUWAN-1-SR-Y	3.0	3.0	2.0	3.0
LSD (0.05)	0.14	0.13	0.12	0.16
Weed management (M)				
Weedy check	3.0	4.0	3.0	4.0
2 HW	2.0	3.0	1.0	2.0
PE Atrazine + 1 HW	2.0	3.0	1.0	2.0
PE Atrazine + POE Nicosulfuron	1.0	1.0	0.0	0.0
LSD (0.05)	0.13	0.12	0.11	0.14
Sowing date (S)				
Early	2.0	2.0	1.0	1.0
Mid	2.0	3.0	1.0	2.0
Late	2.0	3.0	2.0	2.0
LSD (0.05)	0.11	0.10	0.09	0.12
Interaction				
V x M	NS	**	NS	NS
S x V	NS	**	NS	NS
S x M	NS	NS	NS	**
S x V x M	NS	NS	NS	NS

LSD, least significant difference; NS, not significant; *significant at 5% level of probability.

2019 (Table 3). Application of PE Atrazine + POE Nicosulfuron at 8 and 10 WAS in 2018 and 2019 had significantly lower *Striga* shoots than the other treatments (Table 3). However, early-season sowing had the least

Table 4. Interaction effects between variety and weed management practices on *Striga* shoot density at 10 WAS in 2018.

Variety	Weed management practices			
	Weedy check	2 HW	PE Atrazine + 1 HW	PE Atrazine + POE Nicosulfuron
SAMMAZ 15	4.0	3.0	2.0	1.0
SAMMAZ 17	4.0	4.0	3.0	1.0
SAMMAZ 37	4.0	4.0	3.0	1.0
SAMMAZ 40	4.0	3.0	2.0	1.0
SUWAN-1	4.0	4.0	4.0	2.0
LSD (0.05)			0.20	

LSD, least significant difference.

Table 5. Interaction effects between sowing date and variety on *Striga* shoot density at 10 WAS in 2018.

Sowing date	Variety				
	SAMMAZ 15	SAMMAZ 17	SAMMAZ 37	SAMMAZ 40	SUWAN-1
Early	2.0	3.0	3.0	2.0	3.0
Mid	3.0	3.0	3.0	3.0	4.0
Late	3.0	3.0	3.0	3.0	4.0
LSD (0.05)			0.24		

LSD, least significant difference.

number of *Striga* shoots at all the sampling times than all the other sowing times (Table 3).

The interaction between variety and weed management practices on *Striga* shoot density at 10 WAS in 2018 was significant (Table 4). In this case, irrespective of the variety there was a low *Striga* shoot density with the application of PE Atrazine + POE Nicosulfuron. The effect was similar to the application of PE Atrazine + hoe weeding at 6 WAS with SAMMAZ 15 or SAMMAZ 40.

The interaction effects were significant between sowing date and variety on *Striga* shoot density at 10 WAS in 2018 which showed that early season sowing with SAMMAZ 15 or SAMMAZ 40 had lower *Striga* shoot density than the other treatment combinations (Table 5).

The interaction effects were significant between sowing date and weed management practices on *Striga* shoot density at 10 WAS in 2019 which showed that mid- and late-season sowing under PE Atrazine + POE Nicosulfuron had lower *Striga* shoot density than the other treatment combinations (Table 6).

Maize grain yield

Grain yield of maize was significantly higher in SAMMAZ 17 plots compared with other varieties in the two years of study (Table 7). Furthermore, application of PE Atrazine + POE Nicosulfuron at 6 WAS produced significantly higher grain yield but at par with plots given PE Atrazine + hoe weeding at 6 WAS in 2018 (Table 7). The weedy check had the lowest maize grain yield in both years. However, under sowing date, mid-season sowing had a significantly higher grain yield compared to maize sown early and late in the season in both years (Table 7).

Sowing date and weed management practices showed significant interaction effects on maize grain yield in 2018 and 2019 such that there was an increase in grain yield from early- to mid-season sowing beyond which there was a significant decline in both years (Table 8). Plots with mid-season sowing in combination with either hoe weeding at 3 and 6 WAS, in 2018 or application of PE Atrazine + POE Nicosulfuron in 2018 and 2019 had the highest grain yield of maize in this study.

DISCUSSION

The ability of SAMMAZ 15 to delay *Striga* shoot emergence and reduced *Striga* shoot density could be due to the less strigol stimulant secretion and release into the soil environment by the host crop which inhibited *Striga* germination and/or slowed seedling growth and shoot emergence. Also, the variety genetic inheritance might have inhibited *Striga* seed germination, seedling attachment or shoot emergence than the other varieties. This finding is in agreement with the work of Magani et al. (2011) who reported that genetic variation exists among maize germplasm in response to *Striga* parasitism.

Table 6. Interaction between sowing date and weed management practices on *Striga* shoot count (m^{-2}) at 10 WAS in 2019.

Sowing date	Weed management practices			
	Weedy check	**2 HW**	**PE Atrazine + 1 HW**	**PE Atrazine + POE Nicosulfuron**
Early	3.0	1.0	1.0	0.0
Mid	4.0	2.0	2.0	0.0
Late	4.0	3.0	2.0	1.0
LSD (0.05)			0.33	

LSD, least significant difference.

Table 7. Effect of maize variety, weed management practices and sowing date on grain yield in 2018 and 2019.

