Striga management and the African farmer

Paul L. Woomer, Mpoko Bokanga and George D. Odhiambo

Abstract: *Striga asiatica and S. hermonthica are widespread plant parasites of cereals in Sub-Saharan Africa. In maize cropland alone, Striga has infested about 2.4 million ha, resulting in yield loss of 1.6 million tons per year, valued at US$383 million. Because the parasite attacks below ground, conventional weeding is largely ineffective. Researchers have been slow to develop other Striga control practices useful to small-scale African farmers. Two recent technical breakthroughs, however, offer opportunities for better Striga management. First, herbicide-resistant maize lines provide several weeks' chemical protection from infection, resulting in over one ton per ha yield improvement and reducing Striga expression by 80%. Second, many legumes induce Striga seed to germinate and die in the absence of susceptible host roots, a characteristic usefully employed in cereal–legume intercropping and rotation. The challenge is to translate these technical achievements into products and technologies available to and adopted by Africa's poor farmers.*

Keywords: *plant parasites; small-scale farms; Striga; African farmers; African agriculture*

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Striga's invasion of maize cropland

While *Striga* infestation of African cropland has many of the attributes of a biological invasion, it actually results from an indigenous plant parasite of native African grasses. In African savannas and dry woodlands, *Striga* spp. co-evolved with grasses belonging to numerous genera including *Eleusine*, *Loudetia*, *Pennisetum*, *Setaria* and *Sorghum* (Boonman, 1993), as well as several small grains that were later domesticated (Purseglove, 1972). As natural vegetation was cleared for agriculture, many of the native plants were destroyed, but the *Striga* persisted and parasitized the cultivated cereals that followed. Some of these native cereals – for example, sorghum and millet – exhibit partial tolerance or resistance to *Striga*, but exotic ones – particularly maize – remain extremely susceptible to the weed. Nonetheless, maize cultivation swept the African continent between the sixteenth and nineteenth centuries (Figure 1) because of its obvious advantages against an even greater pest of small grains, that is, birds (Rouanet, 1987). In traditional times, entire communities were mobilized to prevent migrating flocks of birds from consuming the exposed, ripening cereals. Maize grains develop within the protection of its ear's wrapper leaves, a visual and physical barrier that prevents feeding by smaller birds. Maize has other advantages related to its ease of storage, milling and preparation. As the frequency and coverage of cereal cultivation increased in Africa, so too did the opportunity for *Striga* to parasitize its cultivated hosts and colonize its cultivated soils. Indeed, *Striga*'s invasion of African cropland results in part from the indigenous weed's attack upon exotic cereal crops, particularly maize. At present, the deleterious effects of *Striga* in Sub-Saharan Africa's maize croplands are massive, as it has infested about 2.4 million ha – resulting in a yield loss of 1.6 million tons per year, valued at US$383 million (Table 1). But the greatest losses are suffered by millions of small-

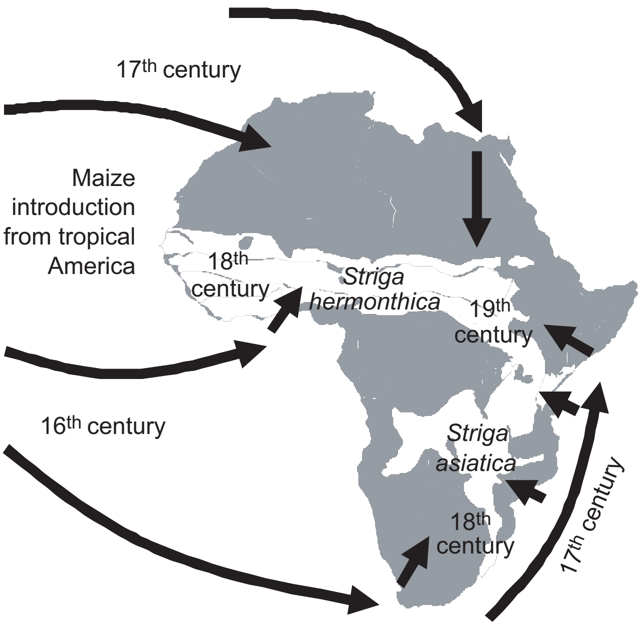

Figure 1. The fact that Africa's cereal belt is colonized by or at risk from *Striga* results partly from the introduction of maize as a susceptible host and its penetration into savanna, woodland and forest margins in East, West and Southern Africa, which were inhabited by indigenous *Striga asiatica* and *S. hermonthica*. *Source:* Rouanet, 1987.

