

Field assessment of *Fusarium oxysporum* based mycoherbicide for control of *Striga hermonthica* in Nigeria

P.S. MARLEY^{1,*} and J.A.Y. SHEBAYAN²

¹Department of Crop Protection, Institute for Agricultural Research/Faculty of Agriculture, Ahmadu Bello University, Samaru, P.M.B. 1044, Zaria, Nigeria;

²Department of Agronomy, Institute for Agricultural Research/Faculty of Agriculture, Ahmadu Bello University, Samaru, P.M.B. 1044, Zaria, Nigeria

*Author for correspondence

Received 3 September 2003; accepted in revised form 15 May 2004

Abstract. *Fusarium oxysporum* (isolate PSM 197) based mycoherbicide was evaluated for its efficacy under field conditions in trials conducted during 1999–2001 cropping seasons in the Nigerian savanna. In the 1999 cropping season, spot application of 5–10 g of mycoherbicide was found to give effective control of *Striga hermonthica*. Results of on-farm trials at Barhim and Dutsen-Ma areas showed the application of the mycoherbicide to significantly ($p = 0.05$) increase stand count at both 3 weeks and at harvest, reduced *Striga* shoot count and increased crop yield in both improved and local sorghum varieties, as compared with the same varieties not treated with the mycoherbicide. Results establish the efficacy of *F. oxysporum* as a mycoherbicide and the need for further development of the mycoherbicide into formulated granules or seed treatment for use in control of *S. hermonthica* under field conditions.

Key words: biological control, *Fusarium oxysporum*, mycoherbicide development, *Striga hermonthica*

Introduction

Striga hermonthica (Del.) Benth, commonly known as parasitic witch weed, is a major biotic constraint to sorghum production in West and Central Africa where many local and improved sorghum varieties are susceptible to the parasite (Ogungbile et al., 1998; Lagoke et al., 2000; Marley et al., 2002). Heavy infestation of the sorghum crop, particularly under drought and low fertility conditions, may lead to 100% yield loss (Hausman et al., 2000). Sorghum (*Sorghum bicolor* [L.] Moench) is a major staple cereal in West and Central Africa, where it is used mainly for human consumption, as well as an industrial raw material in the production of alcoholic and non-alcoholic beverages, livestock feeds and sweeteners (Ogungbile and Marley, 2001).

The potential of *Fusarium oxysporum* as a bio-control agent for the control of *S. hermonthica* in WCA has been reported (Ciotola et al., 1995; Diarra et al., 1996; Kroschel et al., 1996; Abbasher et al., 1998; Marley et al., 1999). Isolates of *F. oxysporum* from *S. hermonthica* have been shown to infect only *Striga* spp. and no other crops or vegetables (Ciotola et al., 1995; Abbasher et al., 1998; Elzein 2003; Marley, unpublished data). Further, isolates of *F. oxysporum* from *S. hermonthica* e.g. M12-4A, Foxy 1 and Foxy 2 are reported not to produce any of the major mycotoxins of concern to human and animal health e.g. fumonisins, deoxynivalenol, nivalenol, T-toxin and zearalenone (Savard et al., 1997; Amalfitano et al. 2002).

The development of *F. oxysporum* into a mycoherbicide in liquid and granular formulations has been reviewed (Hess et al. 2002) and the need for their evaluation for efficacy under field and on-farm conditions emphasised. The present study evaluates *F. oxysporum* (isolate PSM 197), isolated from *S. hermonthica* in the Nigerian savanna (Marley et al., 1999) for its field and on-farm efficacy in the control of the witch weed.

Materials and methods

Stock cultures and inoculum's production

F. oxysporum (isolate PSM 197) was isolated from *S. hermonthica* stems, and stock cultures were maintained on potato dextrose agar amended with streptomycin (PDAS) (PDA, Difco, USA) and stored in the refrigerator at 4 °C. From the stock cultures, starter cultures were prepared when required.

