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AN ASSESSMENT OF INTEGRATED *STRIGA HERMONTHICA* CONTROL AND EARLY ADOPTION BY FARMERS IN NORTHERN NIGERIA

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SUMMARY

Two sets of on-farm trials, each covering two years, were conducted in the northern Guinea savannah of Nigeria over the period 1999–2001, the objective being to compare integrated *Striga hermonthica* control measures (soybean or cowpea trap crops followed by maize resistant to *Striga*) with farmers' traditional cereal-based cropping systems. In both sets of trials, this proved to be highly effective in increasing productivity over the two year period, especially where soybean was used as a trap crop. Resistant maize after a trap crop increased the net benefit over the two cropping seasons in both trials by over 100 % over farmer practice. However, in the second set of trials there was no significant increase in productivity between a trap crop followed by *Striga* resistant maize, and a trap crop followed by local maize especially where legume intercropping and fertilizer had been applied in the farmer practice. There was also no increase in productivity between two years' traditional cereal cropping and one year's local maize followed by *Striga* resistant maize. This indicates the importance of a legume trap crop in the first year in order to ensure high productivity in the second year, regardless of variety. Up to 20 % of farmers obtained higher productivity from their own practices, notably intercropping of cereals with legumes and use of inorganic fertilizers. Leguminous trap crops and *Striga* resistant maize, together with two key management practices (increased soybean planting density and hand-roguing) were seen to be spreading both within and beyond the research villages, indicating that farmers see the economic benefits of controlling *Striga*. Survey findings show that explaining the reasons why control practices work can greatly increase the adoption of these practices. Wider adoption of *Striga* control will therefore require an extension approach that provides this training as well as encouraging farmers to experiment and adapt *Striga* control options for their local farming systems.

INTRODUCTION

Striga hermonthica, a parasitic flowering plant, endemic to Africa, constitutes one of the most severe constraints to cereal production in sub-Saharan Africa. It parasitizes sorghum, maize, millet, rice and sugar cane, as well as pasture and wild grasses, by attaching itself to the roots of the host plant diverting essential nutrients and leaving the host stunted and yielding little or no grain, often causing yield losses in excess of

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50 % (Parker, 1991). Population increase, reduced fallow periods and an increase in maize cropping have further compounded the problem. It has been estimated that over 20 million hectares are infected in sub-Saharan Africa causing annual losses of more than four million tonnes of grain (Sauerborn, 1991) and affecting the lives of about 300 million people (M'Boob, 1989). Yet research on *Striga* has a long history and a range of component technologies have been identified as effective control methods (Parker and Riches, 1993). Examples include weeding of *Striga* plants, use of maize resistant to *S. hermonthica* and use of leguminous trap crops, which stimulate suicidal germination and therefore reduce the seed bank (Berner *et al*., 1996; Kling *et al*., 2000). At the same time farmers have developed a range of coping strategies including hand-roguing, application of inorganic fertilizer, manures and composts as well as crop rotations (Emechebe *et al*., 2004, Debrah *et al*., 1998). However, it has been generally accepted that *Striga* control is more likely to be achieved by combining a range of individual component technologies into a programme of integrated *Striga* control (ISC) to provide more flexible and sustainable control over a wide range of biophysical and socio-economic environments (Berner and Kling 1997, Dashiell *et al*., 2000). The potential for researcher-developed *Striga* control options has already shown that ISC can be highly effective both in terms of reducing *S. hermonthica* incidence as well as increasing grain yields (Schulz *et al*., 2003). This work showed that *Striga* seed density in the soil was significantly lower and its incidence on maize was reduced by more than 70 %: *Striga* resistant maize after a legume trap crop outyielded local maize by more than 60 %.

This paper reports on a second set of trials aimed at complementing earlier results of Schulz *et al*. (2003), which are briefly summarized, by separating the effects of the two *Striga* control component technologies, i.e. the effect of a legume trap crop and of a *Striga* resistant maize cultivar. At the same time, the paper reports the economics of the results of both sets of trials, initial farmer response and uptake of the technology in the surrounding villages.

MATERIALS AND METHODS

Over the period 1999–2001, two on-farm, farmer-managed trials each covering two seasons were carried out in four villages, Rimau (10°41′N, 7°76′E), Mahuta (11°20′N and 7°66′E), Kaya (11°25′N and 7°27′E) and Ankwa (9°85′N and 7°87′E) in the northern Guinea savannah agro-ecozone of Nigeria. Participatory research and extension (Hagmann *et al*., 1998) approaches were used as a basis for farmer involvement. The locations were chosen because of their severe infestation with *S. hermonthica*. The area is characterized by a mono-modal rainfall distribution with an average precipitation of 900–1300 mm with a growing period of 150 to 180 days duration (May–October). Predominant soil types are Alfisols of moderate to low fertility. Important crops are maize (*Zea mays*), sorghum (*Sorghum bicolor*), millet (*Pennisetum typhoides*), soybean (*Glycine max*), cowpea (*Vigna unguiculata*) and ground nut (*Arachis hypogaea*) with both sole and intercropping of legume and cereal being practised.

