Busia and Homa Bay districts was mainly attributed to hand weeding of young desmodium plants, whereas, farmers in Kisii and Teso districts found land preparation and marking of the field for establishment of the technology as being the most labour intensive. The decrease in labour in subsequent years in established 'push-pull' plots was mainly due to reduced weeding, reduced striga uprooting, reduced fodder fending and reduced labour on land preparation (Figure 6).

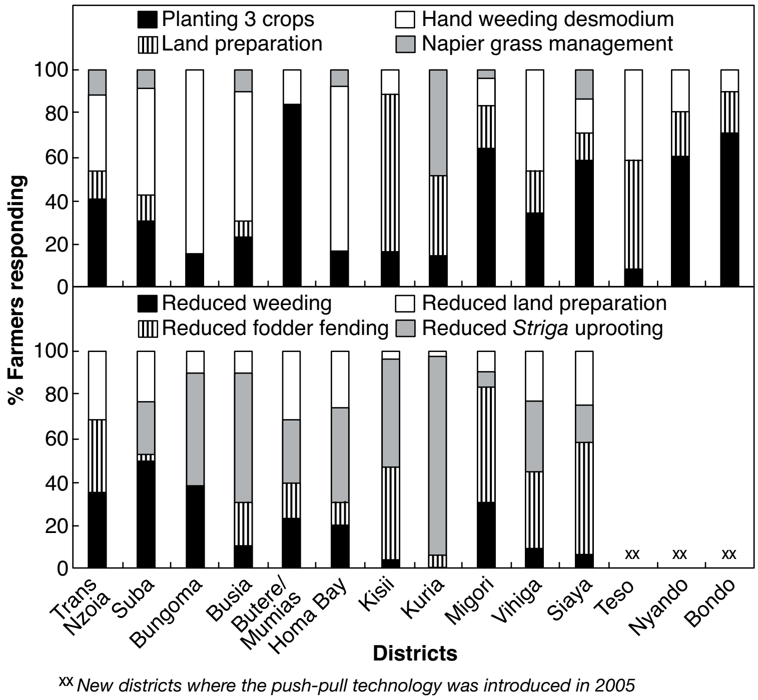

Figure 6. Reasons for changes in the labour requirement following adoption of the 'push-pull' technology

8. *Economics of the 'push-pull' technology*

A formal cost–benefit analysis covering six districts in Kenya (Bungoma, Busia, Kisii, Suba, Trans Nzoia and Vihiga), measured farmers' income, expenditure, use of inputs and labour. Ten farmers were followed from the time they adopted the 'push-pull' technology, and the parameters compared between the push-pull and their conventional cropping system (maize monocrop). Data comprised total variable costs, TVC (labour and non-labour costs), total revenues, TRV (arising from sales of farm produce) and gross benefits (TRV–TVC). The results showed that TVC were significantly higher in 'push-pull' than in traditional maize monocrop plots. However, total gross revenue and gross benefits were also significantly higher with the 'push-pull' technology than with the maize monocrop system, with the benefits outweighing the costs by an average of US$ 530 in the 'push-pull' system but only US$ 140 in the maize monocrop system (Table 6).

Table 6. Economics of 'push-pull' strategy as compared to maize monocrop (control) in six districts in western Kenya, 1998–2004

	Total labour costs ($/ha)		Total variable costs ($/ha)		Total gross revenue ($/ha)		Gross benefits ($/ha)	
District	Push-Pull	Control	Push-Pull	Control	Push-Pull	Control	Push-Pull	Control
Trans-Nzoia **a**	223	128*	493	374*	1290	628**	797	254**
Suba **b**	167	134*	278	250*	679	329**	401	79**
Bungoma **c**	247	222ns	331	300*	867	415**	536	115**
Busia **c**	222	118*	321	243*	862	418**	541	175**
Kisii **c**	184	140*	246	210*	733	334**	487	134**
Vihiga **c**	227	128*	359	331*	423	185**	426	92**

a, **b**, **c** represent data averages for 7, 4 and 3 years respectively.
*Difference significant ($P < 0.05$); **difference significant ($P < 0.01$); ns, difference not significant.

