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Evaluating and scaling-up integrated *Striga hermonthica* control technologies among farmers in northern Nigeria

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Abstract

The results are presented of a project to promote integrated Striga control (ISC) technologies to farmers in the Guinea savanna of northern Nigeria. Extension agents used a participatory research and extension approach (PREA) to encourage farmers to test and adopt ISC technologies. Over a 2-year period, the performance of the technologies was compared with the common farmers' practice with respect to crop yields, Striga seedbank, Striga damage and economics, as well as the adoption and adaptation of ISC technologies among lead farmers and others. ISC improved crop productivity on average by 88%. In the farmers' practice, Striga seedbank increased by 46% in 2 years, while in plots under ISC it was reduced by a similar percentage. ISC resulted in higher margins than the farmers' practice, but increased labour requirements were found to be a limitation for the expansion of the recommended technologies. Improved seed varieties, however, were rapidly adopted by farmers, but often used at lower plant populations than recommended and in mixed cropping systems. It was estimated that the participation of each extension agent resulted in the transfer of knowledge and seed to an average of 240 farmers. In addition, the PREA had improved community, group, and farmer–extension agent relationships. Ongoing demand by Government and NGOs for training in PREA, extension material and improved seed suggested that scaling-up has continued beyond the lifespan of the project.

Keywords: On-farm research; *Striga hermonthica*; Seedbank; Crop yields; Economics; PREA; Adoption

1. Introduction

The parasitic weed *Striga hermonthica* (Del.) Benth. (Striga) has become a severe constraint for cereal production in various parts of Africa, including the moist and dry savannas of West Africa. Intensification of cereal-based systems has increased the area under continuous cereal cropping and reduced the traditional fallow period that used to keep Striga pressure at tolerable levels in the savannas. This has allowed Striga to become a common weed that may cause yield losses of over 50% in cereals, thereby affecting the livelihood of millions of mostly resource-poor farmers (Pieterse and Verkleij, 1991).

In the past, research on Striga control has resulted in the identification of a range of technologies. The use of Striga tolerant or resistant varieties of maize (*Zea mays*), sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*) can be an effective way of reducing Striga damage (Parker and Riches, 1993; Carsky et al., 1996; Kling et al., 2000). The use of trap crops that stimulate the suicidal germination of Striga is another control technology. Effective trap crops include varieties of groundnut (*Arachis hypogaea*), soybean (*Glycine max*), cowpea (*Vigna unguiculata*) and

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sesame (*Sesamum indicum*) (Carsky et al., 2000; Dashiell et al., 2000; Hess and Dodo, 2003). The application of nitrogen fertiliser to cereals on soils of low fertility also reduces crop damage caused by Striga. Although Striga abundance is clearly favoured by low soil fertility (Weber et al., 1995; Debrah et al., 1998), the mechanisms by which nitrogen reduces Striga damage are not well understood, and high levels of nitrogen application, above $120\,\mathrm{kg\,N\,ha^{-1}}$, would be required to achieve a significant reduction in Striga emergence (Kim et al., 1997). Farmers themselves have also developed a range of coping strategies. In a survey in northern Nigeria, farmers mentioned hand-roguing and hoe-weeding, application of inorganic fertiliser, manure or ash, crop rotations, fallowing and early planting (Emechebe et al., 2004). Striga was nevertheless rated as the major constraint for crop production, followed by the related issues of poor soil fertility and fertiliser shortages.

A single measure may not provide satisfactory Striga control, as none of the available options on their own is likely to suit the wide diversity of biophysical and socio-economic environments in which farmers work. In addition, the weed's genetic plasticity may allow it to adapt to individual control measures. Therefore, the need exists for an integrated control strategy that is flexible and robust enough to suit farmers' environments (Berner et al., 1997; Debrah et al., 1998) and is disseminated in a manner that stimulates farmer-to-farmer diffusion. Resource-poor farmers should be able to carry the investments associated with Striga control measures and rapid returns on investments, in terms of enhanced yields and reduced Striga pressure, would be required to convince farmers to adopt (Oswald, 2005). The agronomic and economic potential of an integrated Striga control (ISC) package under farmer-managed conditions in northern Nigeria has been demonstrated on a small scale by Schulz et al. (2003) and Ellis-Jones et al. (2004a). Given the initial successes, the control technology was disseminated to a large number of farmers in northern Nigeria, using a participatory research and extension approach (PREA) (Ellis-Jones et al., 2004b).

This study examines:

- the performance of an ISC package on farmers' fields in the northern Guinea savanna of Nigeria with respect to crop yields, Striga seedbank, Striga damage and economics over a period of 2 years;
- the adoption or adaptation of recommended technologies among farmers, thereby assessing the potential to scale-up ISC technologies through farmer-to-farmer extension.

2. Methodology

To disseminate ISC methods, the project involved 33 State and Local Government extension agents (EAs), NGOs, and commercial seed companies working in 42

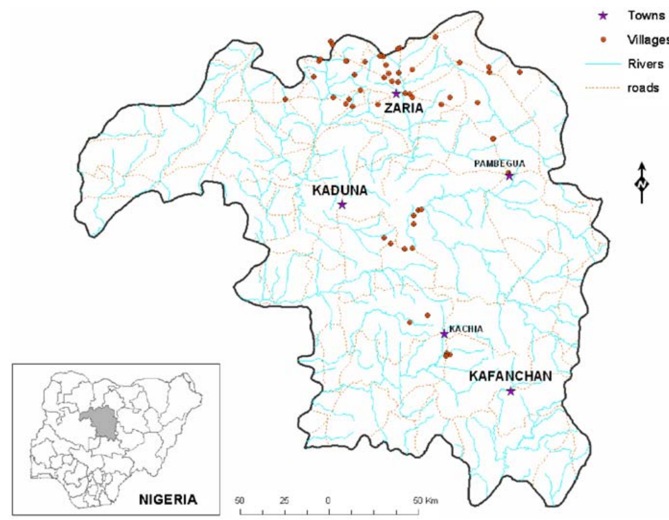

Fig. 1. Map of Kaduna State indicating the villages where lead farmers were located.