Table 1a. Trial 1 (1999–2000). Farmer-managed trial comparing integrated *Striga* control with farmer practice (adapted from Schulz *et al*., 2003).

Treatment†		No. of farmers	1999 crop	2000 crop
Striga control	T1 Sb-Rm (ISC)‡	14	Soybeans¶	Resistant maize††
	T2 Cp-Rm (ISC)	5	Cowpeas¶	Resistant maize††
Farmer practice	T3 Cer-Lm (FP)§	7	Cereal‡‡	Local maize
	T4 Ic-Lm (FP)	10	Cereal intercropped with legume§§	Local maize
	T5 Fal-Lm (FP)	2	Fallow	Local maize

† Sb = Soybean, Cp = Cow peas, Cer = Cereals, Ic = Intercropped cereals, Lm = Local maize, Rm = Resistant maize, Fal = Fallow.
‡ ISC = Integrated Striga Control, § FP = Farmer Practice.
¶ Trap crops, †† Resistant to *S. hermonthica*, ‡‡ Local maize or sorghum, §§ Local maize or sorghum intercropped with local cowpea, soybean or groundnuts.

Table 1b. Trial 2 (2000 and 2001). Farmer-managed trials comparing *Striga* control with farmer practice.

Treatment†	No of farmers	2000 crop	2001 crop
T1a Sb-Rm (ISC)	25	Soybean‡	Resistant maize‡
T1b Sb-Lm (TC only)			Local maize
T2a Cp-Rm (ISC)	4	Cowpea‡	Resistant maize‡
T2b Cp-Lm (TC only)			Local maize
T3a Lm-Rm (RM only)	10	Local maize	Resistant maize‡
T3b Lm-Lm (FP)			Local maize
T4a Ls-Rm (RM only)	19	Local sorghum	Resistant maize‡
T4b Ls-Lm (FP)			Local maize

† Sb = Soybean, Cp = Cow peas, Lm = Local maize, Ls = Local sorghum, Rm = Resistant maize.
ISC = Integrated Striga Control, TC = Trap crop, RM = Resistant maize, FP = farmer practice.
‡ Resistant to *S hermonthica*.

Experimental design

The methodology for trial 1 (1999–2000) was described by Schulz *et al*. (2003). In brief, that trial was carried out in 19 farmers' fields, with farmers as replicates and two treatments in each replicate, i.e. integrated *Striga* control (ISC) and farmer practice (FP). The ISC treatment consisted of a legume trap crop (soybean or cowpea) in the first year, followed by *Striga* resistant maize in the second year. The FP treatment consisted of farmers' traditional cropping practice (sole cereal crop or cereal-legume intercropping or fallow) in the first year, followed by local sole cropped maize in the second year (Table1a).

Trial 2 (2000 and 2001) used a split-plot design and involved 29 farmers with farmers as replicates. In the first year, each replicate consisted of two main-plot treatments i.e. a legume trap crop (soybean or cowpea) and farmers' traditional practice (local maize or sorghum) (Table 1b). In the second year, the main-plots were subdivided into two sub-plots, which were planted to either *Striga* resistant maize or local maize giving a total of eight treatments. This effectively provided four possible scenarios, reflecting the International Institute of Tropical Agriculture (IITA) recommended integrated

Striga control option, with possible modifications that could be considered by farmers, namely:

- Integrated *Striga* control (ISC, as recommended by IITA), involving the use of two-component technologies, a legume trap crop, either soybean (TGx 1448-2E) or cowpea (IT-90K-284-2) in the first year, followed by *Striga* resistant maize (TZL Comp 1) in the second year (Kling *et al*., 2000).
- Trap cropping (TC), being the use of one of the component technologies of ISC, a legume trap crop in the first year, either soybean or cowpeas, designed to induce *Striga* seed to germinate and with no host present to die, sometimes referred to as suicidal germination. This was then followed by local maize in the second year.
- *Striga* resistant maize (RM), being the use of the other component technology of ISC, local maize or sorghum in the first year, followed by *Striga* resistant maize in the second year.
- Farmer practice (FP), being the traditional practices of continuous cereal cropping in both year one and two. Although intercropping cereals and legumes was not included so as to limit the number of treatments tested in this on-farm trial, a number of farmers followed this practice.

In both sets of trials, farmers decided which *Striga* control options they wished to follow.

Agronomic practices

At the onset of both trials, phosphorus (P) was applied to all plots at a rate of 13 kg ha^{-1} to eliminate this element as a limiting factor to plant, particularly legume growth. Thereafter all crops were grown by farmers, using their individual management practices. Consequently agronomic practices varied considerably. Researchers did however ensure that plots within each replicate were treated uniformly in terms of seed rate, fertilizer application and weeding practice 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 m. Average densities were 44 000 plants ha^{-1} for legumes and 34 000 plants ha^{-1} for cereals in trial 1 and 100 000 plants ha^{-1} for legumes and 39 000 plants ha^{-1} for cereals in trial 2. In the second trial farmers were encouraged to decrease intra-row spacing for the legumes to stimulate increased root density and therefore potential suicidal germination. Both cereals and legumes, when intercropped, were planted according to local practice with similar row to row spacings.

