Available online at www.sciencedirect.com

ScienceDirect

Agricultural Systems 97 (2008) 83–94

Agricultural Systems

www.elsevier.com/locate/agsy

The potential of a herbicide resistant maize technology for *Striga* control in Africa

Hugo De Groote [a,*], Lucy Wangare [b], Fred Kanampiu [a], Martins Odendo [c], Alpha Diallo [a], Haron Karaya [a], Dennis Friesen [d]

[a] *International Maize and Wheat Improvement Center (CIMMYT), P.O. Box 1041-00621, Nairobi, Kenya*
[b] *University of Nairobi, Department of Agricultural Economics, P.O. Box 29053, Nairobi, Kenya*
[c] *Kenya Agricultural Research Institute (KARI), P.O. Box 169, Kakamega, Kenya*
[d] *CIMMYT/IFDC, P.O. Box 5689, Addis Ababa, Ethiopia*

Received 5 April 2007; received in revised form 9 December 2007; accepted 20 December 2007
Available online 4 March 2008

Abstract

Striga is an obligate parasitic weed that attacks cereal crops in sub-Saharan Africa. In Western Kenya, it has been identified by farmers as their major pest problem in maize. A new technology, consisting of coating seed of imidazolinone resistant (IR) maize varieties with the imidazolinone herbicide, imazapyr, has proven to be very effective in controlling *Striga* on farmer fields. To bring this technology to the farmer, a sustainable delivery system needs to be developed, preferably with substantial participation of the private sector. To help extension agents and seed companies to develop appropriate strategies, the potential for this technology was analyzed by combining different data sources into a Geographic Information System (GIS). Superimposing secondary data, field surveys, agricultural statistics and farmer surveys made it possible to clearly identify the *Striga*-prone areas in western Kenya. Results found that *Striga* affected a maize area of 246,000 ha annually, with a population of 6.4 million people and maize production of 580,000 tons, or 81 kg/person. Population density in this area is high at 359 people/km^2. A survey of 123 farmers revealed that 70% of them have *Striga* in their fields. A contingent valuation (CV) survey indicated that farmers would, on average, be willing to buy 3.67 kg of the IR-maize seed each at current seed prices, sufficient to sow 44% of their maize area. By extrapolation over the maize area in the zone, total potential demand for IR-maize seed is estimated at 2000–2700 tons annually. Similar calculations, but based on much less precise data and expert opinion rather than farmer surveys or trials, gives an estimate of the potential demand for IR-maize seed in Africa of 153,000 tons.

Keywords: Africa; Maize; Pest control; *Striga*; Herbicide resistant; Weeds (JEL Q12)

1. Introduction

Witchweeds (*Striga* spp.) are pernicious, root-attaching parasitic weeds found mainly in sub-Saharan Africa. They are obligate parasitic weeds of the tropics that attack cereal crops such as maize (*Zea mays* (L.), sorghum (*Sorghum bicolor* (L.) Moench), millet Pennisetum spp.) and rice (*Oryza sativa* L.). The most important species are *Striga hermonthica* (Del.) Benth. and *Striga asiatica* (L.) Kuntze (Oswald, 2005). The *Striga* flower produces large amounts of seed that are triggered into germination when they are close to potential host crop roots. Attaching to crop roots, the parasite becomes a major sink for crop photosynthate, debilitating crop growth and yield (Gurney et al., 1995; Stewart and Press, 1990). Otherwise, the seed can stay dormant in the soil for over 20 years. Infestation is related to continuous mono-cropping and poor soil fertility, and the parasite does most damage to weak plants (Berner et al., 1995). Therefore, it is a particular problem where soil fertility is being eroded through increased population pressure, decreased use of fallow and minimal use of organic or inorganic fertilizers (Combari et al., 1990; Gacheru

* Corresponding author. Tel.: +254 20 722 4600; fax: +254 20 722 4601.
E-mail address: h.degroote@cgiar.org (H. De Groote).

0308-521X/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.agsy.2007.12.003

and Rao, 2001; Mumera and Below, 1993). Most importantly, it seriously affects the livelihoods of poor subsistence farmers in cereal-based, agricultural systems in Africa.

Striga research has been conducted for many years, and several technologies have been developed and proposed for dissemination (Oswald, 2005). However, many of these options do not seem particularly feasible for the main target group: resource-poor farmers. Different technologies are known to be technically effective, but have had little success in adoption. Hand weeding has been promoted for decades, but it is labor intensive and the effect is only felt in subsequent seasons since the parasite has already done its damage. In Kenya, four seasons of hand-pulling were found necessary for sufficient control (Odhiambo and Ransom, 1994). Fallows decrease the *Striga* seed bank in the soil and improve soil fertility (Combari et al., 1990; Gacheru and Rao, 2001; Mumera and Below, 1993). However, in most *Striga*-prone areas, population pressure is too high for this option to work. Proper rotation schemes reduce *Striga* (Carsky et al., 1994, 2000), but markets for the production of these crops are limited. Maize varieties show highly variable tolerance to *Striga* (Oswald and Ransom, 2001), and some varieties with reasonable tolerance have been brought to the market and are appreciated by farmers in Western Kenya. A relatively new development is intercropping with the legume *Desmodium* (Khan et al., 2002). The technology is effective in farmers' fields, but commercial seed is expensive and may be out of reach for poor farmers. Many small-scale African farmers already have experience with applying pesticides, often in novel manners: maize stem borer is commonly controlled with a pinch of insecticide dust or low-analysis granules applied directly into the whorl. *Striga* can also be controlled by spraying herbicides, but this is generally considered too expensive for subsistence farmers. Moreover, *Striga* has done most of its damage to the host before emergence, so post-emergent herbicide applications have little benefit to the current crop.

Over the past few years, a new and promising technology has been developed by the International Maize and Wheat Improvement Center (CIMMYT), in collaboration with the Weizmann Institute of Science and the chemical company, BASF. A natural mutant of maize provides the maize with imidazolinone resistance (IR) (Kanampiu et al., 2003). Imidazolinones are highly effective and widely used herbicides having low toxicity, with an oral LD_{50} for rats of more than 5000 mg/kg, (i.e. immeasurable) (Gagne et al., 1991). Seed dressing of these IR-maize varieties with imazapyr, a systemic herbicide from that group, provides the plant with good protection from *Striga* infestation for several weeks after emerging, largely sufficient to ward off damage (Kanampiu et al., 2001). Unlike herbicide spraying, the IR-maize seed treatment technology allows intercropping with legumes (Kanampiu et al., 2002), which is a common practice in sub-Saharan Africa. The technology has proven to be efficient in the field (Kanampiu et al., 2003), and its efficacy has been confirmed under farmers' conditions (De Groote et al., 2007).

Since herbicide application is localized as a seed coat, the recommended effective dose for controlling *Striga* is low, about 30 g imazapyr per hectare, which is environmentally friendly and affordable. Moreover, the herbicide dissipates easily from the soil well before the next planting season, without any effect on subsequent crops. If farmers were to recycle the seed, they would need to coat it with the herbicide to control *Striga*, a practice which is not feasible nor advisable at the farm level. For this reason, farmers are advised to buy herbicide-treated seeds every season to reap the benefits of this technology. Although farmers have to buy new seed every year, it does provide extra incentive to plant good quality seed. Fortunately, the cost is low and, as shown below, the expected benefits are high.