9. *'Push-pull' and striga seed depletion*

A long-term study at the ICIPE field station at Mbita Point demonstrated a sharp decline in striga seed count in the 'push-pull' plots over 6 years (Figure 7). In another long-term trial, a comparison of maize–desmodium intercrops with maize monocrop and maize–cowpea intercrop showed significant increases in the striga seed counts in the soil in the maize monocrop and maize–cowpea intercrop,

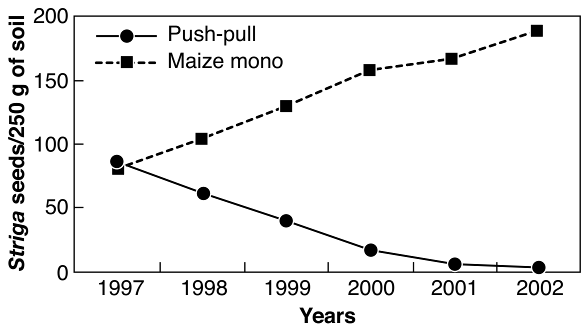

Figure 7. Effect of a long-term push-pull field trial on striga seed density in the soil at ICIPE-Mbita, western Kenya

but significant decreases in the maize–desmodium intercrops (Figure 8).

10. Enhancing biodiversity through the 'push-pull' technology

Biodiversity in agroecosystems has greatly been reduced in the last decades as a result of intensification of cereal agricultural systems, while empirical data show that agroecosystems with an enhanced overall biodiversity have relatively fewer pest problems. As a result of this observation it has often been stated that enhancement of biodiversity within agroecosystems can greatly contribute to the development of sustainable crop protection systems, with a reduced reliance on pesticides. Biodiversity has an intricate role in the functioning of natural and agricultural ecosystems since it performs a variety of ecological services thereby mediating processes such as genetic introgression, natural pest control, nutrient cycling and decomposition. Farming practices that conserve such biodiversity as ground fauna and pests' natural enemies may be a practical alternative to manage pests in agricultural systems. Our results from Kenya and South Africa, using spiders (Araneae) as an indicator group, indicate that the 'push-pull' strategy is associated with an overall enhancement of ground-dwelling arthropod abundance (Table 7).

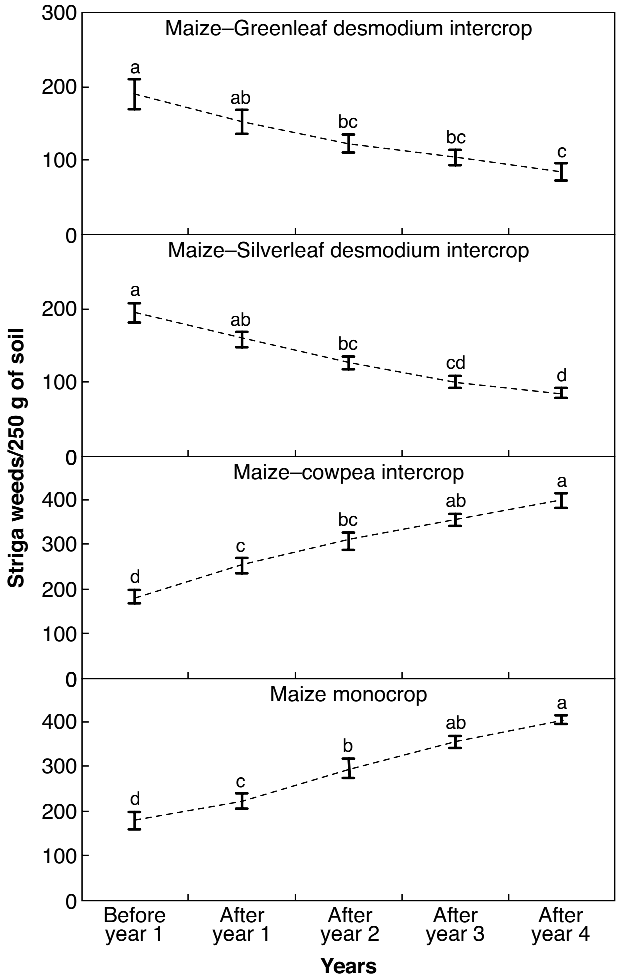

Figure 8. Annual changes in striga soil seed density in different intercrops and maize monocrop. Means marked with different letters within a cropping system are significantly different (P < 0.05)

Table 7. Mean (± SE) number of spiders captured per plot in Kenya (Lambwe and Homa Bay) and South Africa (Potchefstroom), 2004

	Kenya		South Africa
Treatment	Lambwe	Homa Bay	Potchefstroom
Maize monocrop	196.5	55.5	19.7
'Push-pull' system	266.2**	103.0**	48.7*

*Difference significant (P < 0.05); **difference significant (P < 0.01).

