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Reduction of Striga hermonthica parasitism on maize using soybean rotation

(*Keywords: Striga hermonthica*, soybean, P fertilizer, maize, savanna)

R. J. CARSKY*, D. K. BERNER, B. D. OYEWOLE, K. DASHIELL and S. SCHULZ

International Institute of Tropical Agriculture, Ibadan, Nigeria

Abstract. *Striga hermonthica* is a serious parasite of cereals in most of the semi-arid savanna zone of West Africa, causing substantial yield loss. It has been observed that some soybean cultivars are capable of stimulating germination of *S. hermonthica* seed, which would reduce the seed bank in the soil. This study was undertaken to quantify the effect of a soybean crop (compared with a sorghum control) on *S. hermonthica* emergence in subsequent maize in three farmers' fields in northern Nigeria. Soybean cultivar TGx 1740-7F, previously identified as efficacious for *S. hermonthica* seed germination, was grown at four densities without P fertilizer to test the effect of increasing plant density of soybean on subsequent *S. hermonthica* parasitism. The effect of P as single super phosphate was tested on the two highest soybean densities. *S. hermonthica* parasitism on maize was significantly lower after unfertilized soybean than after the sorghum control treatment at two of three trial sites. Soybean rotation increased maize yield by approximately 90% for the three sites combined. Increasing soybean plant density did not result in lower emerged *S. hermonthica*. Application of P to soybean at the higher soybean densities resulted in higher root length density, lower emerged *S. hermonthica* on maize ($P < 0.15$), and significantly higher maize yield. The results suggest that an efficacious cultivar of soybean reduces *S. hermonthica* parasitism on a succeeding maize crop and that the effect is increased by application of P to the soybean.

1. Introduction

Striga hermonthica (Del.) Benth. [Scrophulariaceae] parasitism is the most serious and visible cause of yield loss in cereals (especially sorghum and maize) in the West African savanna (Sallé and Raynal-Roques, 1989). In the northern Guinea savanna of Nigeria, Oikeh *et al.* (1996) estimated yield loss ranging from 0 to 46% and averaging 10% for 66 fields. Sauerborn (1991) estimated that yield loss from all Striga spp. is 24% in six West African studies from which data were available.

The possibility of using soybean as a trap crop for *S. hermonthica* has been mentioned by several authors (Andrews, 1947; Parkinson *et al.*, 1987; Doggett, 1988; Sallé and Raynal-Roques, 1989). Soybean is a relatively new crop in West Africa, whose production has expanded rapidly in some areas (Smith *et al.*, 1993). Therefore its potential contributions to cereal-based cropping systems should be fully exploited. Recently a laboratory screening procedure was developed which permits identification of efficacious trap crops *in vitro* (Berner *et al.* 1996a). The method was used to screen 55 soybean cultivars and many cultivars did not stimulate substantially more germination than a distilled water control. However, several cultivars, including TGx 1740-7F—highly adapted to the dry savanna zone—stimulated germination of more than 50% of *S. hermonthica* seed (Alabi *et al.*, 1994).

Berner *et al.* (1996b) have suggested crop rotation with efficacious grain legumes as the key to an integrated *S. hermonthica* control programme. It can be hypothesized that the ability of the soybean roots to stimulate suicidal germination of *S. hermonthica* seed is a function of soybean root length density (length of root per volume of soil). Root length density can be increased by increasing plant density and by overcoming nutrient limitations. Soils of the West African savannas are low in P (Bationo *et al.*, 1991) and average fertilizer P use in sub-Saharan Africa is less than 2 kg P/ha (Mokwunye, 1995). Legume growth generally responds to P fertilizer application (Bationo *et al.*, 1991; Giller and Wilson, 1991). Soybean generally responds substantially to P in the savanna zone of West Africa (Pal *et al.*, 1989).

This trial was conducted to test the effect of a soybean crop, compared with a sorghum control, on *S. hermonthica* parasitism in a subsequent maize crop. The trial was also designed to test the effects of increasing soybean plant density and P fertilizer application on *S. hermonthica* reduction.