communities in Kaduna State in northern Nigeria (Fig. 1). In all communities targeted by the project, social mobilisation activities and community analyses were conducted as a first stage in the PREA cycle. This provided an assessment of livelihood strategies, natural resources problems, priority crops, local institutions, local coping mechanisms and Striga control methods that farmers saw as priorities for testing (Emechebe et al., 2004). Striga was identified as the major biophysical constraint for crop production in all 42 villages. During these initial activities, community-based organisations (CBOs) in each village were identified and these typically nominated 2–3 farmers to represent each group as a 'lead farmer'. The communities mandated 154 lead farmers, representing 88 CBOs, to establish Striga control trials on their land over 2 years (2002–2003). EAs supported by IITA field staff provided training to the lead farmers. This included not only technical training in Striga biology and control methods, but also in leadership and communication. This was undertaken in interactive sessions where farmers were encouraged to identify, discuss and agree about their own leadership and communication roles as elected members of CBOs. From 2003 onwards, lead farmers were encouraged to work with 4–5 other farmers within the same group, called 'secondary farmers', to initiate their own Striga control testing, thereby encouraging farmer-to-farmer extension. Lead farmers were expected to share seed and information on Striga biology and control methods with other farmers and to assist in evaluating the performance of the Striga control methods during the growing season. Lead farmers' plots acted as a focus for learning during the season in a farmer field school approach.

During the growing seasons, EAs visited the lead farmers' trials about twice a month, each EA working typically with 6–8 lead farmers. EAs were required to work primarily with lead farmers, leaving them to interact with secondary and other farmers. EAs themselves received training during the season on participatory technology evaluations and learning approaches. Training materials included a leaflet and a flannel board picture series on basic Striga biology and control methods for farmers, and a Striga manual with more detailed information on the same topic for EAs.

The lead farmers were located in two areas within Kaduna State (Fig. 1); 98 were based within a radius of 100 km from Zaria town in northern Kaduna State (11°11′N, 07°38′E) in 32 communities, the remaining 56 farmers were based in 10 communities around Kachia and Kasuwan Magani towns in southern Kaduna State (10°24′N; 7°42′E). In northern Kaduna, long-term average annual rainfall is 1050 mm with a growing season of 150 days. In southern Kaduna, mean annual rainfall is 1350 mm with a growing period of 180 days. In both areas, rainfall is mono-modal; shallow Alfisols with sandy loam to sandy clay loam textures make up the dominant soil type.

During 2002–2003, each lead farmer maintained two plots: an ISC plot and a farmers' practice (FP) plot. At the ISC plot, farmers were invited to choose between growing Striga-tolerant maize for two subsequent years or growing a legume crop in the first year, followed by Striga-tolerant maize in the second year. Soybean–maize strip cropping, involving rows with soybean alternated with rows of Striga-tolerant maize in the first year, followed by a sole crop of maize in the second year, was a further option. The ISC package also included improved management practices, notably the spot-wise application of appropriate fertiliser rates, increased crop planting density, Striga hand-roguing and hoe-weeding (Schulz et al., 2003). The ISC maize variety, Across97 TZL Comp.1-W (Acr.97), was a long-duration type that was more tolerant to Striga infestations and showed fewer attacks in terms of the number of emerged Striga plants than the common local varieties (Emechebe et al., 2002). The variety is referred to as Striga-tolerant maize in this paper. Legume trap crops were groundnut, RMP12 and soybean, TGx 1448-2E or TGx 1864 (Table 1). These were new varieties in the area selected for their growth characteristics in the savanna and their *in vitro* ability to stimulate the germination of Striga seed (Emechebe and Ahonsi, 2002). The FP represented farmers' traditional cereal-based system where local maize, millet or sorghum varieties were grown as main crops. Here farmers were free to decide the use of varieties. In the second year, all farmers cultivated local maize in the FP plot to allow a comparison with the maize in the ISC plot.

The plots of 20×20 m were laid out by farmers in conjunction with EAs. In the FP, lead farmers were expected to apply their own management practices. For the ISC plot, lead farmers were advised to follow a set of recommendations. These were, however, not necessarily strictly adhered to and farmers were free to make modifications to suit their circumstances. The advice given was that all crops were to be grown on ridges, at a ridge distance of 0.75 m. Soybean seeds were to be drilled at an intra-row distance of 0.10 m. Groundnut was to be sown at 0.20 m distance using one seed per stand and maize at a distance of 0.50 m using two seeds per stand (Table 1). Prior to planting legumes, farmers were advised to broadcast SSP at a rate of 230 kg ha^{-1}, containing 20 kg P ha^{-1} and 26 kg S ha^{-1} (Table 1). In maize, fertiliser was to be spot-applied in holes and covered with soil at 2 weeks after planting (WAP) at a rate of 47 kg N ha^{-1}, 20 kg P ha^{-1} and 39 kg K ha^{-1}, as NPK compound fertiliser. Additional urea fertiliser was to be applied in a similar way at a rate of 73 kg N ha^{-1} at second weeding, 6 WAP. In plots with strip cropping, recommended seed and fertiliser quantities were changed according the ratio legume:maize strips. In 2002, lead farmers were provided with the crop seeds for the ISC plot. In 2003, in addition to seeds, farmers were provided with the recommended fertilisers for ISC. Striga seedlings in maize were to be hand-rogued in ISC plots at 12 and 14 WAP. Soil cultivation operations prior to planting and weeding to control weeds other than Striga were conducted with a hoe or with ox-drawn tools. Other field operations were carried out manually.

EAs collected data on farmers' field management through an observation sheet. At 12 WAP, Striga damage in cereals was rated at a scale of 1–5, whereby 1 corresponded with no Striga damage and 5 with severe damage. EAs determined grain yields with the farmers at harvest. For maize, representative samples of 20 cobs were shelled and grains were dried to constant weight at 65 °C to determine grain moisture content. Samples of 200–300 g legume grain were dried in a similar manner. Grain yields were converted to 12% moisture. In May 2002 and 2004, soil samples up to a depth of 0.15 m were taken at trial plots of 75 randomly selected lead farmers using a conventional soil auger; each sample consisted of 15 subsamples. Striga seed densities in the soil were determined using the potassium carbonate separation method and were calculated for an assumed soil bulk density of 1.5 g cm^{-3} (Berner et al., 1997).

