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Integrated management of *Striga hermonthica* (Del.) Benth. in sorghum using *Fusarium* inoculum, host plant resistance and intercropping

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ABSTRACT

Objectives: This study aimed at evaluating the individual and synergistic effects resulting from *Fusarium* inoculum (F-inoculum) (*Fusarium oxysporum* 34-FO), host crop resistance and intercropping system and their combination as an integrated *Striga* management (ISM).

Methodology and Results: A two-year experiment was conducted on a *Striga*-affected field at Kouaré Research Station. Treatments involved sorghum resistance (F2-20); F-inoculum incorporation into the seed hills and sorghum (F2-20) / cowpea (IT-89-KD-245) intercrop in alternated rows and their combination were compared to *Striga*-susceptible sorghum variety (S 29). The integration of sorghum resistance with one component from F-inoculum and intercropping system significantly affected *Striga* infestation. Two ISM plots based on sorghum resistance and F-inoculum integrated with intercropping delayed *Striga* emergence date and highly reduced the number of *Striga* emerged plants and dry biomass compared to that recorded on non-ISM plots. Both ISM treatments reduced *Striga* infestation over the cropping season (ASNPC) by 74% and 89%, respectively. The use of ISM including sorghum resistance and F-inoculum resulted in improving sorghum yield by 72%.

Conclusions and application of findings: These results demonstrated that *Striga* bio-control based on F-inoculum incorporation and the intercropping system constitute each of both an effective control method against *S.hermonthica* and their synergistic effect is more effective to reduce *Striga* infestation in field conditions. The intercropping effect would contribute to enhance the efficacy of *F. oxysporum* 34-FO in controlling *S. hermonthica*.

Key words: *Striga hermonthica*, integrated control, *Fusarium* inoculum, sorghum resistance, intercropping

INTRODUCTION

Striga hermonthica (Del.) Benth. (Figure 1), the most economically important parasitic seed plant in the world (Parker and Riches, 1993), is endemic in the African savannah and the Sahel where it devastates the yields of cereal crops. Incidence and severity of *S. hermonthica* are exceptionally high on sorghum, pearl millet and maize, the main staple foods for over 300 million people in sub-Saharan Africa (Scholes and Press, 2008). Crop yield losses due to *Striga* parasitism amount to 10.67 million tons per year in sub-Sahara Africa (Gressel *et al*., 2004). *Striga* infestation is extending in Africa because of the high pressure on land due to population crowding (Berner *et al*., 1995). However, the impact of *Striga* damages depends on ecological conditions, cropping systems, local cultural practices and farmers' skills on the ecology and farming practices.

Figure 1: Sorghum plant affected by the attack of *Striga hermonthica* in red blooms

Cropping systems in Burkina Faso remain traditional and the methods mostly used in controlling *Striga* are hand-pulling, land fallowing, crop rotation, crop seeds treatment with the powder of *Parkia biglobosa* (Jacq.) R. Br. (African locust bean tree) peels before the planting (Traoré *et al*., 2001). Unfortunately, these cultural practices do not lead to significant reduction of the density of *S. hermonthica* in affected-fields (Traoré and Yonli, 2001). Besides, certain control methods are labour intensive to the capital deficient farmers (Mashark *et al*., 2006). Today, the land fallowing method is less and less used because of the reduction of arable land due to the population growth. Regarding crop cultivars, the national programme of cereal breeding has attempted to identify *Striga*-resistant varieties of sorghum, based on the number of emerged *Striga* plants in cultivation plots. The existence of genetic resistance differences to *S. hermonthica* in sorghum has been reported in Burkina Faso (Olivier *et al*., 1992) but no sorghum variety withstood *S. hermonthica* in different local agro-ecological zones. Botanga *et al*. (2003) emphasized that the major problem associated with the use of resistant cultivars is the lack of universal resistance. So, the small-scale farmers rely on *Striga*-tolerant varieties of host crops whose growing may lead to the increasing of *Striga* seed bank in the soil. The use of trap crops, which induce the germination of *Striga* seeds but without being parasitized, is one of the most promising methods and culturally acceptable (Botanga *et al*., 2003). Indeed, the trap cropping induces suicidal germination and leads to depleted *Striga* seed bank. The growing of cereals in intercropping with legumes in the same field is a common cultural practice in Burkina Faso with the outlook for *S. hermonthica* control. Nowadays, the approach of integrated management for controlling *S. hermonthica* is more and more favoured. Intercropping of cereals with legumes, application of organic fertilizers and genetic resistance of host plants are three control methods with a high potential for adoption by farmers (Oswald, 2005). The use of soil-born micro-organisms as bio-control agents against *Striga* such as fungi (Abbasher *et al*., 1998, Marley *et al*., 1999, Yonli *et al*., 2004 and 2006) and bacteria (Ahonsi *et al*., 2002) has been also suggested for an IMP strategy. Ciotola *et al*. (2000) concluded from their experiment that the use of *Fusarium oxysporum* (M12-4A) as a component with other control measures may provide an effective *Striga* control. This study investigated the integrated *Striga* management (ISM) package combining *Fusarium* inoculum with host plant resistance, and intercropping sorghum with a trap crop (cowpea) under field conditions.