Fungal inoculum was produced as described by Marley et al. (1999) on sterilized sorghum grain. Five-hundred grams of gritted (broken) grain was placed in 1 l flat-bottom flasks containing 250 ml of sterile distilled water. Flasks were shaken to ensure that the substrate was properly moistened and excess water was poured off prior to autoclaving for 1 h at 121 °C (103.5 kPa). After cooling, each flask was inoculated with three agar plugs (5 mm diameter) of the isolate and then incubated at 28 °C for 7 days to allow for fermentation. During the incubation period, each flask was shaken daily to allow for full colonization of the gritted grains by the pathogen. Colonized grains were harvested 14 days after inoculation and stored in a refrigerator at 4 °C for use when required.

Field evaluation of F. oxysporum

A field experiment was carried out concurrently at the Institute for Agricultural Research at Samaru, Zaria (11°11' N; 7°38' E) and Kano State Research site

(formerly ICRISAT station) Bagauda, Kano (11°40' N; 8°30' E) in the 1999 cropping season to determine the quantity of inoculum required and the most efficient method of application. Fields used for the trials at both locations are *Striga*-infested plots that have been developed and used for over 5 years. Trials in Samaru were established on July 17, 1999. While in Bagauda, the trials were established on 7 July 1999. Sorghum variety SAMSORG 41 (ICSV 400) was used.

In this trial, we evaluated four methods of inoculum application. The treatments were (i) 15 cm wide band placement of inoculum at the rate of 0.5 kg per 10 m ridge (ii) broadcast application of 2.5 kg of inoculum per plot (iii) spot application of 10 g per hole of sown seed and covered with soil (iv) surface placement of 10 g over sown seed covered with soil and (v) control plot with no inoculum applied. The treatments were arranged in a randomised blocked design with three replications. Each plot consisted of five ridges, 10 m long with buffers between plots of one ridge or 1 m space. Data were collected from three inner rows to minimise border effects and the following observations were recorded: sorghum stand counts at 3 weeks after planting and at harvest, *Striga* shoot counts at 6 weeks after planting and at harvest, number of stands infected by *Striga* at harvest, crop reaction score to *Striga* damage at harvest (damage syndrome score based on a 1–9 visual rating scale (Berner et al., 1997) where 1 = no visible symptoms, 2 = scattered small and vague, whitish leaf blotches visible, 3 = scorching trace on leaf tips, 4 = scorching trace on leaves, 5 = scorching on a small portion of the leaf area, 6 = scorching on about a third of the leaf area, 7 = scorching on about half of the plant's surface, with some broken stalks, 8 = scorching on most of the leaf area, with many broken stalks and 9 = scorching on all leaf area, with dead or nearly dead plants) and number of *Striga* plants showing dieback at harvest.

On-farm evaluation of F. oxysporum

In the 2000 cropping season, evaluation of *F. oxysporum* as a mycoherbicide was conducted on nine farmer's fields at Barhim, Katsina (12°58' N; 7°41' E) in the Sahel agro-ecology. The farms at this location have sandy soils and receive an average annual rainfall of 461 mm. Farms selected were considered representative of the topography and agro-ecological zone. The fields were selected principally on the basis of their history of high striga infestation when monitored earlier (Marley et al., 2002). In the 2001 cropping season, nine fields were selected, based on the above criteria in Dutsen-Ma, in Katsina State (12°10' N; 7°41' E) in the Sudan agro-ecology.

Two sorghum cultivars SAMSORG 41 (ICSV 400) (early maturing, striga susceptible) and a farmer's local, Yar'ruruka (Jollof) (early maturing, striga tolerant) were used in the trials. Seeds of each cultivar were planted 30 cm apart

on 25 rows \times 10 m length plots, and thinned to two plants per stand 3 weeks after emergence. Trials were planted on June 29, 2000 at Barhim and on 30 June 2001 at Dutsen-Ma. The experiment was designed as a randomised block design (RBD) with four treatments as follows: (i) SAMSORG 41 treated with mycoherbicide (41T) (ii) SAMSORG 41 without treatment with mycoherbicide (41NT) (iii) Farmers' local treated with mycoherbicide (FLT) (iv) Farmers' local without treatment with mycoherbicide (FLNT). The trial was carried out on nine farmer's fields and each farm was considered a replicate (because the trial size made it impossible to obtain large plots to carry out within farm replication) (Ray et al., 1989). Treatment was carried out by spot applying 10 g of mycoherbicide on the sown seed before covering with soil. In untreated plots, seeds were covered without applying mycoherbicide. The untreated plots served as the control. Split application of fertilizer with 64 kg N/ha of N:P:K (20:10:10) were applied. The first application was made at first weeding at 3 weeks after crop emergence while the second application was made just before re-moulding of existing ridges at 6 weeks after crop emergence. Land preparation, weeding and all other farm management practices were carried out by farmers. At physiological maturity, the plants were harvested.