2. Materials and methods

The trials were conducted in two villages in southern Bauchi State between latitude 9° 47′ and 9° 49′ and between longitude 10° 01′ and 10° 08′ in northern Nigeria. Annual rainfall in the area averages approximately 850 to 1150 mm and occurs in the months of May to October. Therefore, the area is located on the transition between the subhumid savanna and semi-arid savanna agro-ecological zones (Ker, 1995). Native vegetation in the area is thorny scrub, typical of the Sudan savanna zone (Jones and Wild, 1975). Soils are shallow and infertile but not acid. Organic carbon is low (0.3–0.6%) on continuously cropped fields close to the village (called village fields) except on very small plots near the farm compounds where household and animal waste are frequently applied (Carsky *et al.*, 1998). One trial was established in 1995 on a field located immediately adjacent to a farm compound. Because compound fields have highly variable soil chemical properties, Bray-1 P, total N,

*To whom correspondence should be addressed at: IITA-Benin, BP 08-0932, Cotonou, Benin Republic. Fax: +229 35 05 56; e-mail: r.carsky@cgiar.org

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organic C and *S. hermonthica* seed density were determined in soil taken from each plot. Six samples were taken at random at 0 – 10 cm depth. The farm compound site had substantial variability in number of *S. hermonthica* seeds in the soil and plant available soil P (table 1). Two additional trials were established in 1996 on village fields. These had uniformly degraded soil due to an intensive cropping history with little application of organic amendments. Soil samples were taken as above for initial total N.

The experimental design was an RCB with four blocks per trial and three trials. Plot size was 4.5 m wide (6 rows, 0.75 m apart) and 9 m long. Land preparation consisted of ridging by hand hoe. Cropping system treatments consisted of soybean cv. TGx1740-7F as a sole crop and a sole sorghum (local cultivar) control. The soybean cultivar was planted at four densities without P fertilizer application and two densities with P applied. Planned densities were approximately 20 000, 60 000, 100 000, 140 000 soybean plants/ha without P and 100 000 and 140 000 soybean plants/ha with P fertilizer. In the P treatment, 16 kg P/ha were applied at planting as single superphosphate (SSP). A small furrow was made in the top of the ridge and SSP was applied and covered with soil. In the trial initiated in 1995, soybean seeds were planted at intrarow spacings of 60, 20, 15, and 10 cm. In the trials initiated in 1996, soybean seeds were planted densely and thinned to the desired spacing of 60, 20, 15, and 10 cm (leaving two or three seedlings per planting hole) at 3 w.a.p. (weeks after planting). The method used in 1996 resulted in higher plant densities. The sorghum control crop received 60 kg N/ha as urea. Soybean and sorghum were weeded 2 and 6 w.a.p. Sorghum plant density was approximately 70 000 plants/ha.

Soybean plants were counted at 13 w.a.p. and at harvest. Emerged *S. hermonthica* were counted on sorghum at flowering (11 – 13 w.a.p.). Nothing was done to prevent flowering and capsule formation on the *S. hermonthica* growing on the sorghum. Soybean roots were sampled to 10 cm depth with a 8 cm diameter root auger in the ridge at 11 – 13 w.a.p. This was done in only two treatments in 1995 and in all treatments in 1996. The sampling scheme varied with the planting density treatment. For the 60 and 20 cm intrarow spacing, eight cores were taken per plot, four next to soybean plants and four at a mid-point between two soybean stands. For the 15 and 10 cm spacing, four cores were taken from between soybean stands. Roots were washed immediately to separate them from soil and other debris. Roots were separated from clean water with a sieve (1.4 mm openings) and stored in a freezer until analysis. Roots were then cut with scissors in approximately 2 cm lengths. All roots were placed in a tray of water with a 1 cm grid drawn on the bottom. Intersections between the roots and the gridlines were counted and transformed to root length by multiplying by a factor determined by Tennant (1975) to convert number of intersections to root length (0.7857). Root length was divided by the volume of the soil sample to calculate root length density. Roots were subsequently dried and weighed for the 1996 – 97 trials.

