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**Assessing the potential impact of Bt maize in Kenya**  
**using a GIS based model**

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## Assessing the impact of Bt maize in Kenya using a GIS model

**Key words:** maize, Africa, Genetically Modified Crops, Bt crops

### Abstract

The Insect Resistant Maize for Africa (IRMA) project is currently developing Bt maize for Kenya. So far, Bt genes with resistance to *Chilo partellus*, *Chilo orichalcociliellus*, *Eldana Sacharina*, and *Sesamia calamistis*, four of the five major stemborers were successfully incorporated into elite CIMMYT maize inbred line (CML216) and tested in insect bioassays in Kenya. Participatory Rural Appraisals showed that stem borers are indeed a major pest problems for farmers. Four seasons of on-farm crop loss assessment showed an average crop loss of 13.5%, or 0.4 million tons, valued at US\$ 80 million. If the project manages to find a Bt gene that is effective to the fifth stemborer, *Busseola fusca*, adoption rates are likely to be high, and therefore the returns. Under standard assumptions, the economic surplus of the project is calculated at \$ 208 million over 25 years (66% of which is consumer surplus) as compared to a cost of \$5.7 million. Geographically, the project should focus on the high production moist-transitional zone. However, if such gene cannot be found, Bt maize technology would only be effective in the low potential areas, and adoption rates would be fairly low, although benefits would still exceed costs.

### Introduction

The use of biotechnology, in particular Genetically Modified Crops (GMCs), is a hotly debated issue. The technology has proven remarkably effective, and farmers in North America and several countries have adopted GMCs widely, from 1.7 million ha in 1996 to 44.2 million ha in 2000 (1996), probably the fastest adoption rate of any agricultural

technology ever. The technology is particularly effective in incorporating insect resistance (maize and cotton) or herbicide resistance (canola and soybeans). Europe, influenced by green political parties in different governments and strong consumer and environmental groups, has so far rejected GMCs, despite a lack of evidence that GM crops would be less safe for human consumption or for the environment than corresponding conventional crops or food (Paarlberg, 2000).

Developing countries face a difficult choice. If Europe and North America cannot agree, with all the science and policy analysts available, how can an African country make a rational decision? Africa, where per capita food production is not keeping pace with population growth, and millions face serious food shortages, might not have the luxury of rejecting GM crops. All new technologies have risks, and it is up to African farmers, consumers, and decision makers to weigh the risks against the benefits (Pinstrup-Andersen and Schiøler, 2000). To help make rational decisions in a very heated, and often irrational debate, it is important that scientists contribute their objective analyses to the debate. Since little analysis is possible without hands-on experience, it is equally important that GM crops are tested in Africa. Given the debate, biosafety regulations should be well established and testing should be done under controlled conditions, with a continuous impact assessment: environmental as well as economical.

The Insect Resistant Maize for Africa (IRMA) project, a collaborative effort between the International Maize and Wheat Improvement Centre (CIMMYT) and the Kenya Agriculture Research Institute (KARI), is developing genetically modified maize varieties by incorporation of modified genes (for constitutive expression) derived from the soil dwelling bacteria *Bacillus thuringiensis* (*Bt*). The *Bt* genes code for crystal endo-toxins that control lepidopteran stem borer pest species of maize. So far, cut leaf tissue from maize transformed with different *Bt* events and genes were introduced into Kenya following the laid down

regulations and procedures. Leaf bioassays were performed to test the effectiveness against the five most important stem borer species (*Chilo partellus*, *Chilo orichaociliellus*, *Busseola fusca*, *Eldana saccharina*, and *Sesamia calamistis*). A prospective control was identified for the most destructive and the most widely distributed stem spotted stem borer (*Chilo partellus*) and the other three stem borers. However, no event or gene was found to provide complete control to the fifth stem borer, African stem borer (*Busseola fusca*), which is mainly found in highland ecologies.

