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Evaluating the use of herbicide-coated imidazolinone-resistant (IR) maize seeds to control *Striga* in farmers' fields in Kenya

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Abstract

The performance of imidazolinone-resistant (IR) maize seed, coated with the herbicide, and conventional maize seeds were compared for the control of *Striga* during on-farm trials. The researcher-managed trials from 2002 (on 3 farms with 2 replications, using conventional hybrid maize as control) showed good *Striga* control, especially in the early stages, increasing yields by 2.39 tons/ha. Farmer-managed trials from 2004 (on 60 farms in 3 districts, no replications, using farmer's maize variety as control) showed good control in two districts, increasing average yield by 0.69 tons/ha. In the third district, the IR-maize and control plots showed similar levels of *Striga* infestation, probably caused by heavy rains and flooding which can wash off the herbicide. The yield response to IR-maize seed was categorized at two levels. The germplasm effect was estimated at 0.37 tons/ha. The herbicide effect was estimated at 0.13 tons/ha (49 kg/ha for each reduction of the *Striga* numbers/m^2). With maize prices at US$202/ton, seed prices at US$34/ha and herbicide cost at US$4/ha, the overall marginal rate of return (MRR) was 2.4 (good), with an MRR of 1.9 (respectable) for the germplasm and an MRR of 5.6 (very good) for the IR-maize technology. Farmers generally appreciated the technology and indicated their willingness to pay (WTP), which was, however, very price-sensitive. The methodology of on-farm work can be improved substantially by including a sufficient number of sites, by measuring compounding factors (soil fertility, *Striga* seed bank, rainfall), by involving the farmers more (explain the design better, visit more often), by inviting more farmers for the evaluation and by using experimental auctions of IR-maize seed to estimate their WTP for this new technology.

Keywords: Farmer-managed trials; Herbicide resistance; On-farm trials; Regression analysis

1. Introduction

Striga, a parasitic weed, is one of the major problems of cereals in sub-Saharan Africa. In Kenya, *Striga hermonthica* occurs in an area located around Lake Victoria, from the shore (at 1100 masl) up to between 1600 and 1700 m (Frost, 1994). This area corresponds roughly with the moist mid-altitude zone, which is the maize production zone as defined by Hassan et al. (1998). In this zone, farmers have identified *Striga* as their major pest problem in maize (Odendo et al., 2001), and it reduces maize yields by 30–50% under typical field infestation conditions (Hassan et al., 1994). Farmers in this area produce on average 480,000 tons of maize on 211,000 ha (Ministry of Agriculture, unpublished data). Intensive agriculture, constant monocropping of maize, decline in soil fertility and soil organic matter content has favoured the build up of *Striga* (Oswald et al., 1998).

Several methods to control *Striga* are available, including hand weeding, the use of fallows and the application of organic and inorganic fertilizers. *Striga* is generally associated with low soil fertility, and research has shown that nitrogen application can reduce *Striga* infestation and improve maize yields (Agbobli, 1991; Pieterse and Verkleij, 1991). *Striga* can also be reduced by other indirect methods such as intercropping (Oswald et al., 1998; Khan et al., 2002) and agroforestry (Gacheru et al., 1999). Direct control methods include hand weeding, use of herbicides and host plant resistance (Oswald, 2005). However, hand weeding is very time consuming, herbicides are expensive and often unavailable, and, although some tolerance has

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been found in maize varieties, no resistant varieties are available. However, few farmers have adopted these technologies or other recommendations, probably because they are either not economically feasible or not adapted to the local socio-economic conditions (Debrah and Sanogo, 1993; Debrah et al., 1998).

Recent research by CIMMYT has resulted in the development of a new and promising technology which is highly effective as well as cheap, consisting of the application of the herbicide imazapyr, as a seed coating to imidazolinone-resistant (IR) maize varieties. The herbicide resistance is derived from a natural maize mutant, and this gene has been successfully transferred to several maize varieties adapted to this region. Field trials have shown season-long *Striga* control (Kanampiu et al., 2001), as well as the potential for intercropping IR-maize with herbicide-sensitive beans.

The technology of IR-maize seed, coated with the herbicide, has been incorporated in several varieties adapted to Western Kenya, and by the beginning of 2006 several seed companies had started producing the seed on a commercial basis. The efficacy of the methodology under controlled infestation and researcher-managed trials has been well established (Kanampiu et al., 2003; Diallo et al., 2005). However, before a technology is released to the farmer, it is important that farmers test and evaluate the technologies under their own conditions (CIMMYT, 1988). For this purpose, field trials were organized to see how the varieties perform in farmers' fields. In the first stage, which took place in 2002, trials were organized in farmers' fields but researcher-managed. In these trials, the technology was tested under different fertilizer applications in order to compare and see how to combine. The second stage took place in 2004, on a larger scale and under farmers' management, and was combined with farmers' evaluations and a survey to estimate their willingness to pay (WTP) for this new technology.

2. Methodology

2.1. Researcher-managed trials

Researcher-managed trials were conducted in the Kisumu district of Western Kenya, both in farmers' fields and at the KARI field station in Kibos, during the 2002 long rain season (see map in Fig. 1). The three on-farm sites were deliberately chosen based on a history of high *Striga* infestation, whilst at the field station the plots were artificially infested with *Striga*. The trials consisted of six treatments, resulting from all combinations of two varieties and three fertilizer levels. The IR-maize variety was a single cross hybrid (CML202-IR/CML204-IR), with the seed treated with herbicide (imazapyr) at 30 g active ingredient/ha. The control variety was H513, a popular commercial maize hybrid, without the herbicide treatment, chosen because it is currently the best variety available adapted to the area.