Treatment	Grain yield (kg ha^{-1})	
	2018	**2019**
Variety (V)		
SAMMAZ 15	4015.70	2768.89
SAMMAZ 17	4986.00	3365.28
SAMMAZ 37	4151.90	2609.72
SAMMAZ 40	4235.60	2886.11
SUWAN-1-SR-Y	3919.20	2274.17
LSD (0.05)	327.62	114.71
Weed management (M)		
Weedy check	3244.40	1772.22
2 HW	4375.10	2813.78
PE Atrazine + 1 HW	4621.10	3090.67
PE Atrazine + POE Nicosulfuron	4806.70	3446.67
LSD (0.05)	293.03	102.60
Sowing date (S)		
Early	4438.80	2955.83
Mid	4972.50	3150.00
Late	3374.20	2236.67
LSD (0.05)	253.77	88.85
Interaction		
V x M	NS	NS
S x V	NS	NS
S x M	**	*
S x V x M	NS	NS

LSD, least significant difference; NS, not significant; *significant at 5% level of probability, **highly significant at 1 % level of probability.

The highest grain yield produced by SAMMAZ 17 suggests its superior tolerance to *Striga* parasitism over the other maize varieties studied since it supported more *Striga* shoots but still had better growth and higher yield of maize. Isah et al. (2010) also observed higher growth and yield in some genotypes of maize than the others and attributed it to variation in tolerance and resistance that exist among the host crop genotypes to *Striga* parasitism. Also, our result agrees with the work of Ekeleme et al. (2014) who reported that sorghum KSV 8 cultivar tolerated *Striga* as it supported more *Striga* shoots, and also out yielded the other cultivars.

Treatment with PE Atrazine + POE Nicosulfuron suppressed *Striga* growth (days to first *Striga* shoot

Table 8. Interaction effects between sowing date and weed management practices on grain yield in 2018 and 2019.

Sowing date	Weed management practices			
	Weedy check	**2 HW**	**PE Atrazine + 1 HW**	**PE Atrazine + POE Nicosulfuron**
Grain yield in 2018				
Early	3629.99	4553.00	4511.11	5061.11
Mid	3777.78	5563.31	5211.11	5337.78
Late	2325.55	3008.89	4141.11	4021.11
LSD (0.05)			697.70	
Grain yield in 2019				
Early	1980.00	3001.33	3282.00	3560.00
Mid	2010.00	3140.00	3503.33	3946.67
Late	1326.67	2300.00	2486.67	2833.33
LSD (0.05)			244.30	

LSD, least significant difference.

emergence and *Striga* shoot density) better and had the highest maize grain yield. This may be attributed to effective *Striga* control in our study, which in turn enhanced the use of growth factors in the absence of crop competition and/or parasitism with weeds.

Early season sowing (May) delayed *Striga* shoot emergence and reduced *Striga* shoot density. Efficient *Striga* control was probably made possible due to inadequate soil moisture during the early season for preconditioning of *Striga* seeds in the soil for germination. This finding conforms with the earlier reports by Ekeleme et al. (2014) who observed that early sowing is prone to drought risk, but can favour most cereals crop growth and development before *Striga* seeds are preconditioned and get germinated.

The highest grain yield produced by mid-season sowing may be due to adequate moisture in the soil which resulted in wet dormancy of *Striga* seeds in the soil which in turn supported efficient utilization of growth factors. Our result is in line with the findings of Liaqat et al. (2018) who observed higher grain yield in early season sowing (15th June) due to adequate and optimal utilization of growth factors.

The delay in *Striga* shoot emergence in maize interaction between sowing date and variety was due to the combined effect of the availability of soil moisture at the time of sowing which might have caused wet dormancy of *Striga* seed, and the genetic potential of the maize varieties in tolerating the adverse effect of the *Striga* seedlings. Besides, differences in the production of *Striga* germination stimulants are known to exist among maize cultivars and is likely the reason for the reduction in *Striga* shoot emergence in this study (Midega et al., 2016).

The reduction in *Striga* shoot density in maize of interaction between variety and weed management practice was due to the differences in the genetic potentials of the maize varieties to tolerate *Striga* infestation in combination with the effectiveness of the weed management practice on *Striga* control. In our study, plots with *Striga* tolerant maize varieties and pre- and post-emergence application of herbicides proved to be superior in reducing *Striga* infestation and in enhancing maize growth and yield.

The least *Striga* shoot density in maize of interaction between sowing date and variety was due to the combined effect of the availability of soil moisture at the time of sowing and differences in the genetic potentials of the maize varieties to inhibit *Striga* infestation. In this study, plots with *Striga* tolerant maize varieties and early season sowing proved to be superior in reducing *Striga* infestation.

The reduction in *Striga* shoot density and improved maize grain yield of interaction between sowing date and weed management practice was due to available soil moisture at sowing time which suppressed *Striga* germination and its subsequent attachment to the host maize. Also, the weed control method was effective in controlling *Striga* which supported better *Striga* suppression and use of available growth factors and hence higher maize grain yield. In our study, early season sowing with pre-emergence application of Atrazine and post-emergence Nicosulfuron reduced *Striga* growth and improved maize grain yield.

Conclusion

The study has shown that farmers can reduce *Striga* infestation by using *Striga* tolerant maize varieties, such as SAMMAZ 15 and SAMMAZ 40 in combination with the application of PE Atrazine + POE Nicosulfuron with early-season sowing (May) for maize production. SAMMAZ 17 in combination with the application of PE Atrazine + POE

Nicosulfuron with mid-season sowing (June) resulted in the highest maize grain yield, and therefore recommended for the production of maize in a *Striga* infested environment in this agro-ecological zone in Nigeria.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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