At the same time, accompanying research was conducted to estimate crop losses due to these species, as well as the socio-economic and biophysical environments for which the varieties are being developed.

In this paper, an *ex ante* impact assessment of *Bt* maize for Kenya is presented. It uses a model, developed to combine primary and secondary geo-referenced data, from different sources and disciplines, to estimate the impact of different interventions, applied here to estimate the potential impact of *Bt* maize in Kenya. Specific to the approach is the interdisciplinarity, and the use of geo-referenced data, all incorporated into an economic surplus model.

## **Methodology**

The basic model calculates the economic surplus from a supply shift, due to decreasing crop losses due to stem borers. Crop losses were measured for different agro-ecological zones in Kenya, and linked to the distribution of the different species that were measured in those zones. For crop loss measurement, a stratified three-stage sampling scheme was used. The six maize growing agroecological zones were used as strata, and in each stratum, 4 to 5 villages were selected, in total 27. In each village, 5 farmers were selected at random, with one field from each farmer, or 135 fields in total. In each selected field, two adjacent plots of 100 m<sup>2</sup>

were laid out. One plot was left unprotected, while the other plot was treated with a systemic insecticide for borer control (Bulldock, Bayer: active ingredient: *beta cyfluthrin*, in granular form with 0.5 g of A.I./kg), applied in the maize whorl at about 2-3 weeks or at the 6-leaf stage. If necessary, the treatment was repeated in the protected plot later in the season. Otherwise, there was no interference with farmers' normal practices. Yields were measured in both the long and short rainy season of 2000, and the yield difference between the two plots was assumed to be the crop loss due to stem borers. We believe this is a valid assumption as other field insect pests in maize are typically of minor importance (Nye, 1960)

Secondary data include farmers' perception of losses, agro-ecological information of six zones specific to maize production, the effectiveness of different *Bt* genes, population data, maize production data, adoption levels of improved maize varieties, and maize prices. An overview of the sources and a summary of the analysis are presented in the next section.

### **Maize and Stem borers in Kenya**

Maize is the most important food crop in Kenya. On average, 2.4 million tons of maize per year are produced (Hassan, 1998). Production is spread very unevenly over the country. A study by CIMMYT and KARI defined six major agroecological zones for maize production in Kenya (Hassan, 1998). Moving from east to west, we first find the Lowland Tropics (LT) on the Indian Ocean coast, followed by the Dry Mid-altitudes (DM) and Dry Transitional (DT) zones southeast of Nairobi. These three zones are characterized by low yields (less than 1.5 t/ha); although they cover 29% of maize area in Kenya, they only produce 11% of the country's maize (Table 1). In Central and Western Kenya, we find the Highland Tropics (HT), bordered on the west and east by the Moist Transitional (MT) zone (transitional between mid-altitudes and highlands). These zones have high yields (more than 2.5 t/ha) and

produce 80% of the maize in Kenya on 30% of the area (see Table 1). Finally, around Lake Victoria, is the Moist Mid-altitude (MM) zone, which produces moderate yields (1.44 t/ha), covers 22% of the area and produces 9% of maize in the country.

The very diverse geography of Kenya has also brought a very uneven distribution of the population. By superposing the population census data on the agroecological map, each division can be assigned, with its population, to one zone. Similarly, maize production data from 1998 from the Ministry of Agriculture were linked to the population map, and combining these with the population census of 1999, the food security situation in each zone can be assessed (Table 1). In Kenya, average maize production per person is 80 kg per capita, but only the high potential zones (MT and HL) have a higher per capita production. Together the two zones have a population of about 11 million people, 40% of the Kenyan population, but they produce 80% of the maize.

Stem borers have been studied extensively in Kenya, and crop losses have been estimated between 15 and 45% (Ajala and Saxena, 1994; Seshu Reddy and Sum, 1991; Seshu Reddy and Sum, 1992). However, none of these estimates included crop loss measurement and farmers' assessment over a large geographic area. During a survey in 1992 (Hassan, 1998), farmers were asked to estimate the extent of the stem borer problem, and the damage.