Table 1. *Striga* coverage, yield reduction and economic loss in Africa's maize croplands.

Area	Coverage (× 1,000 ha)	Maize grain loss (tons per year)	Economic loss (US$ per year)
Sub-Saharan Africa	2,363	1,623,838	$383,290,000
Southern Africa	589	372,802	$69,708,000
Malawi	291	208,221	$27,900,000
West Africa	1,243	790,084	$250,095,000
Nigeria	835	505,308	$205,660,000
East Africa	531	460,953	$68,487,000
Kenya	217	182,227	$28,610,000

scale African farmers who see their crops destroyed season after season, unable to grow enough food to feed their families or make modest improvements in their lives.

Striga's damage is largely inflicted on crops below ground where *Striga* roots enter the host, feeding on its nutrients and moisture and releasing toxins into the plant, causing twisted, discoloured and stunted growth (Ejeta and Butler, 1993). After feeding below ground for 4–5 weeks, a fast-maturing shoot emerges, which produces attractive spikes of violet or red flowers that mature into capsules containing abundant, tiny, long-lived seeds. The appearance of parasitized cereals has given *Striga* its common name of witchweed because the affected plants appear to have been cursed. This is no supernatural curse, however, because the spread and severity of *Striga* largely result from the field practices of ill-informed farmers.

It would prove difficult to convince an independent observer that some farmers do not enjoy having *Striga* in their fields. First, they inadvertently transport its seeds between farms through the movement of seeds, crop residues, livestock and unclean field tools. Once the seeds are dispersed across the soil surface, routine field operations incorporate them to a convenient depth surrounded by large numbers of planted host cereals. Through periodic weeding, farmers remove plants from the understorey that would otherwise interfere with the later emergence of *Striga*'s weak, succulent shoots. They apply fertilizer to the host maize while it provides the parasite with its moisture and nutrients. Sometimes farmers might cut and remove those shoots, but they make no effort to detach its underground parts from the host roots, and new shoots are readily formed and sent above ground. As the host cereal approaches maturity, farmers weed less frequently and ignore *Striga* as it flowers and sets seed. Even though herbicides are available that can destroy *Striga* without injuring its host cereal (Odhiambo and Ransom, 1993; PCPB, 2006), these are seldom applied. Finally, farmers move through their fields at harvest, searching for their stunted ears of maize while spreading recently-formed *Striga* seeds to new areas, only to repeat the process during subsequent seasons. Indeed, farmers may be *Striga*'s best friend, but when they have access to information and potent technologies, they can become its worst enemy!

Past approaches to *Striga* management

Researchers were slow to develop *Striga* control practices compatible with small-scale African farming. *Striga* was first recognized as a threat during the colonial days and early independence. In many cases, agricultural officers required farmers to pull up the parasitic weed and place it in piles as proof that they were actively fighting it. However, each maize plant can be attacked by three to ten *Striga* plants so that one hectare of maize can contain 450,000 weeds weighing three tons (fresh weight). The labour required to remove these weeds often conflicts with other household priorities, but the consequences of not doing so are much more severe. If left undisturbed, every mature *Striga* plant produces tens of thousands of very small seeds that may remain dormant for 20 years waiting to attack its hosts. Currently, extension agents generally advise farmers to uproot *Striga*, bury or burn the weeds in affected fields and to direct livestock manure toward infested areas.