The genes that confer imidazolinone resistance have now been transferred to several maize varieties adapted to the region, including several open-pollinated varieties (OPVs) and hybrids. Four hybrids were fully released in Kenya in February 2005, and several others are being tested in West, East and Southern Africa. Eleven new varieties, including 10 OPVs and one hybrid were nominated by three seed companies and Kenya Agricultural Research Institute (KARI) for evaluation in the national performance trials for 2005. Best performing varieties were registered for commercialization in early 2005, and the first seed came onto the market in 2007.

Because farmers should not recycle the seed, appropriate seed systems are essential for the production, treatment and distribution of the herbicide-resistant maize varieties. For extension services and seed companies, public or private, to take on such a new technology, it is important to be able to estimate the potential of that technology and the likely size of the market. In general, the potential for a new technology to control a pest problem is determined by: (i) the extent of the problem, in particular the area infested; (ii) the intensity of the problem, especially the damage level and the crop loss; (iii) the technical and economic performance of the technology on farmers' fields; and (iv) the perception of the farmers towards the pest and the control options, and their willingness to pay for the new technology.

In this paper, we attempt to determine the potential market for IR-maize for *Striga* control in Africa. First, the potential is analyzed in detail for Kenya, since good quality data are available, including maize statistics, several geo-referenced farmer surveys, and trials of IR-maize. Based on national statistics, expert opinion and literature review, we then extend the analysis to a preliminary assessment of the potential market for the whole of Africa.

2. Background: maize and *Striga* in Western Kenya

The Kenya Maize Data Base or KMDB (Hassan et al., 1998) defines the six major agroecological zones relevant to maize production in the country, based on GIS data, especially rainfall and altitude, and a survey of 1407 farmers from all maize production areas. *S. hermonthica* is found in the zone around Lake Victoria (Hassan et al., 1994) defined as the moist mid-altitude zone (the hatched area on the map in Fig. 1). This zone has two rainy seasons, and rainfall increases with altitude, from 700 mm per annum by the lakeshore to 1800 mm in the highest areas further inland. Mean annual temperature is 22 °C, with an average minimum temperature of 13 °C and an average maximum of 30 °C. Soils are mainly clay-loams and sandy–loams of low fertility since there is little volcanic or other young parent material (Jaetzold and Schmidt, 1983). Maize is the most important food crop in the moist mid-altitude zone. However, a farmer survey in 2002 found that only 46% of farmers in the zone adopted improved varieties, as compared to more than 90% of farmers in the high-potential zones (De Groote et al., 2006).

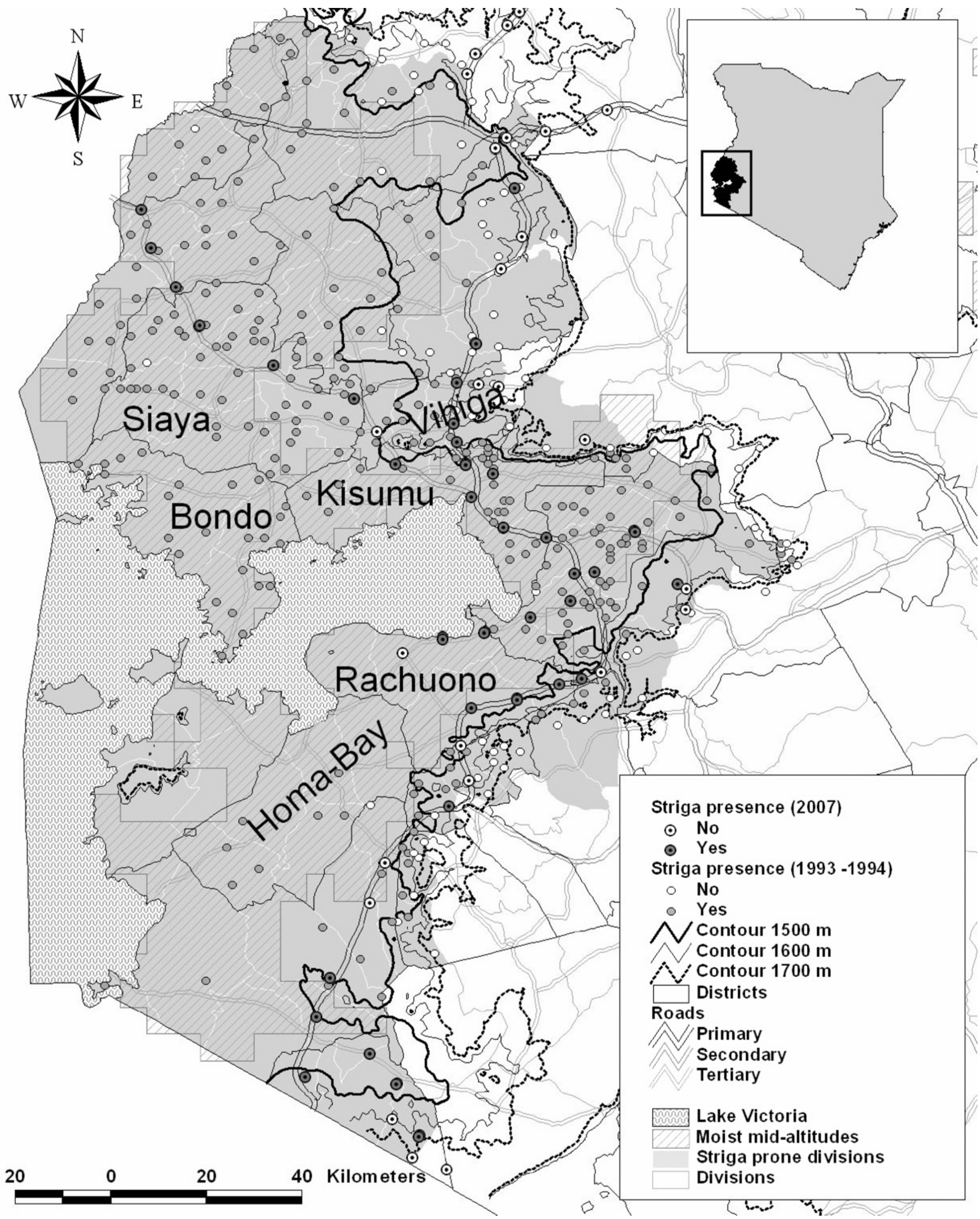

Fig. 1. *Striga*-prone area in Western Kenya (*Source*: survey of 367 farmers, 1993–1994).

In 2000, participatory rural appraisals (PRAs), consisting of 43 group discussions with more than 900 farmers in randomly selected villages, were conducted in all maize production zones of Kenya (De Groote et al., 2004). In the moist mid-altitude zone, the most important constraints on maize production, as reported by the farmers, were low soil fertility, availability of cash and poor extension service (Odendo et al., 2001). The cash constraint is a major problem, and its alleviation would lead to the alleviation of many other constraints. The next group of constraints included the lack of farm implements and the related lack of labor, followed by *Striga*. As a result of cash and other constraints, farmers recycle varieties for many seasons, especially the local varieties, but also the hybrids. They apply little or no fertilizer and no pesticides in maize fields. Among pest problems, *Striga* was generally ranked first, followed by weevils and stem borers. There is a second region of Kenya where *Striga* has also been reported: the coastal lowlands of Kenya, but the species is *S. asiatica* (Frost, 1994). In this zone, however, farmers did not mention *Striga* among their pest problems during the PRAs.