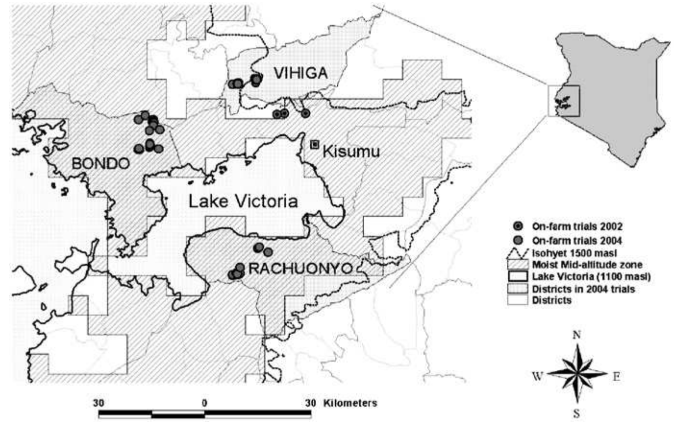

Fig. 1. Study area with on-farm trial sites.

There were three fertilizer levels: no fertilizer, medium (30 kg N/ha, 77 kg P/ha) and high fertilizer (60 kg N/ha, 77 kg P/ha). These levels were chosen to represent the common farmer practice, an intermediate level and the rate recommended by the extension service. This design also allows to analyze the interaction between herbicide and fertilizer, and to calculate their individual and combined feasibility. Fertilizer was applied in the form of di-ammonium phosphate (DAP) (18:46:0) during planting and top dressing with calcium ammonium nitrate (CAN) (26:0:0). Nitrogen application was split, with 50% applied at planting while the remainder was applied as a top dressing at 6 weeks after planting. Hand weeding was done twice. The maize was planted in blocks of 8 rows of 5 m long at spacing of $0.75\,m \times 0.50\,m$ with 3 seeds per hill, thinned to 2. The trials were arranged in a completely randomized block with 3 replicates in Kibos and 2 replicates in each of the 3 selected farms. All the plots were researcher-managed, and inputs provided by the project team.

Grain yields were measured for the entire plots, and adjusted to 15% moisture content. To measure the effect of the technology on the weed, emerged *Striga* plants were counted 6, 8, 10 and 12 weeks after planting. The effectiveness of herbicide-coated seed in reducing *Striga* losses was determined using a regression of yield on *Striga* counts at different times. In order to avoid the problem of autocorrelation, the *Striga* counts at different time periods were regressed separately on yield using the formula:

$$Y = a_0 + a_i S_i, \tag{1}$$

where Y is the yield (kg/ha, adjusted to 15% moisture content), S_i the *Striga* count at period i (at 6, 8, 10 and 12 weeks after planting), a_i the regression coefficient estimating the effect of *Striga* plants at time i on yield. To determine the separate effects of fertilizer and imazapyr as well as their interaction, a quadratic production function was used:

$$Y = b_0 + b_1 H + b_2 F + b_{22} F^2 + b_{12} HF, \tag{2}$$

where Y is the maize output (kg/ha), H the herbicide dummy, F the fertilizer rate used (kg N/ha), HF the interaction between the two variable inputs, b_i the regression coefficients.

2.2. Farmer-managed trials

The farmer-managed trials took place during the long rainy season of 2004, and were set up in April. Three non-bordering districts (Rachuonyo, Vihiga and Bondo) were selected from the six districts in the *Striga*-prone area closest to Kisumu (see map in Fig. 1). In each district, one division was randomly selected and visited, and farmer groups were invited to participate (Table 1). In Rachuonyo, an informal group around a local leader agreed to participate. In Vihiga, no suitable group was identified, so one location (administrative unit below district), was chosen, where farmers were selected based on geographic distribution and willingness to collaborate. In Bondo, two closely related groups were found willing to collaborate. In each division, 20 farmers were selected for the on-farm trials, making 60 in total.

The experimental design consisted of a pair-wise comparison of the IR-maize with a control, consisting of the farmers' variety, leaving all other factors constant. For the IR-maize variety, farmers were provided with 250 g of seed, free of charge, intended for a $5 \times 5\,m^2$ plot. Farmers were, however, allowed to plant at the density they preferred, so the plot sizes differed substantially. Similarly, farmers used their preferred cultural practices, including time of operations such as planting and weeding, and the amounts of inputs such as fertilizer and manure. For the control, a plot of the farmers' preferred variety was marked next to the plot with the IR-maize variety, with the same size (approximately $5\,m \times 5\,m$).

The participating farmers were visited three times by a scientist and a technician: at the time of planting (in April), just before the harvest (July) and after the harvest (August). Four sets of data were collected during and after the trials: scientists' evaluation, farmers' evaluations, household characteristics and farmers' WTP for IR-maize. For the scientists' evaluation, the spacing between and within rows was measured at the first visit to calculate plot sizes. During the second visit, the variety in the control was noted, and the numbers of emerged *Striga* plants in each plot were counted. The farmers' recall of fertilizer use and dates of planting and weeding were noted. Farmers harvested the plots individually and kept the harvest of the IR-maize and the control plot separately. At the last visit, the scientist and technician would measure the grain weight and moisture content, to adjust the weight to standard 15% moisture content.

