Expl Agric. (2003), volume 39, pp. 99–108 © *2003 Cambridge University Press*
DOI: 10.1017/S0014479702001084 *Printed in the United Kingdom*

EVALUATION OF INTEGRATED *STRIGA HERMONTHICA* CONTROL TECHNOLOGIES UNDER FARMER MANAGEMENT

By S. SCHULZ†, M. A. HUSSAINI‡, J. G. KLING†, D. K. BERNER†
and F. O. IKIE†

†*International Institute of Tropical Agriculture, Oyo Road, PMB 5320 Ibadan, Nigeria and*
‡*Institute for Agricultural Research, Ahmadu Bello University, PMB 1044, Zaria, Nigeria*

(*Accepted 30 July 2002*)

SUMMARY

On-farm trials were conducted in the northern Guinea savanna of Nigeria. The objective was to compare integrated *Striga hermonthica* control measures (soyabean or cowpea trap crop in the first year followed by maize resistant to Striga in the second year) with farmers' traditional practices (cereal-based cropping systems) under farmer-managed conditions.

Integrated control proved to be highly effective in terms of reducing Striga incidence both in terms of reduced seed density in the soil and decreased infection in maize. Resistant maize following the soyabean trap crop yielded 1.58 t ha^{-1} of grain and out-yielded local maize following traditional practices by more than 80%. Similarly, the overall productivity over the period of the experiment was highest with the integrated control treatment using soyabean. Conversely, resistant maize after the cowpea trap crop yielded only 0.92 t ha^{-1} (possibly due to the poor performance of the cowpea crop in the first year), and maize yields were similar to those obtained with farmer practices. Initial Striga seed density in the soil was negatively correlated ($r = -0.33$) with soil nitrogen, but nitrogen-fertilizer application rates did not seem to affect the level of Striga infection in maize.

INTRODUCTION

Striga hermonthica (Del.) Benth., a root-parasitic flowering plant, is endemic in Africa and constitutes one of the most severe constraints to cereal production in sub-Saharan Africa (Dashiell *et al.*, 2000). Traditional cereal-based cropping systems included prolonged fallow periods that kept Striga infestation at tolerable levels. As land use intensified with more cereal monocropping and reduced fallow periods, infestation levels increased, threatening the livelihood of millions of people. Sauerborn (1991) estimated that more than 5×10^6 ha were infested in six West African countries and that around 21×10^6 ha might be infested in Africa as a whole, resulting in annual losses of more than four million tonnes of grain (US$ 480 million).

Research on *S. hermonthica* has a long history, and a range of effective component technologies have been identified as effective control methods (Parker and Riches, 1993). Examples are host-plant resistance and the use of trap crops, i.e., non-hosts that stimulate the suicidal germination of Striga seeds and therefore reduce the seed bank

Mailing address of corresponding author: Dr. S. Schulz, IITA, c/o Lambourn & Co., 26 Dingwall Road, Croydon CR9 3EE, UK; Email: S.Schulz@cgiar.org

in the soil. Kling *et al*. (2000) reported that in researcher-managed trials with artificial infestation, resistant hybrid maize (cv. 9022-13) yielded 2.5 t ha^{-1} of grain whereas the susceptible check variety (cv. 8338-1) produced only 0.7 t ha^{-1}. In the context of this paper, the term 'resistant maize' refers to cultivars that show less attack in terms of the numbers of emerged *S. hermonthica,* as defined by Parker and Riches (1993). The effectiveness of leguminous trap crops in reducing the *S. hermonthica* seed bank was demonstrated by Sauerborn *et al*. (1999) in field experiments in Ghana where annual double cropping of trap crops (soyabean, sunflower, cotton) reduced the seedbank by around 30% each year. Carsky *et al*. (2000) reported that Striga incidence in maize after soyabean, compared with maize after sorghum, was significantly reduced from 3.2 to 1.3 emerged Striga plants per maize plant, resulting in greatly improved maize yields.

In addition to host-plant resistance and trap crops, a substantial amount of work has been carried out to study the effects of soil fertility on Striga infestation. It has been shown that infestation is frequently associated with low soil fertility (Lagoke *et al*., 1991; Weber *et al*., 1995; Ransom, 1999). Hence, improved soil fertility conditions are likely to lead to reduced infestation (Debrah *et al*., 1998). The mechanisms involved are not yet fully understood, and there is a need to quantify the relationship between soil fertility parameters and Striga incidence (Pieterse and Verkleij, 1991).