Table 1
Recommended crop varieties and field management in ISC plots

Crop	Variety	Plant spacing (m)	Seed rate (seeds ha^{-1})	NPK fertiliser rate (kg ha^{-1})
Maize (ISC)	Acr.97	0.75×0.50	53×10^3	120N 20P 39K
Soybean	TGx 1448/TGx 1864	0.75×0.10	133×10^3	20P
Groundnut	RMP12	0.75×0.20	67×10^3	20P

2.1. Statistical data analyses and presentation

The treatment structure of the trials was an incomplete block design with every lead farmer's trial representing one block. As the different cropping strategies were unequally represented within the area, the data were unbalanced. Therefore, residual maximum likelihood (REML) analyses were used to assess differences in crop yields between the FP and the ISC plots and differences between the ISC cropping strategies (Robinson et al., 1982). In 2002, when different crops were grown, all yields were converted to maize equivalents using the average crop price in 2001–2003 to facilitate the statistical analyses. Both maize equivalent yields predicted by the statistical model and crop yields, converted back from the predicted maize yields using the same crop price, are presented in this paper. In 2003, all crops were maize and conversions were not required. Since Striga seed counts can be affected by both the number of Striga plants and the quantity of seed produced by individual plants, each having its own probability model. Combining the appropriate probability models gave rise to a negative binomial distribution for the numbers of Striga seeds. The 'regressions' are summarised in tables of means for statistically significant effects. These were the main effect for crop rotation (a one-way table of means) and the two-factor interaction between years and crop treatment (a two-way table of means). Data on Striga damage rating in maize were analysed following the method of McCullagh and Nelder (1990) for ordinal data. In 2002, farmers preferred to plant maize or strip cropping on plots with lower Striga infestations than plots with soybean and groundnut. Therefore, treatments were not allocated randomly and inferences about treatment strategies should be made with care.

Statistical analyses were carried out using the package GenStat 4.2 (Genstat, 2000). Differences between treatments were considered significant at a probability level of $P<0.05$. Variability of means is presented as standard errors of the differences between means (s.e.d.) or as standard errors (s.e.). In tables, n represents the number of plots on which the means were based. As many Eas lacked experience in data collection, the data showed gaps and only items where both the ISC and the FP plots were monitored for a farmer in a given year were included.

2.2. Economic analysis

An economic assessment of the performance of ISC at lead farmers' plots was based on

(i) Comparing crop grain yields and their values (gross returns) from each treatment over the 2-year period. Yields derived from the statistical analysis of yield data formed the basis of determining gross returns.
(ii) A partial budget analysis deducting the main costs (seed, fertiliser and labour), which vary between treatments, from the gross return to determine the margins of ISC and FP.
(iii) Assessing the Benefit:Cost (B:C) ratio of each treatment.
(iv) Undertaking a sensitivity analysis on commodity prices and labour costs.

In the economic analyses, local cereal was a weighted average of local maize, sorghum and millet. Crop prices were based on the mean farm gate price over the last 3 years (2001–2003) at harvest, when most farmers sell their crops, while seed and fertiliser values were based on the prices at planting (Table 2). Since new ISC varieties were not yet widely available, it was assumed that there was likely to be a premium of 25% on their values. A study by Douthwaite et al. (2006) was used to estimate labour requirements and costs associated with ISC and the FP (Table 3). In this study, farmers were asked to estimate labour requirements for land preparation, crop care and harvest operations associated with growing legume and maize traditionally or using the ISC method. Groundnut was considered to have labour requirements similar to soybean until harvest time, but to require more than twice as much labour for picking and shelling. The costs of labour were set at 2.0 US\$ day^{-1}, being based on local hire rates, even when family labour was used. A sensitivity analysis was conducted examining a number of scenarios to establish the effects of different commodity values and labour requirements. These were (i) reducing labour input to FP levels, (ii) increasing the price of soybean to price of groundnut, a 200% increase, (iii) increasing maize prices by 25%, and (iv) increasing fertiliser prices by 50%.

2.3. Further adoption

In establishing further adoption by farmers through farmer-to-farmer extension, we built on earlier work by Douthwaite et al. (2003) and Ellis-Jones et al. (2004a) in

Table 2
Value and cost assumptions in the economic analysis

Crop	2001	2002	2003	Three year mean
Grain (US \$ t^{-1})		Price at harvest		
Maize	197	223	141	187
Groundnut	339	468	506	438
Soybean	153	192	285	210
Seed (US \$ kg^{-1})		Price at planting		
Maize	0.39	0.45	0.28	0.37
Groundnut	0.68	0.94	1.01	0.88
Soybean	0.31	0.38	0.57	0.42
Fertiliser (US \$ kg^{-1})		Prices at planting		
N	0.52	0.63	0.87	0.67
P	1.24	1.5	2.07	1.60
K	0.65	0.79	1.09	0.84

assessing farmer up-take of Striga-tolerant maize, leguminous trap crop varieties, or field management practices associated with ISC. Sources of information were: (i) monitoring numbers and management practices of secondary farmers during the 2003 season, (ii) a formal survey including 95 lead and 152 secondary farmers conducted in 2004, and (iii) case-study assessments of 40 farmers undertaken after the 2004 season. In addition, views were obtained from participating EAs of their experiences and continued use of PREA. Discussions were also held with representatives of the two major seed companies in Zaria, Alheri Seeds and Premier Seed, to obtain data on perceptions and seed sales of varieties used in ISC.

3. Results and discussion

In total, 154 lead farmers established ISC trials. 41 (27%) selected a continuous Striga-tolerant maize practice, while the remaining farmers included groundnut or soybean in the ISC rotation (Table 4). As a local cereal in the FP in 2002, 83 farmers cultivated maize, 56 selected sorghum, and four farmers chose millet. The choice of crops was unequally distributed over the area (Fig. 1). In northern Kaduna, many farmers preferred to grow continuous Striga-tolerant maize at their ISC plot, while in southern Kaduna, most farmers chose a legume–maize rotation. Female lead farmers constituted 12% of the total number of farmers, usually representing women's groups within the community.

Lead farmers followed the recommended planting densities reasonably well. The observed mean row distance of 0.82 m in 2002 slightly exceeded the recommended distance of 0.75 m, while in 2003, the observed distance closely approached the recommendation. In the FP, spacing of cereals was wider than in the ISC. The observed intra-row distance between plants was close to the recommendation for all crops, except that soybean was planted at a wider spacing (0.13 m) than recommended (0.10 m). Also, the observed number of maize plants per stand, 1.8 in both local maize and improved maize, was close to the recommendation of 2.0 plants per stand. Fertiliser rates applied in cereals were below the recommendation in 2002 (Table 5). In 2003, when farmers received the recommended rates for ISC from the project, the actual rates were close to or slightly above the recommendation. The fertiliser rates applied in cereals in the FP were slightly below those in ISC maize. In legumes, farmers often failed to follow the recommended rates, applying more nitrogen and potassium and less phosphorus than advised (Table 5).