11. 'Push-pull' technology and IR maize

In collaboration with CIMMYT, TSBF and national partners, demonstrations with best-bet technologies for the control of striga and stemborers, and enhancement of soil fertility were continued in 2005 in both the long rainy season (March to July) and the short rainy season (September to January) in Kenya and Uganda. *(See 2002–2003 ICIPE Annual Scientific Report.)* Components of these best-bets were cropping systems (maize intercropped with stemborer moth-repellent *Desmodium* ['push'] with stemborer moth-attractant Napier grass ['pull'] planted around the field ['push-pull' system], continuous maize and rotations with grain [soybean] and herbaceous [*Crotolaria*] legumes). Their effect on suppression of striga and stemborers and soil fertility improvement were compared using two maize varieties (Imidazolinone-resistant [IR] and an improved commercial variety) under two fertiliser levels (no fertiliser and medium fertiliser). Stemborer damage to maize varied substantially between locations and seasons and the 'push-pull' technology was observed to suppress stemborer damage (Figures 9 and 10). The push pull technology consistently suppressed striga emergence in both seasons (Figures 11 and 12). Fertiliser application did not show significant reductions in either stemborer or striga infestations. Striga seed count before and after six cropping seasons showed that the 'push-pull' system and *Crotolaria* rotation were the only systems where there was a decrease in striga seed population while all the other cropping systems resulted in seed density increases (Figure 13).

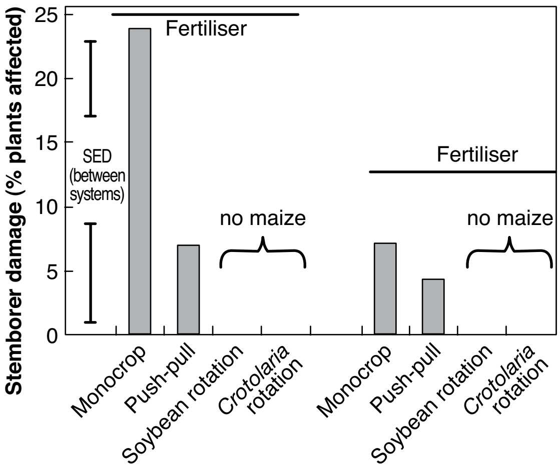

Figure 9. Effect of cropping systems by fertiliser, or lack of, on plant damage by stemborers in Busia District, Uganda

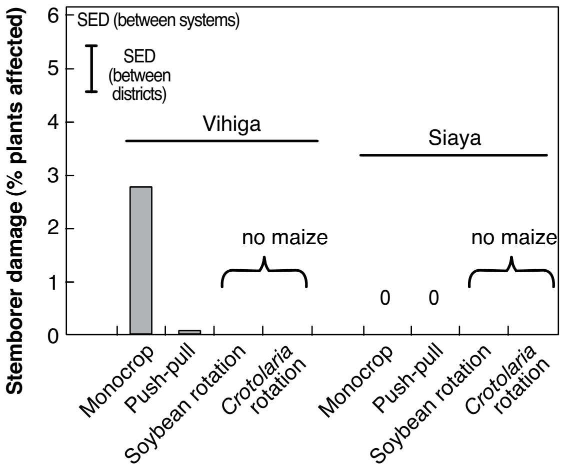

Figure 10. Effect of cropping systems by district on plant damage by stemborers during the long and short rainy season of 2005 in western Kenya