Data on stand count was recorded at 3 weeks after crop emergence and also at harvest. *Striga* count and the number of stands infected were recorded at harvest. After harvest, grain weight was recorded. Data obtained were subjected to analysis of variance (ANOVA).

Results and Discussion

Determination of simple and effective method of inoculum application

Three weeks after establishing the trial at Bagauda, stand count averaged 105.9–168.3 between the treatments, while at harvest, stand count was significantly ($p = 0.05$) different only between mycoherbicide treated plots that had higher counts than the control with lower count (Table 1). Similar results were obtained at Samaru. When the number of plant stands infected with *Striga* was assessed at harvest there were no significant differences between the treatments with mycoherbicide, but the control treatment had significantly ($p = 0.05$) higher stands infected with *Striga* (Table 1) at both locations.

Striga emergence at 6 weeks after planting was significantly ($p = 0.05$) higher in the control plots at both locations except compared with broadcast application at Bagauda. Similarly, at harvest, the control treatment had significantly ($p = 0.05$) more emerged *Striga* plants than the treatments. Spot application was by far the best treatment at both locations. The broadcast application resulted in more *Striga* infected plants than any other treatment,

Table 1. Effect of method of mycoherbicide application on plant stand count and number infected by *Striga hermonthica* at Bagauda and Samaru, 1999 cropping season

Treatment	Stand count				Stands infected with striga at harvest	
	Bagauda		Samaru		Bagauda	Samaru
	3 Weeks	Harvest	3 Weeks	Harvest		
Band placement	168.3	164.4	200.0	176.7	8.7	11.7
Broadcast application	164.0	160.0	200.7	175.3	10.0	14.3
Spot application	166.3	165.0	200.0	187.3	4.7	10.0
Surface placement	163.3	158.7	198.0	178.3	7.7	20.3
Control (no mycoherbicide applied)	105.9	89.2	141.7	125.0	132.3	97.7
Mean	153.5	147.4	188.1	168.5	32.7	30.8
SE	7.15	10.17	7.07	7.01	13.84	9.03
DF	14	14	14	14	14	14

but it was still significantly better than the control. There were no significant ($p = 0.05$) differences in emerged *Striga* plants between band placement, surface placement and spot application treatments. At Samaru, spot application had significantly lowest *Striga* emergence at harvest (Table 2). Overall, spot application recorded the highest average reduction in *Striga* emergence with 89.7%, band and surface applications gave 78.7% and 76.3% reduction, respectively, while broadcast application provided the lowest reduction in *Striga* emergence with 74.5%. The impact of *Striga* on the crop was most severe on the control plants with a reaction score of 7.0 at Bagauda and 6.3 at Samaru (Table 2). Spot application treatment had the lowest crop reaction score of 3.0 and 3.7 at Bagauda and Samaru, respectively. The number of *Striga* plants showing dieback symptoms was significantly ($p = 0.05$) higher in all the treatments when compared to the control, especially the broadcast application treatment Bagauda (reaction score 7.0) and the spot application at Samaru (reaction score 6.0). The effect of the various treatments on grain yield is shown in Figure 1. Spot application gave the highest yield of 2.7 t/ha at Bagauda and 3.3 t/ha at Samaru while the control had the lowest yield at both locations.