In both trials, farmers did not prevent *Striga* from seeding in the cereal crop in the first year, as per normal practice. In the second season, all farmers applied N fertilizer, mostly urea, to all maize crops. In 2000 this averaged 121 kg ha^{-1} (range 42–333 kg N ha^{-1}), and in 2001 this averaged 56 kg ha^{-1} (range 17–149 kg N ha^{-1}).

Sampling and analytical procedures

Crop yields and *Striga* plant densities were determined in each plot from six randomly selected plots, of 10–15 m^2 in area. Grain and crop residue yields were

Table 2. Income and cost prices (2001) (US$)†.

Item	Purchase prices May–Aug (US$ kg^{-1}) Market	Purchase prices May–Aug (US$ kg^{-1}) *Striga* resistant varieties (assumed)	Sale prices (grain) Sept–Dec (US$ t^{-1})	Sale prices (crop residues) Sept–Dec (US$ t^{-1})
NPK (15:15:15)	0.32	–	–	
Urea	0.38	–	–	
SSP	0.40	–	–	
Maize	0.42	0.46	210	50
Sorghum	0.42	–	210	50
Cowpea	0.62	0.68	270	10
Soybean	0.29	0.32	180	10
Groundnuts	0.60	–	230	10

† Naira 100 = US$ 1.00.

determined by drying representative samples to constant weight at 65 °C and grain yields adjusted to 12 % moisture content. These data on *Striga* plant density were transformed using the root square transformation $(x + 0.5)^{1/2}$. These were converted using the logarithmic transformation $\log_{10}(x + 1)$. Statistical analyses were carried out using GENSTAT 4.2 (2000), but because data were unbalanced due to having different numbers of farmers and treatment combinations within each village, REML (Patterson and Thompson, 1971) has been used for the analyses with the results presented in tables of predicted means. This takes into account differences between locations and farmer practices. Probabilities are taken from the appropriate Wald statistics.

Economic assessment

During community workshops (Emechebe *et al*., 2004) farmers' evaluation criteria for *Striga* control were identified as being: labour requirement, effectiveness in *Striga* control, availability of materials, risks associated with adoption of the new technology, cost and yield increases. Interestingly a ranking system of local *Striga* coping strategies, based on the use of these criteria, had indicated that legume-cereal rotations were the most highly rated *Striga* control measure, suggesting that introduction of a legume trap crop is likely to be well accepted. Economic analysis has been based on quantification of the benefits and costs identified by farmers and valued at 2001 market prices (Table 2). The value of the crop residues (stover) has been based on prices for sales between farmers.

Partial budget (PB) analysis has been used to compare the effects of the *Striga* control practices with farmers' traditional practices over the two-year period. In both trials we were able to compare the two-component integrated *Striga* controls (ISC) and farmer practice (FP). In the second trial we were able to make further comparisons namely: the two-component ISC, the trap crop only (TC), resistant maize only (RM) and farmer practice (FP). PBs have taken into account: the increased gross benefit (crop yield × farm-gate market price) resulting from the *Striga* control practices over the two year period and the increase (or decrease) in costs of using these methods compared to farmer practices. Cost differences largely relate to quantities of seed and fertilizer actually used. Although soybean and cowpea trap crop seed are not yet commercially available, they have been valued at 10 % more than local seed varieties. The PB excluded all items that did not vary between treatments. This included costs of land preparation, planting and weeding costs, as farmers had indicated at the time that there were no differences between treatments even when *Striga* populations varied. Increased planting costs of high density legumes especially in the second trials were balanced by reduced weeding costs later in the season, although there were concerns from farmers about the increased labour requirement when managing areas larger than the experimental plots.

Net Present Benefits (NPB), being the present value of future benefits, were determined by adding the net benefits for each year, after the second year benefits had been discounted by 20 %. This high discount rate was used to reflect a possible farmer view of the value of future benefits. Lower rates (0 % and 5 %) were used within a sensitivity analysis to substantiate any effect that this discount rate might have. The NPB obtained from applying each treatment can be expressed mathematically, as:

$$NPB = \sum_{f=1}^{N(t)} \sum_{t=1}^{2} d^{t-1} [(Y_s(f,t)P_s(f,t) - C_s(f,t)) - (Y_F(f,t)P_F(f,t) - C_F(f,t))]$$

where

NPB = Net Present Benefit ($\$$ ha^{-1}), d is the discount factor,
$Y_s(f,t)$ = Yield from the *Striga* control plot at farm f in year t,
$Y_F(f,t)$ = Yield from the farmer practice plot at farm f in year t,
$C_s(f,t)$ = Cost associated with growing the crop under a *Striga* control practice at farm f in year t,
$C_F(f,t)$ = Cost associated with growing the crop under a farmer practice at farm f in year t.
$P_F(f,t)$ = Market value of the crop grown in the farmer practice system at farm f in year t
$P_s(f,t)$ = Market value of the crop grown in the *Striga* control system at farm f in year t

A sensitivity analysis based on an a 50 % increase or decrease in output prices and variations in the discount rate (0 %, 5 % and 20 %) were used to establish the robustness of the findings over the base case.