In the KMDB (survey of 1992), farmers were also asked about their pest problems, and area infested. Farmers in the moist mid-altitudes estimated the area under *Striga* at 39% with an average percentage loss of 51% in infested areas (Hassan and Ransom, 1998). The survey used a multi-stage, stratified sampling design based on the National Sampling Frame, but only the 65 sampling units or survey sites were geo-referenced, of which only nine were in the moist mid-altitudes. With such a limited number of points in the *Striga* area, no further analysis was possible.

3. Methodology

3.1. Identifying Striga-prone areas and maize area affected

The area prone to infestation by *Striga hermontica* was determined using data from a farmer survey conducted by CIMMYT in 1993 (Frost, 1995) covering 367 farmers in Western Kenya who were interviewed specifically on *Striga*. All farmers were geo-referenced, presenting a geographically well-distributed sample of the whole *Striga*-infested zone (Fig. 1).

To check if this information was still accurate, a small additional survey was conducted in September–October 2007. The survey took place along the major roads in the zone. At a systematic stop every 10 km, a farm was selected from the field 100 m from the road, alternately left or right. The farmer was then asked if his or her field contained *Striga.* In total, 97 farmers were interviewed, and the *Striga* map adjusted accordingly (Fig. 1).

To determine the maize area affected, this *Striga* map was overlaid with the administrative map at the division level (administrative unit just below the district level), and the affected divisions identified. Maize area and production in those divisions were then extracted from a data base compiled by the International Livestock Research Institute (ILRI, unpublished data). The number of people living in these divisions was obtained from the 1999 population census (Central Bureau of Statistics, 2001).

3.2. Determining the intensity of the Striga problem

A farmer survey was conducted in 2002 in which 123 farmers were interviewed concerning their maize production and the extent of their *Striga* problem, as well as their interest and willingness to pay for the IR-maize technology. Two groups of farmers were included: those farmers who had previously observed the technology, and those who had not. For the first group, a list of names was obtained of the 78 farmers who had visited the Kibos field station (near Kisumu, Western Kenya) and evaluated the on-station IR-maize trials of 2002. From this list, 22 farmers were randomly selected. Since these farmers came from a limited zone and were self-selected, it was necessary to enlarge the sample with a representative group of farmers from the larger region. Therefore, four districts were purposely selected for their high levels of *Striga* infestation, their relative ease of access from Kisumu, and geographical spread over the zone: two districts north of the lake (Siaya and Vihiga) and two south of the lake (Homa Bay and Rachuonyo) (Fig. 1). Two divisions from each of these districts were randomly selected. Within each of those divisions, two locations were randomly selected and, from each of the locations, two sub-locations. Three or four farmers, depending on the size of the sub-location, were randomly selected within each sub-location, resulting in a sample of 101 farmers without prior knowledge of IR-maize. Farmers were interviewed using a formal questionnaire to obtain socio-economic and crop production data, farm and farmer characteristics (household size, age, sex, education level, extension, credit and occupation), maize production activities, and knowledge and perception of *Striga* control practices. Farmers were asked what their current maize production is, and how much they would estimate their production would be if their fields had not been affected by *Striga*. The difference gives us a farmer estimate of crop loss due to the weed.

3.3. Testing the technology on-farm and economic analysis

To test the feasibility of IR-maize technology to control *Striga* in the field, several sets of on-farm trials were organized; the results of two of them are discussed here. The first set of on-farm, researcher-managed trials took place during the long rains of 2002 on 78 farms in Western Kenya spread over four districts (Kisumu, Homa Bay, Siaya and Vihiga). These trials consisted of a simple comparison of two IR-maize hybrids with two conventional varieties: a popular local OPV, Nyamula, and the hybrid H513, recommended for the zone but sensitive to *Striga*. On each farm, the four varieties were planted in adjacent plots, randomly assigned.

Since researcher management can be quite different from farmer management, another set of on-farm trials was organized, this time farmer-managed. These trials took place on 20 farms in each of three districts in 2004, and compared the IR-maize varieties with the farmers' preferred variety. Fertilizer use was left to the discretion of the farmer. The methodology, results, and economic analysis of these farmer-managed trials are presented in more detail elsewhere (De Groote et al., 2007). In this paper, we only present a summary of the economic analysis, which used partial budget analysis and the marginal rate of returns (CIMMYT, 1988).

3.4. Soliciting farmers' interest in the technology

To understand farmers' interest in the technology, contingent valuation (CV) methods were used. This is a survey-based method of finding out how people evaluate goods and services not yet found in the market place (Alberini and Cooper, 2000). The good or service, in this case IR-maize, needs to be well explained or demonstrated. These surveys only give meaningful results if they are properly grounded in a utility maximization framework (Hanemann and Kanninen, 1998): it is generally assumed that people maximize their utility subject to a budget constraint and will, therefore, choose the option that gives them the highest utility. Willingness to pay (WTP) is the maximum amount of money someone would be willing to pay for the new product, and this can be estimated through open-ended or close-ended questions. Open-ended questions provide direct estimates and are easy to analyze, but people often find it difficult to state their WTP for a new product (Hanemann and Kanninen, 1998). Close-ended questions are closer to real-life situations and have, therefore, become the method of choice (Arrow et al., 1993). CV methods are now widely accepted, even in developing countries (Whittington, 1998).

For this study, the 123 farmers of the 2002 survey were given a short presentation on the IR-maize seed coating technology, and then asked if they would be interested in purchasing the seed. The starting price consisted of the current average price for improved seed, US\$1.65/kg (KShs130/kg, at US\$1 = KShs 79 in 2002), plus the price of the herbicide, estimated at US\$0.15 (1.2 g/kg seed, at US\$13/g), that is US\$1.80 for the IR-maize seed. If farmers were willing to buy at the initial offer, the price per kg was increased by increments of US\$0.13 (KShs10) until the farmer was no longer interested. If the farmer was not interested in buying the IR-maize seed at the initial offer, the price was decreased in steps of US\$0.13/kg until the farmer accepted the offer or until the limit of US\$0.63/kg (KShs50) was reached. At each of the prices the farmers had indicated they would be interested in buying the IR-maize seed, they were subsequently asked the quantity they would buy at that price.

3.5. Estimating the potential market for IR-maize seed

To invest in a pest reduction technology, farmers take into consideration the level of infestation, the crop loss caused by the pest, the cost of the technology, its effectiveness, and the cash constraint (or access to credit) at the time of application. The farmer needs to take into account the high variability in the farming systems, in terms of both productivity and price, determining the profitability of her enterprise. According to this optimization process, a proportion, $\pi_{a,}$ of farmers will adopt the technology. Obviously, farmers will only adopt the *Striga*-reducing technology in areas where this is a problem. After identifying the *Striga* area, the administrative units, i, where *Striga* is found can be identified, and for each unit its number of farmers, N_i. If A is the average area under maize per household, and ρ is the average seed rate per hectare, the market for seed can be calculated as

$$M = \sum_i N_i A_i \pi_i \rho_i$$

The parameters for this formula were assembled for Western Kenya, as explained in the previous sections, and fed into this formula. This provided an estimate of the market for IR-maize seed in Kenya. To estimate the market for IR-maize seed in Sub-Saharan Africa (SSA), estimates were obtained from the expert opinion of maize breeders. Participants of a maize breeders' course in Nairobi in 2005, including maize breeders from 21 African countries, were asked to estimate the proportion of the maize area in their country infested by *Striga,* and specify the region infested.