From our results and observations, spot application of the mycoherbicide provided better *Striga* control as it reduced *S. hermonthica* emergence better than the other methods used. Further, it gave the highest yield of grain. Our results on reduction of *Striga* emergence are similar to those reported by Ciotola et al. (2000). They reported up to 92% reduction in *S. hermonthica* emergence due to application of *F. oxysporum* isolate M12-4A. Earlier reports showed that *F. oxysporum* isolates reduced *Striga* emergence from between 88 to 100% when applied pre-sowing (Ciotola et al., 1995; Kroschel et al., 1996; Marley et al.,

Table 2. Effect of method of mycoherbicide application on *Striga* shoot count, crop reaction score and number of *Striga* plants showing dieback symptoms, at two locations in the Nigerian savanna, 1999 cropping season

Treatment	<i>Striga</i> shoot count				Crop reaction score at harvest ^c		<i>Striga</i> plants with dieback at harvest	
	Bagauda ^a		Samaru ^b		Ba-ga- gauda	Sa- maru	Ba- ga- gauda	Sa- maru
	6 Weeks	Har- vest	6 Weeks	Har- vest				
Band placement	3.0	20.0	2.3	29.3	5.3	4.3	5.0	3.0
Broadcast application	15.0	34.7	1.0	31.0	4.7	4.7	7.0	4.3
Spot application	1.7	11.7	1.3	14.3	3.0	3.7	5.3	6.0
Surface placement	4.7	21.7	3.0	31.7	3.7	5.3	3.7	3.3
Control (no mycoherbicide applied)	21.0	145.3	16.0	114.7	7.0	1.3	1.3	0.0
Mean	9.1	46.7	4.7	44.2	4.7	3.9	4.5	3.3
SE	2.22	13.63	1.54	10.06	0.44	0.39	0.58	0.57
DF	14	14	14	14	14	14	14	14

^a Bagauda = located in the Sudan savanna of Nigeria.

^b Samaru = located in the northern Guinea savanna of Nigeria.

^c Crop reaction score to *Striga* damage at harvest based on a 1–9 visual rating scale where 1 = no visible symptoms, 2 = scattered small and vague, whitish leaf blotches visible, 3 = scorching trace on leaf tips, 4 = scorching trace on leaves, 5 = scorching on a small portion of the leaf area, 6 = scorching on about a third of the leaf area, 7 = scorching on about half of the plant's surface, with some broken stalks, 8 = scorching on most of the leaf area, with many broken stalks and 9 = scorching on all leaf area, with dead or nearly dead plants) and number of *striga* plants showing dieback at harvest.

1999). In addition, the quantity of mycoherbicide used by this method is lower than with the other methods, thus maybe suitable for use in small farms. This method was found to permit proper positioning of the mycoherbicide in the immediate environment for effective control and allowed for a uniform inoculation of the field. Similarly, Abbasher et al. (1995), Ciotola et al. (1995) and Kroshchel et al. (1996) reported the use of 3–10 g of inoculum of *Fusarium* isolates applied at pre-sowing to be effective in *Striga* infestation reduction. We found this method to be most suitable, simple and effective in field conditions.

On-farm evaluation of F. oxysporum

At Barhim, sorghum varieties SAMSORG 41 and farmers' local treated with mycoherbicide showed significantly ($p = 0.05$) higher plant establishment than