Table 1. Variable levels of emerged Striga hermonthica *per sorghum host (Sh/Sorg),* S. hermonthica *seed density (ShSeed), initial soil P (BrayP) in 1995 and emerged* S. hermonthica *per maize at harvest in 1996 (Sh/Maize) and maize grain yield encountered on site used for 1995 – 96 trial*

	1995			1996	
Block	Sh/Sorg	ShSeed (no./20 g)	Bray P (μg/g)	Sh/Maize	Maize grain (kg/ha)
1	2.36	7.3	22.1	0.43	2760
2	2.46	5.7	10.6	0.61	2360
3	1.25	13.4	8.0	0.48	2050
4	3.57	20.3	4.9	0.57	1600

Crop residues were removed from the 1995 – 96 trial field and fed to animals. The field was protected with a fence of thorny branches. On the 1996 – 97 trial fields, soybean residues were removed, stored during the dry season, and returned to the plots before maize planting. Sorghum residues were left on the plots and were grazed by livestock. There was no trace of sorghum or *S. hermonthica* residues on the soil surface at maize planting.

In the second year of each trial, maize cultivar Oba Super 1 (IITA hybrid 8321-18) was planted in all plots at a density of 35 000 plants/ha. An effort was made to plant the maize in the same rows as the previous crop. Weeding was done at 2 and 6 w.a.p. and 30 kg N/ha was applied as urea at second weeding. Maize plants and emerged *S. hermonthica* plants were counted at 12 w.a.p. and at harvest. Maize grain yields were determined on four central rows excluding border hills at maize maturity. Total ears were weighed and a sub-sample of 10 ears was weighed, shelled, weighed again and grain moisture determined in a moisture tester. Total stover was weighed and a sub-sample was weighed, oven-dried and weighed again to determine stover moisture.

Emerged *S. hermonthica* plant density was divided by maize plant density to derive *S. hermonthica* per host plant. Data were first analysed separately for the 1995 – 96 site because soybean densities were low and because of the substantial spatial variability encountered on the compound field. Pre-plant total N, organic carbon, Bray-1 P, *S. hermonthica* seed density (ShSeed), and emerged *S. hermonthica* on sorghum control plots (Sh/Sorg) were tested as covariates for emerged *S. hermonthica* on maize and maize grain yield using Proc MIXED (SAS, 1989). Significant covariates were used to adjust means using least squares (LSMEANS) for treatments. Single degree of freedom contrasts were calculated based on the LSMEANS to test the effects, on maize grain yield and emerged *S. hermonthica* on maize, of different treatment combinations. These included the effect of crop (soybean vs sorghum), soybean density (low vs medium and high), and P fertilizer application to higher soybean densities (with P vs without P fertilizer). Linear and quadratic effects of *S. hermonthica* seed density (ShSeed) on subsequent emerged *S. hermonthica* on maize were tested using Proc GLM.

The data from the 1996 – 97 trials were analysed together because they were both conducted on uniform village fields and root sampling was done in all treatments. Root dry matter and root length density were modelled and the P fertilizer and soybean density effects were estimated. The emerged *Striga hermonthica* density and maize yield data were analysed using emerged *S. hermonthica* on previous sorghum control plots (Sh/Sorg) and initial soil N (SoilN96) as covariates. The pattern of the relationship with (Sh/Sorg) was modelled with Proc GLM.

Finally emerged *S. hermonthica* density and maize grain yield were analysed for the three sites combined and effects of crop, P fertilizer, and soybean density were estimated using emerged *S. hermonthica* on sorghum control plots (Sh/Sorg) and initial soil N (InitialN) as covariates. Also Proc GLM was used to examine the pattern of response (linear and quadratic) of emerged *S. hermonthica* to previous soybean density without fertilizer P.

3. Results

In the first trial soybean density ranged from 30 000 to 100 000 plants/ha and was not affected by P fertilizer application. Soybean root length density (RLD) was 0.242 cm/cm^3 for the low soybean plant density without P and 0.844 cm/cm^3 for high plant density with P applied. There were 2.3 emerged *S. hermonthica* per sorghum stand.