Farmers' evaluation took place during the second and third visits. Farmers evaluated only their own plots, both IR-maize and control, using a scale of 1 (very poor) to 5 (very good). At the second visit, farmers evaluated the varieties for germination, development, plant size, appearance and *Striga* parasitism. After the harvest, evaluations were done for maturity, cob size and productivity.

Household and farm characteristics were observed using a structured questionnaire, administered at the first visit. Farmers' WTP for IR-maize was obtained using contingent valuation during the last visit. Since all farmers had, by now, been sufficiently exposed to the new technology, there was no need for dichotomous valuation methods and the continuous method was used (Arrow et al., 1993; Alberini and Cooper, 2000). Farmers were asked how much IR-maize seed they would be willing to purchase at different price levels. Farmers were also asked how much each variety would yield if there had been no *Striga* present. The respondent was usually the household head or their spouse. In Bondo, however, the group leader provided the information on behalf of unavailable farmers, based on their records.

The appropriate analysis for the original design, two treatments (IR-maize and a control) under the same farmer-managed conditions, would be a pair-wise *t*-test. However, visiting officials observed that the IR-maize plots did not always look very good and encouraged farmers to put more fertilizer on it. Therefore, the results were also analyzed using a regression model with yield difference as dependent variable, and differences in fertilizer application and *Striga* count as independent variables.

2.3. Economic analysis and analysis farmer evaluation

A marginal analysis was performed to determine the economic efficiency of maize technologies including im-

Table 1
Location of the sites and number of participating farmers

Year	District	Division	Location	Sub-location	Village	Longitude (decimal deg.)	Latitude (decimal deg.)	Number of farmers	Repetitions/farmer
2002	Kisumu	Maseno	Kisumu North	Bar A	Kandalo	34.6998	−0.0378	1	3
	Kisumu	Maseno	Kisumu North	Bar	Kwa Mudhi	34.6821	−0.0395	1	3
	Kisumu	Winam	Kisumu East	Mkendwa	Kasongo	34.7543	−0.0369	1	3
2004	Rachuonyo	East Karachuonyo	Wangchieng	Kajiey	Kanyang'wena	34.7384	0.3607	20	1
	Vihiga	Luanda	N. Bunyore	Ebulonga	Ematioli	34.6174	0.0453	20	1
	Bondo	Maranda	N. Sakwa	Abom	Kamayuje	34.3677	0.0544	20	1

proved seed, IR-maize technology and fertilizer. The maize price was calculated from the monthly average prices provided by the Kenyan Ministry of Agriculture from 2003 to 2005. The average price, calculated from the major consumer markets (Nairobi and Kisumu), production markets (Eldoret and Nakuru) and transit market (Mombasa) was calculated at US$202.36/ton (1392 Kenyan Shilling per 90 kg bag). Fertilizer prices and the cost of application were obtained from a farmer survey in four *Striga* infested districts in western Kenya, resulting in US$0.4/kg DAP, US$0.3/kg CAN and US$3.9/ha labor for application. The price of imazapyr, US$133.3/kg, was provided by the producer BASF in South Africa.

For the economic analysis, the marginal rate of return (MRR) was calculated, as the ratio of the marginal benefit over the marginal cost (ΔC). The marginal benefit is the extra revenue generated, calculated as the extra yield (ΔY) multiplied by the price p, minus the extra costs:

$$\mathrm{MRR} = \frac{\Delta Yp - \Delta C}{\Delta C}.$$

For a technology to be profitable, the marginal benefit first needs to be positive, or the farmer would lose money. Secondly, the extra benefits need to be large relative to the extra costs, to provide a sufficiently good return to the farmers' investment. Experience has shown that farmers are unlikely to adopt a new technology if the *MRR* is lower than 50% (for small changes), and even 100% if the new technology represents a major change (CIMMYT, 1988). In other words, the farmer would expect a return of 2 dollars for every dollar invested to adopt a technology.

Farmer evaluation scores were analyzed using ordinal regression (Coe, 2002), with each score as dependent variable, IR-maize as the main factor (using a binary variable), and adding a fixed effect for each farmer (binary variable) to avoid the autocorrelation.

3. Results of the researcher-managed trials

3.1. Effect of Striga on yield, and the impact of IR-maize

Researcher-managed trials were organized on three farms in 2002, with 2 replicates at each site. First the relationship between *Striga* and yield was analyzed using linear regression of yield on *Striga* counts at different periods of time (6, 8, 10 and 12 weeks after planting). Since the counts at different times are very highly correlated, representing a certain level of the *Striga* seed bank in the soil, only one factor could be used at a time in the regression. The regression results are presented in Table 2, and each column represents the analysis for the *Striga* counts at a particular time, all using Eq. (1). The first column, for example, shows that without *Striga* in the 6th week, average yields are 2.3 tons/ha, and that the yield is reduced by 454 kg for each emerged *Striga* plant/m^2 found at week 6. The effect of *Striga* counts at later times decreases from −165 kg in week 8 to −41 kg at week 12, but the standard errors are smaller. The best prediction of yield ($R^2 = 31\%$) is found at the 10th week, using the estimated function: $Y = 2{,}688–69$ *Striga*/m^2.