Mean Striga seed densities in the soil were similar in the FP and ISC at the start of the rotation in 2002 (Table 6). Over the 2-year rotation, seed densities in the FP increased by 46%. The cultivation of Striga-susceptible cereals thus greatly enhanced the Striga soil seedbank. In ISC treatments, the mean Striga soil seed density reduced by 46% over the 2-year rotation (difference with FP significant at $P<0.001$). The initial Striga seed densities in 2002, as well

Table 3
Estimated labour requirements for land preparation, crop care and harvest activities for ISC and traditional practice in growing legumes and maize (person day ha^{-1})

Operation	Soybean/groundnut				Maize			
	n	FP	ISC	% increase	*n*	FP	ISC	% increase
Ridging/planting	19	22	47	114	9	13	30	131
Weeding	18	36	55	53	10	25	49	96
Fertilising	0	0	0	0	6	7	14	100
Weeding Striga	0	0	0	0	8	9	18	100
Harvesting	16	23	32	39	10	19	30	58
Threshing	14	29	38	31	9	23	35	52
Total		110	172	56		96	176	83
Shelling groundnut		40	40					
Total groundnut		150	212	41				

Table 4
Type of trial and crops on farmers' practice (FP) and integrated Striga control (ISC) plots in 2002 and 2003, as selected by the participating lead farmers

Plot	2002 crop	2003 crop	*n*	%
FP	Local cereal (LC)	Local maize (LM)	154	100
ISC	Striga-tolerant maize (SM)	Striga-tolerant maize (SM)	41	27
	Improved soybean (Sb)	Striga-tolerant maize (SM)	75	49
	Improved groundnut (Gn)	Striga-tolerant maize (SM)	20	13
	Soybean–maize strip cropping (Sb/SM)	Striga-tolerant maize (SM)	18	12

Local cereals are local varieties of maize, sorghum or millet.

Table 5
Recommended and observed mean nitrogen, phosphorus and potassium application rates for various crops in 2002 and 2003 (kg N, P and k ha^{-1})

	Recommended NPK rate	Observed NPK rate	
		2002	2003
n		50	106
Local cereal	—	75, 12, 23	106, 14, 26
Improved maize	120, 20, 39	88, 13, 25	149, 20, 38
Legume	0, 20, 0	56, 11, 21	
Strip cropping		71, 12, 22	

No recommendation given.

Table 6
Predicted Striga soil seed density at the beginning and the end of the rotation for each treatment (May 2002 and May 2004, respectively) (10^3 Striga seeds m^{-2})

Treatment	*n*	2002 seeds	s.e.	2004 seeds	s.e.	% increase
LC–LM (FP)	75	9.86	2.04	14.38	3.02	46
All crops–SM (ISC)	75	9.55	3.02	5.15	1.05	−46
SM–SM (ISC)	15	4.79	1.15	3.39	0.69	−29
Sb–SM (ISC)	39	12.05	2.91	6.01	1.39	−50
Gn–SM (ISC)	13	10.16	2.85	5.50	1.29	−46
Sb/SM–SM (ISC)	8	5.25	1.69	3.62	0.91	−31

LC = local cereal, LM = local maize, SM = Striga-tolerant maize, Sb = soybean, Gn = groundnut, FP = farmer practice, ISC = integrated Striga control.

Table 7
Percentage of farmers in the various Striga damage rating categories in 2003 (relative scale of 1–5, where rating 1 corresponds with no damage and 5 with severe Striga damage)

Treatment	Striga damage category					
	n	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
LC–LM (FP)	142	3	32	29	25	11
All crops–SM (ISC)	142	68	20	11	1	0
SM–SM (ISC)	38	55	32	10	3	0
Sb–SM (ISC)	68	75	15	9	1	0
Gn–SM (ISC)	20	80	5	15	0	0
Sb/SM–SM (ISC)	16	50	31	19	0	0

LC = local cereal, LM = local maize, SM = Striga-tolerant maize, Sb = soybean, Gn = groundnut, FP = farmer practice, ISC = integrated Striga control.

as the relative reduction over the experiment, varied among ISC treatments (Table 6). Where groundnut or soybean was grown, initial Striga seed densities were more than double that of ISC continuous maize or strip crop plots. Over the 2-year period, the greatest reductions were in groundnut–maize (46%) and soybean–maize (50%). Lower reductions were achieved with Striga-tolerant maize (29%) and strip cropping (31%), but from a lower base. Striga damage rating in cereals in 2003 partly reflected the Striga seedbank densities with the highest damage rating recorded in the FP and the lowest rating in ISC plots (difference with FP significant at $P<0.001$) (Table 7). The damage rating in ISC rotations with legumes was slightly below that in ISC with continuous maize. This difference could not be attributed to differences in Striga seedbank densities (Table 6), as the 2004 seedbank data indicated a higher seed density in ISC legume–maize rotations than in continuous maize.

The predicted yields of Striga-tolerant maize ranged between 2.91 and 3.44 t ha^{-1} and were well above that of local cereals averaging 1.46 t ha^{-1} (Table 8). In 2002, monoculture of soybean yielded 1.36 t ha^{-1} and of groundnut 1.29 t ha^{-1}. On average across treatments, production in ISC in terms of maize equivalents increased over the FP by 77% in 2002 and by 99% in 2003. The high maize yields in ISC were likely to be related to the genetic characteristics of the ISC maize variety, Acr.97, such as Striga-tolerance and perhaps a better nitrogen-use efficiency than local cereals. A reduced Striga seedbank in ISC in 2003 and differences in field management probably contributed to the high yields of Acr.97 as well. In 2003, when Acr.97 was cultivated on all ISC plots, maize yields in the various ISC rotations were not significantly different. So, no beneficial effect of the inclusion of legumes in maize-based systems above continuous maize was observed.