Farmer adoption

A 'Follow the Technology' (FTT) approach (Douthwaite *et al.*, 2001) and Impact Pathway Evaluation (Douthwaite *et al.*, 2003) were used to identify and evaluate the learning, adaptation and adoption processes initiated by the on-farm experimentation.

From October 2001 to January 2002 a survey was carried out to identify the extent to which participating farmers had increased the use of *Striga* control methods on their own farms, as well as the extent of farmer-to-farmer diffusion. The experimental and expansion plots of the original participating farmers were mapped using a hand-held geographic positioning system (GPS). In addition, another 245 new or expansion farmers, using one or more *Striga* control options, were identified by asking key informants in each village. From February to June 2002, an in-depth survey was carried out on a random sample of 152 of the participating and expansion farmers. The position of the farmers' households was also mapped. The survey established farmers' existing *Striga* control practices and sought explanations for farmers' adoption and modification decisions, their understanding of *Striga* control and to find out from where farmers received the technologies, and to whom they passed them. The questionnaire specifically asked whether farmers passed on any of the agronomic information (such as closer legume spacing), in addition to distributing seed. Then, in February to April 2003, a sub-sample of these farmers was revisited and asked to draw maps of their farms, identifying for each field what they had grown over the period 1999 to 2002. This triangulated the data from the first two surveys, as well as giving more insight into farmers' decision-making processes. A total of 30 farmers were interviewed in this way, selected from both participating and expansion farmers in three wealth categories (poor, medium, rich).

RESULTS

Crop yields and Striga *incidence*

In the first trial (Schulz *et al*., 2003), in the first season, the soybean trap crop (T1) yielded well (0.90 t ha^{-1}), but the cowpea trap crop (T2) had a lower yield (0.51 t ha^{-1}) primarily because of high pest and disease incidence (Table 3a). In the farmer practice group sole cereal crops (T3) yielded less than 0.69 t ha^{-1}, while the legume-cereal

Table 3a. Trial 1 (1999–2000). Legume and cereal predicted mean yields.

Treatment†		No of farmers	1999 Crop	1999 Yield (t ha^{-1}) Grain	1999 Yield (t ha^{-1}) Stover	2000 Crop	2000 Yield (t ha^{-1}) Grain	2000 Yield (t ha^{-1}) Stover
Striga control	T1 ISC	14	Soybean	0.90	0.72	Resistant maize	1.74	2.78
	T2 ISC	5	Cowpeas	0.51	0.36	Resistant maize	1.59	2.31
Farmer practice	T3 FP	7	Sole cereal	0.69	1.20	Local maize	1.23	1.90
	T4 FP	10	Inter-crop	0.63c 0.42l	1.22c 0.31l	Local maize	1.07	1.48
	T5 FP	2	Fallow	–	–	Local maize	1.39	2.47
			sed	0.118	0.215		0.271	0.508
			Significance	***	***		***	***

ISC = Integrated Striga Control, FP = Farmer Practice, c = cereal, l = legume.
*** Significant at $p < 0.001$.

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Table 3b. Trial 2 (2000–2001). Legume and cereal predicted mean yields.

		2000			2001‡		
			Yield (t ha^{-1})			Yield (t ha^{-1})	
Treatment	No of farmers	Crop	Grain	Stover	Crop	Grain	Stover
T1a Sb-Rm (ISC)	25	Soybean	1.63	1.59	Resistant maize	1.65	2.89
T1b Sb-Lm (TC)					Local maize	1.23	2.43
T2a Cp-Rm (ISC)	4	Cowpea	0.69	1.33	Resistant maize	1.53	2.49
T2b Cp-Lm (TC)					Local maize	1.11	2.04
T3a Lm-Rm (RM)	10	Local maize	1.42	2.40	Resistant maize	0.94	1.65
T3b Lm-Lm (FP)					Local maize	0.52	1.21
T4a Ls-Rm (RM)	19	Sorghum	0.74	2.02	Resistant maize	1.16	2.04
T4b Ls-Lm (FP)					Local maize	0.74	1.60
		Significance	**	ns			
		sed	0.37	0.56			

ISC = Integrated *Striga* Control; TC = Trap Crop, Sb = Soybean, Cp = Cow pea, Rm = Resistant Maize, Lm = Local maize, Ls = Local sorghum, FP = Farmer Practice.
‡ Yield data for 2001 has been constructed from Tables 2c and 2d.
** Significant at $p < 0.005$, ns = not significant.

Table 3c. Trial 2 (2000–2001). Effect of 2000 crop on 2001 predicted maize yields (averaged over *Striga* resistant maize and local maize) and mean *Striga* counts.