Extrapolating from the survey results, an aggregate crop loss of 12.9% was obtained (De Groot, 2002). Based on an estimated maize production of 2.6 million tons during that year (Ministry of Agriculture, unpublished data), this would lead to a yearly loss of 0.39 million tons. Using an average maize price over the last 5 years (\$193/ton), the economic losses were estimated at \$76 million.

## **Impact assessment**

### *Crop loss measurement*

To verify farmers' estimates, crop losses were assessed directly in farmers' fields, in a representative sample of all regions. Crop losses were thus estimated at 13.5%, with a value of \$80 million (Table 2), very close to the farmers' estimates. Crop losses range from 9% in the highlands to 20% in the dry transitional zone. The distribution of the value of the losses over the regions is quite revealing. Almost half of the losses (US\$ 29 million) occur in the moist transitional zone. This area also has a high adoption rate of improved varieties (95%) making it a promising target for dissemination of new technologies. In the dry areas, losses are relatively high (20%), but its low yields reduce potential benefits. For open pollinated varieties (OPV), however, these benefits would be distributed fairly evenly over the populations of these marginal areas, making a significant difference to their food security.

### *Crop loss by species and zone*

It is important to assign maize losses to different species of stemborers, because *Bt* genes can be very specific. A complex of five stem borer species cause damage to maize in Kenya; *B. fusca*, *C. partellus*, *S. calamistis*, *C. orichalcociliellus* and *E. saccharina*, and their geographic distributions defined (Zhou et al. 2001). These geo-referenced data were superposed on the agroecological zones map, and average distributions were calculated for each zone (Table 3), showing a clear pattern. Two species account for 85% of all stem borers found in any of the zones: *B. fusca* and *C. partellus*. *C. partellus* accounts for more than 90% of borers in the lowland and mid-altitude areas, but is almost absent in the high potential areas (transitional zone and highlands), *B. fusca* shows the opposite pattern, and is dominant in the high potential transitional and highland areas. The other three borers are of less importance, with *C. orichalcociliellus* restricted to the lowland coastal area, *S. calamistis*



widely distributed, but at low densities, and *E. saccharina* found at low densities in western Kenya near Lake Victoria. (Zhou et al. 2001). .

Assuming crop damage due to stem borers can be attributed to the different species proportionate to their frequency; we can attribute the crop losses over the different species by combining Table 2 and Figure 1. The results (Table 3) show that only four stem borer species cause crop losses higher than 10% in at least one region, and only two species are of major economic importance: *B. fusca* (82% of all stem borer losses in Kenya) and *C. partellus* (16%). Multiplying the numbers from Table 2 with the total value of crop losses in Kenya (\$80 million) results in the estimation of economic losses due to different stem borers in different zones (Figure 3). These results have immediate implications for *ex ante* impact assessment. The highest benefits can be expected from developing varieties resistant to *B. fusca* for the moist transitional and highland tropics (\$ 27 and \$21 million in yearly losses respectively), followed by varieties resistant to *C. partellus* for the moist transitional (\$10 m), the dry areas (\$8 m) and the moist mid-altitude (\$5 m). Except for the highlands and the lowlands, developing combined resistance to both species is indicated.

The IRMA project has already imported different *Bt* genes into Kenya, in the form of cut leaves from transformed maize inbred lines. Seven *Bt* gene events were tested on 5 different species using insect bioassays. Cross combinations of the *Bt* gene events were also introduced and tested against Kenya stem borers.. Several cry proteins (different toxins produced by different *Bt* genes) were found to be very effective against *C. partellus* and the other stem borers. Unfortunatley, no Cry genes was completely effective against *B. fusca*. Cross combinations were more effective than straight events but asstill fell short of complete control.