It is widely recognized that sustainable control of Striga through single control options is likely to be precluded by the parasite's genetic plasticity, which enables it to become adapted to individual control methods (Dashiell *et al*., 2000). In addition, the diversity of African farming systems implies that all control options will not be universally acceptable and effective. Hence, successful control is more likely to be achieved by combining a range of individual component technologies into integrated programmes to provide flexible and sustainable control over a wide range of biophysical and socio-economic environments (Berner and Kling, 1997).

The potentials of Striga control options have been demonstrated under controlled, researcher-managed conditions; it is necessary, therefore, to demonstrate that these technologies work efficiently under farmer-managed conditions and are indeed appropriate for African farmers (Fischer, 1999). The objectives of this investigation were to validate integrated control measures under farmer-managed conditions and to study the effects of soil chemical parameters on Striga incidence.

MATERIALS AND METHODS

Over the period 1999 to 2000, farmer-managed trials were carried out in three villages, Rimau (10° 25'N and 7° 46'E), Mahuta (11°12'N and 7° 40'E), and Kaya (11°15'N and 7°16'E), in the northern Guinea-savanna agro-ecozone of Nigeria. These locations were chosen because of their severe infestation with *S. hermonthica* and for logistical reasons, i.e., accessibility and availability of field technicians. The area is characterized by a mono-modal rainfall distribution, an average annual precipitation of 900 to 1300 mm, and a growing period of 150 to 180 d (May to October). The predominant soil types are sandy Alfisols of moderate to low fertility. Important crops are maize

(*Zea mays*), sorghum (*Sorghum bicolor*), millet (*Pennisetum typhoides*), soyabean (*Glycine max*), cowpea (*Vigna unguiculata*), and groundnut (*Arachis hypogaea*). Both sole and intercropping of legumes and cereals are practised.

Experiment design

The trial was carried out in 19 farmers' fields that had a history of severe Striga infestation and poor soil fertility. The experiment was managed entirely by farmers, and researcher input was limited to providing technical advice and collecting data. A randomized complete blocks design was used, with farmers as replicates and two treatments in each replicate (Table 1). The trial comprised five treatments grouped into two groups i.e., 'integrated control' and 'farmer practice'. The former group consisted of two treatments, i.e., 'soyabean', (14 farmers) and 'cowpea' (five farmers) as legume trap crops in 1999, followed by Striga-resistant maize in 2000 (Kling *et al.*, 2000). The latter group consisted of three treatments, i.e., sole cereal (seven farmers), intercropping of local cereals and legumes (10 farmers), and fallow (two farmers) in 1999, followed by local maize in 2000. The fallow treatment had to be included because these fields were degraded to such an extent that farmers were unwilling to grow a cereal crop in 1999. At the onset of the trial, each farmer chose one treatment from the integrated-control group and one treatment from the farmer-practice group. The number of treatments tested per farmer was limited to two to ensure proper implementation and, since the treatments were the farmers' choice, the number of replications (farmers) per treatment varied (Table 1). Each of the treatments was tested in a plot 900 m^2 in area (30 × 30 m), to compensate for the expected variability in Striga seed density in the soil and to allow for sufficiently large border areas (5 m) around each plot. All data were taken from the inner 20 × 20 m square of each plot.

Using the cut-root assay as described in Berner *et al.* (1997), recommended improved and popular local soyabean and cowpea cultivars were screened for their capacity to stimulate germination of Striga seeds collected from the trial locations. The most effective soyabean cultivar (TGx 1448-2E) stimulated around 20% germination of the viable Striga seeds and the best cowpea cultivar (IT-90K-284-2) stimulated around 26%. No such effect was observed for the local legume varieties.

Table 1. Integrated-control and farmer-practice treatments applied in 1999 and 2000.