	Maize Yields (t ha^{-1})		
2000 crop	Grain	Stover	Striga plants† (ha^{-1})
Soybean	1.44	2.66	1374 (3.14)
Cowpea	1.32	2.27	1125 (3.05)
Local maize	0.73	1.43	1622 (3.21)
Local sorghum	0.95	1.82	2600 (3.42)
Significance	***	***	***
sed	0.29	0.47	0.14

† Means of transformed data back-transformed (from log $base_{10}$).
*** Significant at $p < 0.001$.

inter crops (T4) produced 0.63 t ha^{-1} of cereal grain and 0.42 t ha^{-1} of legume grain. In the second season, *Striga* resistant average maize grain yields of 1.66 t ha^{-1} and stover yields of 2.54 t ha^{-1} were significantly higher than from other treatments, which averaged 1.23 t ha^{-1} of grain and 1.95 t ha^{-1} of stover.

In the second trial (Table 3b), in the first season, the soybean and cowpea trap crops (T1 and T2) yielded more than the corresponding 1999 yields (1.63 t ha^{-1} and 0.69 t ha^{-1} respectively), due to reduced pest and disease incidence and higher legume plant densities. In the farmer practice group (T3 and T4), maize yielded 1.42 t ha^{-1} and sorghum 0.74 t ha^{-1}. In the second season, no significant interactions were observed between treatments in the first year and subsequent maize treatments. However significant differences ($p < 0.001$) were observed between 'previous crop' treatments and the 'maize' treatments for both grain and stover (Table 3c). Maize after

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Table 3d. Trial 2 (2000–2001). *Striga* resistant maize and local maize predicted average yields in 2001 and *Striga* counts.

	Maize Yields (t ha^{-1})		
	Grain	Stover	*Striga* plants† (ha^{-1})
Resistant maize	1.32	2.27	1089 (3.04)
Local maize	0.90	1.82	2344 (3.37)
Increase	0.42 (47 %)	0.45 (25 %)	− 1255 (− 53 %)
Significance	**	*	***
sed	0.10	0.15	0.068

† Means of transformed data back-transformed (from log base$_{10}$).
*** Significant at $p < 0.001$, ** Significant at $p < 0.005$, * Significant at $p < 0.01$.

soybean (1.44 t ha^{-1}) significantly out-yielded both maize after local maize (0.73 t ha^{-1}) and maize after sorghum (0.95 t ha^{-1}). In comparison, maize after cowpea yielded 1.32 t ha^{-1}. On average, maize after a previous legume trap crop yielded 1.38 t ha^{-1} but only 0.84 t ha^{-1} after a previous cereal crop. In addition mean *Striga* resistant maize grain yields of 1.32 t ha^{-1} were significantly higher ($p < 0.005$) than those of local maize, whose mean yields were 0.90 t ha^{-1}, 47 % less than the *Striga* resistant maize yields (Table 3d).

Treatment effects observed on the incidence of emerged *Striga* were significant ($p < 0.001$) (Tables 3c and 3d). Trap crops reduced *Striga* incidence in the following maize crop at 12 weeks after planting by 40 % in terms of *Striga* plants ha^{-1}, and 53 % less *Striga* was observed on *Striga* resistant maize compared with local maize or sorghum ($p < 0.001$).

Economic assessment

NPBs comparing integrated *Striga* control with farmer practice are shown for each farmer, ranked from highest to lowest NPB over the two year cropping period for both sets of trials (Table 1a and 1b). Results for the first trial (19 farmers) show a mean NPB over farmer practice of \$54 ha^{-1} in the first year and \$126 ha^{-1} in the second year, an overall increase in productivity of \$180 or 108 % over farmer practice (Tables 4 and 5). This increase is highly significant ($\text{Wald}_{(1)} = 2.68$, $p < 0.001$). There is also a significant net benefit from using soybean rather than cowpea ($\text{Wald}_{(1)} = 7.34$, $p = 0.007$). Results for the second trial show a mean NPB of \$203 ha^{-1} in the first year and \$132 ha^{-1} in the second year, an overall significant increase in productivity of \$335 or 125 % for integrated *Striga* control over farmer practice ($p < 0.001$). However, in both sets of trials there was considerable variability around these means.

In the first year of both trials, 63 % and 76 % of farmers respectively derived a benefit from using the legume trap crop rather than local maize, sorghum or fallow. In the second year, 84 % and 96 % respectively derived a benefit from growing *Striga* resistant maize. For both sets of trials, 89 % and 79 % respectively, derived an overall net benefit from two years of *Striga* control. This meant that, 11 % and 21 % of farmers in the two sets of trials derived a greater benefit from using their own practices.