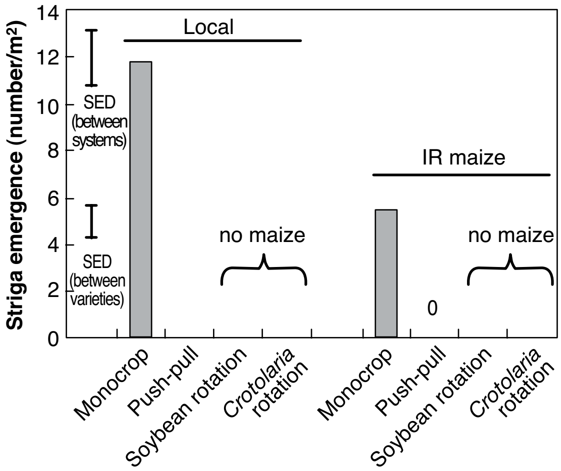

Figure 11. Effect of cropping systems by variety on striga emergence during the long and short rainy season of 2005 in western Kenya

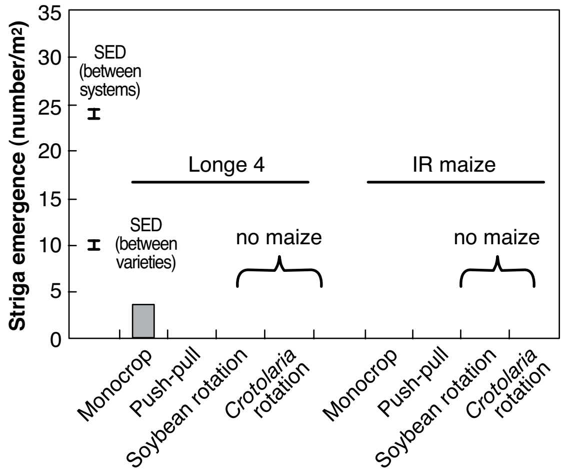

Figure 12. Effect of cropping systems by variety on striga emergence during the long and short rainy seasons of 2005 in Busia District, Uganda

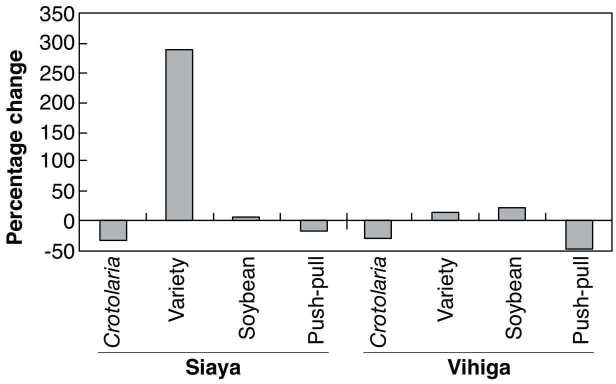

Figure 13. Percentage change in striga seed population in the soil after 6 cropping seasons with different management options in western Kenya

Farmers' perceptions and evaluation of 'push-pull', IR maize and crop rotation

In collaboration with CIMMYT and KARI, a total of 142 farmers in Siaya and Vihiga districts of western Kenya evaluated these trials using striga and stemborer control, soil fertility enhancement, grain yield, labour saving, crop vigour, fodder supply, soil erosion reduction and overall crop performance as the main criteria. They scored each treatment for each criterion, and an overall score of the treatment, using a scale of 1 (very poor) to 5 (very good). Using ordinal regression analysis, a short model was estimated as $Yj = f(Xj)$, where Y is overall farmer evaluation score from

1–5 of treatment Xj. Results showed that treatments were significantly different, with the 'push-pull' trials being generally more preferred (Table 8) than the other technologies.

The estimated 15 coefficients are log-odds ratios compared to the last entry, here the maize monocrop of local variety without fertiliser application. For example, the estimate 1.99 is an exponent and its antilog yields the number of times (7.3) that treatment 1 ('push-pull' with IR-maize and fertiliser) is more preferred compared to treatment 16 (local maize monocrop with no fertiliser application). Overall, the 'push-pull' treatments were generally the most preferred, 4.4 to 7.3 times. The preference of maize–soybean and maize–crotolaria rotations ranged between 1.8 and 5.4 times and 3 and 3.3 times respectively. However, when split, treatments were rated significantly different in the two districts. Farmers in Siaya generally rated the 'push-pull' combinations higher than those in Vihiga, who rated maize–legume rotations higher. The monocrop was rated the lowest in both districts. These results show an overall preference of the 'push-pull' combinations over the other technologies. Further studies are needed over a range of socioeconomic situations and agroecological zones to validate these findings.