Treatment			Year	
Group	Number	Number of farmers	1999	2000
Integrated control	1	14	Soyabean trap crop (TGx 1448-2E)	Resistant maize† (TZL Comp 1)
	2	5	Cowpea trap crop (IT-90K-284-2)	Resistant maize (TZL Comp 1)
Farmer practice	3	7	Sole cereal‡	Local maize
	4	10	Intercrop§	Local maize
	5	2	Fallow	Local maize

†Resistant to *S. hermonthica*, open-pollinated.

‡Local maize or sorghum.

§Local maize or sorghum intercropped with local cowpea, soyabean, or groundnut.

Sampling and analytical procedures

Prior to trial establishment in 1999, 10 soil samples were taken from each plot at 0–150 mm depth, bulked, and sub-sampled to produce one composite sample. The procedure was repeated at planting in 2000. Chemical soil properties were measured following routine procedures (IITA, 1981). Striga seed densities in the soil were determined using the potassium carbonate separation method and were calculated for a soil depth of 150 mm with an assumed dry bulk density of 1.5 g cm^{-3} (Berner *et al.*, 1997).

Crop yields as well as Striga plant densities were determined in each plot from six randomly selected subplots each of 10–15 m^2 in area. Grain and stover dry-matter yields were determined by drying representative samples to constant weight at 65 °C, and grain yields were then adjusted to 12% moisture content. Legume seed yields obtained in 1999 in treatments 1, 2, and 4 were converted into maize-equivalent yields (Oswald *et al.*, 2002) according to their market price in northern Nigeria (average of November and December 1999) to be able to compare the productivity of the five treatments.

Statistical analyses were carried out with SAS (SAS Institute Inc., 1989) applying the mixed model and correlation procedures. The data on Striga plant density were transformed using the square-root transformation $(x + 0.5)^{1/2}$. Striga seed density in the soil was converted using the logarithmic transformation $\log_{10}(x + 1)$. Unless stated otherwise, results are presented as treatment means and mixed model contrast probabilities are based on least square means.

Agronomic practices

At the onset of the experiment in 1999, phosphorus (P) was applied to all plots at a rate of 13.1 kg ha^{-1} to eliminate this element as a limiting factor to plant (particularly legume) growth. Thereafter, since the objective of the experiment was to test the treatments under farmer-managed conditions, all crops were grown according to individual farmer preferences. Consequently, agronomic practices varied among farmers. The authors ensured, however, that the plots within each replicate (i.e., both varieties of maize on each farm) were treated uniformly in 2000 in terms of seed rate, fertilizer application, and weeding practices, even though these practices varied from farm to farm. All crops were planted in rows. For legume crops, the inter-row spacing varied between 0.5 and 0.9 m and for cereal crops between 0.75 and 1.00 m, resulting in average plant densities of 44 000 plants ha^{-1} for legumes and 34 000 plants ha^{-1} for cereals. In the cereal crop in 1999, farmers did not prevent Striga from seeding. In 2000, all farmers applied nitrogen (N) fertilizer, mostly as urea, to maize at an average rate of 121 kg ha^{-1} (range 42–333 kg N ha^{-1}).

RESULTS

At the onset of the trial, total soil N, organic carbon (c), and available phosphorus (P) contents varied considerably between sites but were, on average, very low; indicating that soils in these fields were degraded and of poor inherent fertility (Table 2). Prior to the start of the trials, soils were heavily infested with Striga with an average initial

Table 2. Chemical properties of soil (0–150 mm) from the experiment fields (n=19) prior to the establishment of the trials in 1999.

	pH (in water)	N (%)	Bray-1 P (mg kg^{-1})	Organic C (%)
Mean	5.1	0.069	6.6	0.61
Range	5.0–5.2	0.048–0.089	2.0–28.2	0.44–0.97
s.e.	0.009	0.0014	0.90	0.019

seed density of more than 23 000 seeds m^{-2}. Although the average seed density in the integrated-control plots (30 081 seeds m^{-2}) appeared to be higher than in farmer-practice plots (16 594 seeds m^{-2}), the difference was not significant ($p > 0.88$).