The number of *S. hermonthica* on maize after soybean was not significantly different from the number after sorghum. *Striga hermonthica* seed density was a significant covariate for emerged *S. hermonthica* on maize at the harvest in 1996 (table 2). The variables were positively correlated at $P = 0.09$. Emerged *S. hermonthica* on previous sorghum control plots was not a significant covariate because of variability (table 1). The adjusted treatment effect was significant for emerged *S. hermonthica* on maize at harvest but none of the contrasts was significant (table 2).

Maize grain yield after soybean was significantly higher than maize grain yield after sorghum (table 2). Plant available P was a significant covariate for maize grain yield. Maize yield was not significantly increased as a result of P application to soybean or when soybean density was increased from the lowest (30 000 plants/ha) to the other levels (averaging 75 000 plants/ha).

Subsequent trials were conducted in 1996–97 on fields with more uniform soil properties. Soybean plant density was generally higher than for the first trial, ranging from 57 000 plants/ha to 143 000 plants/ha (table 3). There was no effect of P fertilizer application on soybean plant density. P fertilizer application resulted in significantly higher plant available P in the topsoil. Soybean root dry matter ranged from approximately 400 to 1400 kg/ha. P fertilizer application and soybean plant density had highly significant positive effects on soybean root dry matter and root length density. There were 1.5 emerged *S. hermonthica* per sorghum stand in these trials.

Emerged *S. hermonthica* on sorghum in 1996 was a significant covariate for emerged *S. hermonthica* on maize in 1997. The variables were positively correlated at $P = 0.0001$ and the response was a quadratic one with the quadratic term negative at $P = 0.0001$. Least squares means were adjusted for both the linear and quadratic terms of covariate (table 3). Emerged *S. hermonthica* on maize at flowering and at harvest was significantly lower after soybean than after sorghum. Emerged *S. hermonthica* on maize were not significantly lower following P fertilized soybean than after soybean without P. There was no effect of increasing soybean density on number of emerged *S. hermonthica* (table 3). Although the slope of Sh/Maize regressed on previous soybean plant density was negative as hypothesized, it was not significantly different from zero when sites were analysed separately.

Maize grain yield was adjusted for emerged *S. hermonthica* on previous sorghum and for initial soil N (significant covariates). Average maize grain yield for the two trials was 320 kg/ha after sorghum, 840 kg/ha after soybean, and 1260 kg/ha after soybean with P fertilizer. The crop and P effects were statistically significant but the soybean density effect was not.

A combined analysis was done for the three environments (table 4). Average plant density ranged from approximately 50 000 to 130 000 plants/ha. Soybean grain yield averaged 465 kg/ha for the lowest density without P application, 812 kg/ha for the moderate to high densities without P, and 1293 kg/ha for high soybean density with P applied. Maize grain yields were adjusted for emerged *S. hermonthica* on previous sorghum and initial soil N. Mean maize grain yields were 680 kg/ha after sorghum, 1190 kg/ha after soybean at low density without P, 1310 kg/ha after soybean at moderate to high density, and 1732 kg/ha at high density with P applied to the soybean. The

Table 2. Mixed model tests of treatment (adjusted for covariates) and covariate effects, and estimates for emerged Striga hermonthica *per maize (Sh/Maize) and maize grain and total dry matter in 1996 after 1995 soybean and sorghum*

	Sh/Maize		Maize dry matter	
	13 w.a.p.	Harvest	Grain	Total
Fixed effects (Type III) and covariates probabilities				
Treatments	0.288	0.031	0.049	0.118
ShSeed	—	0.044	—	—
Bray-P	—	—	0.012	0.014
Contrast estimates			(kg/ha)	(kg/ha)
Crop effect	0.59	0.15	920	1809
Density effect	−0.26	−0.04	540	1334
P effect	−0.21	−0.11	552	224
Contrast probabilities				
Crop effect	0.092	0.312	0.053	0.063
Density effect	0.461	0.766	0.248	0.169
P effect	0.482	0.390	0.176	0.784

Crop effect: Soybean without P vs sorghum without P.
Density effect: Soybean at medium to high density vs soybean at low density.
P effect: Soybean with P vs soybean without P.
ShSeed: S. hermonthica seed density at 0–10 cm depth.