MATERIAL AND METHODS

Site, characteristics and genetic material: The study was conducted during the 2001 and 2002 cropping seasons at the INERA (Institut de l'Environnement et de Recherches Agricoles) Kouaré Research Station (11°95'03" N and 0°30'58" E) in the eastern Sudan-Savannah region of Burkina Faso. Soil properties have been described by Yonli *et al*. (2011). *Striga*-susceptible sorghum variety (S 29) and *Striga*-resistant sorghum variety (F2-20) were used as host crops for *Striga hermonthica*. Cowpea variety IT-89-KD-245, resistant to *S. gesnerioides* which is a parasitic plant for cowpea, was used as a trap crop for *S. hermonthica*. *Fusarium oxysporum* 34-Fo used as a biological control agent of *S. hermonthica*, has demonstrated its efficacy in controlling *Striga* from previous studies (Yonli *et al*., 2006, 2010). *Fusarium* inoculum (F-inoculum) was prepared using *Fusarium oxysporum* 34-FO and a growth medium according to the technique described by Yonli *et al*. (2006). The growth medium consisted of autoclaved compost whose the physicochemical characteristics have been described by Yonli *et al.* (2011). The urea ($(CO)_2NH_2$, with 46% N) and NPK in 12-24-12 were the mineral fertilizers employed.

Experimental design : To investigate host plant resistance, biocontrol (*Fusarium* inoculum), intercropping sorghum with cowpea and possible interactions on *Striga* emergence and crop growth and productivity, the following treatments were evaluated: 1) Sorghum variety S29 (*Striga*-susceptible variety, standard control) (SUS); 2) Sorghum variety F2-20 (*Striga*-resistant variety, control) (RES); 3) Sorghum variety F2-20+30 g of sterilized growth medium (without *Fusarium* isolate inoculation) hill^{-1} (RES+MED); 4) Sorghum variety F2-20 intercropped with cowpea in alternated rows (i. e, one row of sorghum alternated with one row of cowpea (1/1)) (RES+INT); 5) Sorghum variety F2-20 intercropped with cowpea in alternated rows (1/1)+30 g of sterilized growth medium hill^{-1} (RES+INT+MED); 6) Sorghum variety F2-20 + 30 g of F-inoculum hill^{-1} (RES+INO); 7) Sorghum variety F2-20 intercropped with cowpea in alternated rows (1/1)+30 g of F-inoculum hill^{-1} (RES+INT+INO). The experimental design was a randomized complete block with four repetitions. In pure sorghum cropping, the main plot consisted of four rows of 2.4 m length with 0.8 m between rows and 0.4 m between plants within rows. Whereas in intercropping of sorghum with cowpea, the main plot consisted of three rows of sorghum and three rows of cowpea, all of 2.4 m length with 0.8 m between rows and 0.4 m between plants within rows. A total area of 1.92 m² and 3.84 m² were harvested from the centre of each plot in pure sorghum and intercropping system, respectively.

Crop management and rainfall: Experimental plots were chosen with heavy natural infestation of *S. hermonthica*, at least 30 plants m^{-2} (Yonli *et al*., 2004). The trials were sown on 17 July in 2001 and on 23 July in 2002. The cowpea was sown 14 days after sorghum planting in order to reduce the competition between both crops. F-inoculum and the growth medium were incorporated into seeds hills at the planting. Fertilizers were applied by spreading and incorporating uniformly in the plots. Mineral fertilizer (100 kg ha^{-1} of NPK) was applied to the plot at sowing and 50 kg ha^{-1} of urea was applied at the booting growth stage. Plots were weeded twice with hand hoes before the emergence of *S. hermonthica* (14 and 30 days after sowing (DAS)). The main plot of each treatment was bounded by a bund immediately after the planting to prevent runoff from one plot to another, which can cause significant changes in treatments. To avoid the influence of treatments on the results from one year to another, the second experiment (in 2002) was not set up on the same experimental plots from the previous year. Rainfall recorded in 2001 was 832.7 mm in 28 rain events and with 62.3% of rain falling during the crop growth period. In 2002, 693.7 mm of rainfall fell in 29 rain events with 57.9% falling during the crop growth period.