3.1. Economic assessment

In the base case scenario, in the first year, the analyses suggested that ISC gave on average a 91% higher gross return than the FP (Table 9). Margins over costs were often negative owing to the high opportunity cost of labour, even when family labour was used. The highest returns came from groundnut and Striga-tolerant maize, with lower returns obtained from strip cropping and soybean. Although the yield difference between soybean and groundnut was insignificant, the price of groundnut was nearly double that of soybean, making it the most attractive alternative. On average, ISC cost 62% more than the FP, which can largely be attributed to increased labour costs in ISC. Margins of ISC over the FP were on average 32% higher, with the greatest B:C ratio achieved with Striga-tolerant maize and groundnut. Soybean gave a lower B:C ratio than the FP. In 2003, when all plots were under maize, margins over costs of all ISC treatments were greater than the FP (on average \$88 ha^{-1} vs. \$−15 ha^{-1}), with no significant difference between ISC treatments. Over both years (Table 9), ISC gave a gross return that was 95% greater than the FP, while ISC costs were 64% greater than the FP. The greatest B:C ratio was achieved with the continuous maize rotation, followed by groundnut–maize, strip cropping and soybean–maize, all giving a better B:C ratio than the FP.

ISC as recommended required on average 87% more labour than the FP. The sensitivity analysis showed that, if

Table 8
Predicted legume and cereal grain yields and maize grain equivalents of the yields for each treatment in 2002 and 2003 (t ha^{-1})

Treatment	2002			2003	
	n	Maize equivalents[a]	Crop yields[b]	*n*	Maize yields
LC–LM (FP)	116	1.24	1.24	121	1.68
All crops–SM (ISC)	116	2.20	—	121	3.35
% increase over FP		77			99
s.e.d.		0.125	—		0.139
SM–SM (ISC)	33	2.91	2.91	37	3.44
Sb–SM (ISC)	52	1.66	1.36	55	3.39
Gn–SM (ISC)	16	3.17	1.29	13	3.43
Sb/SM–SM (ISC)	15	2.11	0.87 Sb/1.06 SM	16	2.71
s.e.d. (ISC)		0.476	—		0.459

LC = local cereal, LM = local maize, SM = Striga-tolerant maize, Sb = Soybean, Gn = groundnut, FP = farmer practice, ISC = integrated Striga control.
[a]Crop yields converted to maize equivalents using a 3-year mean crop prices.
[b]Yields of individual crops converted from maize equivalents using a 3-year mean crop prices.

Table 9
Summary of the economic analysis with mean crop values, costs, margins and benefit:cost (B:C) ratios for each treatment in 2002 when ISC crops were different, and 2002 and 2003 combined (US\$ ha^{-1})

Treatment	Gross return	Costs				Margins over costs	Margins over FP	B:C ratio	Rank
		Seed	Labour[a]	Fertiliser	Total				
2002									
LC–LM (FP)	232	22	192	90	305	−73	0	0.76	3
SM–SM (ISC)	544	33	352	101	486	58	131	1.12	1
Sb–SM (ISC)	286	37	344	74	455	−169	−96	0.63	5
Gn–SM (ISC)	565	72	424	74	570	−5	68	0.99	2
Sb/SM–SM (ISC)	381	27	348	86	461	−80	−8	0.83	4
Average (ISC)	444	42	367	84	493	−49	24		
Difference (Av ISC-FP)	212	20	175	−7	188	24			
% increase (Av ISC-FP)	91	91	91	−8	62	32			
2002 and 2003									
LC–LM (FP)	546	44	384	205	634	−88	0	0.86	5
SM–SM (ISC)	1187	66	704	265	1035	152	240	1.15	1
Sb–SM (ISC)	920	70	696	238	1004	−84	3	0.92	4
Gn–SM (ISC)	1206	105	776	238	1119	87	175	1.08	2
Sb/SM–SM (ISC)	950	60	700	250	1010	−60	27	0.94	3
Average (ISC)	1066	75	719	248	1042	24	111		
Difference (Av ISC-FP)	520	31	335	42	408	111			
% increase (Av ISC-FP)	95	71	87	21	64	127			

LC = local cereal, LM = local maize, SM = Striga-tolerant maize, Sb = soybean, Gn = groundnut, FP = farmer practice, ISC = integrated Striga control.
[a]Based on an opportunity cost of US \$2 per day.

labour costs could be maintained at the same level as that required for the FP without affecting yield, it would make a considerable difference to the economic results (Table 10, Option 1). Productivity of ISC technologies would increase over 400% over the FP, with all ISC options showing a B:C ratio of more than 1. Positive results were achieved with groundnuts in the baseline, as groundnut sale prices were twice that of soybean. Soybean is, however, a relatively new crop for which markets are still developing. If soybean could attract a price similar to groundnut, the productivity associated with its use could increase to that of groundnuts. It would however require a doubling of soybean prices (Table 10, Option 2). Clearly, any change in maize prices would affect the ISC continuous maize alternative. An increase in maize prices would be likely to encourage maize production, while a decrease would result in more legumes being produced, despite a productivity decline in all production options (Table 10, Option 3). The availability and affordability of fertiliser is a concern of many farmers and without government interference to reduce its costs or

Table 10
Results of the sensitivity analysis

Scenario	Margin over FP	B:C ratio	Rank
Base line			
LC–LM (FP)	0	0.86	5
SM–SM (ISC)	240	1.15	1
SB–SM (ISC)	3	0.92	4
GN–SM (ISC)	175	1.08	2
SM/Sb–SM (ISC)	27	0.94	3
Option 1: Labour reduced to same as non ISC costs			
LC–LM (FP)	0	0.86	5
SM–SM (ISC)	553	1.64	1
Sb–SM (ISC)	313	1.32	3
Gn–SM (ISC)	331	1.25	4
SM/Sb–SM (ISC)	339	1.36	2
Option 2: Soybean price increased by 200%			
LC–LM (FP)	0	0.86	5
SM–SM (ISC)	240	1.64	1
Sb–SM (ISC)	289	1.32	3
Gn–SM (ISC)	175	1.25	4
SM/Sb–SM (ISC)	779	1.36	2
Option 3: Maize price reduced by 25%			
LC–LM (FP)	0	0.65	5
SM–SM (ISC)	79	0.86	3
Sb–SM (ISC)	−19	0.76	4
Gn–SM (ISC)	151	0.93	1
SM/Sb–SM (ISC)	114	0.89	2
Option 4: Fertiliser increases by 50%			
LC–LM (FP)	0	0.74	5
SM–SM (ISC)	210	1.02	1
Sb–SM (ISC)	−13	0.82	4
Gn–SM (ISC)	159	0.97	2
SM/Sb–SM (ISC)	5	0.84	3

LC = local cereal, LM = local maize, SM = Striga-tolerant maize, Sb = soybean, Gn = groundnut, FP = farmer practice, ISC = integrated Striga control.

increase its availability, fertiliser costs may rise. If crop prices remain similar, an increase in fertiliser costs would make the ISC with legumes relatively more attractive (Table 10, Option 4). The effect of such change was, however, modest and the ISC continuous maize was still the most attractive option, as the relatively high maize price sufficiently compensated for the rising fertiliser costs. Discounting future benefits and costs even at a relatively high rate of 25% had no significant effect on the base-line scenario results.