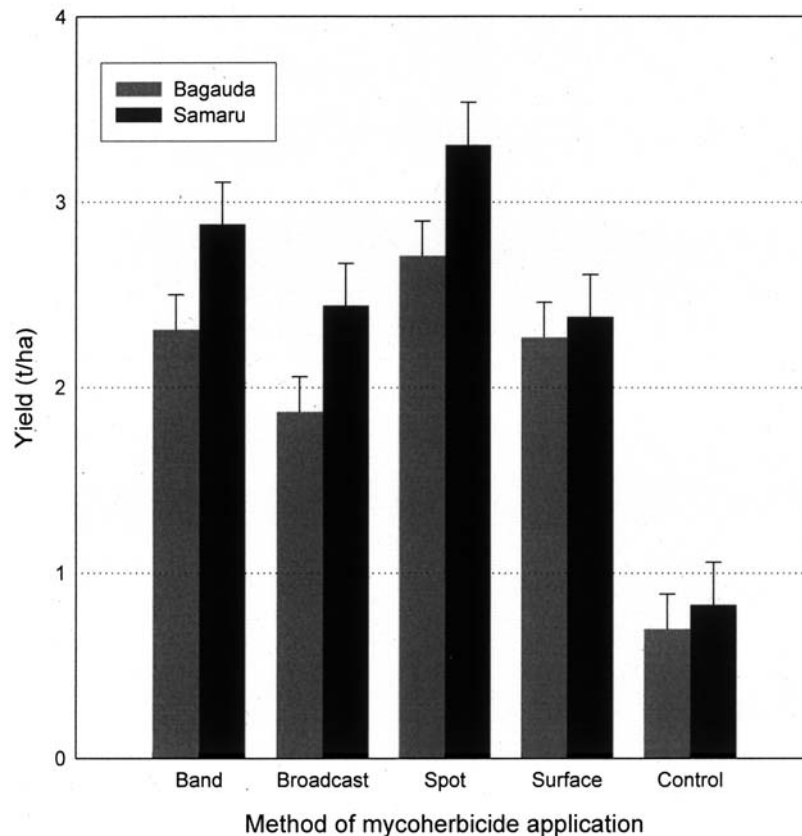


Figure 1. Types of integration errors.

untreated plots at both 3 WAP and also at harvest (Table 3). A similar result was obtained at Dutsen-Ma though here, the increase of farmers' local variety was relatively small. The number of plant stands infected with *Striga* at both locations was significantly ($p = 0.05$) higher in untreated plots of both varieties. Table 4 shows the level of *Striga* infestation in the trials at both locations. Plots not treated with the mycoherbicide had significantly ($p = 0.05$) higher *Striga* infestation than the treated plots for both varieties. Generally, the level of *Striga* infestation was higher at Dutsen-Ma than Barhim. Table 4 also shows grain yield obtained at harvest in both locations. Treatments with mycoherbicide gave significantly ($p = 0.05$) higher grain yield at both locations for both SAMSORG 41 and farmers' local. This indicates yield advantages in the use of the mycoherbicide.

These results confirm that the mycoherbicide applied pre-sowing using spot-application can significantly reduce *Striga* incidence under field conditions in the Nigerian savanna. The efficacy of *F. oxysporum* in our field trials indicate that it

Table 3. Effect of mycoherbicide treatment on plant population and infestation with *Striga hermonthica* at two locations in the Nigerian savanna during 2000 and 2001 cropping seasons

Treatment	Location					
	Barhim (2000)			Dutsen-Ma (2001)		
	Stand count		Stands infected at harvest	Stand count		Stands infected at harvest
	3 Weeks	Harvest		3 Weeks	Harvest	
SAMSORG 41T ^a	242.9	239.7	23.4	334.4	327.6	14.6
SAMSORG 41NT ^b	167.4	130.8	84.2	168.9	140.9	86.6
Farmers local T	246.0	240.9	30.8	287.0	259.7	43.1
Farmers local NT	191.6	173.9	97.8	250.0	217.1	199.0
Mean	212.0	196.3	59.1	260.1	236.3	85.8
SE	7.03	8.75	6.01	12.23	11.87	12.00
DF	35	35	35	35	35	35

^aT – treated with mycoherbicide.

^bNT – not treated.

attacks *Striga* right from un-germinated seeds and symptoms are expressed up till the flowering stage as shown by the number of *Striga* plants showing dieback symptoms. Although many reports (e.g. Abbasher and Sauerborn, 1992; Ciotola et al., 1995; Kroschel et al., 1996; Abbasher et al., 1998; Marley et al., 1999) have shown that *Fusarium* based mycoherbicides applied pre-sowing reduce

Table 4. Average *Striga* shoot count^a and grain yield of sorghum (SAMSORG 40 and Farmer's local) at harvest time on nine farmer's fields each at Barhim (2000 cropping season) and Dutsen-Ma (2001 cropping season) villages in the Nigerian savanna

Treatment	<i>Striga</i> count (plot)		Grain yield (t/ha)	
	Barhim (2000)	Dutsen-Ma (2001)	Barhim (2000)	Dutsen-Ma (2001)
SAMSORG 41 T ^b	8.2	12.6	2.1	3.1
SAMSORG 41NT ^c	127	165	1.0	1.1
Farmers local T	10	19.4	2.0	2.6
Farmers local NT	139	201.6	0.6	1.3
Mean	71.1	99.7	1.4	2.0
S.E.	10.95	14.83	0.12	0.15
DF	35	35	35	35

^a per plot (plot size = 19 m × 10 m ≡ 25 rows, 10 m long).