Crop yields

Legume seed and cereal grain yields obtained over the period of the experiment are shown in Table 3. In 1999, the soyabean trap crop (T_1) in the integrated-control group, yielded well (0.77 t ha^{-1}) but the cowpea trap crop (T_2) had a low yield (0.28 t ha^{-1}), primarily because of high pest and disease incidence. In the farmer-practice group, sole cereal crops (T_3) yielded less than 0.70 t ha^{-1} and legume-cereal intercrops (T_4) produced only 0.35 t ha^{-1} of cereal grain and 0.16 t ha^{-1} legume seed. In terms of maize equivalent yield in 1999, the soyabean trap crop out-yielded ($p < 0.001$) all other treatments; however, the yields obtained with the cowpea trap crop were not significantly different from those of treatments 3, 4, and 5 (Table 3). Similarly, in 2000, maize grain yields of 1.58 t ha^{-1} were higher ($p > 0.05$) in T_1 compared with the other treatments, the only exception being T_3 (sole cereal – local maize) where the difference was only marginally significant ($p = 0.08$).

Table 3. Treatment effects on legume and cereal grain yields (t ha^{-1}) and selected contrast probabilities.

Treatment				Year				
				1999			2000	1999+2000
	Number	1999 crop	Number of farmers	Cereal yield	Legume yield	Equivalent yield[†]	Maize yield	Cumulative productivity[‡]
Integrated-control	1	Soyabean	14	–	0.77	2.60	1.58	4.18
	2	Cowpea	5	–	0.28	0.67	0.92	1.58
Farmer-practice	3	Sole cereal	7	0.69	0	0.69	1.15	1.84
	4	Intercrop	10	0.35	0.16	0.79	0.73	1.52
	5	Fallow	2	0	0	0	0.56	0.56
Contrast probabilities for selected least square means								
T_1 *vs.* T_2						<0.01	<0.01	<0.01
T_1 *vs.* T_3						<0.01	0.08	<0.01
T_1 *vs.* T_4						<0.01	<0.01	<0.01
T_1 *vs.* T_5						<0.01	0.03	<0.01

[†] Legume (soyabean, cowpea, groundnut) yields obtained in 1999 were converted into maize equivalents using average (November and December 1999) market prices in northern Nigeria, prices in $US per 1000 kg (1 $US = 100 Naira): soyabean = $370; cowpea = $260; groundnut = $350; maize and sorghum = $110.

[‡] Cumulative productivity=maize equivalent yields in 1999+maize yield in 2000.

Table 4. Treatment effects on emerged *S. hermonthica* plants at 12 weeks after planting in 2000, per unit area and per maize plant, and selected contrast probabilities.

				Year	
Treatment	Number	1999 crop	Number of farmers	2000 Striga plants ha^{-1}	2000 Striga plants maize plant^{-1}
Integrated-control	1	Soyabean	14	7119	0.14
	2	Cowpea	5	3010	0.06
Farmer-practice	3	Sole cereal	7	12 552	0.43
	4	Intercrop	10	16 750	0.46
	5	Fallow	2	16 879	0.66
Contrasts probabilities for least square means					
T_1 *vs.* T_2				0.81	0.64
T_1 *vs.* T_3				0.08	0.03
T_1 *vs.* T_4				<0.01	<0.01
T_1 *vs.* T_5				0.06	0.02

In terms of cumulative productivity, T_1 produced the highest overall yield (4.18 t ha^{-1}) and out-yielded (($p < 0.001$) all other treatments, including T_2. No other significant differences were observed (Table 3).

Striga seed and plant density

In 2000, substantial treatment effects were observed on the Striga seed bank and incidence of emerged Striga (Table 4). Both integrated-control treatments (T_1 and T_2) compared with the farmer-practice treatments (T_3, T_4, and T_5) reduced ($p < 0.05$) Striga incidence in maize by up to 91% in terms of emerged Striga plants per maize plant. Treatment effects in terms of Striga plants per unit area followed a similar trend but were not as pronounced. In 2000, the two integrated-control treatments resulted in a similar Striga incidence. In 1999, within the farmer-practice group, no differences ($p > 0.05$) were observed in Striga emergence between farmers who sole-cropped cereals and those who intercropped cereals and legumes.

When, in 2000, individual treatments within the integrated-control and the farmer-practice groups, were averaged, the Striga seed bank in the soil was lower ($p = 0.06$) in plots of the integrated-control group plots (average seed density 15 390 seeds m^{-2}) compared with farmer-practice plots (average seed density 26 042 seeds m^{-2}) (Figure 1). No differences between individual treatments were detected in terms of Striga seed density, possibly due to the large variability between different fields and the limited number of replications for some of the treatments.