4. Results

4.1.1. Determining the extent of the Striga problem in Western Kenya

Mapping the farmers' *Striga* observations from the 1993 to 1994 survey clearly reveals, in sufficient detail, the *Striga* area (Fig. 1). Farmers with *Striga* in their fields are marked by a grey filled circle; those without *Striga,* with a white filled circle. All farmers located between the shore of Lake Victoria (1150 m) and the 1500 m contour line (thick line) clearly faced *Striga* problems. Between 1500 m and 1600 m, some farmers had *Striga*, but there were none above the 1600 m contour line, likely due to the low temperature which is unfavorable for *Striga.* The road-side survey of 97 farmers in 2007, marked with dotted circles, largely confirmed the information, although some farms with *Striga* were found higher than the 1600 m contour line, in particular by the Tanzanian border and the North Eastern section. The final map shows that the *Striga* zone largely overlaps with the moist mid-altitude maize production zone (hatched area), although it is somewhat wider in the middle.

The *Striga* map was then combined with the administrative map of Kenya at the division level, and all divisions falling wholly or partly in the *Striga* zone were identified (grey area on the map). In total, 87 divisions in 21 districts were found to fall into the *Striga*-affected area, mostly in Nyanza and Western provinces (Table 1).

Table 1
Population and agricultural statistics of *Striga* prone area in Western Kenya

Province	District	Divisions[a] (Number)	Population[b]	Area[b] (km^2)	Density (n/km^2)	Maize area[c] (ha)	Maize yield[c] (tons/ha)	Maize production[c] (tons)	(kg/cap)
Nyanza	Bondo	4	238,780	987	242	7985	1.91	15,244	64
	Gucha	2	126,712	200	633	26,450	3.14	82,990	655
	Homa-Bay	5	307,975	1160	265	14,178	2.72	38,563	125
	Kisii Central	3	238,492	337	707	5370	6.94	37,278	156
	Kisii North	2	267,887	396	676	10,840	2.38	25,773	96
	Kisumu	4	504,359	919	549	5641	1.29	7267	14
	Kuria	4	128,792	527	244	4612	2.28	10,530	82
	Migori	7	498,015	1961	254	18,237	1.46	26,662	54
	Nyando	5	299,930	1168	257	8490	2.22	18,859	63
	Rachuonyo	4	307,126	945	325	28,892	1.46	42,039	137
	Siaya	7	480,184	1520	316	31,120	2.12	65,884	137
	Suba	5	155,666	1056	147	9295	1.8	16,731	107
	Total	52	3,553,918	11,176	318	171,110	2.27	387,820	109
Rift valley	Kericho	2	87,571	498	176				0
	Nandi	1	96,220	386	249	8224	3.86	31,776	330
	Total	3	183,791	884	208	8224	3.86	31,776	173
Western	Bungoma	6	548,011	1295	423	16,730	4.64	77,706	142
	Busia	6	370,608	1124	330	11,571	1.5	17,365	47
	Butere-Mumias	4	476,928	939	508	7012	2.03	14,269	30
	Kakamega	6	570,877	1317	434	10,346	2.01	20,821	36
	Lugari	1	44,578	102	437				0
	Teso	4	181,491	559	325	3,200	2.7	8640	48
	Vihiga	5	438,940	466	942	17,900	1.2	21,480	49
	Total	32	2,631,433	5802	454	66,759	2.40	160,281	61
Total		87	6,369,142	17,862	357	246,093	2.36	579,877	91

[a] Divisions identified through overlapping with the *Striga* area.
[b] *Source*: 1999 census (Central Bureau of Statistics, 2001).
[c] International Livestock Research Institute, GIS Unit, unpublished data.

The maize production data from ILRI were assembled for these 87 divisions, leading to an estimate of 0.58 million tons of maize on 246,000 ha, with an average yield of 2.36 tons/ha (average for 1994–1999) (Table 1). Similarly, by aggregating the population of the 87 divisions (Central Bureau of Statistics, 2001), the total population living in the *Striga*-prone area was estimated at 6.4 million people in 1.4 million households (Table 1). The total area is calculated at 16,500 km^2, resulting in a very high average population density of 357 people/km^2.

4.2. Determining the intensity of Striga infestation and crop loss

During the farmer survey of 2002, conducted in six districts of the *Striga*-prone zone, farmers were asked to estimate their current maize production, maize area infested with *Striga*, and what the production would have been without *Striga.* Annual maize production per household was estimated at 557 kg per household, of which 54% was produced in the long rains, with an average yield of less than half a ton per ha (Table 2). Almost all farmers (93%) had *Striga* in their maize fields. From their estimates, it was calculated that about 68% of their maize area was infested: a third of the area (33%) with high levels of infestation, a small portion (12%) with medium infestation, and about a fifth (21%) with low levels of infestation (Table 2). From farmers' estimates, average crop loss due to *Striga* was calculated at 54% (of the estimated potential yield if *Striga* had not been present) (Table 2). Estimates varied considerably between districts, from 35% in Siaya to 72% in Bondo. A weighted mean, using the district maize production data (from Table 1) as weights, resulted in an estimated average crop loss due to *Striga* of 55% of the potential yield.

4.3. Testing the new technology on farmers' fields

To test the performance of the IR-maize technology in controlling *Striga* and increasing yield, it was compared to conventional maize during several sets of on-farm trials in Western Kenya. A first set of on-farm, researcher-managed trials compared two IR-maize hybrids with two conventional varieties on 78 farms spread over four districts during the long rains of 2002. The average yield for IR-maize was 3.4 tons/ha, or double the controls' average yield of 1.7 tons/ha. The average number of *Striga* plants emerged at 12 weeks over the four plots was used as an indicator of *Striga* infestation on the farm. Three levels of *Striga* infestation were distinguished: low (<10 plants/m^2), medium (10–50 plants/m^2) and high (>50 plants/m^2). The results clearly show the effect of *Striga* on maize yields.

Table 2
Maize production and losses due to *Striga* (*Source*: farmer survey 2002, $N = 123$)

District		Maize production					Proportion of maize area by *Striga* infestation level				Crop loss		
		Area (ha)	Production (kg/household)	% in first season	Yield (kg/ha)	*N*	None	Low	Medium	High	kg/household	% of potential	*N*
Bondo	Mean	0.45	239	61	530	4	0	0	0	100	628	72	4
	Std. Dev.	0.25	82								313		
Homa-Bay	Mean	1.41	635	55	450	28	28	20	18	28	837	56	25
	Std. Dev.	0.90	945								934		
Kisumu	Mean	1.63	929	61	569	6	38	32	0	31	653	41	6
	Std. Dev.	1.27	972								566		
Rachuonyo	Mean	1.50	526	61	351	30	23	12	16	51	800	60	31
	Std. Dev.	0.76	709								2341		
Siaya	Mean	1.11	579	43	523	30	45	19	12	23	309	35	27
	Std. Dev.	0.72	1018								1112		
Vihiga	Mean	0.54	434	58	803	24	36	36	8	20	623	66	19
	Std. Dev.	0.40	794								1044		
Total	Mean	1.13	557	54	494	122	32	21	12	33	646	54	112
	Std. Dev.	0.83	859								1482		

While the commercial check yielded slightly higher than the local check at low *Striga* levels (2.5 tons/ha), this was reduced by half under medium *Striga* infestation, and down to a quarter in high infestation areas (Fig. 2). The local check was less sensitive: its yield was only reduced by a quarter under low *Striga* levels, but by half under high infestation. The IR-maize hybrids did not suffer any yield loss under medium *Striga* infestation, and their yields were reduced by only 20% under high infestation levels.