Data collection and analysis: The treatments combining two or more Striga control methods were considered integrated Striga management (ISM) approach. The following observations were made in both years: 1) fungal diseases on sorghum and cowpea; 2) number of emerged Striga plants every week from four to twelve weeks after the first emergence of Striga ; 3) a visual estimation of vigour of emerged Striga plants recorded using a rating scale of 0 to 9, where 0= no emerged Striga plant, 9= mean height of Striga plants > 40 cm, with more than 10 branches (Haussmann *et al*., 2000); 4) weight of Striga dry biomass at sorghum harvest; 5) Sorghum and cowpea yields. *Striga* count data were used to calculate area under the *Striga* number progress curve (ASNPC) according to Haussamann *et al*. (2000). Data were checked to determine need for transformation (Gomez and Gomez, 1984) before performing ANOVA (SAS Institute, Cary, NC). Means were separated using LSD's test and differences between treatments were considered significant at $P < 0.05$.

RESULTS

During the 2-year study, sorghum and cowpea plants didn't show any fungal disease. Emerged *Striga* plants were observed as well in sorghum S 29 plots as in sorghum F2-20 plots.

Effect of F-inoculum, sorghum resistance and intercropping on *Striga* infestation: ANOVA revealed significant difference between treatments for *Striga* emergence date (P<0.003), number of emerged *Striga* plants 80 and 101 DAS (P<0.0001), ASNPC and *Striga* dry biomass. The *Striga* emergence date was delayed by 19 days in ISM plot of "RES+INT+INO" and by 17 days in ISM plot of "RES +INO" , compared to the control "SUS" (45 DAS) (Table 1). *Striga* emergence was observed later in ISM plots treated with F-inoculum. The number of emerged *Striga* plants in ISM plots of "RES+INT+MED", "RES+INO" and "RES+INT+INO" at 80 and 101 DAS was the weakest. These three treatments reduced *Striga* infestation at least by 93.6% 80 DAS and more than 88.3% 101 DAS compared to the control and among them, "RES+INT+INO" was the most effective treatment. *Striga* infestation over the cropping season expressed as the ASNPC was significantly reduced in ISM plots including Sorghum F2-20, F-inoculum with or without trap crop (cowpea). The other treatments including Sorghum F2-20 led to reduction rates of ASNPC varying between 21.5% and 58.5% (Table 1).

Table 1: *S. hermonthica* emergence, development and biomass in response to the different control treatments.

Treatments	*Striga* emergence date	Number of *Striga* m^{-2}		ASNPC m^{-2}	Vigour of *Striga* plants		*Striga* dry biomass (kg/ha)
		80 DAS§	101 DAS		80 DAS§	101 DAS	
RES+INT+INO	64 a!	0.23 c	0.91 d	118.38 c	1.25 d	1.57 e	3.26 c
RES+INO	62 ab	0.46 c	1.04 d	119.09 c	2.00 c	1.88 de	16.28 bc
RES+INT+MED	56 abc	0.52 c	2.34 cd	188.76 bc	2.00 c	2.25 cd	8.14 c
RES+INT	56 abc	1.76 bc	8.98 bc	315.53 ab	1.88 c	2.25 cd	50.78 abc
RES	53 bcd	2.08 bc	10.22 b	304.50 abc	2.88 ab	3.13 b	65.10 ab
RES+MED	51 cd	4.95 ab	12.57 ab	357.54 ab	2.38 bc	2.75 bc	65.10 ab
SUS	45 d	8.20 a	19.21 a	456.25 a	3.38 a	4.63 a	94.40 a
Mean	55	2.60	7.90	265.72	2.25	2.65	43.29
Standard Error	1.45	0.59	1.30	29.21	0.11	0.15	7.97

§: Days after sowing, ! Means within a column followed by the same letter are not significantly different (P ≤ 0.01) according to LSD's test. SUS: Sorghum S29 RES: Sorghum F2-20 RES+MED: Sorghum F2-20 + Growth medium
RES+INT: Sorghum F2-20 + Cowpea RES+INT+MED: Sorghum F2-20 + Cowpea + Growth medium
RES+INO: Sorghum F2-20 + F-inoculum RES+INT+INO: Sorghum F2-20 + Cowpea + F-inoculum