^bT = treated with mycoherbicide.

^cNT = not treated.

S. hermonthica under controlled conditions, only reports by Diarra et al. (1996) and Ciotola et al. (2000) show that *F. oxysporum* can be effective in the control of *Striga* under field conditions. These reports agree with our results.

This approach clearly shows the potential of mycoherbicides to contribute to control of *S. hermonthica*. However, successful *Striga* management will result if the approach is developed into an integrated control system together with other measures such as cultural and especially host plant resistance where available. We estimated that using the rate of 5 g of mycoherbicide per sorghum stand, a hectare would require about 167 kg. Although we consider this amount to be high, this is an improvement over the reports of Bedi (1994) who used approximately 800 kg ha⁻¹ and Müller-Stover (2001) who calculated a requirement of 300 kg ha⁻¹ for *F. oxysporum* based inoculum used in the control of *Orobanche* spp. in sunflower. The volume of mycoherbicide involved necessitates the development of the mycoherbicide into forms that reduce the quantity to be applied. Hess et al. (2002) reported that formulated granules have added advantage of a longer shelf life and a reduction in the quantity of inoculum applied to the field. Further, since direct pre-sowing spot application of the mycoherbicide is the most effective, a technology that combines these two key characteristics will be most suitable. In this regard, we therefore find the development of *F. oxysporum* based mycoherbicide into formulated granules or a seed treatment mycoherbicide most desirable.

Acknowledgements

We are grateful to Messers A. Abdulrahman, M. Ahmed and T. Ochibe for technical assistance. We wish to sincerely acknowledge the assistance of A. Mustapha, Rabe Kaita (Zone 1) and Zone III Extension staff of Katsina State Agricultural Development Authority (KTARDA) for field monitoring and data collection. Thanks to Messers Joel Makama and Danladi Jarma for data analysis. We remain grateful to anonymous reviewers for their useful suggestions on the manuscript. This study was partly funded by West and Central Africa Sorghum Research Network, ICRISAT, BP 320, Bamako, Mali.

References

- Abbasher, A.A. and J. Sauerborn, 1992. *Fusarium nygamai*, a potential bioherbicide for *Striga hermonthica* control in sorghum. *Biol. Cont.* 2: 291–296.
- Abbasher, A.A., J. Kroschel and J. Sauerborn, 1995. Microorganisms of *Striga hermonthica* in northern Ghana with potential as biocontrol agents. *Biocontrol Sci. Technol.* 5: 157–161.