Results of correlation analyses showed that the initial (1999) Striga seed density in the soil was negatively correlated ($r = -0.33$; $p < 0.05$) with the soil total N content. However, no other soil parameter (organic C, P, pH) appeared to affect the Striga seed density. In 2000, the incidence of emerged Striga on maize at 12 weeks after planting (WAP) was positively correlated ($r = 0.34$; $p < 0.05$) with the number of Striga seeds in the soil sampled in that year, and maize grain yields were negatively ($r = -0.32$; $p < 0.06$) correlated with incidence of emerged Striga at eight WAP. However,

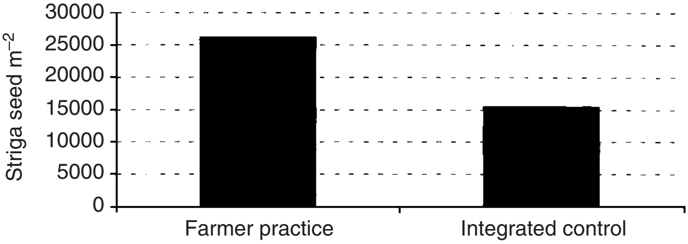

Figure 1. Effect of integrated-control (average of T_1 and T_2) and farmer-practice (average of T_3, T_4 and T_5) treatments on *S. hermonthica* seed densities in the soil in 2000 (treatment difference significant at $p = 0.0560$).

N-fertilizer application rate and Striga incidence in maize at 12 WAP were not correlated.

DISCUSSION

Although many farmers applied N fertilizer at high rates, average maize grain yields in 2000 were less than 1.2 t ha^{-1}. This lack of response to N fertilizer, in combination with low total soil N, P, and C contents, showed that soils at these sites were indeed highly degraded. Despite these unfavourable soil conditions, however, in 2000 T_1 increased the maize yield by more than 80% over the average yield obtained with farmer practices (0.87 t ha^{-1}) to levels which were slightly above the Nigerian average maize yield of 1.39 t ha^{-1} (FAO, 2001). In terms of cumulative productivity, the soyabean – resistant maize rotation, which produced 4.18 t ha^{-1}, clearly out-performed all other treatments. However, this result should be interpreted with caution as it depends on market prices, which tend to fluctuate over years. For example, by reducing legume prices by 30%, the cumulative productivity of the soyabean – resistant maize rotation would have fallen by almost 20% to 3.4 t ha^{-1} whereas the sole cereal rotation would not have been affected.

T_1 and T_2 were equally effective in reducing Striga incidence, however, the latter performed poorly with regard to both legume and grain yields. In 1999, cowpea seed yields of only 0.28 t ha^{-1} were disappointing and below the national average yield of 0.42 t ha^{-1} (FAO, 2001). This is partly explained by the fact that cowpea is not commonly grown as a sole crop in this area and farmers lack the experience and technology, particularly in terms of plant protection, to produce high-yielding cowpea crops. Cowpea, therefore should only be further promoted as a legume trap crop for integrated Striga control, if the productivity of the cowpea – maize rotation can be increased substantially.

It has been shown in various studies that intercropping cereals with legumes compared with sole-cropping cereals can decrease the number of Striga plants and seeds that mature. This, in turn, is likely to lead to reduced Striga infestation in the following cereal crop (Carsky *et al.*, 1994; Odhiambo and Ransom, 1994). How intercrops affect Striga is still not completely understood. They may act as trap crops, thereby reducing the Striga seed bank or they may suppress Striga seed germination and subsequent development due to changes in the microclimate, e.g. shading under the legume crop's canopy (Oswald *et al.*, 2002). In this study, however, no treatment differences in terms of Striga infestation were observed in 2000 between farmers who had sole-cropped cereals, or those who had intercropped cereals and legumes in the farmer-practice group in 1999. This may be due to the relatively low legume plant densities of less than 20 000 legume plants ha^{-1} in the intercrop treatment compared with 44 000 plants ha^{-1} in the legume trap crop treatments, and the 42 000 legume plants ha^{-1} reported by Carsky *et al.* (1994) for legume-cereal intercrops that successfully reduced Striga infestation. These findings suggest that legume-cereal intercropping (as opposed to sole-cropping) may affect Striga infestation in the following year only if the legume plant density is sufficiently high. Further research might be warranted to study the interactions between legume density in intercrops and their effect on Striga infestation.