The results showed difference (P<0.0001) between treatments to inhibit the growth of *Striga* plants 80 and 101 DAS. The average value of *Striga* plant vigour was less than 2 or equal to 2 in ISM plots of "RES+INT", "RES+INT+MED", "RES+INO" and "RES+INT+INO", 80 and 101 DAS. The vigour of *Striga* plants was significantly reduced with treatments excepted "sorghum F2-20" at 80 DAS and with all treatments at 101 DAS as compared to the control "SUS". ISM treatment "RES+INT+INO" induced the weakest vigour of *Striga* plants 80 and 101 DAS (Table 1). *Striga* dry biomass recorded in ISM plots of "RES+MED" and "RES+INT+MED" was less than 10 kg ha^{-1} against 94 kg ha^{-1} in the plot of "SUS". ISM treatments "RES+INO", "RES+INT+MED" and "RES+INT+INO" significantly reduced (P<0.0070) *Striga* dry biomass by 82.7% to 96.5% compared to the control "SUS". *Striga* dry biomass obtained in "SUS" control plot was not statistically different from that recorded in the two plots of "RES" and "RES+MED". However, it was reduced by 31% and 46.2% in both plots, respectively (Table 1).

Effects of F-inoculum, sorghum resistance and intercropping on crops yield: Dry biomass and grain yield of sorghum recorded in "RES+MED" and "RES+INO" plots were only more than 3 t ha^{-1} and 0.6 t ha^{-1}, respectively (Table 2). Sorghum aerial dry biomass obtained in pure sorghum « RES» was greater than that obtained in intercropping plot. Only sorghum grain recorded in intercropping plot treated with F-inoculum (RES+INO") was significantly similar to that of pure sorghum "RES" plots. Aerial dry biomass (P<0.0001) and grain yield (P<0.0292) of sorghum were greatest in "RES+MED" plot and weakest in intercropping plot of sorghum/cowpea (Table 2). With respect to cowpea yield, the dry weight of cowpea pods ranged from 0.8 t ha^{-1} to 1 t ha^{-1} and the dry weight of grains from 0.5 t ha^{-1} to 0.7 t ha^{-1} (Table 2). The results showed no significant difference between intercropping plots for cowpea yield.

Table 2: Crop biomass and grain yield in response to the different *Striga* control treatments.

	Sorghum yield (kg/ha)		Cowpea yield (kg/ha)	
Treatments	**Aerial dry biomass**	**Weight of grains**	**Dry weight of pods**	**Weight of grains**
RES+MED	3365.9 a	657.60 a	-	-
RES+INO	3020.80 ab	605.50ab	-	-
RES	2330.70 b	576.20 ab	-	-
RES+INT+INO	1025.40 c	452.50 abc	791.00	543.60
RES+INT+MED	877.30 c	345.10 bc	826.80	605.50
RES+INT	680.30 c	260.40 c	1009.10	729.20
Means	1883.41	482.86	875.65	626.09
Standard Error	193.74	41.9687	56.30	44.53

Means within a column followed by the same letter are not significantly different ($P \leq 0.01$) according to LSD's test.
SUS: Sorghum S29 RES: Sorghum F2-20 RES+MED: Sorghum F2-20 + Growth medium
RES+INT: Sorghum F2-20 + Cowpea RES+INT+MED: Sorghum F2-20 + Cowpea + Growth mediium
RES+INO: Sorghum F2-20 + F-inoculum RES+INT+INO: Sorghum F2-20 + Cowpea + F-inoculum

DISCUSSION

The absence of fungal attack on plant crops revealed that sorghum and cowpea should be immune to the pathogenicity of the isolate *Fusaium oxysporum* 34-FO. With respect to *Striga* emergence on both sorghum varieties, this study results confirmed the susceptibility of sorghum variety S 29 to *Striga hermonthica* and showed that sorghum variety F2-20 was not totally resistant to the local *Striga* strain. *Striga* emergence was delayed in ISM plots including intercropping sorghum with cowpea in alternated rows or F-inoculum. The trap crop (cowpea variety IT-89-KD-245) may cause suicidal germination of some of *Striga* seeds (Botanga *et al*., 2003) whereas the F-inoculum would inhibit *Striga* seed germination or the ground growth of *Striga* seedlings (Yonli *et al*., 2006). IPM plots which were intercropped or treated with F-inoculum significantly reduced *Striga* infestation. Indeed, reductions of emerged *Striga* by more than 79% and 53% were respectively recorded 80 and 101 DAS in the intercropped plot as compared to the control plot (SUS). The relatively low number of *Striga* plants in the intercrop was due to a reduced potential for flowering, capsule production and consequently, a reduced capacity of increasing the *Striga* seed bank in the soil. This study results confirmed that of Dembélé and Kayentao (2002) who reported that the intercropping sorghum/cowpea in alternated rows (1/1) reduced by 83% emerged *Striga* in Mali. Mashark *et al.* (2006) also reported that the maize varieties grown in Ghana under intercropping supported fewer *Striga* plants compared to those grown in sole cropping. West African soils are low in phosphorus (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). The growing of cowpea as a trap crop for *Striga* may also respond substantially to P which could affect *Striga* emergence in the intercropped plots. Dembélé and Kayentao (2002) concluded from their study that the volume of sorghum roots is reduced in the intercropped plot due to the weak number of sorghum seed hills. It can be hypothesized that the ability of the sorghum roots to stimulate germination of *S. hermonthica* seed is a function of sorghum root length density (length of root per volume of soil).