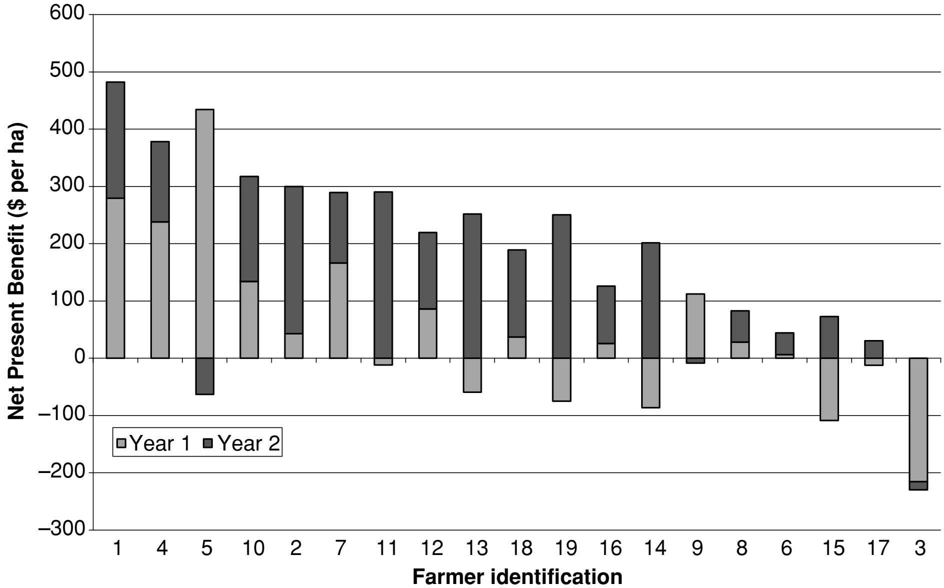

Figure 1. Trial 1 (1999–2000). Net Present Benefit of integrated *Striga* control over farmer practice (US$ per ha^{-1}) (n = 19).

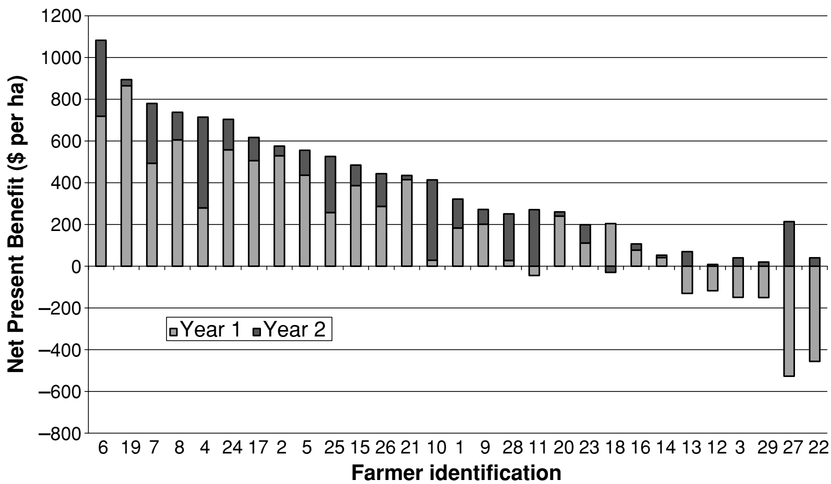

Figure 2. Trial 2 (2000–2001). Net Present Benefit of integrated *Striga* control over farmer practice (US$ per ha^{-1}) (n = 29).

In the second trial, where the two-component/two-year ISC was compared with either the single-component trap crop in the first year followed by local maize, or local maize in the first year followed by *Striga* resistant maize in the second year or local maize or sorghum over two years, the first year of *Striga* control proved critical in achieving higher productivity over the two-year period. Although predicted

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Table 4. Trial 1 and 2, mean Net Present Benefit of *Striga* control and marginal returns over farmer practice over a two year period (US\$ ha^{-1}).

	Integrated *Striga* control TC-RM	Trap crop only TC-LM	Resistant maize only LM-RM	Farmer practice LM-LM	*sed* significance
Trial 1 1999–2000 (n = 19)					
Mean Net Present Benefit	346			166	77.4
Range	4–897			– 27 to 609	***†
Marginal return over FP	180				
% increase	108 %				
Trial 2 2000–2001 (n = 29)					
Mean Net Present Benefit	602	568	273	267	41.4
Range	33 to 1200	31 to 1062	– 43 to 757	– 41 to 899	***‡
Marginal return over FP	335	301	6	–	
% increase	125 %	113 %	2 %	–	

TC = Trap crop, RM = *Striga* resistant maize, RM = Resistant maize, LM = Local maize.
†*** significant at $p < 0.001$ between TC-RM, and LM-LM.
‡*** significant at $p < 0.001$ between TC-RM, TC-LM and LM-RM, LM-LM.
with nsd between TC-RM and TC-LM or LM-RM and LM-LM.

Table 5. Trials 1 and 2 (1999–2000 and 2000–2001). Mean Net Present Benefit of integrated *Striga* control over farmer practice (US\$ ha^{-1}).

	1999–2000			2000–2001		
Scenario	Y1	Y2	*Total*	Y1	Y2	*Total*
2001 market prices†	54	126	*180*	203	132	*335*
Legume price increases 50 %	108	126	*234*	440	138	*493*
Legume price decreases 50 %	0	126	*126*	90	138	*236*
Maize price increases 50 %	11	171	*183*	154	205	*359*
Maize price decreases 50 %	96	81	*177*	385	71	*456*
Maize price decreases 50 %‡ Legume price increases 50 %‡	150	81	*231*	556	71	*542*
Maize price increases 50 %§ Legume price decreases 50 %§	– 43	171	*129*	– 103	205	*187*

† Most realistic scenario, ‡ Best case scenario, § Worst case scenario.
Y1 = Year 1, Y2 = Year 2.

mean yield results showed increased yields from *Striga* resistant maize (Table 3c), there was no significant difference in NPB between ISC and the use of a trap crop only or between *Striga* resistant maize only and continuous cereals. However there was a significant increase ($p < 0.001$) when comparing ISC and use of a trap crop only with *Striga* resistant maize only and continuous cereals for both sets of trials (Table 4).