Striga invaded the south-eastern USA and, once its threat was recognized during the 1950s, a broad-based eradication effort was conducted (Sand *et al*, 1990). Mandatory spraying of *Striga*-infested fields with broadleaf herbicides was initiated; field equipment was quarantined; the worst affected lands were removed from cereal production; and rewards were even offered for identifying remnant stands of the parasite. Unfortunately, most of these control measures were based upon high-input, mechanized agriculture and offer little opportunity for *Striga* eradication in Africa, other than serving as a practical example to large-scale commercial cereal producers.

As *Striga* became increasingly recognized as a serious threat in Africa, several different control strategies were developed (AATF, 2006; Woomer *et al*, 2005). Farmers identified *Striga*-tolerant landraces, and these were collected by plant breeders and the traits incorporated into improved maize populations. Basically, there are two types of tolerance. Some maize expresses rapid early growth and deep root systems, thus evading *Striga* seeds residing within the cultivated soil horizon. Interestingly, this trait is also associated with drought tolerance. Other maize varieties appear to be less susceptible to witching symptoms, so that normal, albeit reduced, plant growth and development occurs despite *Striga* parasitism (Ejeta and Butler, 1993). In many cases, *Striga* tolerance is an insufficient control measure because these maize lines become overwhelmed in highly infested soils. *Striga*-resistant lines that cannot become parasitized constitute an unachieved, but extremely important objective within crop improvement (Akanvou and Doku, 1998).

Several legumes adversely affect *Striga* through allelopathy and induced suicidal germination. *Desmodium*, a pasture legume possessing both attributes, was packaged into an agroecological approach to *Striga* management referred to as 'push–pull' (Khan *et al*, 2005). In this system, *Desmodium* is intercropped with maize in order to suppress *Striga* and provide symbiotically fixed atmospheric nitrogen. The system does not produce an edible pulse, but *Desmodium* is a nutritious livestock feed. Suicidal germination occurs when root exudates of a non-host induce *Striga* to germinate and then perish in the soil. Several grain legumes, including cowpea, soyabean, groundnut and lablab, also possess this trait, providing the basis for *Striga* management through cereal–legume rotation and intercropping (Carsky *et al*, 1994).

These new technologies worked, although sometimes not as well on farmers' fields as they did under research conditions (Ransom, 2000; Woomer *et al*, 2005). Most of them required that poor farmers either invested too much money or labour, or sacrificed land from their important food crops, or encouraged them to grow crops that had little market value, or assumed they had developed advanced understanding of *Striga*'s complex ecology (Table 2). In many cases, just overcoming *Striga* alone was not sufficient to restore maize productivity because of low soil fertility, plant diseases and insect pests (Esilaba *et al*, 2000). Even the few farmers who wholeheartedly endorsed these new technologies did not eliminate *Striga* from their fields, but rather suffered less severely from it.

Table 2. Advantages and disadvantages of different *Striga* management practices.

Management practice	Advantages	Disadvantages
Hand weeding	Requires no external inputs and prevents *Striga* from setting seed	Ineffective against below-ground *Striga* and requires excessive labour under severe infestation
Herbicide-resistant maize	Improves maize yield while reducing *Striga* biomass and soil seed bank	Currently available only for maize; requires accompanying technologies
Striga-tolerant varieties	Maintains maize yield under modest *Striga* infestation	Does not reduce *Striga* infestation; over-whelmed under severe infestation
Push–pull system	Compatible with IR and tolerant varieties; also reduces stemborer; lasts many seasons; and provides livestock feed	Difficult and slow to establish; more difficult to weed; no opportunity for grain legume inter-cropping; lower net return
Innovative intercropping	Compatible with IR and tolerant varieties; improves pulse selection	More difficult to plant and weed; requires several accompanying technologies
Legume rotation	Produces higher-value oil seed; reduces *Striga* biomass and seed bank	Requires large amounts of legume seed and that maize should be grown in rotation; raises P requirement
Herbicide application	Compatible with IR and tolerant varieties; kills *Striga* shoots; suitable for different cereal crops	Expensive; seed bank unaffected; precludes legume intercropping; requires several accompanying technologies
Trap cropping	Low-cost; *Striga* life-cycle disrupted; seed banks reduced; provides livestock feed	Shortens crop-growing season; larger labour requirement; little economic return