ASNPC was significantly reduced in ISM plots of intercropping system or treated with F-inoculum. This result highlighted the pathogenicity of *F. oxysporum* 34-FO against *Striga* and the synergy between F-inoculum and the creeping trap crop (cowpea) to control *Striga* infestation. A similar study carried out in Nigeria's field showed that ISM plots combining myco-herbicide based on *F. oxysporum* (isolate PSM 197) with sorghum resistance had significantly lower *Striga* counts than non-ISM plots and *Striga* emergence was reduced in ISM plots by around 95% (Marley *et al*., 2004). With regard to intercropping with efficacious grain legumes on *Striga*, Udom *et al*. (2007) emphasized that any *Striga* control package to be developed for small scale farmers should consider intercropping system with *Striga* host and non-host crops like sorghum/cowpea as a central focus.

The vigour of *Striga* plants was weaker in ISM plots combining sorghum resistance with intercropping or F-inoculum. So, each of these components had a depressive effect on the growth of *S. hermonthica* plants. *Striga* dry biomass was reduced by 46.2% in pure *Striga*-resistant sorghum variety plot compared to *Striga*-susceptible sorghum variety plot. ISM controls based on intercropping system, F-inoculum or both in combination significantly reduced *Striga* dry biomass. This study results confirmed the observations of Dembélé and Kayentao (2002) who reported in Mali, a reduction of *Striga* biomass by 92% in the intercropped plot of sorghum with cowpea. Indeed, a creeping trap crop suffocated juvenile *Striga* plants that succeeded in emerging and then, they were killed by the competition effect between trap crop and *Striga* seedlings. In addition, when the cowpea plants covered the soil, the temperature decreased while the air humidity increased under cowpea leaves and stalks. The interaction of these environmental factors may create a micro-climate that would affect the emergence and the growth of *Striga* plants and then *Striga* biomass should be significantly reduced. On the other hand, the created micro-climate is favourable to the growth of micro-organisms such as *Fusaria* that may be bio-control agents against *Striga*. This hypothesis corroborated this study results showing that combined effect from creeping trap crop and F-inoculum proved to be more noxious on *Striga* infestation than individual effects. So, delayed *Striga* emergence, significant reduction of emerged plants, vigour and dry biomass of *Striga* in ISM plot including intercropping and F-inoculum revealed an additional effective effect resulted from these components to control *S. hermonthica*. ISM measure integrated F-inoculum with intercropping highly affected all vegetative stages of *S. hermonthica* and its impact on *Striga* infestation is much more significant on *Striga* dry biomass at sorghum harvest. Aerial sorghum biomass was significantly high in pure sorghum plot than intercropped plot. This difference in sorghum biomass is probably due to the double of sorghum shoots counted in pure sorghum. Dembélé and Kayentao (2002) reported that sorghum grain yield had been improved from 37% to 80% in the intercropped plots of sorghum with cowpea. In this study, only sorghum grain yield obtained in ISM plot combining intercropping system and F- inoculum incorporation was similar to that recorded in pure sorghum plot. This similarity of sorghum grain yield would be due to the synergistic effect resulted from trap crop and *F. oxysporum* 34-Fo on *S. hermonthica*. The comparison of treatment means for *Striga* and sorghum parameters showed that the treatment combining sorghum resistance and growth medium (RES+MED) was as effective as treatments including *Fusarium* inoculum. This effectiveness was probably due to the amount (937.5 kg ha^{-1}) of sterilized compost applied to each planting hole. Indeed, this amount may have constituted a micro dose of well-composted organic fertilizer for enhanced sorghum growth as well as a growth medium for microbial agents present in the soil. Berner *et al.* (1996) investigated soil samples from Nigeria and demonstrated that natural soil suppressiveness to *S. hermonthica* is of microbial origin. So, the incorporation of uninoculated growth medium in the soil may boost the growth of edaphic pathogens that then attack *Striga*. However, on-farm participatory testing will be considered for the evaluation of ISM on crop yield and incomes for farmers and then, to show the agronomical as well as economic benefits of ISM.

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