Sensitivity analysis shows positive NPBs for ISC over FP over the two-year period in all the scenarios examined, except where the price of maize increased by 50 % and legumes decreased by 50 % (the worst case scenario), and then in the first year only (Table 5). Conversely the highest NPB (the best case scenario) was achieved where the

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legume price increased by 50 % and the maize price declined by 50 %. Discount rate had little effect on sensitivity, although higher rates did favour higher legume price.

Farmer adoption

The surveys found that the great majority (84 %) of participating farmers had expanded the use of at least one component of *Striga* control technology from their experimental plots to their farm. The most common was soybean used as a trap crop, found in 78 % of expansion fields. *Striga* resistant maize and cowpea were found in 13 % and 4 % of fields, respectively. The mapping survey showed that 27 % of farmers growing legumes were using a plant spacing of 0.2 m or less, and thus, had adopted the close legume spacing, recommended as part of *Striga* control. In the second survey, 82 % of farmers reported that they had adopted hand-roguing as a result of what they had learnt about the *Striga* life-cycle from regular training sessions given in their respective villages by the research technicians supervising the experimental trials, or from other farmers. While hand-roguing was reported as a traditional control practice (Emechebe *et al*., 2004), few farmers in this area practiced it before learning about the *Striga* life-cycle. Indeed, training was also important in the adoption of other *Striga* control technologies, and was universally appreciated by farmers. A sentiment expressed by one farmer, but shared by many others was: 'The training helped me realise that I was wasting effort out of ignorance. I now know how to control *Striga*'. Also in the second survey, 81 % of farmers said they had adopted a rotation of cereals and legumes. The resource mapping survey found that this adoption was often limited to just one or two fields where cereal yields had fallen as a result of *Striga* or low soil fertility, and that farmers knew that legumes could improve soil fertility before the SC project began. Again, like weeding of *Striga*, training in its control has supported a local *Striga* control measure by providing farmers with a better understanding of why it works.

Figure 3 shows the position of the households of the participating farmers and another 108 expansion farmers. It illustrates, as one might expect, that most of the adoption is by farmers living close to the homes of the participating farmers. However, the figure also shows that adoption in some cases 'jumps' and new adoption clusters form. The furthest jump identified was from Mahuta to Dan Ayamaka, a distance of over 40 km. All these jumps occurred as a result of farmers or village assistants employed by the project giving seed and information to other farmers. The second survey found that 62 % of farmers were giving or selling seed to an average of three other farmers, often in other villages. Of the farmers who gave seed, 94 % gave trap crop soybean and 21 % gave *Striga*-resistant maize. Almost no farmers gave trap crop cowpeas. About 50 % of farmers indicated that they were giving instructions about *Striga* control of which the most common was close legume spacing. Nearly all farmers (94 %) said they were saving either trap crop soybean or *Striga* resistant maize germplasm.

Two-thirds of farmers had made at least one modification to the practices in the experimental plots. Nearly all these modifications involved abandoning the sole crop

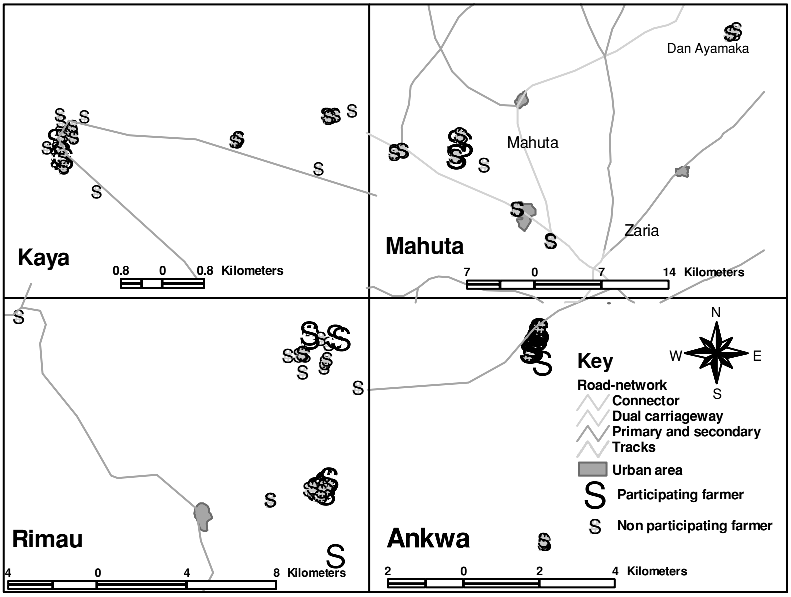

Figure 3. Adoption and spread of integrated *Striga* control technologies in four villages. Each point represents one farmer's field. Two or more legends superimposed on one point mean that the farmer adopted two or more technologies.

legume recommendation and planting cereals in various patterns. The reasons farmers gave for this included 'to double harvest', 'for maximum use of land', 'not to leave the land bare after harvesting soybean', and to 'guard against crop failure'.