Technological breakthroughs and dissemination challenges

Recently, an exciting new approach to *Striga* management has emerged that allows farmers to grow maize and kill *Striga* at the same time. Herbicide resistance by maize permits the application of relatively small amounts of imazapyr to maize seeds, which in turn provides several weeks' chemical protection from parasitic *Striga* (Kanampiu *et al*, 2002). This technology results from over 12 years of research and development by several organizations. Imazapyr resistance (IR) was incorporated into African maize varieties by the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with several international and national research organizations (Kanampiu *et al*, 2006). At its earliest stage of technical development, herbicide was sprayed on to maize in the conventional manner, but later the Weizmann Institute of Science in Israel demonstrated the usefulness of seed dressing. BASF is a multinational corporation that manufactures imazapyr and markets it under the trade name Strigaway®. This product is planned for commercial application throughout Africa, following regulatory approval and licensing. During 2005 and 2006, IR maize was field-tested on over 13,000 farms in west Kenya (Otieno *et al*, 2005) and most farmers were very enthusiastic about the technology (see Box 1). In addition, eight different *Striga* management practices (Woomer *et al*, 2005) were evaluated on 120 farms over four consecutive growing seasons. Considerable improvement was observed in *Striga* suppression, crop yield and economic return in IR maize (Table 3).

The efficacy of a new technology alone does not,

Box 1. Farmers' impressions of *Striga* infestation and IR maize as a control measure in Kenya.

Teresa Lubusi, Vihiga. 'I stopped growing maize over the past three years because of poor yields resulting from *Striga*. During that period, I would harvest only 60 kg of maize from my 1.5 acre plot and my family endured severe food shortages. Since the introduction of IR maize, I now produce enough maize to feed my family. I harvested 135 kg of maize from only one kg of seed planted on 0.1 acre. My neighbours were very curious about the sudden improvement in my farm and I encouraged them to plant IR maize too.'

Dick Morgan, Sabatia. 'In our village, *Striga* weed poisons both maize and the soil. Farmers have named the new IR maize seed as Saviour. It is drought tolerant, fast maturing and performs better than any other maize where *Striga* is a problem. The best part about IR maize is that it seems to kill *Striga* in the soil.'

John Kundu, Bungoma. 'An Extension Officer visited my farm in 2004 and was shocked by the *Striga* damage to my maize and since then many more came to witness that damage. That was before I planted IR maize to fight *Striga*. Now, I invite the same farmers to see the improvement. Everyone wants to buy IR maize now and it must become better available in the market soon.'

Rose Katete, Teso. 'I pulled and buried *Striga* on my five acre farm for the past 17 years and the problem only grew worse. During a farmer field day we learned about herbicide-treated seeds and I was one of the first farmers in the community to receive the new IR maize seed. Ua Kayongo ["Striga Killer", the first IR maize hybrid released in Kenya] has provided the best crop of maize that I have ever grown!'

unfortunately, determine its adoption by small-scale African farmers (Eicher, 1999). Effective dissemination also depends upon the accessibility of products that embody the technology, the applicability and attractiveness of the technology in new areas that share similar constraints (scalability) and the ability of the solution to achieve sufficient momentum so that it persists in the absence of external support in order to achieve its full potential (sustainability). Key developmental questions that address dissemination approaches for each of these factors appear in Table 4. Furthermore, effective *Striga* management requires not only that control products such as IR maize should be purchased and planted by farmers, but they must also understand the basic life-cycle of *Striga* and practise field sanitation that prevents proliferation of the parasite's seed in the soil. In this way, effective *Striga* management is both market-driven and knowledge-intensive.