Table 8. Appreciation of technologies in general and by district, short rains 2005

	Components of treatment			Estimates of odds ratio			
Treatment	Technology	Maize variety	Fertiliser	Both districts (short model)	Standard error	Vihiga	Cross effect of Siaya
1	Push-pull	IR	yes	1.99***	0.218	0.73**	3.00***
2		IR	no	1.54***	0.216	0.53*	2.42***
3		Local	yes	1.48***	0.216	0.68**	2.00***
4		Local	no	1.63***	0.216	0.64**	2.60***
5	Maize–soybean	IR	yes	1.69***	0.218	1.04**	1.60***
6		IR	no	0.66***	0.215	0.11	1.13***
7		Local	yes	1.11***	0.216	1.29***	-0.48
8		Local	no	0.56**	0.215	1.68***	-2.81***
9	Maize–*Crotolaria*	IR	yes	1.16***	0.217	1.91***	-1.91***
10		IR	no	1.19***	0.216	0.95***	0.57*
11		Local	yes	1.10***	0.216	2.11***	-2.35***
12		Local	no	1.17***	0.216	0.95***	0.47
13	Monocrop	IR	yes	0.08	0.215	-0.02	-0.08
14		IR	no	0.05	0.214	-0.23	0.32
15		Local	yes	0.53**	0.215	1.11***	-1.60***
16		Local	no	0	.	0	-0.35
Log likelihood					1115.8	431.54	
χ^2					246.02	234.49	

***significant at 1%, **significant at 5%, *significant at 10%.

12. Benefits of incorporating the Bt-technology into the 'push-pull' strategy

Transgenic (Bt-maize) maize cultivars have been developed to control cereal stemborers. These have a foreign gene from *Bacillus thuringiensis* (Bt), a bacterium that produces insecticidal crystalline proteins during sporulation, incorporated into the DNA of maize making it toxic to some species of lepidopteran pests that feed on it. The usefulness of the cultivars may be cut short should the target pests develop resistance to them. Our studies have indicated that the 'push-pull' strategy significantly reduces stemborer infestations in the main crop. Any tactic that appreciably reduces the number of individuals of the target pest getting exposed to the Bt-toxin is desirable in an integrated resistance management strategy. Our studies in South Africa show that incorporating push-pull into the Bt-technology significantly reduces infestation of the maize by the stemborers (Figure 14), significantly enhances predator populations (Figure 15) and their efficacy on *C. partellus* eggs (Figure 14). Our studies indicate a potential role of the system becoming a component in Bt-resistance

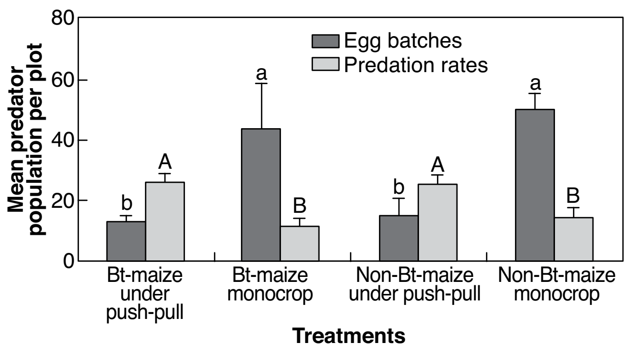

Figure 14. Mean number of *Chilo partellus* egg batches and % egg predation rates per plot at Potchefstroom, South Africa, 2004

management for the pest. Further studies are needed to elucidate the socioeconomics of the system compared with 'push-pull' based on non-Bt maize.

13. Ability of the 'push-pull' strategy to sustain its benefits in a different environment

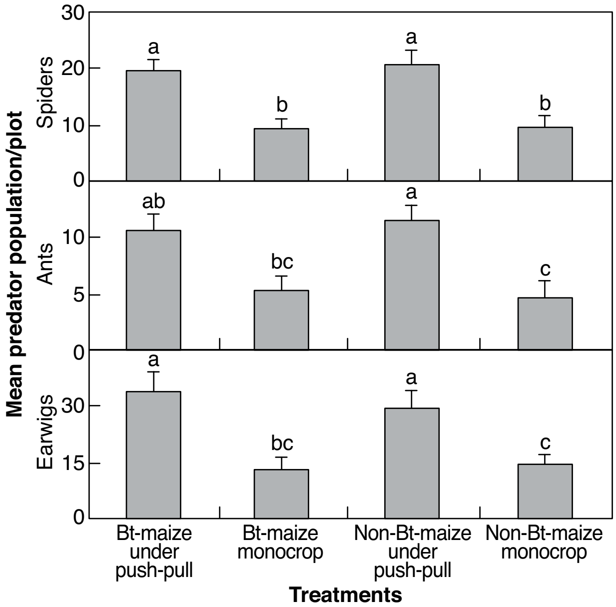

Figure 15. Mean number of stemborer egg predators per plot in Potchefstroom, South Africa 2004