Researcher's management might be quite different from farmer's management, making it difficult to extrapolate the results of these trials. A second set of trials was, therefore, conducted under farmer management on 60 farms without replications using the farmer's preferred variety as a control (De Groote et al., 2007). The yield of IR-maize was, on average, double the yield of the control, an increase of 0.69 tons per hectare. Economic analysis showed an overall marginal rate of return (MRR) of 2.4 (good), with a MRR of 1.9 (respectable) for the variety, and an MRR of 5.6 (very good) for the IR-maize technology. The details of the calculations are presented elsewhere (De Groote et al., 2007).

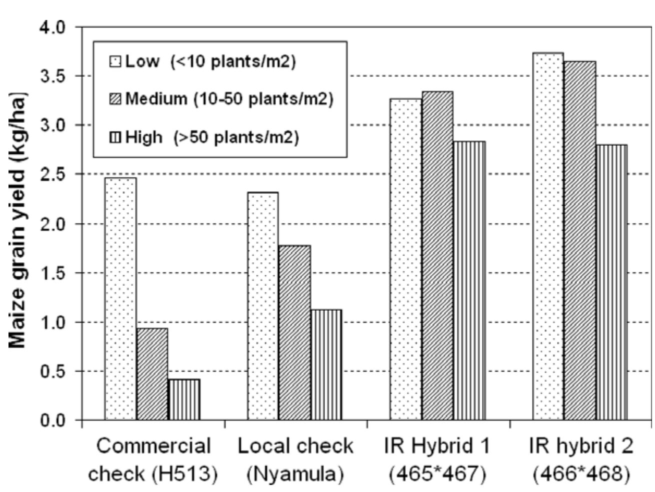

Fig. 2. Comparison of maize yields of imazapyr-treated IR-maize with commercial and local checks, under different levels of *Striga* infestation (*Source*: 78 on-farm, researcher managed trials, 2002).

4.4. Soliciting farmers' interest in the IR-maize technology

The survey of 123 farmers in 2002 found that only 28% of them used improved maize seed. Based on their average use of improved seed (7.3 kg in the first season and 5.3 in the second season) and their average seeding rate, the area in improved seed can be calculated at 51%, over both seasons (Table 3).

During the survey, farmers were given a brief explanation of the IR-maize technology and subsequently asked if they would be interested in purchasing IR-maize seed. At the current price for seed of improved varieties (US$1.6/kg), 67% of the farmers said they would buy, on average, 5.6 kg each, equivalent to 3.8 kg per farmer over all farmers. There was a clear difference between the farmers who had visited the trials: all but one (95%) would be willing to by IR-maize seed at the current price, compared to 60% of those who had not. Using the average actual seed rate (18.6 kg/ha, which is substantially less than the recommended rate of 25 kg/ha), the expected proportion of the *Striga* zone that would be planted to IR-maize is estimated at 44%. This is a large proportion of the current area in improved maize which is 57% of the total maize area. However, the demand for the new seed was highly elastic: at KSh50/kg the average stated purchase per farmer was 5.5 kg while at KSh200 it falls to only 2 kg/farmer (see Fig. 3).

Since the imazapyr herbicide can be added with the regular seed treatment, the added cost of treating IR-maize

Table 3
Results of the farmer survey in the *Striga*-prone zone, with farmers' characteristics, maize seed use, and Willingness to Pay (WTP) for herbicide resistant maize (*Source*: 2002 farmer survey, $N = 123$)

Type	Variable	Mean
Farm characteristics	Farmers who buy improved seed (proportion)	0.28
	Maize area (ha/farmer)	0.68
	Amount of improved maize seed purchased (kg/farmer)	7.22
	average maize seed rate (kg/ha)	18.60
	Area in improve seed (ha/farmer)	0.39
	Area in improve seed (% of maize area)	57.08
WTP for IR-maize	Percentage of farmers willing to buy IR-maize seed at US$ 1.6/kg	66.67
	Amount of IR-maize seed farmers would buy at US$1.6/kg (kg/farmer willing to buy)	5.63
	Amount of IR-maize seed farmers would buy at US 1.6/kg (kg/all farmers)	3.76
	Expected area in herbicide resistant maize (ha/farmer)	0.30
	Expected area in herbicide resistant maize (% of maize area)	44.04
	Expected area in herbicide resistant maize (ha/farmer)	0.30

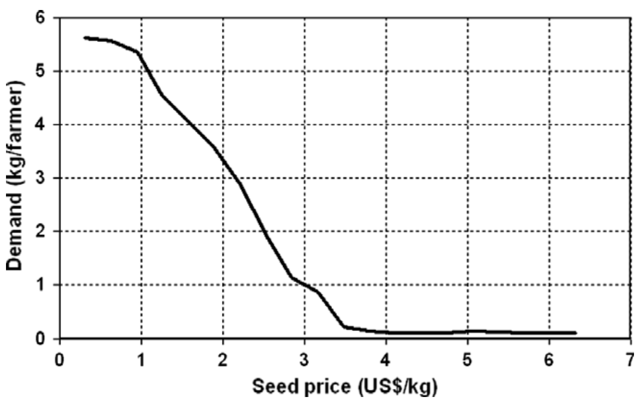

Fig. 3. Farmers willingness to pay for IR-maize: seed quantity per farmer in function of the price (*Source*: survey of 123 farmers, 2002).

Table 4
Estimation of market size for improved maize seed and IR-maize seed in Kenya (*Source*: 2002 farmer survey, $N = 123$)

	Under observed seed rate	Under recommended seed rate
Total area in *Striga* (ha)	246,093	246,093
Seed rate (kg/ha)	18.6	25
Total maize seed used (tons)	4577	6152
Area in improved maize varieties (%)	57%	57%
Estimated market for improved maize seed (tons)	2609	3507
Area in IR-maize (% expected)	44%	44%
IR-maize seed market (tons)	2014	2707

seed would be limited to the cost of the herbicide itself. For each kg of seed, about 1.2 g of herbicide is used, at a cost of about US$0.16 (price obtained from the producer, BASF). The herbicide can, however, harm non-IR-maize seed, so IR-maize seed treatment requires a completely separate plant, at a cost of about US$70,000 (estimate from an IR-maize seed producer). Still, seed companies indicated, during discussions at different fora, that they would be most interested in selling the IR-maize seed at the same price as conventional varieties.

4.5. Potential demand for herbicide-resistant maize

Bringing all these parameters together allows us to estimate the potential market for IR-maize in Kenya. Starting from the total maize area in the *Striga*-prone zone, estimated at 246,000 ha, the total amount of maize seed used annually can be estimated at between 4600 tons (at the observed seed rate of 18.6 kg/ha) and 6200 tons (at the recommended seed rate of 25 kg/ha) (Table 4). The area in improved maize seed is estimated at 57%, so the market for improved maize seed can be estimated at between 2600 tons and 3500 tons, under the respective seed rates. Since the potential area for IR-maize is estimated at 44% of total maize area, this would lead to a market for IR-maize in Kenya of between 2000 and 2700 tons.

Another estimate can be derived from the average expected IR-maize seed purchase of 3.76 kg per farmer. Assuming that at least half of the 1.4 million households in the *Striga*-prone area grow maize and they would, on average, buy this amount of IR-maize seed, the market size for Kenya can be estimated at 2600 tons for Kenya.