Market-led adoption assumes that improved profitability and access to markets will motivate farmers to invest in new technology, particularly the integration of new varieties with improved soil management options. It is based in part upon the disappointing past experiences of developing and promoting seemingly appropriate food production technologies, only to have them rejected by poor, risk-averse farmers unable or unwilling to invest in additional inputs. Basically, many African farmers are aware of technologies that raise production levels, but they are reluctant to invest in them without assurances that the resulting crop surpluses can be readily marketed. In this way, demand for produce drives the supply of farm inputs. Improvement in farmers' market intelligence and access to fairer buyers are viewed as necessary and sufficient to catalyse farmer adoption of new or improved input products.

In the case of herbicide resistance as a breakthrough technology to overcome *Striga*, this paradigm assumes that households victimized by *Striga* will find the means to purchase these maize seeds despite the proximity or price advantage of other available crop varieties. Once obtained, the substantially greater yields achieved from growing herbicide-resistant maize in heavily infested fields will enter expanding produce markets and set a positive example for other *Striga*-infested areas. Over time, herbicide resistance will become a necessary attribute of all cultivated cereals in *Striga*-infested areas, and supporting market innovations, such as short-term credit to producers and contract buying, will become commonplace.

While the commercialization of breakthrough technologies into available and affordable products is a necessary condition to overcome *Striga*, the assumption that marketing innovations will necessarily accompany this opportunity is questionable. Farmers not only lack market information, but experience difficulty in complying with quality control standards, have poor access to transportation and suffer a host of unnecessary transaction costs, particularly exploitative middlemen. These difficulties may only be overcome through providing farmers with other locally adapted technologies and special incentives to invest in *Striga* management products through farmers' collective action (Mlosa-Banda and Kabambe, 1996; Sibuga *et al*, 2005).

IR maize performs best when nested into other knowledge-based approaches to *Striga* suppression, particularly induced suicidal germination (Table 3). For this reason, innovations in IR maize–legume intercropping have an important role to play in *Striga* reduction because the parasite is attacked on two fronts. Innovative intercropping permits cultivation of a wider range of pulses that antagonize *Striga*, particularly cowpea, groundnut and soyabean. Combining IR maize with *Desmodium* in the 'push–pull' system provides farmers with more effective *Striga* control, as well as an improved supply and quality of livestock feed. Far greater dissemination occurs when farmers are offered special incentives to test, adapt and adopt herbicide-resistant maize in *Striga*-infested fields. In this way, solutions to *Striga* are both product-led and knowledge-driven (Table 4).

An Africa without *Striga*

Ultimately, effective *Striga* management has one of two agroecological outcomes. Farmers will either rely continuously upon purchased farm inputs or field sanitation practices that keep *Striga* at bay, or their efforts will result in a steady decline in the *Striga* seed bank until it no longer represents a pressing concern (AATF, 2006). Despite these new technologies, the eradication of *Striga* also depends upon field sanitation because after IR maize is harvested, remnant *Striga* persist in the field, then flower, set seed and reintroduce themselves into the soil (Odhiambo and Woomer, 2005). *Striga* is a semi-parasite

Table 3. Average maize yields, seasonal economic returns and suppression of *Striga* among different managements on 24 *Striga*-infested farms (initial *Striga* seed bank >100 million per ha) over four consecutive seasons in west Kenya.

Management practice	Maize yield (kg per ha)	Net return ($ per ha per season)	Benefit–cost ratio	*Striga* expression stems per plant
Susceptible maize hybrid	1,579	228	2.0	2.6
Striga-tolerant OPV	2,323	348	2.6	1.4
Striga-evasive hybrid	2,461	365	2.6	1.3
Push–pull system	2,103	128	1.5	0.5
Innovative intercropping	2,288	314	2.2	0.5
Herbicide-resistant maize	2,601	371	2.6	0.5

Table 4. Options for the dissemination of herbicide-resistant maize as a *Striga* control measure in Africa.