The 'push-pull' system is expanding in East Africa and trials are also ongoing in South Africa following an extensive survey of wild hosts of stemborers and studies on colonisation, growth and survival of stemborers in indigenous grasses in the country. Studies conducted in Kenya have consistently shown the system's effectiveness in controlling the pests and enhancing grain yields. It was thus desirable to assess whether the strategy would offer similar levels of benefits in a different environment. This is important as the pest management mechanisms of the 'push-pull' strategy may vary regionally/locally because herbivore assemblages may differ as well as characteristics of the plants. We therefore carried out a step-wise assessment of the impact of this system on maize stemborer colonisation, crop damage and yield in the dominant maize production systems of Kenya and South Africa. Results established that *C. partellus* and *B. fusca* were the main stemborer species at all sites, with the former being relatively more abundant in Kenya while the latter was relatively more abundant in South Africa. The numbers of egg batches of both species were significantly higher in the maize monocrop than the 'push-pull' systems in both countries. The incidence of the larvae and pupae (combined for both species) was significantly higher in maize monocrop than 'push-pull' systems in both countries (Table 9). There was significantly more plant damage (number of entry/exit holes per plot, the percentage number of plants with leaf damage and plants with broken stems) caused by stemborer larval feeding in the maize monocrop than in the 'push-pull' plots in both countries (Table 10).

Table 9. Average (± SE) number of stemborer egg batches and larvae and pupae per plot in Kenya (Lambwe and Homa Bay) and South Africa (Potchefstroom), 2004

Stemborer life stage		Kenya: Lambwe	Kenya: Homa Bay	South Africa: Potchefstroom
Chilo partellus egg batches/ plot	Monocrop	27.1	19.4	16.5
	Push-pull	11.2**	7.9**	4.2**
Busseola fusca egg batches/ plot	Monocrop	20.2	16.6	19.0
	Push-pull	8.1**	5.1**	5.2**
Larvae and pupae/plot	Monocrop	54.7	37.2	39.7
	Push-pull	20.1**	20.8*	16.2**

*Difference significant (P< 0.05); **difference significant (P < 0.01).

Table 10. Mean (± SE) maize plant damage levels per plot in Kenya (Lambwe and Homa Bay) and South Africa (Potchefstroom), 2004

Damage parameter		Kenya: Lambwe	Kenya: Homa Bay	South Africa: Potchefstroom
% plants with foliar damage	Monocrop	32.9	26.7	44.3
	Push-pull	12.1**	5.8**	11.1**
% dead plants	Monocrop	3.9	4.0	1.4
	Push-pull	1.2**	1.0**	1.2ns
Stemborer entry/ exit holes	Monocrop	15.5	14.6	14.9
	Push-pull	8.1**	6.7**	8.9*
% plants with broken stems	Monocrop	4.7	4.2	3.6
	Push-pull	0.8**	0.9**	1.5*

*Difference significant (P < 0.05); **difference significant (P < 0.01); ns, difference not significant.

14. Electrophysiological responses of stemborers to the volatiles from wild and cultivated host plants

Volatiles released by two cultivated hosts, sorghum and maize (*Sorghum bicolor* and *Zea mays*), and two wild grass hosts (*Pennisetum purpureum* and *Hyparrhenia tamba*), were collected by air entrainment. Electrophysiologically active components in these samples were located by coupled gas chromatography-electroantennography (GC-EAG) and the active peaks identified by gas chromatography-mass spectrometry and co-injection with authentic standards. A total of 41 compounds were identified from the four plant species, all of which, as well as two unidentified compounds, elicited an electrophysiological response from one or both of the stemborers. The compounds included a number of greenleaf volatiles and other aliphatic aldehydes, ketones and esters, mono- and sesquiterpenoids and some aromatic compounds (Figure 16).