Unfortunately, data of similar quality are hard to obtain for other African countries, especially regarding the extent of *Striga*-infested areas, the intensity of the infestation and the damage levels. A maize breeding course, held in Nairobi in 2005, brought together maize breeders from 21 African countries. They were asked to estimate the proportion of maize area in their country infested by *Striga* (Table 5). Estimates for some other countries were provided by the authors, based on our own experience, combined with expert opinion, literature, and discussions with colleagues. It should be noted that these are expert opinions, and they are not based on actual measurements. Still, most participants and other experts consulted agree that, in West Africa, *Striga* is a major problem in the savannahs, not in the forest zone. In many West African countries a large proportion of the maize is grown in the savannah, so estimates of maize in *Striga*-infested areas can be high, especially in Benin (65%), Nigeria (40%) and Mali (35%). In

Table 5
Maize area under *Striga* and potential market for IR-maize maize seed in Sub-Saharan Africa

Region	Country	Maize area (1000 ha)[a]	% maize area in *Striga*[b]	Distribution	*Striga* infested area (1000 ha)	Potential IR-IR-maize seed market (tons)[d]
East	Burundi	116	5	North of the country	6	145
	Ethiopia	1410	22.5	North West, North East	317	7929
	Kenya	1665	13	Lake Victoria basin	216	5410
	Rwanda	115	12	East and North Eastern part	14	345
	Sudan	80	10[c]	East	8	200
	Tanzania	2000	33	Central, South of Lake Victoria	660	16,500
	Uganda	750	5	Along the Kenyan border	38	938
	Subtotal east	6135	21		1259	31,466
South	Angola	1068	25	Highlands	267	6,675
	Malawi	1538	80		1230	30,753
	Mozambique	1312	5		66	1,640
	Namibia	23	10[c]		2	58
	South Africa	3204	2	Kwazulu, but government has an eradication program with herbicides	64	1,602
	Swaziland	54	6	Highlands and Central	3	82
	Zambia	631	3	Marginal and lowlands	19	473
	Zimbabwe	1200	3		36	900
	Subtotal south	9030	19		1687	42,182
West	Benin	714	65	Across the savannah	464	11,605
	Burkina Faso	380	5	Central region, mostly on sorghum	19	475
	Cameroon	504	20[c]		101	2,521
	Congo (DRC)	1483	12.5	Central and Southern	185	4634
	Côte d'Ivoire	1000	22.5[c]		225	5625
	Ghana	733	14	North and upper regions, Sudanese savannah	103	2565
	Guinea	90	20		18	450
	Mali	459	35	Savannah	161	4016
	Nigeria	4466	40	Across savannah	1786	44,661
	Togo	380	30		114	2850
	Subtotal west	10,209	31		3176	79,402
	Total	25,374	24		6122	153,050

[a] FAOSTAT (2004 data).
[b] Expert opinion of national maize breeders, except where indicated.
[c] Estimate by the authors.
[d] Calculated based on a 25 kg/ha seed rate.

East Africa, the proportions are generally lower, the highest being in Tanzania (33%), Ethiopia (22%) and Kenya (13%). In Southern Africa, only two countries with high levels of maize in *Striga*-prone areas were identified: Malawi (80%) and Angola (25%).

Multiplying these proportions with the total national maize areas as estimated by FAO provides an estimate of the maize area in *Striga*-prone zones. SSA has about 26 million ha of maize, most of it grown in 25 countries (Table 5). The total area infested by *Striga* in these countries can be estimated at around 3.2 million ha annually, or about 24% of the total maize area. This percentage is higher in West Africa (31%) but lower in East Africa (21%) and Southern Africa (19%). Some countries stand out and need further attention: Ethiopia and Tanzania in East Africa, Malawi and Angola in Southern Africa, and Nigeria and Benin in West Africa. At a 25 kg/ha seed rate, farmers in these areas use about 150,000 tons of seed, which can be considered the upper limit for the potential market for IR-maize seed. At the current price of about US$2/kg of seed, the total value of this market would be approximately $300 million.

5. Discussion

The present study shows how the different steps outlined in the introduction provide a logical framework for the analysis of pest problems and their proposed solutions. Clearly, some of the data sets are not ideal, and some of the methods leave room for improvement. For this study some older data sets were used, in particular the 1993–1994 farmer survey (Frost, 1995) and the maize production data from ILRI from the early 1990s. However, a recent survey from 2002 comparing current maize production systems with those found in the KMDB (from 1992) shows little change in intensification in Western Kenya (De Groote et al., 2006), and the road-side survey of 2007 also indicated little change.

Use of the opinion of geo-referenced farmers, as pioneered by Frost, turned out to be a convenient way to map *Striga*. The 2007 survey found a few points with *Striga* higher than 1600 m, but none above 1700 m. Combining it with other GIS information, such as altitude, helps to explain its distribution, and combining it with agriculture and population statistics provides good estimates of the area and the number of people affected. Two more studies, in Tanzania and Ethiopia, are underway using the same methodology.

Crop loss, or yield reduction in maize due to *Striga*, on the other hand, is particularly difficult to measure in the field. Most empirical studies rely on controlled experiments. Studies in West Africa compared yields of susceptible and tolerant varieties in fields under natural *Striga* infestation with yields of the same varieties in non-infested fields (Kim et al., 2002). In the savannahs of Nigeria, a yield reduction of 31% was found in tolerant varieties, and 62% in the susceptible varieties (1985 trials). Trials in Cameroon in the same year produced lower estimates: 21% reduction for the tolerant varieties, and 41% for the susceptible varieties. Under different levels of artificial infestation in Nigeria, yield loss for the tolerant varieties varied between 27% (at 2250 *Striga* seeds per hill) and 35% (at 4500 seeds per hill). For the susceptible varieties, yield loss ranged from 43% (at 750 seeds/hill) to 74% (at 3750 seeds per hill) (Kim and Adetimirin, 1997).

Farmers' estimates of crop losses are much easier to obtain, although there are no independent observations available with which to compare their estimates. No direct estimates of crop losses from *Striga* under farmer-managed conditions are available from Kenya (or elsewhere, as far as we know), given the difficulties of obtaining a good control, especially since *Striga* does most of its damage before it emerges. Still, farmers' estimates seem to be consistent: the results used here, 54%, are similar to the estimate of 51% obtained from the KMDB (Hassan and Ransom, 1998).

Even more difficult to verify are the estimates by experts, so the estimated areas infested with *Striga* (6.12 million ha or 24%) should be understood as potentially having a fairly large margin of error. They came from people with substantial experience in their country, and were verified with a group discussion and triangulation. Nevertheless, a previous exercise, conducted with staff from CIMMYT and BASF, provided a more conservative estimate (3.64 million ha, or 14%). It is clear that only a more systematic study like the one in Western Kenya can provide good estimates. On-going studies in Tanzania and Ethiopia will provide some feed-back. In the West African savannahs, however, the method is likely to need adjustment. In this region, large areas are prone to *Striga* infestation but they are not as clearly defined by altitude as in Kenya.

As was shown here, the technology can be tested in both researcher-managed and farmer-managed trials. While the first set provides a controlled environment to study technical performance, to use it for economic analysis would likely result in overestimation of the benefits. The second set is more likely to present the farmers' conditions and is needed for the economic analysis, in particular using partial budget and MRR. The MRR represents the return to the investment a farmer has made in a new technology and should, according to CIMMYT experience, be at least 1.5 and preferably 2 (CIMMYT, 1988). The MRR obtained from the farmer-managed trials was 2.4, so the technology can be considered profitable.