Dissemination factor and (in italics) key question	Dissemination strategy	
	Product-led	Knowledge-driven
Feasibility *Is herbicide resistance in maize able to overcome Striga as a stand-alone technology?*	*Yes:* IR maize is able to suppress *Striga* by > 80% and improve maize yields by > 1 ton per ha with the addition of mineral fertilizers applied at modest rates, but …	*No:* (1) IR maize performs best when nested into other approaches to *Striga* suppression, particularly induced suicidal germination. (2) New production constraints emerge once *Striga* is controlled.
Accessibility *Is the commercialization of herbicide-resistant maize seed sufficient to reach a full cross-section of Striga's victims?*	*Yes:* Households victimized by *Striga* will find means to purchase the seeds whatever the price or access to farm input suppliers, but…	*No:* Farmers producing herbicide-resistant OPVs and coating their own seed with inexpensive products will greatly improve access to the technology by the poorest households.
Scalability *Will market forces developing around herbicide-resistant maize achieve sufficient momentum to expand input supply and produce markets into new Striga-affected areas?*	*Yes:* The substantially greater yields achieved from growing herbicide-resistant maize represent a developmental breakthrough that will contiguously vitalize markets in new and adjacent *Striga*-infested areas, but…	*No:* Far greater expansion occurs when farmers are offered special incentives to test, adapt and adopt herbicide-resistant maize in *Striga*-infested fields, particularly through collective action in farmer associations.
Sustainability *Is herbicide-resistant maize best employed in the continuous control of Striga without seeking its eradication?*	*Yes:* herbicide resistance will become a necessary attribute of all cultivated cereals in *Striga*-infested areas throughout the foreseeable future, but…	*No: Striga* eradication is the larger developmental goal because it permits greater diversification of farm enterprises in response to new market opportunities.

because it is able to grow and reproduce following the death or harvest removal of its host. Convincing farmers to weed after crop harvest is difficult, and inexpensive tools must be developed to make this task easier. For example, lightweight weeding hoes, wick-applied herbicides and oxen-drawn sickles would better motivate farmers to perform post-harvest weeding. Furthermore, *Striga* eradication has a strong collective component because care is required to prevent the further spread of *Striga* into new fields or its reintroduction after it has been brought under control. Soil conservation structures that confine run-off from infested fields, restricting the movement of livestock between infested and non-infested farms and aggressively controlling new outbreaks are examples of necessary collective measures if *Striga* is to be eradicated. Most importantly, peer pressure must be focused upon bringing every affected farm household into collective *Striga* management actions in a manner that relies upon attractive incentives rather than penalties for non-compliance. Establishing a community-based mechanism to monitor *Striga* reduction within farms, certify its elimination and offer a modest reward to successful households offers both an incentive to farmers and a means of documenting the impacts of *Striga* reduction efforts.

African farmers stand to benefit from the eradication of *Striga* at farm, community and national levels. Maize fields freed from *Striga* allow for household food security and maize surpluses. Some of this land can also be planted with higher-value cereals and grasses, such as sugar cane, upland rice and finger millet, in response to market conditions. The same producers' associations that led the *Striga* eradication effort can collectively market these surpluses, generating revenue for the organizations and securing higher prices for members. Modest improvements in household well-being will occur as sheet-metal or tile roofs, cement floors, improved latrines, bicycles, radios and mobile telephones become commonplace. New-found prosperity spills over into local market centres as well, with smallholders better able to purchase essential goods, buy and sell handicrafts and use services such as neighbourhood restaurants, bicycle mechanics, hair salons and Internet cafes. Modest levies placed upon these transactions may be used to improve local infrastructure through community-led public works. Rubbish can be collected and recycled, muddy paths and roads drained and paved, market stalls improved, and town centres landscaped. More vibrant rural communities will retain many of those who would otherwise migrate to urban slums. National planners may better rely upon domestic cereal production to alleviate chronic food deficits in maize, rice and sugar, permitting limited foreign exchange to be spent in more strategic ways, such as in rural electrification, schools, hospitals and improved road networks. Empowering *Striga*'s victims today is a first step to a very bright future, and rural development projects that disseminate the required technologies and evoke farmer collective action are a crucial means to that end.

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References

AATF – African Agricultural Technology Foundation (2006), *Empowering African Farmers to Eradicate Striga from Maize Croplands*, AATF, Nairobi.