3.2. Further adoption

In 2003, EAs identified 763 secondary farmers who had tested at least one component of ISC during the year. The survey indicated that 65% of the secondary farmers selected soybean and 15% Striga-tolerant maize (Table 11). In comparison with lead farmers, secondary farmers grew more soybean at the expense of maize. Of the secondary farmers, 66% obtained their ISC seed (maize, soybean or groundnut) as a gift or loan from lead farmers, while the others purchased the seed. Most secondary farmers had received support from lead farmers, increasing their knowledge on Striga biology and control, as well as receiving practical training on lead farmers' ISC plots.

Table 11
ISC crops cultivated by lead farmers and secondary farmers

	Lead farmers (2002)	Secondary farmers (2003)	All farmers
n	154	162	315
Striga tolerant maize (%)	27	15	21
Soybean (%)	49	65	57
Groundnut (%)	13	10	11
Soybean–maize strip cropping (%)	12	10	11

In addition to the trial plots, 65% of the lead and secondary farmers were using ISC seed elsewhere on their farms; 37% were using improved soybean, 29% Striga-tolerant maize, 9% groundnut, while 40% were following a legume–maize rotation. Nearly half the farmers indicated that they had also given or sold seed to others in 2004 (Table 12). The mean quantities of seed sold or given were 108 kg maize, 70 kg soybean and 30 kg groundnut per farmer (Table 12). Detailed discussions with 40 lead and secondary farmers indicated that the mean number of individuals per farmer to whom seed was given or sold was 10, of whom seven were in the same village and three were outside the village (Table 13). Lead farmers had more contacts with other farmers than secondary farmers, although there was considerable variation among individuals. Extrapolation of the contacts indicated by the 40 case-study farmers to the total number of participating farmers identified in 2003 suggested that over 8000 new farmers may have benefited from ISC seed in 2004 (Table 13). This represents a ratio of 1 EA to 5 lead farmers, 23 secondary farmers and over 240 other contacts.

Both the case studies and the survey revealed that almost half the farmers had modified the recommended ISC by adopting some form of strip or mixed cropping (maize and legume). Although seed was seen as the most important means of spreading ISC, lead farmers also provided advice on field management. Consequently, many secondary farmers had also adopted new management practices of planting high population densities of legumes and spot-wise application of fertilisers in holes. However, many complained of the additional labour required and said they were unlikely to plant large areas in this way. Thirty two percent of the farmers had tried out other ways of controlling Striga in conjunction with the trials, such as early planting of cereals, the use of manure, potash, ash and urea, and burying Striga by remoulding ridges.

Most farmers indicated that, as a result of the project approach, community and group cohesion were better and working relationships between farmers and EAs had

Table 12
Seed distribution by farmers (% farmers giving or selling seed and quantities of seed sold or given)

	Farmers giving or selling seed			Quantity sold or given (kg farmer^{-1})		
	Lead farmers	Secondary farmers	All farmers	Lead farmers	Secondary farmers	All farmers
n	95	152	263			
Maize	32%	10%	18%	135	88	108
Soybean	37%	28%	26%	80	60	70
Groundnut	5%	2%	3%	23	45	30

Table 13
Observed number of contacts per farmer in case studies and estimated total number of farmer-to-farmer contacts exchanging seed and/or knowledge on ISC as a result of the project

	Observed number of contacts			Estimated total number of contacts		
	Lead farmers	Secondary farmers	All farmers	Lead farmers	Secondary farmers	All farmers
n	14	26	40	154	763	917
Inside village	7.5	6.4	6.9	1155	4883	6038
Outside village	5.8	1.5	3.1	893	1145	2038
Total	13.3	7.9	10.0	2048	6028	8076

improved. EAs believed that lead farmers and their respective CBOs played an important role in problem identification and resolution through technology selection, design, implementation and evaluation. EAs highly valued the PREA training received and were using either all or some of the components elsewhere in their work. Participatory approaches are now widely applied in the Kaduna State extension service (Danbaba, SG 2000, Kaduna, personal communication).

With regard to the commercial seed market, Alheri Seed Company had become aware of Acr.97 as an open pollinating Striga-tolerant maize variety in 2001, when they started collaborating with the Striga project. They reported that the project helped rural communities to establish community-based seed production with farmers themselves producing seeds for their communities. Although some seed-producing farmers had became contract growers for Alheri Seed, the advent of community-based seed production had resulted in low sales of Acr.97. They have, therefore, embarked on groundnut and soybean seed production in 2004 and believe their future business lies with the sale of hybrid maize seed (Hassan, 2004). Premier Seeds became aware of Acr.97 only in 2004 and have also indicated that selling open pollinating maize varieties is not attractive, as 70% of their sales are hybrid varieties. They would prefer Striga-tolerant genes to be transferred into a hybrid seed (Oke, Managing Director, Premier Seed, Zaria, Personal Communication).

4. General discussion

ISC as promoted by the project reduced the Striga seedbank and produced higher crop yields than the FP. The relative performance of the various ISC options, with regard to yield and Striga suppression, showed considerable variation. However, as the different ISC rotations were unequally represented within the area and the data were unbalanced, comparisons between ISC rotations should be made with care. In the lead farmers' trial, 2 years of cultivating Striga-tolerant maize along with an improved field management appeared less effective in reducing the Striga seedbank than legume–maize rotations. The Striga-tolerant variety Acr.97 allowed some Striga plants to set seed, whereas the non-host legumes did not. Acr.97 nevertheless produced satisfactory yields of 2.0–3.5 t ha^{-1} and the variety could be recommended to farmers aiming to produce maize in Striga-infested areas. However, if farmers in such areas intend to incorporate in the rotation cereals that are highly susceptible to Striga attacks, such as local maize and sorghum varieties, they may need to grow legumes first to reduce the Striga seedbank.