Table 3. Soybean plant density and phosphorus application effects on soybean root dry matter (DM) and root length density (RLD) in 1996 soybean and emerged Striga hermonthica *on maize (Sh/Maize) and maize grain yield in 1997 after 1996 soybean or sorghum*

Soybean density (no./ha)	P applied (kg/ha)	Bray P (μg/g)	Root DM (kg/ha)	RLD (cm/cm^3)	Sh/Maize 12 w.a.p.	Sh/Maize 16 w.a.p.	Maize grain (kg/ha)
Least squares means							
57210	0	4.22	410	0.205	0.85	1.16	897
89990	0	4.11	390	0.232	0.88	1.13	745
94200	0	4.51	810	0.568	1.04	1.53	865
143560	0	5.06	810	0.498	0.95	1.82	867
109120	16	6.46	1380	0.798	0.61	1.05	1511
133610	16	6.46	1330	0.803	0.49	0.84	990
Sorghum	0	5.19	—	—	2.21	3.17	337
Fixed effects (Type III) and covariates probabilities							
Treatments		0.198	0.000	0.000	0.024	0.012	0.000
Sh/Sorg		0.006	—	—	0.000	0.000	0.000
(Sh/Sorg)^2		—	—	—	0.000	0.000	—
SoilN96		—	—	—	—	—	0.021
Contrast estimates							
Crop effect		−0.71	—	—	−1.28	−1.76	506
Density effect		0.34	263	0.227	0.11	0.33	−71
P effect		1.67	540	0.268	−0.44	−0.73	384
Contrast probabilities							
Crop effect		0.431	—	—	0.002	0.001	0.002
Density effect		0.714	0.009	0.009	0.788	0.531	0.651
P effect		0.041	0.000	0.000	0.200	0.110	0.007

Crop effect: soybean without P vs sorghum without P.
Density effect: soybean at medium to high density vs soybean at low density.
P effect: soybean with P vs soybean without P.
Sh/Sorg: *S. hermonthica* count on previous sorghum crop (one plot per rep).
SoilN96: total soil N at 0–10 cm depth before trial initiated.

crop rotation effect and the P fertilizer effect were both highly significant (table 4). Emerged *S. hermonthica* on previous sorghum was not a significant covariate for emerged *S. hermonthica* on maize. Emerged *S. hermonthica* on maize at harvest averaged 2.22 parasites per maize host plant after sorghum, 1.13 after soybean, and 0.81 after soybean with P fertilizer. The crop effect was highly significant and the P effect was significant at $P = 0.127$. Soybean density was not significant for emerged *S. hermonthica* on maize.

4. Discussion

This set of trials demonstrated the potential of an appropriate soybean cultivar to reduce *S. hermonthica* parasitism in subsequent maize. The soybean cultivar was carefully chosen after screening *in vitro* using *S. hermonthica* seed from northern Nigeria. There is no guarantee that other soybean varieties would do the same. Indeed, Alabi *et al.* (1994) found that among 55 cultivars, there was substantial variability in the ability of root pieces to stimulate germination of *S. hermonthica* with some cultivars stimulating very little germination. Usefulness of the screening method was highlighted by Berner *et al.* (1996a) who reported that when four cultivars of soybean were tested in the field, the results were rank correlated with laboratory screening results.

Soybean reduces the viable *S. hermonthica* seed bank by exuding a germination stimulant (Berner *et al.*, 1996a). Since the stimulant is exuded by the soybean root system, our working hypothesis was that increasing the soybean root surface would increase the effect of soybean on the seed bank. More specifically, it was hypothesized that increasing density of soybean, and P application to soybean would contribute to reduction of *S. hermonthica* parasitism. Soybean root dry matter was doubled by increasing soybean plant density and tripled by P fertilizer application at high soybean density. Root length density followed the same pattern. However, simply increasing soybean density did not result in lower numbers of emerged *S. hermonthica* on the subsequent maize. At one site, there was no change in the number of emerged *S. hermonthica* with increasing soybean RLD. The reduction in *S. hermonthica* parasitism due to a soybean crop was approximately 70% for all treatments. At the other site, the reduction in the number of emerged *S. hermonthica* was 50% when previous soybean density was high and increased to 70% when P was applied to the soybean. This shows a tendency for increasing soybean root length density to be related to *S. hermonthica* reduction, but the difference between the two groups of treatments was not significant.