Table 2
Regression of maize yield (in kg/ha) on *Striga* counts (emerged plants per m^2) at different periods after planting (2002 on-farm trials, researcher-managed)

	Week 6	Week 8	Week 10	Week 12
Constant	2300 (242)***	2587 (230)***	2688 (237)***	2698 (246)***
B	−454 (178)*	−165 (36)***	−69 (14)***	−41 (9)***
R^2 (%)	11	29	31	28
N	54	54	54	54

*Significant at 5% level, ***significant at 0.1% level, with (standard deviations between brackets).

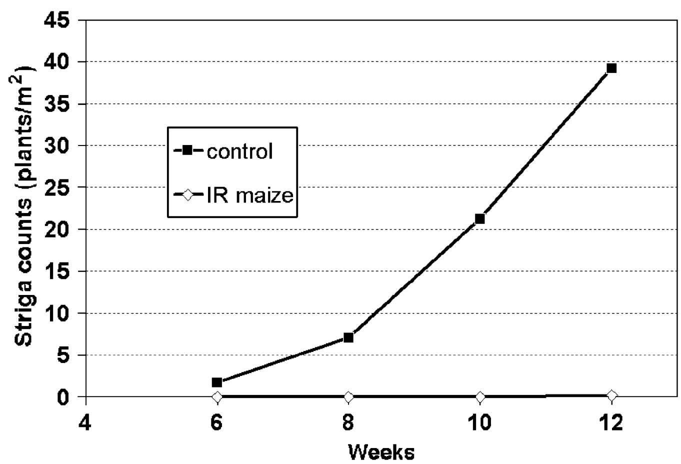

Fig. 2. *Striga* counts at different times in IR-maize and control plots, 2002 on-farm trials.

The on-farm trials clearly showed how IR-maize suppresses the emergence of *Striga* (Fig. 2). In the plots without the herbicide, *Striga* starts to emerge in week 6, and increases on average up to 18 plants/m^2 in week 12 on the research station and up to 38 plants/m^2 in week 12 in the farmers' fields. In the plots with herbicide-treated seed, no *Striga* emerged at all on-station and on-farm only 0.2 plants/m^2 were observed on average in week 12. Imazapyr is clearly highly effective in controlling *Striga*. There was, however, no significant difference between *Striga* counts at the different fertilizer levels.

3.2. Effect of IR-maize on yield

Comparing the average maize yields shows how the herbicide increases yields dramatically (Fig. 3). However, there is no significant effect of the fertilizer. On-farm, only the herbicide has a significant effect: it increased yields by 2.3 and 2.7 tons, respectively. Surprisingly, fertilizer use had no significant effect on yields. The high yield of the herbicide treatment without fertilizer (more than 3.5 tons/ha) indicates that the soils of the experimental plots were actually quite fertile, and that the *Striga* infestation was the

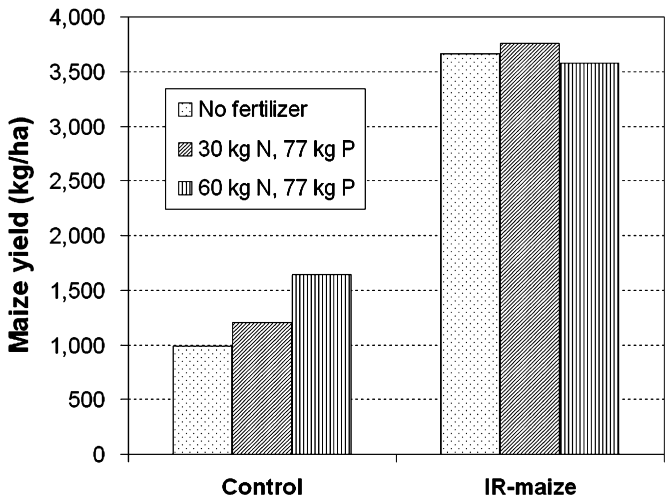

Fig. 3. Maize yield of IR-maize at different fertilizer levels, with control (2002, on-farm researcher-managed trials).

major limiting factor. Therefore, the herbicide could increase yields dramatically by suppressing *Striga,* but the extra fertilizer had no significant effect.

To properly estimate the effect of herbicide and fertilizer, as well as their interaction, a quadratic production function was estimated, following Eq. (2). The results put the estimated effect of the IR-maize, coated with the herbicide, at 2.7 tons per ha, while the fertilizer still had no significant effect (Table 3). The coefficient of the interaction of herbicide with fertilizer interaction was not significant either. The high yields without fertilizer indicate that on these farms, which were selected mainly for their very high *Striga* levels, soil fertility was high, but yields were suppressed severely by the high *Striga* levels. Suppressing the *Striga* allows the maize crop to exploit the full soil fertility potential, dramatically increasing yields. Under such conditions, fertilizer applications are not likely to increase yield.

Table 3
Production function analysis (2002 on-farm trials, researcher-managed)

Variable	Description	Estimated coefficient	Standard deviation
	Constant	943	561*
HF	Herbicide dummy	2763	756***
F	Fertilizer rate	11.9	37
F^2	Quadratic response to fertilizer	−0.02	−0.6
HF	Herbicide and fertilizer interaction	−0.4	−0.7
	F	6.4	
	R^2	45%	
	Standard error	1435	
	N	36	

*Significant at 10% level, ***significant at 1% level.

3.3. Economic analysis

For the economic analysis, the different treatments are ranked in order of increasing net benefits, and IR-maize without fertilizer comes out best at US$737/ha (Table 4). This results from an increased yield of 239 kg/ha, valued at US$0.202/kg, at a cost of US$4/ha. To see if the technology is worth the investment, marginal benefits are compared to marginal costs. The net benefits of IR-maize are US$542/ha higher than the control (both without fertilizer), for a cost of only US$4/ha, resulting in an MRR of 134. In other words, for every dollar invested in herbicide, the farmers recover the cost and receive a return of US$134 for their investment.