The design of this study did not allow the authors to separate the effects of the legume trap crop and of the Striga-resistant maize. However, the latter has been tested in the past under farmer-managed conditions. For example, Carsky *et al.* (1998) compared the performance of an open-pollinated cultivar (STR Syn-W), resistant to Striga, with that of local cultivars in 37 farmer-managed trials in northern Nigeria and found no differences in terms of emerged Striga plants and maize grain yield. By contrast, the authors' findings showed that the combined use of legume trap crops and Striga-resistant maize reduced the Striga seed density in the soil and Striga infection on maize, and, in the case of the soyabean trap crop, increased maize grain yields. Compared with the results obtained with resistant cultivars only, therefore, it is likely that a substantial additional benefit can be attained under farmer-managed conditions by rotating legume trap crops and resistant cultivars of maize.

The processes governing the interaction between soil fertility and Striga infestation are not yet well understood (Pieterse and Verkleij, 1991). The authors' findings showed that soil N and the initial Striga seed density in the soil were negatively correlated ($r = -0.33$). Similarly, Weber *et al.* (1995) reported a significantly lower Striga seed density in soils in northern Nigeria with a low C : N ratio compared with soils with a high C : N ratio. Hence, there is increasing evidence that soil N and organic C play a role in reducing Striga seed density in the soil.

Apart from indirectly reducing Striga incidence, N is also widely reported to affect directly Striga infection if applied as inorganic fertilizer. A comprehensive review by Pieterse and Verkleij (1991) concluded that N fertilizer, in particular in the forms of urea and ammonium, may reduce Striga infection. However, the effect may not always be apparent because, for example, on highly degraded, infertile soils, N fertilizers seemed to stimulate Striga infection. In this study, N was applied to maize in 2000 at rates ranging from 42 to 333 kg ha^{-1}. However, the correlation analysis did not indicate a relationship between N-fertilizer application rates and Striga infection as measured by the number of emerged parasites. This observation could be an indicator of the high degree of soil degradation in the experiment's fields with the application of N fertilizer stimulating Striga infection. It is likely, however, that the repeated use of N fertilizer would reduce Striga incidence in the long term by gradually increasing total soil N.

Acknowledgements. This paper is a product of a project partially funded by the UK Department for International Development (DFID). The views expressed are not necessarily those of DFID. The contribution of Messrs L. Tobe and S. Bako to data collection in farmers' fields are gratefully acknowledged.

REFERENCES

Berner, D. K. and Kling, J. G. (1997). Sustainable control of *S. hermonthica* spp. through a focused integrated pest management program. In *Contributing to Food Self-sufficiency: Maize Research and Development in West and Central Africa*, 1–11 (Eds B. Badu-Apraku, M. O. Akoroda, M. Ouedraogo and F. M. Quin). Ibadan, Nigeria: International Institute of Tropical Agriculture.

Berner, D. K., Winslow, M. D., Awad, A. E., Cardwell, K. F., Mohan Raj, D. R. and Kim, S. K. (1997). Striga Research Methods. *Manual, The Pan-African Striga Control Network (PASCON) and the International Institute of Tropical Agriculture.*

Carsky, R. J., Singh, L. and Ndikawa, R. (1994). Suppression of *Striga hermonthica* on sorghum using a cowpea intercrop. *Experimental Agriculture* 30:349–358.

Carsky, R. J., Nokoe, S., Lagoke, S. T. O. and Kim, S. K. (1998). Maize yield determinants in farmer-managed trials in the Nigerian northern Guinea Savanna. *Experimental Agriculture* 34:407–422.

Carsky, R. J., Berner, D. K., Dashiell, K., Oyewole, B. and Schulz, S. (2000). Reduction of *Striga hermonthica* parasitism on maize using soyabean rotation. *International Journal of Pest Management* 46:115–120.