The cultivation of full-season soybean or groundnut followed by a Striga-tolerant cereal reduced the Striga seedbank up to 50% over a relatively short time of 2 years. It is uncertain to what extent the observed decline in the Striga seedbank in legume-maize rotations should be attributed to a legume-induced suicidal germination of Striga seeds, or to natural seed mortality under field conditions in the absence of a host in the first year. Gbèhounou et al. (2003) observed a rapid decline in Striga seed viability in the first rainy season after seed burial in the field, and it is possible that natural mortality was the main driving factor behind the observed rapid decline.

It is generally accepted that the inclusion of legumes in cereal-based systems of the savanna has beneficial effects on soil fertility, weed and disease control, etc., resulting in enhanced cereal yields (Schulz et al., 2001; Alvey et al., 2001; Franke et al., 2004). In the current trial, however, no such effect was observed. Differences in maize yield in 2003 between ISC continuous maize and ISC with legumes were insignificant. ISC trials with continuous maize were often located on soils with lower initial Striga seed densities than the ISC trials with legumes. This may have influenced the comparison between ISC rotations. Possibly, farmers made a conscious decision to plant the more susceptible maize crop on plots where Striga infestation was known to be lower.

The economic analysis indicated that the highest economic productivity was achieved when Striga-tolerant maize was used, rather than legumes. Rotations with soybean, in particular, achieved a low productivity. A substantial increase in soybean prices would be required to bring productivity to the same level as that of continuous maize. Secondary farmers nevertheless cultivated more soybean and less Striga-tolerant maize than lead farmers in the first year of the ISC rotation. This is likely to be related to lead farmers' observation that continuous Striga-tolerant maize is less effective in controlling Striga than legume-maize rotations. Also, the relatively high price of inorganic fertilisers in 2003 may have contributed to the large number of secondary farmers opting for soybean. Lead farmers had the tendency to apply more nitrogen and potassium and less phosphorus than recommended in soybean. These fertiliser rates are likely to be uneconomical, being the result of a lack of knowledge among farmers on soybean fertiliser requirements and the poor availability of P-based fertilisers, such as SSP and TSP, at local markets, that encouraged farmers to use urea and NPK compound fertiliser. Given the growing popularity of soybean for home consumption and sale in northern Nigeria (Sanginga et al., 2003), a need for improved extension on soybean cultivation was identified.

The economic analysis showed that increased labour demands for ISC, as compared with the FP, had a large impact on the profitability of ISC rotations. Also in the adoption survey, farmers frequently mentioned increased labour input in a period when labour is relatively scarce and labour opportunity costs are high, as a disincentive to expanding ISC, as recommended, to other parts of their farm. Dense planting of legumes and maize, weeding in densely planted crops, spot-wise application of fertiliser in holes and roguing of Striga seedlings all contributed to the large labour requirements for ISC. The survey also showed that many farmers had already modified the ISC technology or ignored certain recommendations to reduce labour demands, for example, by widening the spacing of legume plants. Furthermore, many farmers adopted ISC varieties and some ISC management practices in their own fields, but applied them in mixed cropping systems, which is in line with traditional planting practices. These systems can be regarded as a risk management strategy that maximises the likelihood of one crop or another providing an adequate yield when others fail, and are likely to remain important for households where food security is a major concern. Little information is available on the effect of the observed farmers' modifications, such as intercropping ISC varieties, on Striga population dynamics, and a study would be worthwhile (Carsky et al., 1994; Oswald et al., 2002).

The two seed companies involved in this project abandoned the production and sale of the Striga-tolerant maize variety, Acr.97, being more supportive of hybrid maize. This suggests that farmers will largely depend on their own multiplication schemes for their maize seed in the future. As Acr.97 is an open-pollinating variety, out-crossing with local maize varieties that lack Striga-tolerance may easily occur in the field when farmers fail to isolate the crop. This implies it may be difficult for farmers to obtain pure lines of Acr.97 in the future. Out-crossing in the short term is less likely to occur with the recommended soybean and groundnut varieties.

The approach to scale-up ISC through government and non-government extension workers using PREA resulted in the transfer of ISC crop varieties and some ISC management practices to an estimated 8076 farmers in 2004, highlighting the potential of farmer-to-farmer extension to reach large numbers. In addition, improved community and CBO cohesion and better relationships between farmers and extension workers were positive indicators that problems other than Striga can be tackled using PREA. The approach facilitated improved farmer-to-farmer extension, which is likely to continue after project completion. Towards the end of the project and afterwards, project employees frequently received requests for Striga extension materials and training in PREA and Striga control methods from NGOs and government extension organisations based in various States of northern Nigeria outside the project area. These organisations were often willing to contribute financial and human resources to obtain extension materials, receive training on Striga biology and control, and improve the effectiveness of their Striga extension services. Also, those NGOs and government extension organisations that were directly involved in the project stated their willingness to continue investing in improved Striga extension using PREA methods at the end of the project. Although it is currently too early to assess to what extent the impact of the project will be sustainable over a period of several years, the results indicate that the project has had an institutional impact beyond the project's lifespan and the geographic boundaries of Kaduna State.

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References

Alvey, S., Bagayoko, M., Neumann, G., Buerkert, A., 2001. Cereal/legume rotations affect chemical and biological activities in two West African soils. Plant Soil 231, 45–54.

Berner, D.K., Winslow, M.D., Awad, A.E., Cardwell, K.F., Mohan Raj, D.R., Kim, S.K., 1997. Sustainable control of *S. hermonthica* spp. through a focused integrated pest management program. In: Badu-Apraku, B., Akoroda, M.O., Ouedraogo, M., Quin, F.M. (Eds.), Contributing to food self-sufficiency: maize research and development in West and Central Africa. International Institute of Tropical Agriculture, Ibadan, Nigeria, pp. 1–11.

Carsky, R.J., Singh, L., Ndikawa, R., 1994. Suppression of *Striga hermonthica* on sorghum using a cowpea intercrop. Exp Agric 30, 349–358.

Carsky, R.J., Ndikawa, R., Kenga, R., Singh, L., Fobasso, M., Kamuanga, M., 1996. Effect of sorghum variety on *Striga hermonthica* parasitism and reproduction. Plant Var. Seeds 9, 111–118.

Carsky, R.J., Berner, D.K., Oyewole, B.D., Dashiell, K., Schulz, S., 2000. Reduction of *Striga hermonthica* parasitism on maize using soybean rotation. Int. J. Pest Manag. 46 (2), 115–120.

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

Debrah, S.K., Defoer, T., Bengaly, M., 1998. Integrating farmers' knowledge, attitude and practice in the development of sustainable Striga control interventions in southern Mali. Netherlands J. Agric. Sci. 46, 65–75.