The fertilizer treatments in this trial had no economic benefit. In the control, the low fertilizer dose has a lower net benefit (US$176/ha) than the zero fertilizer (US$199) at a higher cost or a negative return to the investment. The

Table 4
Partial budget analysis (2002 on-farm trials, researcher-managed)

		Control			IR-maize		
		0 kg N, 0 kg P	30 kg N, 77 kg P	60 kg N, 77 kg P	0 kg N, 0 kg P	30 kg N, 77 kg P	60 kg N, 77 kg P
Benefits	Average yield (kg/ha)	985	1200	1644	3663	3761	3575
	Gross field benefits (US$)	199	243	333	741	761	723
Costs	Cost of herbicide (US$/ha)	0	0	0	4	4	4
	Cost of fertilizer (US$/ha)	0	62	125	0	62	125
	Cost of labour to apply fertilizer (US$/ha)	0	4	4	0	4	4
	Total costs that vary (US$/ha)	0	66	129	4	70	133
	Net benefits (US$/ha)	199	176	204	737	690	590
Analysis	Extra benefit (compared to control, no fertilizer)		43	133	542	561	524
	Extra cost (compared to control, no fertilizer)		66	129	4	70	133
	MRR (compared to control, no fertilizer)		−0.34	0.04	135.4	7.0	2.9

high fertilizer dose has a slightly higher net benefit than the zero fertilizer, but the MRR is only 4% and clearly not very interesting to the farmer. In the IR-maize plots, fertilizer application does not increase net benefits and is therefore also not economical.

Sensitivity analysis was used to analyze how costs and benefits change when input and output prices change. A doubling of the herbicide price, for example, hardly changes net benefits and, although the MRR would be cut in half, it would still be very high. A drop in maize prices by half, on the other hand, would result in a proportionate drop in benefits, which would decrease the MRR. But even a 90% drop in maize price would not bring the marginal return below the 50% threshold. Fertilizer prices would have to drop to a third of current prices to make reach the required MRR of 1.5 and make their use profitable.

However, these results need to be treated with care, First, the number of farmers was small, and they were not randomly selected. Secondly, the high fertility levels observed in these farms are unlikely to be representative of the soils in the area. Finally, results in researcher-managed trials might be quite different from results under farmer-management. For those reasons, a second set of trials was organized, including a large number of farms, in the soils typical for the area and at their own management.

4. Results of farmer-managed trials 2004

4.1. Farm household characteristics

In 2004, 60 farmers were invited to try out the IR-maize in their fields. The household survey showed a high proportion (47%) of female-headed households. This was higher in Vihiga (65%) and lower in Rachuonyo (30%) (Table 5). Only a few households (13%) were polygamous. The average age of the household heads was 46 years, and the large majority had at least some primary education, with an average school attendance of 7.4 years. Most participants were experienced farmers, with an average experience of 17 years. Farms are small, on average covering 0.72 ha, of which 0.43 ha (57%) is planted in maize. Farms are distinctly smaller in Vihiga, with an average farmer size of only 0.48 ha. Since maize is the major staple food, however, households will still dedicate 0.35 ha (73%) to maize production. Almost half of the participating farmers (46%) felt that the soil fertility of their farms was good.

Most participating farmers grow local varieties (76%); while only a quarter grow improved open-pollinated varieties (OPVs) (24%) and only few grow hybrids (14%). Local varieties are, indeed, local: Nyamula dominates in Rachuonyo (67% of farmers), Rachar in Bondo (53%), and Anzika and Anyole in Vihiga (40% and 26%). The adoption of improved varieties is quite different between districts. Kakamega synthetic is only grown in Bondo (37% of farmers), while W502 is grown in Bondo and Rachuonyo (16% each). Of the hybrids, H513 is grown in Bondo (16%) and Rachuonyo (5%), Maseno double cobber in Bondo only (16%). PH1 and H614 are grown by only 1 farmer each.

4.2. *Striga* counts and yields

The key variables were calculated by district to compare the performance of IR-maize with the control (Table 6). *Striga* levels were high in Bondo (on average 11 plants/m^2 in the control plot) and Rachuonyo (8 plants/m^2), but low in Vihiga (1.7 plant/m^2). The IR-maize technology clearly reduced *Striga*, especially in Bondo (by two thirds, down to only 4 plants/m^2) and in Vihiga (to only 0.4 plants/ha). However, in Rachuonyo, there was no statistical difference in *Striga* counts between the two treatments. Although plots were selected for high historic *Striga* levels, there were still fields that did not show any *Striga* during the trial season (25% of IR-maize and 18% of control plots).