- Abbasher, A.A., D.E. Hess and J. Sauerborn, 1998. Fungal pathogens for biological control of *Striga hermonthica* on sorghum and pearl millet in West Africa. *Afr. Crop Sci. J.* 6: 179–188.
- Amalfitano, C., R. Pengue, A. Andolfi, M. Vurro, M.C. Zonno and D.A. Evidente, 2002. HPLC analysis of fusaric acid, 10,11 dehydrofusaric acid and their methyl esters, toxic metabolites produced by weed pathogenic *Fusarium* species. *Phytochem. Anal.* 13(5): 277–282.
- Bedi, J.S., 1994. Further studies on control of sunflower broomrape with *Fusarium oxysporum* f. sp. *Orthoceros* – a potential mycoherbicide. In: A.H. Piertese, J.A.C. Verkleij and A.J. Ter Borg (eds), *Proceedings of Third International Workshop on Orobanchae and related Striga Research*. Royal Tropical Institute, Amsterdam, The Netherlands. pp. 539–544.
- Berner, D.K., M.D. Winslow, A.E. Awad, K.F. Cardwell, D.R. Mohan raj and S.K. Kim, 1997. *Striga Research Methods*. 2nd edn. International Institute for Tropical Agriculture, Ibadan, Nigeria. 81 pp.
- Ciotola, M., A.K. Watson and S.G. Hallett, 1995. Discovery of an isolate of *Fusarium oxysporum* with potential to control *Striga hermonthica* in West Africa. *Weed Res.* 35: 303–309.
- Ciotola, M., A. Ditommaso and A.K. Watson, 2000. Chlamydospore production, inoculation methods and pathogenicity of *Fusarium oxysporum* M12-4A, a biocontrol for *Striga hermonthica*. *Biocontrol Sci. Technol.* 10: 129–145.
- Diarra, C., M. Ciotola, S.G. Hallett, D.E. Hess and A.K. Watson, 1996. Field efficacy of *Fusarium oxysporum* for the control of *Striga hermonthica*. *Nuisibles-Pests-Pragas* 4: 257–263.
- Elzein, A.E.M., 2003. Development of a granular mycoherbicide formulation of *Fusarium oxysporum* “Foxy 2” for the biological control of *Striga hermonthica* (Del.) Benth. In: J. Kroschel (ed), *Tropical Agriculture: Advances in Crop Research 2*. Margraf Verlag, Weikersheim, Germany. 174 pp.
- Haussmann, B.I.G., D.E. Hess, H.G. Welz and H.H. Geiger, 2000. Improved methodologies for breeding striga-resistant sorghums. *Field Crops Res.* 66: 196–211.
- Hess, D.E., J. Kroschel, D. Traore, A.E.M. Elzein, P.S. Marley, A.A. Abbasher and C. Diarra, 2002. Striga: Biological control strategies for a new millennium. In: J.F. Leslie (ed), *Sorghum and Millet Diseases 2000*. Iowa State University Press, Iowa, USA. pp. 165–170.
- Kroschel, J., A. Hundt, A.A. Abbasher and J. Sauerborn, 1996. Pathogenicity of fungi collected in northern Ghana to *Striga hermonthica*. *Weed Res.* 36: 515–520.
- Lagoke, S.T.O., I. Kureh, D.A. Aba and S.C. Gupta, 2000. Host plant resistance for striga control in sorghum – activities at IAR, Samaru, Nigeria. In: B.I.G. Haussmann, D.E. Hess, M.L. Koyama, L. Grivet, H.F.W. Rattunde and H.H. Geiger (eds), *Breeding for Striga Resistance in Cereals*. Margraf Verlag, Germany, pp. 325–334.
- Marley, P.S., S.M. Ahmed, J.A.Y. Shebayan and S.T.O. Lagoke, 1999. Isolation of *Fusarium oxysporum* with potential for biocontrol of the witch weed (*Striga hermonthica*) in the Nigerian Savanna. *Biocontrol Sci. Technol.* 9: 159–163.
- Marley, P.S., J.A.Y. Shebayan, I. Onu, D.A. Aba and R. Musa, 2002. Analysis of biotic constraints limiting sorghum production in the Nigerian Sudano-Sahelian savanna. *Samaru J. of Agricult. Res.* 18: 41–53.
- Müller-stover, D., 2001. Possibilities of biological control of *Orobanchae crenata* and *O. cumana* with *Ulocladium botrytis* Preuss and *Fusarium oxysporum* Schlecht f. sp.

- orthocera* (Appel & Wollenw.). *Agroecology* 3. Ph.D thesis, University of Hohenheim, Stuttgart, Germany. 174 pp.
- Ogungbile, A.O., R. Tabo, N. Van Duivenbooden and S.K. Debrah, 1998. Analysis of constraints to agricultural production in the Sudan savanna zone of Nigeria using multi-scale characterization. *Netherlands J. Agricult. Sci.* 46: 27–38.
- Ogungbile, A.O. and P.S. Marley, 2001. Industrial utilization of cereals: the case of sorghum and maize. In: *Agricultural Technology Transfer and Commercialization in Nigeria*. Proceedings of the OAU/STRC-SAFGRAD/IITA/USAID Stakeholders Consultation Workshop held at IITA, Ibadan, Nigeria. 9–11 April 2001. pp. 57–72.
- Ray, P.A., B. Unamma and F.O. Anuebunwa, 1989. On-farm evaluation of chemical, manual and cultural practises in integrated weed management in a yam + maize intercrop. In: Murasears, H.J.W. and P. Walker (eds), *On-farm research in theory and practice*. International Institute for Tropical Agriculture, Ibadan, Nigeria. pp. 161–167.
- Savard, M.E., J.D. Miller, M. Ciotola and A.K. Watson, 1997. Secondary metabolites produced by a strain of *Fusarium oxysporum* used for Striga control in West Africa. *Biocontrol Sci. Technol.* 7: 61–64.