The combined data suggest an absolute reduction in *S. hermonthica* from one year to the next from one soybean crop by comparing *S. hermonthica* emergence on the previous sorghum with the *S. hermonthica* emergence on the subsequent maize. In this set of trials, we observed 1.76 *S. hermonthica* per sorghum stand in the first year. In the following year we counted

Table 4. Soybean plant density and phosphorus application effects on emerged Striga hermonthica *on maize (Sh/Maize) and maize grain yield in three trials*

Soybean density (no./ha)	P applied (kg/ha)	Sh/Maize Flowering	Sh/Maize Harvest	Maize grain (kg/ha)
Least squares means				
47750	0	1.27	0.95	1191
84780	0	1.09	0.86	1324
91930	0	1.29	1.17	1347
129850	0	1.40	1.53	1249
103100	16	1.07	0.88	2110
122720	16	0.89	0.74	1354
Sorghum	0	1.91	2.22	680
Fixed effects (Type III) and covariates probabilities				
Treatments		0.228	0.050	0.0001
Sh/Sorg		—	—	0.0016
InitialN		—	—	0.0002
Contrast estimates				
Crop effect		− 0.65	− 1.09	597
Density effect		− 0.02	0.23	115
P effect		− 0.37	− 0.54	434
Contrast probabilities				
Crop effect		0.040	0.007	0.001
Density effect		0.961	0.565	0.535
P effect		0.193	0.127	0.009

Crop effect: soybean without P vs sorghum without P.
Density effect: soybean at medium to high density vs soybean at low density.
P effect: soybean with P vs soybean without P.
Sh/Sorg: *S. hermonthica* count on previous sorghum crop (one plot per rep).
InitialN: Total soil N at 0 – 10 cm depth before trial initiated.

2.22 *S. hermonthica* per maize stand after sorghum and 1.02 *S. hermonthica* per maize stand after soybean. Increasing numbers of *S. hermonthica* is not surprising as traditional sorghum cropping has been linked to increased *S. hermonthica* seed banks and emerged *S. hermonthica* on maize crops in the northern Guinea savanna of Nigeria (Weber *et al.*, 1995). In that study, the multiplication rate (ratio of seed shed at harvest to the number of *S. hermonthica* seeds at the beginning of the season) on sorghum was estimated to be almost 50 times higher than on maize. In our study, nothing was done to prevent *S. hermonthica* flowering and seed production on the sorghum control plots. Thus we can be reasonably sure that *S. hermonthica* seed bank increased on the sorghum. Actual reduction of *S. hermonthica* seed bank from one crop of soybean was overestimated by comparing with sorghum rotation. Actual estimation of seed bank reduction must be carefully done because it depends on the host crop (and variety), time of observation, soil characteristics, and weather. Also, observation of parasitism is not a perfect indicator of the seed bank because only 10 – 30% of *Striga* attached to the roots of the host plant usually emerge above the soil surface (Thalouarn and Fer, 1993).

Maize grain yield was significantly increased by previous soybean (compared with sorghum) and P application of soybean for all trials combined. The yield increase from soybean rotation was due to a combination of reduced *S. hermonthica* parasitism and improved N supply. The increase from P application to soybean was due to reduced *S. hermonthica* parasitism, improved N supply and improved P supply. Increasing soybean density did not have a significant effect on subsequent maize yield in the combined analysis.

Inclusion of soybean in the cropping system serves to diversify the farmer's enterprise. There is already a substantial market for soybean in many parts of Nigeria due to its inclusion into traditional and modern foods. Since 1993, the price of soybean in Nigeria is twice that of cereal (FAO, 1999). Soybean currently has few pests in West Africa. Yield of soybean for the three trials was approximately 1200 kg/ha for medium to high density with P applied. With additional benefits of improved soil fertility and reduction of *S. hermonthica* parasitism, carefully chosen soybean varieties can bring multiple benefits to farming households.

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