The contingent valuation method to solicit farmers' interest in this new technology was used here for the first time in rural Western Kenya. The method initially took some effort by all participants, researchers, enumerators and farmers, but turned out to be a convenient way to obtain WTP estimates. The method does hinge on the farmers' understanding of the technology, hence the importance of a proper presentation or, preferably, demonstrations, which are more expensive. Hence, it is understandable that farmers who witnessed the trials were more interested in buying the new seed. However, these farmers also came from different districts, generally with better market access, so the results should be treated with caution.

A second limitation to the CV method is that farmers might be tempted to provide overestimates of their WTP, especially if they perceive that the enumerator is linked to the institute that developed the technology and would appreciate a higher WTP. An alternative technique, increasingly used in consumer studies, is experimental auctions, where participants bid for the new products and an actual exchange takes place when the participant's bid surpasses that of a randomly drawn number (Shogren, 2005). A first application, also in Western Kenya but on consumers' acceptance of yellow maize and interest in fortified maize, showed that WTP estimates obtained through CV methods were substantially higher than those obtained through experimental auctions (Kimenju et al., 2005).

The objective of this paper was to provide insights into the potential of the IR-maize technology, estimate the market, and provide the basis for a sustainable delivery system. The research provided some useful insights for such a system. First, the imazapyr herbicide is highly effective, meaning that it will kill any non-resistant crop. Therefore, an effort was made to educate all participants in the seed production and distribution chain in Kenya. Secondly, farmer education is an important component and will be continuous as this technology becomes more available. At present, an information brochure is enclosed in all packages of certified seed on the market in Western Kenya. The information includes safe practice for intercropping (at least 15-cm away from hills of treated maize), and warns farmers against mixing seeds, but advises them to use the gloves which are packaged with the seed, and to wash their hands after planting imazapyr-treated seeds and before touching other seed. The seed industry indicates that they will sell the IR-maize seed at the same price or at a small premium over conventional seed. The economic analysis indicates that the technology will make it more profitable for farmers to buy improved seed. This is expected to increase the seed sales in the *Striga*-prone region. The liberalization of the seed market has increased the number of companies in Kenya (Wangia et al., 2004), and the technology is available to all interested, so the competition is likely to keep the prices down. So, while the seed sector is expected to increase its profits through increased sales and maybe a small price increase, most of the benefits will go to the farmers through the increased production. The consumer will also benefit through a decrease in grain prices. For BASF, the increased sales of the herbicide with this technology are rather small, and the company does not expect any windfall profits.

Finally, the IR-maize technology is only part of the solution to a more complex problem of which poor soil fertility is an important component. If *Striga* were controlled, the next constraint, poor soil fertility, needs to be addressed. Research is, therefore, needed to design appropriate combinations of seed with organic or inorganic fertilizers, and decide how to disseminate these packages. Secondly, a resistance management strategy needs to be developed to delay the development of *Striga* resistance to the herbicide. Hand pulling of any emerging *Striga* plants before they flower is an important management strategy to prevent the build-up of resistance. Third, the technology does not work well in areas with seasons of heavy rainfall. This is likely due to leaching of the herbicide away from the seed before it can be absorbed sufficiently by the seedling as well as the often long maize growing period in those areas. A slow release formulation is currently under development, intended to address this limitation.

6. Conclusion

This paper demonstrates how data from different sources can be integrated into a general GIS framework for analysis to draw conclusions that would not be possible from individual data sets. Superimposing secondary data, field surveys, agricultural statistics and farmer surveys makes it possible to identify clearly the *Striga*-prone areas in Western Kenya, estimated at 246,000 ha of maize. The area has a population of 6.4 million people and an annual maize production of 580,000 kg, or 91 kg/person. These statistics were combined with a farmer survey through which crop losses due to *Striga* are estimated at 54%. Contingent valuation methods indicate that farmers would be willing to buy on average 3.67 kg of the new seed each. This translates into a potential coverage of 44% of maize area in IR-maize, or a market demand in Kenya of between 2000 and 2700 tons.

Similar calculations, but based on much less-precise data and expert opinion on the extent of the *Striga* problem rather than farmer surveys or trials, estimate the *Striga*-infested area in SSA at 6.12 million ha with a potential market for IR-maize of 153,000 tons.

The analysis shows that even poor farmers are interested in a technology that addresses their needs, and that they can form a profitable market for the private seed sector. There is a large potential, especially in East and Southern Africa where seed companies are well established. However, this research needs to be followed up by monitoring farmers' interest through demonstration trials and adoption surveys to verify if the potential is realized after the release and dissemination of the new varieties. In Kenya, the first IR hybrid (Ua Kayongo) was released in 2005, followed by the release of three more hybrids and two OPVs in 2006. Large scale demonstrations of Ua Kayongo were organized in 2006, and the commercial launch took place in December 2006. The first batch of commercial IR-maize seed was produced in 2006, aimed at the long rains of 2007, but unfortunately did not meet the minimum germination level required by the Kenya Plant Health Inspectorate Services (KEPHIS), and was therefore not released. A second batch (about 12 tons) was produced in 2007, and about 800 kg were sold at the end of the year for the short rainy season.

In Western Africa, the proportion of maize area under *Striga* is high as is the potential demand for IR-maize seed. Unfortunately, seed companies are not well established there, so special attention needs to be given to developing sustainable seed systems to bring this technology to the farmers.

Acknowledgements

The authors would like to thank Dana Berner from IITA for sharing his knowledge on crop losses, Russ Kruska from ILRI and the GIS laboratory from ICIPE for sharing their maps, the Kenyan Ministry of Agriculture for providing the agricultural statistics, Peter Mbogo for helping with logistical support in western Kenya, John Lynam and Rashid Hassan for providing the data of the 1992 survey, Joel Ransom and Hugh Frost for providing the data from the 1993 survey, Andreas Oswald for his help with the literature review, BASF officials for helping to estimate the *Striga*-prone areas in sub-Saharan Africa, Kathy Sinclair for the editing, and Simon Kimenju for helping with the data analysis. We are grateful to the participants of the CIMMYT maize breeding course, held in Nairobi in 2005, for providing the estimates of *Striga*-prone area in their respective countries. Finally, we thank the Rockefeller Foundation for their financial support.

References

Alberini, A., Cooper, J., 2000. Applications of the Contingent Valuation Method in Developing Countries, A Survey FAO, Rome.

Arrow, K., Solow, R., Leamer, E., Portney, P., Radner, R., Schuman, H., 1993. Report on the NOAA panel on contingent valuation. US Federal Reg. 58 (10), 4602–4614.

Berner, D.K., Kling, J.G., Singh, B.B., 1995. *Striga* research and control: A perspective from Africa. Plant Dis. 79, 652–660.

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

Central Bureau of Statistics, 2001. Population and Housing Census, vol. 1. Population Distribution by Administrative Areas and Urban Centres: 1999 Government Printer, Republic of Kenya, Nairobi, Kenya.

CIMMYT, 1988. From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Completely revised edition CIMMYT, Mexico, D. F.

Combari, A., Pineau, R., Schiavon, M., 1990. Influence du degre de decomposition de produits organic sur la germination de graines de *Striga hermonthica*. Weed Res. 30, 29–34.

De Groote, H., Wangare, L., Kanampiu, F., 2007. Evaluating the use of herbicide-coated imidazolinone-resistant (IR) maize seeds to control *Striga* in farmers' fields in Kenya. Crop Prot. 26, 1496–1506.