### *Impact Assessment*

Factors other than crop loss will determine the eventual impact of Bt maize, in particular the likelihood of finding a *Bt* gene effective against *B. fusca*, and the adoption rate of the Bt maize varieties. From Hassan (1998) we know the adoption rate of new maize varieties for the different areas, which vary from 40 to 95% (Table 4). We can now consider two scenario's. First, assume the new *Bt* maize varieties are efficient against all stem borers, and two-thirds of farmers who previously adopted improved varieties will also adopt *Bt* maize varieties. Under this scenario, production will increase by 0.25 million ton (+9.4%), a value of US\$ 48 million. If, however, no resistance against *B. fusca* is found, farmers in the high potential areas are unlikely to adopt the new varieties. In this scenario, production would only increase by 29,000 tons (+1.1%), valued at US\$ 5.4 million.

The shifts in the production function can now be incorporated in the conventional economic surplus model (Alston *et al.* 1998), using standard assumptions (supply elasticity =0.8, demand elasticity=-0.4, discount=10%, closed economy, adoption is linear and starts at 5 years). The principle behind this model is that when supply increases, prices and demand adjust, so that part of the benefits goes to the consumers. The costs of the project, which started in 1999, is US\$ 1 million per year, and is expected to last 10 years, at a total discounted cost of \$6.76 million ( $\sum_{i=0}^9 1(1+0.1)^{-i} = 6.76$ ) in 1999 dollars. In scenario, a full resistance to all stem borers, the yearly benefits reach \$49 million per year, of which two thirds go to the consumers (Table 5). Discounted benefits over 25 years reach \$ 208 million, compared to discounted costs of \$ 6.76 million. This produces a benefit/cost ratio of 31:1, and an internal rate of return (IRR) of 83%. In the second scenario, no resistance to *B. fusca*, yearly benefits only reach \$ 5 million. Total benefits over 25 years reach \$24 million, with a benefits/cost ratio of 3, and an IRR of 30%.

### *Other impacts of the Project*

Although not the main focus of this paper, other impacts of the project should be considered.

First, the Bt genes will be incorporated into germplasm with some level of conventional resistance, an important factor in pyramiding factors of resistance and therefore make it difficult for stem borers to develop resistance against Bt toxins. The BT maize varieties will also be in genetic backgrounds with tolerance to major abiotic stresses such as drought and low-Nitrogen and resistance to common leaf diseases such as the maize streak virus disease. Second, it is important to assess the environmental impact of Bt maize, as well as to develop appropriate insect resistance management techniques. These activities are being developed by a team of CIMMYT and KARI entomologists. Further, the project has already had a tremendous impact on Kenya's capacity to conduct research with GM crops. Many scientists and technicians were trained in biotechnology, and information and guidance was provided to help the National Biosafety Committee deal with this new technology. Infrastructure was also provided to execute the research. On top of regular equipment such as cars and computers, biosafety laboratories, greenhouses, and a quarantine station were provided. The project is likely to have a spillover effect as Kenya gains experience in GM technology.

### **Conclusions**

If the IRMA project manages to identify a Bt gene that is effective against *B. fusca*, adoption rates are likely to be high. Economic analysis shows that the returns are likely to be very high: under standard assumptions, the economic surplus is calculated at \$208 million over 25 years, compared to a cost of \$6.76 million. In this case, the project should concentrate first on the moist-transitional zone, where adoption and impact is expected to be highest, and where a good competition of different seed companies can assure rapid dissemination. Most

of the benefits go to the maize consumers and, since poor families have higher food expenses, the project could make a substantial impact in poverty reduction.

If no gene for *B. fusca* is found, however, adoption rates would be low, and the benefit/cost ratio would be much lower than the scenario above. The project would also become more susceptible to criticism in the prevailing socio-political environment. Moreover, in this scenario the project should only consider incorporating *Bt* into maize varieties adapted to low potential areas. Unfortunately, not many seed companies are interested in these areas, so extra attention will be required for effective dissemination. On the other hand, poverty is higher in the low potential areas, so the poor would be relatively better helped.