Dashiell, K., di Umba, U., Kling, J. G., Melake-Berhan, A. and Berner, D. K. (2000). Breeding for integrated management of *Striga hermonthica.* In *Breeding for Striga Resistance in Cereals*, 273–281 (Eds B. I. G. Haussmann, D. E. Hess, M. L. Koyama, L. Grivet, H. F. W. Rattunde and H. H. Geiger). Weikersheim, Germany: Margraf Verlag.

Debrah, S. K., Defoer, T. and Bengaly, M. (1998). Integrating farmers' knowledge, attitude and practice in the development of sustainable Striga control interventions in southern Mali. *Netherlands Journal of Agricultural Science* 46:65–75.

FAO (2001). *FAOSTAT Agriculture Data*, http://apps.fao.org/cgi-bin/nph-db.pl?subset=agriculture, Rome, Italy: Food and Agriculture Organization of the UN.

Fischer, P. A. (1999). *Action Research in Extension Material and Message Development: The Striga Problem of Northern Ghana revisited.* Weikersheim, Germany: Margraf Verlag.

IITA (1981). Analytical Services Laboratory Manual, Ibadan, Nigeria: International Institute of Tropical Agriculture.

Kling, J. G., Fajemisin, J. M., Badu-Apraku, B., Diallo, A., Menkir, A. and Melake-Berhan, A. (2000). Striga resistance breeding in maize. In *Breeding for Striga Resistance in Cereals*, 103–118 (Eds B. I. G. Haussmann, D. E. Hess, M. L. Koyama, L. Grivet, H. F. W. Rattunde and H. H. Geiger). Weikersheim, Germany: Margraf Verlag.

Lagoke, S. T. O., Parkinson, V. and Agunbiade, R. M. (1991). Parasitic weeds and their control methods in Africa. In: *Combating Striga in Africa*, 3–14 (Ed S. K. Kim). Ibadan, Nigeria: International Institute of Tropical Agriculture.

Odhiambo, G. D. and Ransom, J. K. (1994). Preliminary evaluation of long-term effects of trap cropping and maize management on Striga. In: *Biology and Management of* Orobanche, 505–512 (Eds A. H. Pieterse, J. A. Verkleij and S. J. ter Borg). Amsterdam, The Netherlands: Royal Tropical Institute.

Oswald, A., Ransom, J. K., Kroschel, J. and Sauerborn, J. (2002). Intercropping controls Striga in maize-based farming systems. *Crop Protection* 21:367–374.

Parker C. and Riches, C. R. (1993). *Parasitic Weeds of the World: Biology and Control.* Wallingford, UK: CABI Publishing.

Pieterse, A. H. and Verkleij, J. A. C. (1991). Effect of soil conditions on Striga development – a review. *Proceedings of the 5th International Symposium of Parasitic Weeds, Nairobi, Kenya*, 329–339.

Ransom, J. K. (1999). The status quo of Striga Control: Cultural, chemical and integrated aspects. In *Advances in Parasitic Weed Control at On-farm Level, Vol I, Joint Action to Control Striga in Africa*, 133–144 (Eds J. Kroschel, H. Mercer-Quarshie and J. Sauerborn). Weikersheim, Germany: Margraf Verlag.

SAS Institute Inc. (1989). *SAS/STAT User's Guide, Version 6, 4 edition, Vol. 2.* Cary, NC, USA: SAS Institute Inc.

Sauerborn, J. (1991). The economic importance of the phytoparasites Orobanche and Striga. *Proceedings of the 5th International Symposium of Parasitic Weeds, Nairobi, Kenya, 1991*, 137–143.

Sauerborn, J., Sprich, H. and Mercer-Quarshie, H. (1999). Parasitic weed infestation of maize and sorghum as influenced by crop rotation. In *Advances in Parasitic Weed Control at On-farm Level, Vol I, Joint Action to Control Striga in Africa*, 161–169 (Eds J. Kroschel, H. Mercer-Quarshie and J. Sauerborn). Weikersheim, Germany: Margraf Verlag.

Weber, G., Elemo, K., Award, A., Lagoke, S. T. O. and Oikeh, S. (1995). *S. hermonthica* in cropping systems of the northern Guinea savanna. *Resource and Crop Management Research Monograph, International Institute of Tropical Agriculture, No. 19.*