Table 5
Characteristics of participating farm households (2004 trials)

		Bondo		Rachuonyo		Vihiga		Total	
		Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
Type of household	Nuclear (%)	75.0		89.5		70.0		78.2	
	Polygamous (%)	18.8		5.3		15.0		12.7	
	Extended (%)	6.3		5.3		15.0		43.0	
Household head	Female (%)	45.0		30.0		65.0		47.0	
	Age	47.4	12.0	49.6	18.2	41.0	12.0	45.9	14.5
	Education (years in school)	7.7	2.7	6.6	4.2	7.8	2.5	7.4	3.2
	Farming experience (years)	15.0	10.0	20.6	18.9	14.6	11.5	16.6	13.9
Farm	Total size (ha)	0.79	0.54	0.86	0.67	0.48	0.48	0.72	0.58
	Maize area (ha)	0.50	0.39	0.43	0.36	0.35	0.33	0.43	0.36
	N	20		20		20		60	

Working under farmer conditions did bring some complications. First, encouraged by visiting officials, 22 farmers (out of 60) put more fertilizer on the IR-maize plot than on the control. Only in Rachuonyo was no chemical fertilizer applied to either of the plots. A second complication was in Rachuonyo, where the IR-maize and control plots showed similar levels of *Striga* infestation, probably caused by heavy rains and flooding which can wash off the herbicide. Third, the gene that transfers resistance to the herbicide was put in an improved OPV of short maturity. So the new IR-maize varieties bring herbicide resistance, but also improved genetic material, while the farmers use largely local varieties or land races, which were used as a control. Finally, more farmers intercropped the control (77%), than intercropped the IR-maize plots (33%).

Planting distances were similar between IR-maize and control plots, with an average distance of 0.8 m between rows and 0.6 m between, and an average of 2 seeds per hill. Chemical fertilizer was used by a third of the participating farmers, although this varied from none in Rachuonyo to more than half in Bondo. The most popular fertilizer on maize or CAN (26% nitrogen), DAP (18% N) and urea (46% N). From the different doses of the different fertilizers, the total N in kg/ha could be calculated for each plot (fifth and sixth column in Table 6). There was a significantly different N application between IR-maize and control plot in Bondo (43.3 vs. 7.0 kg/ha) and Vihiga (26.7 vs. 5.8 kg/ha).

Overall, the maize yield on IR-maize plots was double that of the control plots (1.3 vs. 0.6 t/ha), albeit with large differences between the districts. This yield difference can, however, not be attributed to the IR-maize technology alone, but is a combination of the IR-maize technology suppressing *Striga*, the improved germplasm and fertilizer.

4.3. Regression analysis

A linear regression model was therefore applied, using the yield differences between each pair of plots (in kg/ha) as dependent variable, and the difference in N application (in kg N/ha) as independent variable (model 1 in Table 7). The results show no significant effect for a 2-sided t-test ($p = 0.163$), although it can be argued that since a negative effect can be excluded, the 1-sided test (with $p = 0.081$) is more appropriate, and that a 10% margin of error is acceptable for on-farm trials. The estimated coefficient indicates that for each difference in treatment of 1 kg N/ha would lead to a 6.9 kg/ha increase in yield. The average difference in N application between the treatments (20.1 kg/ha) would therefore account for 138 kg/ha yield difference, and IR-maize (herbicide plus improved germplasm) for 485 kg/ha.

The major effect of IR-maize is expected from an increase in yield through a reduction of *Striga* parasitism. Therefore, the model can substantially be improved by including as independent variable the difference in *Striga* counts (per m^2) between the treatments (model 2 in Table 3). The coefficient of this variable is highly significant, and its estimation indicates that a reduction of 1 *Striga* plant/m^2 would increase the maize yield by 48.6 kg/ha. Inclusion of the *Striga* count difference reduces the constant to 370 kg/ha while keeping the N coefficient at 7 kg/ha. If we accept these coefficients (p for a 1-sided test would be 7.6% for the constant and 5.5% for the N coefficient) the interpretation would be that there is a 370 kg/ha variety effect, observed in the absence of *Striga* or if the herbicide was not able to suppress it. The yield increase in Rachuonyo can therefore largely be attributed to the variety effect, while the yield differences in Vihiga can be seen as a combined effect of variety and *Striga* control, and the difference in Bondo as a combination of

Table 6
Results of on-farm, farmer-managed trials comparing IR-maize with a farmer-selected variety in adjoining plots (2004 farmer-managed trials)

District		*Striga* (counts/^{2})		Nitrogen (kg/ha)		Maize yield (kg/ha)	
		IR-maize	Control	IR-maize	Control	IR-maize	Control
Bondo	Mean	3.68	10.75*	43.3	7**	1701.5	631.7*
	Std.	6.05	18.91	54.8	15.2	1669.6	796.7
	N	19	19	19	19	19	18
Vihiga	Mean	0.43	1.67**	26.7	5.8***	831.1	276.4
	Std.	1.11	2.55	73.4	12.1	1070.5	290.8
	N	20	19	17	17	12	13
Rachuonyo	Mean	9.17	8.15	0	0	1157.2	824.7
	Std.	20.93	12.35	0	0	1042.9	1345.4
	N	18	18	19	17	17	16
Total	Mean	4.27	6.93	23.2	4.4**	1291.1	599.1*
	Std.	12.58	13.57	54.2	11.6	1354.5	945.7
	N	57	55	55	53	48	47

*, **, ***Significantly different at the 5%, 1% and 0.1% levels, respectively (2-sided pair-wise t-test).