In the future, the present model will be extended to calculate economic surplus for different scenarios for different zones, so that more precise policy and strategy advice can be offered. It is also essential to continue and complete the on-going ecological assessment of *Bt* maize, and make the results widely available to scientists, policy-makers and the public, so that informed decisions on the deployment of this new technology can be made.

Finally, we hope that the information and analysis of this paper helps to reduce tensions in the overheated debate, by offering objective calculations of the economic costs and benefits of this GM crop.

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Table 1. Agroecological zones and food security in Kenya

Zone	Area (1992) <sup>a</sup>		Production (1992) <sup>a</sup>		Population (1999) <sup>b</sup>	Maize production (1998) <sup>c</sup>		
	1000 ha	%	1000 ton	%	1000 %	1000 ton	kg/person	
Lowland Tropics	41	3	53	2	1,987	7	28	14
Dry Midaltitude	166	15	162	6	2,342	8	87	37
Dry-Transitional	66	11	76	3	1,304	5	38	29
Moist-transitional	466	23	1,234	46	7,537	26	1,024	136
Highlands	316	6	909	34	3,812	13	403	106
Moist Midaltitude	173	22	231	9	3,018	11	210	70
< 0.5% maize					5,942	21	210	35
Other					2,637	9	423	160
<b>Total</b>	<b>1,244</b>	<b>100</b>	<b>2,671</b>	<b>100</b>	<b>28,579</b>	<b>100</b>	<b>2,424</b>	<b>85</b>

<sup>a</sup>Hassan (1998), <sup>b</sup>Central Bureau of Statistics (2001), <sup>c</sup> Ministry of Agriculture (unpublished data)

**Table 2. Crop loss assessment in maize from stem borers, extrapolated from field data from the long rains (LR) and short rains (SR) of 2000 and 2001.**

	Production <sup>a</sup> (1000 tons)			losses (%)			Losses (\$ million)		
	LR	SR	Total	LR	SR	Total	LR	SR	Total
Lowland Tropics	45	8	53	9	6.1	8.5	0.9	0.1	1.0
Dry Mid-altitude	122	40	162	17	8.4	15	4.8	0.7	5.5
Dry-Transitional	45	32	76	26	8.4	19.8	3.1	0.6	3.6
Moist Mid-altitude	170	62	231	13.1	5.6	11.3	4.9	0.7	5.7
Moist-transitional	1170	64	1234	16.6	16.6	16.6	44.9	2.5	47.4
Highlands	893	16	909	9	9	9	17.0	0.3	17.4
<b>Total</b>	<b>2,395</b>	<b>276</b>	<b>2671</b>	<b>14.1</b>	<b>8.4</b>	<b>13.5</b>	<b>75.9</b>	<b>4.9</b>	<b>80.5</b>

<sup>a</sup>Hassan (1998), <sup>b</sup>De Groote et al. (2002), <sup>c</sup> estimated at \$193/ton



Table 3. Distribution of total crop losses over different species and zones

Agroecological zone	<i>Chilo partellus</i>	<i>Busseola fusca</i>	<i>Sesamia calamistis</i>	<i>Eldana sacharrinna</i>	<i>Chilo orichalcilielus</i>	Total
Highlands	0.0%	24.9%	1.3%	0.0%	0.0%	26.2%
Moist-transitional	12.3%	31.7%	2.7%	0.5%	0.0%	47.3%
Moist Mid-altitude	5.9%	4.4%	0.7%	0.2%	0.0%	11.2%
Dry Mid-altitude and transitional	9.8%	1.8%	1.8%	0.0%	0.0%	13.4%
Lowland Tropics	1.4%	0.0%	0.1%	0.0%	0.4%	1.9%
Total	16.5%	81.8%	0.1%	0.0%	1.7%	100.0%

Source: overlapping maize agroecological zones (Hassan, 1998) with georeferenced data from the International Centre of Insect Physiology and Ecology.