EAG studies with authentic samples, conducted at two discriminating doses for all compounds, and dose-response curves for 14 of the most highly EAG-active compounds, showed significant differences in relative responses between species. The compounds which elicited large responses in both species of moth included linalool, acetophenone and 4-allylanisole, while a number of compounds such as the aliphatic aldehydes octanal, nonanal and decanal elicited a large response in *Busseola fusca*, but a significantly smaller response in *Chilo partellus* (Table 11). Furthermore, the wild hosts produced significantly higher levels of physiologically active compounds, overall, compared with either of the cultivated hosts. This study provides insights into possible host location kairomones used by these two species of stemborers and into the differential attraction/oviposition between cultivated and wild hosts observed in the field. In particular, it provides some essential scientific input required for sustainability of the 'push-pull' strategy.

15. *Mechanisms of striga suppression by* Desmodium uncinatum

It has been demonstrated that a combination of two allelochemicals (germination stimulant and post-germination radicle inhibition) is responsible for continual elimination of striga seeds observed in maize–*Desmodium* intercrops. *(See 2002–*

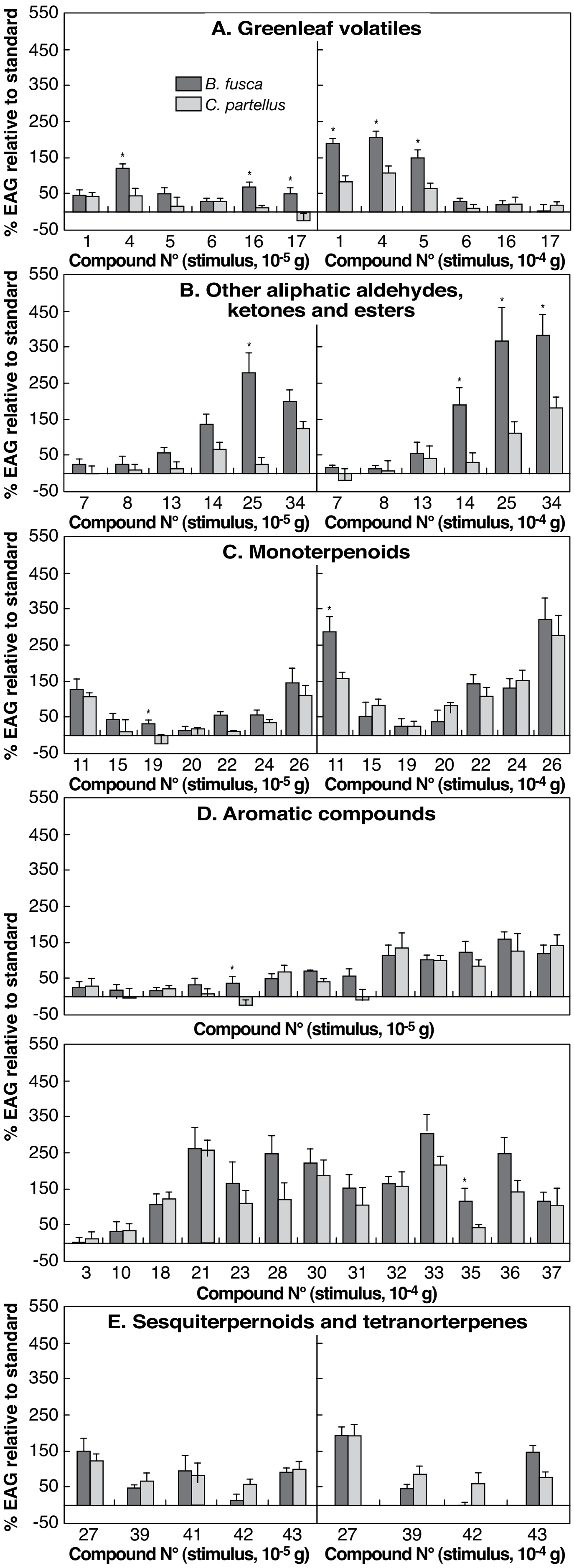

Figure 16. Electrophysiological activity for *Busseola fusca* and *Chilo partellus*, relative to that of 4-allylanisole (10^{-5} g), of authentic compounds; *indicates a significant difference between the responses of the two species ($P < 0.05$)