Table 7
Regression of yield difference between IR-maize and control (dependent variable) on differences in N application and *Striga* counts (2004, farmer-managed trials)

Variables (differences)	Model 1 (without *Striga*)			Model 2 (with *Striga*)		
	B	Standard error (±)	*p*	*B*	Standard error (±)	*p*
Constant	485.5	281.3	0.092	369.5	252.8	0.152
N/ha	6.9	4.9	0.163	7.0	4.3	0.113
Striga count/ha				−48.6	14.5	0.002
R^2	0.05			0.27		
N	40			40		

Table 8
Economic analysis of the use of IR-maize (2004, farmer-managed trials)

	Variety effect, on:		IR-maize effect, on:			Combined effect		MRR		
	Yield (kg/ha)	Revenue (US$/ha)	*Striga* counts	Yield (kg/ha)	Revenue (US$/ha)	kg/ha	US$/ha	Variety	IR-maize technology	total
Bondo	370	75	−7.07	346.43	70	716	145	1.9	16.5	3.9
Vihiga	370	75	−1.24	60.76	12	431	87	1.9	2.1	1.9
Rachuonyo	370	75	0		0	370	75	1.9	−1.0	1.5
Total	370	75	−2.66	130.34	26	500	101	1.9	5.6	2.4

the three effects. Using dummy variables for districts in the regression did not lead to significant coefficients, so the variety effect can be assumed constant for the different districts.

4.4. Economic analysis

The complication experienced in the execution of the trials made it difficult to use the straightforward comparison of means and to attribute the important and significant yield differences uniquely to the IR-maize treatment for an economic analysis. However, using multiple linear regression, a first attempt could be made to estimate the variety effect at 370 kg/ha, and the IR-maize effect at 49 kg/ha for each unit reduction of the *Striga*/m^2. In Bondo, where the IR-maize treatment reduced the *Striga* counts by 7 plants/m^2, the effect can thus be calculated at 346 kg/ha, valued at US$70/ha (Table 8). In Vihiga, where the initial *Striga* count was quite low and the reduction was estimated at 1.24 plants/m^2, the IR-maize effect was calculated at 60 kg/ha (US$12/ha). In Rachuonyo, there was no IR-maize effect, only the variety effect of 370 kg/ha (very similar to the difference in means, although the last one is not significant, given the low sample size and high standard error). The combined effect of the variety effect and the herbicide effect therefore varies from US$75/ha in Rachuonyo to US$145/ha in Bondo.

The extra cost to obtain the variety effect can be valued at the cost of improved maize seed, on average US$1.69/kg during the study period, minus the cost of local seed, estimated at twice the grain price of US$0.202/kg, leading to an extra cost of US$1.28/kg or US$25.7/ha (assuming a seed rate of 20 kg/ha). The MRR of the variety effect can then be calculated at an acceptable 1.9. The extra cost of the herbicide is estimated at US$4/ha, leading to an average very good MRR of 5.6, albeit with big differences between districts. Similarly, the overall MRR is a good 2.4, going from a low 1.5 in Rachuonyo to a high 3.9 in Bondo.

5. Farmer appreciation of IR-maize

5.1. Farmer evaluation

Most of the farmers expressed a liking for the IR-maize, especially at the evaluation at the second visit, during the vegetative phase. Using ordinal regression with the evaluation on the different criteria as dependent variables, IR-maize was evaluated significantly better on all criteria (Table 9). The log-odds ratio, or the estimated coefficient, for *Striga* parasitism was the highest at 6.3. Calculating the exponent of the log-odds ratio results in the easier-to-interpret odds ratio of 541. This means that the ratio of the probability of farmers preferring IR-maize to the control over the probability that they prefer the control is 541:1. The log-odds ratios of the other criteria were also high and significant. They were, in descending order, germination, development, plant size, maturity period and appearance. The last criterion still obtained a log-odds ratio of 3.7.

Farmers observed that *Striga* parasitism was lower in the IR-maize than in their own variety. The few plants that emerged did so later in the season and grew some distance away from the maize plants. However in Rachuonyo *Striga* counts were high even in the IR-maize plots. This may reflect the heavy rains at planting which may have removed

Table 9
Results of farmer evaluation of IR-maize (ordinal regression, fixed effects), (2004, farmer-managed trials)

		Log-odds ratio for preferring IR-maize		Model		
		Estimated coefficient	Standard error (±)	McFadden R^2	−2 log likelihood	N
Vegetative stage (second visit)	Germination	6.29	1.08***	0.62	89.02	57
	Development	5.97	0.96***	0.62	103.58	57
	Plant size	5.41	0.87***	0.60	106.34	54
	Appearance	3.36	0.61***	0.45	151.60	53
	Striga parasitism	6.67	0.96***	0.47	136.36	44
After harvest (third visit)	Maturity period	3.69	1.17**	1.00	0.00	53
	Disease resistance	2.27	1.04*	1.00	0.00	53
	Pest resistance	1.60	0.85	0.52	66.12	53
	Yield	−0.20	0.82	1.00	0.00	48
	Grain size	−0.57	0.81	0.62	61.04	53
	Cob size	−1.03	0.76	0.60	72.56	53

the herbicide coating, leaving the seeds exposed to *Striga* infestation.

Generally, farmers observed that IR-maize germinated better than their own variety. The main problem that affected germination was destruction of planted seeds by pests (mainly Bondo), water logging (mainly Rachuonyo) and late planting (mainly Vihiga).

The development of IR-maize was also generally considered to be better than the control. The major problem encountered during the trial was the prolonged drought, especially after the second weeding, which continued during tasseling. In some parts of Rachuonyo, heavy rains resulted in flooding during planting, which affected development. Farmers appreciated the short maturity period of the IR-maize, which most of them found comparable to that of their own variety.