Akanvou, L., and Doku, E. V. (1998), 'Heritability of traits associated with Striga (*Striga hermonthica* (Del.) Benth.) resistance in open-pollinated maize population', *African Crop Science Journal*, Vol 6, pp 129–135.

Boonman, J. G. (1993), *East Africa's Grasses and Fodders: Their Ecology and Husbandry*, Kluwer Academic Publishers, Dordrecht.

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

Eicher, C. K. (1999), 'Institutions and the African farmer', CIMMYT Economics Program, Third Distinguished Economist Lecture, CIMMYT, Mexico.

Ejeta, G., and Butler, L. G. (1993), 'Host–parasite interactions throughout the *Striga* life cycle and their contributions to *Striga* resistance', *African Crop Science Journal*, Vol 1, pp 75–80.

Esilaba, A. O., Reda, F., Ransom, J. K., Bayu, W., Woldenewahid, G., and Zemicheal, B. (2000), 'Integrated nutrient management strategies for soil fertility improvement and Striga control in Northern Ethiopia', *African Crop Science Journal*, Vol 8 pp 403–410.

Kanampiu, F., *et al* (2006), 'Launch of *STRIGA*WAY® (IR-maize) technology for *Striga* control in Africa', *Proceedings of the Launch of the STRIGAWAY® (IR-maize) Technology, 5–7 July 2005, Kisumu, Kenya*.

Kanampiu, F. K., Ransom, J. K., Friesen, D., and Gressel, J. (2002), 'Imazapyr and pyrithiobac movement in soil and from maize seed coats to control Striga in legume intercropping', *Crop Protection*, Vol 21 pp 611–619.

Khan, Z. R., *et al* (2005), *A Primer on Planting and Managing "Push–Pull" Fields for Stemborer and Striga Control in Maize: A Step-by-Step Guide for Farmers*, ICIPE Science Press, Nairobi.

Mlosa-Banda, H. R., and Kabambe, V. H. (1996), 'Integrated management for striga control in Malawi', *African Crop Science Journal*, Vol 4, pp 263–273.

Odhiambo, G. D., and Ransom, J. K. (1993), 'Effect of dicamba on the control of *Striga hermonthica* in maize in western Kenya', *African Crop Science Journal*, Vol 1, pp 105–110.

Odhiambo, G., and Woomer, P. L. (2005), 'Striga emergence and seed bank dynamics under different maize management practices in western Kenya', *African Crop Science Conference Proceedings*, Vol 7, pp 473–477.

Otieno, H., Maina, J., Omare, M. N., Omanya, G., and Woomer, P. L. (2005), 'Field testing imazapyr-resistant maize to control *Striga* in western Kenya', *African Crop Science Conference Proceedings*, Vol 7, pp 461–465.

PCPB – Pest Control Products Board (2006), *Pest Control Products Registered for Use in Kenya*, 3 ed, PCPB, Nairobi.

Purseglove, J. W. (1972), *Tropical Crops: Monocotyledons*, John Wiley and Sons, New York.

Ransom, J. K. (2000), 'Long term approaches for the control of *Striga* in cereals: field management', *Crop Protection*, Vol 19, pp 759–763.

Rouanet, G. (1987), *Maize* (*The Tropical Agriculturalist Series*, R. Coste, Series ed), CTA and Macmillian Publishers, London.

Sand, P. F., Eplee, R. E., and Westbrooks, R. G., eds (1990), *Witchweed Research and Control in the United States*, Weed Science Society of America, Champaign, IL.

Sibuga, K. P., Hella, J. P., Rweyemamu, C. I., and Kwacha, J. C. (2005), 'Integrated management of witchweed in maize under farmer conditions: experiences from working with farmers in Muheza district, eastern Tanzania', *African Crop Science Conference Proceedings*, Vol 7, pp 499–503.

Woomer, P. L., Tungani, J., Odhiambo, G., and Mwaura, F. M. (2005), 'Striga management options in western Kenya', *African Crop Science Conference Proceedings*, Vol 7, pp 479–484.