DISCUSSION

Both sets of farmer-managed trials, each covering a two-year period, have shown that the highest productivity was obtained by combining two-component *Striga* control technologies (legume trap crop followed by a *Striga* resistant maize variety). *Striga* resistant maize yields increased by 35 % over local maize in the first trial and by 47 % in the second trial. From the second trial, we were able to further substantiate the effects of the legume trap crop and the *Striga* resistant maize as two equally important component technologies of an integrated *Striga* control practice leading to yield increases of over 64 % (effect of previous legume trap crop) and 47 % (effect of the resistant maize). Moreover, the findings of this trial suggest that substantial synergistic effects occur if these two-component technologies are combined. For example, resistant maize after soybean (1.65 t ha^{-1}) outyielded local maize after sorghum (0.74 t ha^{-1}) by more than 120 %. However, yield increases after cowpea, which performed poorly compared to soybean, were less pronounced. This indicates that effective, high yielding legume trap crops are important for realising these synergistic effects and corroborates earlier observations by Schulz *et al.* (2003) that only high yielding legumes should be promoted as trap crops.

Striga resistant maize grown after a leguminous trap crop (predicted average grain yield of 1.59 t ha^{-1}) appeared to be significantly more productive than local maize (1.17 t ha^{-1}) and at the same time *Striga* resistant maize grown after local cereals (1.05 t ha^{-1}) also appeared to outperform continuous local cereal production (0.63 t ha^{-1}).

Striga counts were 69 % lower in maize following leguminous trap crops than following local maize or sorghum, and 53 % less in *Striga* resistant maize than local maize. This result differs from earlier work (Carsky *et al*., 1998) who found no difference in terms of either emerged *Striga* plants or maize grain yields when comparing a *Striga* resistant maize (STR Syn-W) with local cultivars. It does however demonstrate the importance of using a legume trap crop in the first season and not relying solely on a *Striga* resistant maize variety as a means of *Striga* control. In cases where farmer practice outperformed researcher-developed *Striga* control methods, this included a legume in a cereal-legume intercrop. Carsky *et al*. (1994) showed that intercropping legumes with cereals can decrease the number of *Striga* plants, leading to reduced *Striga* infestation in the following cereal crop. This may be due to the legume acting as a trap crop, suppressing *Striga* germination or providing a shading effect (Oswald *et al*., 2002). The high production of the cereal-legume intercrop in the first year of the first trial does show the potential for cereal-legume intercropping as a control measure, and helps to explain this modification by farmers to the *Striga* control methods they have seen on the trials.

Another reason identified for farmers' practices outperforming the *Striga* control method was the use of inorganic fertilizers. A review by Pietrse and Verkleij (1991) concluded that N fertilizer, particularly in the form of urea or ammonium, may reduce *Striga* infection. Repeated use of inorganic fertilizer may control *Striga* and clearly remains a control option for those farmers who have access to cash or credit, and provided fertilizer is available for purchase when required. However, the practice by farmers to use excessively high rates of N (in one case up to 333 kg N ha^{-1}) should be discouraged otherwise the long term soil productivity will be impaired.

Economic analysis has confirmed that returns in excess of 100 % over farmer practice can be achieved by growing resistant maize after a trap crop, with soybean being more effective than cowpea. Adoption by farmers indicates that farmers see the economic benefits of *Striga* control and hence potential for wider uptake. Interestingly most farmers gave, sold or saved soybean or *Striga* resistant maize seed, with almost no farmers giving cowpeas. The survey findings show that explaining the reasons why local control practices work can greatly increase their adoption. Wide adoption of *Striga* control technologies will require an extension approach that provides this knowledge as well as allowing farmers to experiment and adapt *Striga* control options into their local farming systems. Strategies need to be developed to strengthen farmer capacity in germplasm maintenance.

Our base case scenario has indicated the viability of integrated *Striga* control measures. It should however be noted that the price of legumes relative to maize is likely to have a major effect on adoption of *Striga* control measures. Present prices provide an economic incentive to adopt. However if the prices of legumes were to drop by 50 % due to possible oversupply, and cereal prices were to increase by 50 % due to possible production shortfalls, this would discourage the growing of legumes and probably increase the demand for maize, albeit a *Striga* resistant variety, but without the added advantage of a trap crop. As the price of legume increases relative to that of cereals, it becomes increasingly more attractive to grow the legume and hence adopt integrated *Striga* control measures

CONCLUSION

The work reported in this paper demonstrates:

- That both increased yields and productivity (NPB) can be obtained from the use of integrated *Striga* control measures over farmer practice.
- The importance of growing a leguminous trap crop, with soybean outperforming cowpeas, in the first year of a two-year rotation.
- That farmers in the villages surrounding the trials have seen economic merit and have started to adopt different component parts of ISC.
- Most farmers have modified the technologies and are using leguminous trap crops, mostly soybeans in a legume-cereal intercrop.

It is important that scientists take note of these farmer modifications in further refinement of *Striga* control measures.

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