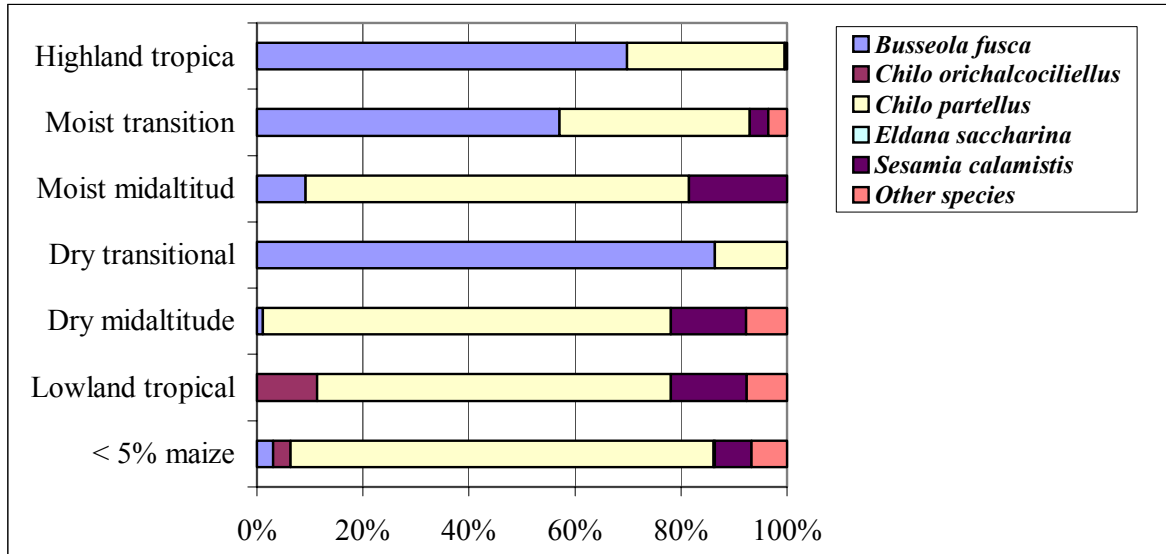
Table 4. Impact Assessment –Annual potential gain

	production (1000 ton)	Crop loss (1000 ton)	B. fusca Adoption (%)					Potential gain (\$ m)		Potential gain (tons)	
			value (\$)	%	Improved maize vars	Scenario A (Bt maize, full resistance)	Scenario B Bt maize (no <i>B. fusca</i> resistance)	Scenario A	Scenario B	Scenario A	Scenario B
Lowland Tropics	53	5	1	0.0	40	26.4	26.4	0.3	0.3	1.30	1.30
Dry Mid-altitude	162	29	6	1.1	65	42.9	42.9	2.4	2.3	12.26	12.26
Dry-Transitional	76	19	4	86.4	75	49.5	0	1.8	0.0	9.29	0
Moist Mid- altitude	231	29	6	9.2	90	59.4	59.4	3.4	3.4	17.48	17.48
Moist-transitional	1234	246	47	57.0	95	62.7	0	29.7	0.0	154.00	0
Highlands	909	90	17	69.5	95	62.7	0	10.8	0.0	56.37	0
Total	2671	417	80					48.3	5.96	250.70	31.04

Table 5. Impact assessment - Economic Surplus Model

Scenario	period	discount rate	Elasticities		Economic surplus (benefits)			Costs (discounted)	Benefit/costreturn ratio	Internal Rate of (IIR)
			supply	demand	producer	consumer	total			
A	1 year	10	0.8	-0.4	16.3	32.7	49	6.76	31	83
	25 years	10	0.8	-0.4	69.5	139	208.5			
B	1 year	10	0.8	-0.4	1.9	3.8	5.7	6.76	3.6	30
	25 years	10	0.8	-0.4	8.1	16.1	24.2			

**Figure 1. Distribution of different stem borer species by agroecological zone in Kenya**



**Figure 2. Crop losses due to different stem borers by agroecological zone.**