De Groote, H., Kimenju, S., Owuor, G., Wanyama, J., 2006. Market liberalization and agricultural intensification in Kenya (1992–2002). Paper presented at the 26th Conference of the International Association of Agricultural Economics, 12–18 August, Gold Coast, Australia.

De Groote, H., Okuro, J.O., Bett, C., Mose, L., Odendo, M., Wekesa, E., 2004. Assessing the demand for insect resistant maize varieties in Kenya combining participatory rural appraisal into a geographic information system. In: Sperling, L., et al. (Eds.), Participatory Plant Breeding and Participatory Plant Genetic Resource Enhancement: An Africa-wide Exchange of Experiences. Proceedings of a workshop held in Bouake, Ivory Coast. May 7–10, 2001. CGIAR System wide Program on Participatory Research and Gender Analysis, Cali, Colombia. pp. 148–162.

Frost, H., 1994. KARI/ODA/CIMMYT *Striga* Research Programme – Final Report, Kisumu, Kenya Agricultural Research Institute.

Frost, H., 1995. *Striga hermonthica* surveys in Western Kenya. In: Brighton Crop Protection Conference – Weeds – 1995, Brighton. pp. 145–150.

Gacheru, E., Rao, M.R., 2001. Managing *Striga* infestation on maize using organic and inorganic nutrient sources in western Kenya. Intl. J. Pest Manage. 47, 233–239.

Gagne, J.A., Fischer, J.E., Sharma, R.K., Traul, K.A., Diehl, S.J., Hess, F.G., Harris, J.E., 1991. Toxicology of the imidazolinone herbicides. In: Shaner, D.L., O'Connor, S.L. (Eds.), The Imidazolinone Herbicides. CRC Press, Boca Raton, pp. 179–182.

Gurney, A.L., Press, M.C., Ransom, J.K., 1995. The parasitic angiosperm *Striga hermonthica* can reduce photosynthesis of its sorghum and maize hosts in the field. J. Exp. Bot. (46), 1817–1823.

Hanemann, M.W., Kanninen, B., 1998. The statistical analysis of discrete-response CV Data. Working Paper No. 798, Department of Agricultural and Resource Economics and Policy. University of Carlifornia, Berkeley.

Hassan, R., Ransom, J.K., 1998. Determinants of the incidence and severity of *Striga* infestation in Maize in Kenya. In: Hassan, R.M. (Ed.), Maize Technology Development and Transfer. A GIS Application for Research Planning in Kenya. CAB International, Oxon, UK, pp. 163–174.

Hassan, R., Ransom, J.K., Ojiem, J., 1994. The spatial distribution and farmers' strategies to control *Striga* in maize: survey results from Kenya, In: Jewell, D.C. et al. (Eds.), Maize research for stress environments, Proceedings of the Fourth Eastern and Southern Africa Regional Maize Conference, held at Harare, Zimbabwe, 28 March–1 April, 1994. CIMMYT, Mexico DF, pp. 250–254.

Hassan, R.M., Njoroge, K., Corbett, J.D., Njoroge, K., 1998. Combining geo-referenced survey data with agroclimatic attributes to characterize maize production systems in Kenya. In: Hassan, R.M. (Ed.), Maize Technology Development and Transfer. A GIS Application for Research Planning in Kenya. CAB International, Oxon, UK, pp. 43–68.

Jaetzold, R., Schmidt, H., 1983. Farm Management Handbook: Natural and Farm Management Information vol. II/B Ministry of Agriculture and Livestock Development, Nairobi, Kenya.

Kanampiu, F.K., Ransom, J.K., Gressel, J., 2001. Imazapyr seed dressings for *Striga* control on acetolactate synthase target-site resistant maize. Crop Prot. 20, 885–895.

Kanampiu, F.K., Ransom, J.K., Friesen, D., Gressel, J., 2002. Imazapyr and pyrithiobac movement in soil and from maize seed coats to control *Striga* in legume intercropping. Crop Prot. 21 (8), 611–619.

Kanampiu, F.K., Kabambe, V., Massawe, C., Jasi, L., Friesen, D., Ransom, J.K., Gressel, J., 2003. Multi-site, multi-season field tests demonstrate that herbicide seed-coating herbicide-resistance maize controls *Striga* spp. and increases yields in several African countries. Crop Prot. 22 (5), 697–706.

Khan, Z., Hassanali, R.A., Overholt, W., Khamis, T.M., Hooper, A.M., Pickett, J.A., Wadhams, L.J., Woodcock, C.M., 2002. Control of witchweed *Striga hermonthica* by intercropping with *Desmodium* spp., and the mechanism defined as allelopathic zone. J. Chem. Ecol. 28 (9), 1871–1885.

Kim, S.K., Adetimirin, V.O., 1997. *Striga hermonthica* seed inoculum rate effects on maize hybrid tolerance and susceptibility expression. Crop Sci. 37 (4), 61–66.

Kim, S.K., Adetimirin, V.O., The, C., Dossou, R., 2002. Yield losses in maize due to *Striga hermonthica* in West and Central Africa. Int. J. Pest Manage. 48 (3), 211–217.

Kimenju, S.C., Morawetz, U.B., De Groote, H., 2005. Comparing contingent valuation method, choice experiments and experimental auction in soliciting consumer preference for maize in Western Kenya: Preliminary results. Paper presented at the African Econometric Society 101th Annual Conference in Econometric Modeling in Africa, Nairobi, Kenya.

Mumera, L.M., Below, F.E., 1993. Crop ecology, production and management. Crop Sci. 33, 758–763.

Odendo, M., De Groote, H., Odongo, O.M., 2001. Assessment of Farmers' preferences and constraints to maize production in the moist Midaltitude Zone of Western Kenya. In: ACSA (Ed.), African Crop Science Conference, Proceedings (5th International ACS Conference, Lagos, Nigeria October 21–26, 2001), vol. 5. African Crop Science Association, Kampala, pp. 769–775.

Odhiambo, G.D., Ransom, J.K., 1994. Long term strategies for *Striga* control. In: Jewell, D.C., et al. (Eds.), Maize Research for Stress Environments, Proceedings of the Fourth Eastern and Southern Africa Regional Maize Conference, held at Harare, Zimbabwe, 28 March–1 April, 1994. CIMMYT, Mexico DF, pp. 263–266.

Oswald, A., 2005. *Striga* control-technologies and their dissemination. Crop Prot. 24 (4), 333–342.

Oswald, A., Ransom, J.K., 2001. *Striga* control and improved farm productivity using crop rotation. Crop Prot. 20 (2), 113–120.

Shogren, J.F., 2005. Experimental methods and valuation. In: Mäler, L.-G. et al. (Eds.), Handbook of Environmental Economics, vol. 2. Elsevier. (Chapter 19).

Stewart, G.R., Press, M.C., 1990. The physiology and biochemistry of parasitic angiosperms. Ann. Rev. Plant Physiol. Plant Mol. Biol. 41, 127–151.

Wangia, C., Wangia, S., De Groote, H., 2004. Review of maize marketing in Kenya: Implementation and impact of liberalisation, 1989–1999. In: Friesen, D.K., Palmer, A.F.E. (Eds.), Integrated approaches to higher maize productivity in the new Millennium. Proceedings of the 7th Eastern and Southern Africa Regional Maize Conference Nairobi, Kenya, February 2002. CIMMYT, Mexico, DF.

Whittington, D., 1998. Administering contingent valuation surveys in developing countries. World Devel. 26 (1), 21–30.