Douthwaite, B., Kuby, T., Fliert, E. van de, Schulz, S., 2003. Impact pathway evaluation: an approach for achieving and attributing impact in complex systems. Agric. Syst. 78, 243–265.

Douthwaite, B., Schulz, S., Olanrewaju, A.S., Ellis-Jones, J., 2006. Impact pathway evaluation of an integrated *Striga hermonthica* control project in Northern Nigeria. Agric. System, accepted for publication

Ellis-Jones, J., Schulz, S., Douthwaite, B., Hussaini, M.A., Oyewole, B.D., Olanrewaju, A.S., White, R., 2004a. An assessment of integrated *Striga hermonthica* control and early adoption by farmers in northern Nigeria. Expl Agric 40, 353–368.

Ellis-Jones, J., Schulz, S., Chikoye, D., de Haan, N., Kormawa, P., Adedzwa, D., 2004b. Participatory research and extension approaches: a guide for researchers and extension workers for involving farmers in research and development. International Institute for Tropical Agriculture, Ibadan, Nigeria and Silsoe Research Institute, UK.

Emechebe, A.M., Ahonsi, M.O., 2002. In-vitro whole-seedling assays for studying differences in ability of non-host crop plants to cause germination of *Striga hermonthica* seeds. In: Improving and intensifying cereal–legume systems in the moist and dry savanna of West and Central Africa, Annual Report 2002, 79–80, IITA, Ibadan, Nigeria.

Emechebe, A.M., Ellis-Jones, J., Schulz, S., Chikoye, D., Douthwaite, B., Kureh, I., Tarawali, G., Hussaini, M.A., Kormawa, P., Sanni, A., 2004. Farmers' perception of the *Striga* problem and its control in northern Nigeria. Expl Agric 40, 215–232.

Emechebe, A.M., Menkir, A., Badu-Apraku, B., 2002. Comparative study of 22 maize cultivars from IITA for their reaction to *Striga hermonthica* at three inoculation levels in the southern and northern Guinea savanna. In: Improving and intensifying cereal–legume systems in the moist and dry savanna of West and Central Africa, Annual Report 2002, 36–38, IITA, Ibadan, Nigeria.

Franke, A.C., Schulz, S., Oyewole, B.D., Bako, S., 2004. Incorporating short-season legumes and green manure crops into maize-based systems in the moist Guinea savanna of West Africa. Expl Agric 40, 463–479.

Gbèhounou, G., Pieterse, A.H., Verkleij, J.A.C., 2003. Longevity of Striga seeds reconsidered: results of a field study on purple witchweed (*Striga hermonthica*) in Bénin. Weed Sci 51, 940–946.

GenStat, 2000. GenStat for Windows. Release 4.2, 5th ed. VSN International Ltd, Oxford.

Hassan, G., 2004. Adoption of integrated Striga management methods: experience from a seed company. Alheri Seeds Nigeria. Paper Presented at the Second Striga Stakeholders Workshop, Zaria, Nigeria, 8–10 September 2004.

Hess, D.E., Dodo, H., 2003. Potential of sesame to contribute to integrated control of *Striga hermonthica* in the West African Sahel. Crop Prot 23 (6), 515–522.

Kim, S.K., Adetimirin, V.O., Akitunde, A.Y., 1997. Nitrogen effects on *Striga hermonthica* infestation, grain yield, and agronomic traits of tolerant and susceptible maize hydrids. Crop Sci 37, 711–716.

Kling, J.G., Fajemisin, J.M., Badu-Apraku, B., Diallo, A., Menkir, A., Melake-Berhan, A., 2000. Striga resistance breeding in maize. In: Haussman, B.I.G., Hess, D.E., Koyama, M.L., Grivet, L., Rattunde, H.F.W., Geiger, H.H. (Eds.), Breeding for Striga resistance in cereals. Margraf Verlag, Weikersheim, Germany, pp. 273–281.

McCullagh, P., Nelder, J.A., 1990. Generalized Linear Models. 2nd ed. Chapman & Hall, London.

Oswald, A., 2005. Striga control—technologies and their dissemination. Crop Prot 24, 333–342.

Oswald, A., Ransom, J.K., Kroschel, J., Sauerborn, J., 2002. Intercropping controls *Striga* in maize-based systems. Crop Prot 21, 367–374.

Parker, C., Riches, C.R., 1993. Parasitic weeds of the world: biology and control. CABI Publishing, Wallingford, UK, pp. 1–74.

Pieterse, A.H., Verkleij, J.A.C., 1991. Effect of soil conditions on Striga development—a review. In: Ransom, J.K., Musselman, L.J., Worsham, A.D., Parker, C. (Eds.), In: Proceedings of the Fifth International Symposium on Parasitic Weeds, Nairobi, Kenya, June 24–30, 1991, pp. 329–339.

Robinson, D.L., Thompson, R., Digby, P.G.N., 1982. REML, a programme for the analysis of non-orthogonal data by restricted maximum likelihood. In: Compstat 1982, Proceedings in Computational Statistics, Part II (supplement). Physica-Verlag, Vienna, pp. 231–232.

Sanginga, N., Dashiell, K.E., Diels, J., Vanlauwe, B., Lyasse, O., Carsky, R.J., Tarawali, S., Asafo-Adjei, B., Menkir, A., Schulz, S., Singh, B.B., Chikoye, D., Keatinge, D., Ortiz, R., 2003. Sustainable resource management coupled to resilient germplasm to provide new intensive cereal–grain–legume–livestock systems in the dry savanna. Agric. Ecosystem Environ. 100, 305–314.

Schulz, S., Carsky, R.J., Tarawali, S.A., 2001. Herbaceous legumes: the panacea for West African soil fertility problems? In: Tian, G., Keatinge, J.D.H., Ishida, F. (Eds.), Sustaining Soil Fertility in West Africa. SSSA Special Publication No 58, Madison, WI, USA, pp. 179–196.

Schulz, S., Hussaini, M.A., Kling, J.G., Berner, D.K., Ikie, F.O., 2003. Evaluation of integrated *Striga hermonthica* control technologies under farmers' management. Expl Agric 39, 99–108.

Weber, G., Elemo, K., Awad, A., Oikeh, S., 1995. Population dynamics and determinants of *Striga hermonthica* on maize and sorghum in savanna farming systems. Crop Prot 14 (4), 283–290.