After the harvest, however, many farmers were not available or had a hard time assessing the IR-maize and the control, resulting in many missing variables. IR-maize was evaluated significantly better for its shorter maturity period, and for disease and pest resistance (in that order). Evaluation for production traits such as cob size, grain size and yield was not significantly different between the varieties, partly because of the missing values.

The farmers also noted some problems with the IR-maize. In Bondo, they observed that the maize was more susceptible to termite attack, which caused a lot of lodging. In Vihiga, the IR-maize was more susceptible to drought than their variety. In Rachuonyo, there was a problem of *Striga* emergence even in the IR-maize.

5.2. Farmers WTP for IR-maize

Finally, farmers were interviewed about their WTP for the IR-maize. The average price farmers paid for improved varieties at the time of the survey was US$1.79/kg. All participating farmers in Rachuonyo and Bondo declared they would be willing to pay a similar amount for herbicide-treated seed, but in Vihiga, that was only 62%. At a price increase or premium of 10%, a large majority of Bondo farmers (95%) would still buy the seed, but only half the farmers in Rachuonyo (50%) and only few in Vihiga (15%).

6. Discussion and conclusion

6.1. Interpretation of the results

The results of the researcher-managed trials clearly showed that the coating of IR-maize seeds with imazapyr suppresses the development of *Striga*, especially in the early stages. This suppression tripled yields, with a spectacular increase of 2.39 tons/ha. However, yields did not increase with higher fertilizer doses, an indication of high soil fertility in the test plots. Economic analysis showed a high profitability for the IR-maize technology, but not for fertilizer use. These results, however, need to be interpreted carefully since the number of sites was limited; they might not be representative of the region and researcher's and farmer's management might be quite different.

The second round of trials was therefore held under farmer management, and included a larger number of sites distributed over three districts. In two of the three districts, the IR-maize established good control of *Striga*, but not in the third district, possibly reflecting heavy rainfall that removed the herbicide. Nevertheless, IR-maize produced double the yield of the control (an increase of 0.69 tons/ha), even where *Striga* was not suppressed. This last effect can be attributed to the improved germplasm of IR-maize, compared to the controls which were mostly local varieties.

Regression analysis allowed differentiation between the variety effect, estimated at 0.37 tons/ha, and the herbicide effect, calculated at 49 kg/ha for each unit reduction of the *Striga* count/m^2. Since *Striga* counts were, on average, reduced by $2.66/m^2$, the average herbicide effect was calculated at 130 kg/ha. Marginal analysis resulted in an overall MRR of 2.4 (good), with an MRR of 1.9 (respectable) for the variety and an MRR of 5.6 (very good) for the IR-maize technology. However, the MRR on the IR-maize technology was quite different between districts, ranging from −1.0 to 16.2. At a cost of about US$4/ha, the IR-maize technology needs to reduce *Striga* infestation by 1.3 plants/m^2 to reach an MRR of 2, the preferred level for introducing new technologies.

At the vegetative stage, farmers' evaluation strongly favoured the IR-maize variety, with significant differences for all criteria (germination, development, plant size, appearance and *Striga* parasitism, in that decreasing order of preference for IR-maize). At harvest time, IR-maize was evaluated significantly better for its shorter maturity period, and for disease and pest resistance (in that order). Evaluation for production traits such as cob size, grain size and yield was, however, not significantly different between IR-maize and the control. Factors that influence these results were the missing values, high variability and lack of *Striga* control in one district.

6.2. Potential for improving the methodology

Research on *Striga* control measures in farmers' fields is notoriously difficult. It is important therefore to evaluate regularly the methods used and indicate how they can be improved. The researcher-managed trials showed a clear advantage of good control and obtaining significant results with relatively few replications. However, their external validity is limited, as was observed in the 2002 trials, and their use should therefore be limited to the initial stages of the research.

In the farmer-managed trials, control is problematic and many confounding factors play a role, and the technology did not perform well in one district, Rachuonyo. The results of these trials indicate that the sample size needs to be sufficiently large, preferably higher than the size of this trial (60). To avoid preferential treatment of the technology being evaluated, the communication with the farmers needs to be improved. It needs to be explained that, for the best possible comparison, the new technology and the control need to be treated the same. Farmers need to be followed up more closely, and visited more often than the three visits over one season made here. To take into account the compounding effect of other variables, they need to be carefully measured, in particular the *Striga* seed bank present in the field, and its soil fertility. To distinguish between the effect of the herbicide and that of the hybrid, it would also be useful to compare the yield of the new varieties to the popular varieties in the region in fields without *Striga*. The inefficacy of the technology in Rachuonyo poses a particular challenge. A sample of the seed batch used should be set aside and conserved for future evaluation in case of failure. The effect of washing could be estimated by measuring the rainfall.

For the farmer evaluation, scoring on a scale of 1–5 on the farmers' declared criteria and analysis by ordinal regression turns out to be both theoretically correct and convenient. The sample size could be increased substantially by inviting neighboring farmers to come and evaluate the technology. Finally, farmers' interest was estimated by soliciting the declared WTP (stated preferences). The quality of these results depends on farmers' full understanding of the technology, and can also be influenced by strategic behavior and a desire to please the visitor. In the future, this could be tested by measuring revealed preference through experimental auctions. In these auctions, farmers are asked to bid, with real money, for a given amount of seeds and the transaction is executed when their bid surpasses that drawn from a particular random distribution (Kimenju et al., 2006). Alternatively, their actual purchase of IR-maize seed can be monitored after the varieties are released in the market.

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