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Full Length Research Paper

Assessing the potential economic impact of *Bacillus thuringiensis* (Bt) maize in Kenya

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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 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.

Key words: Maize, genetically modified crops, *Bacillus thuringiensis*, adoption, economic impact.

INTRODUCTION

Application of biotechnology, in particular genetically modified (GM) (Fan et al., 2007) crops, is still hotly debated. The technology has proven remarkably effective and has been very successful; first introduced in 1996, the area under transgenic crops increased from 1.7 million ha to 114.3 million ha in 2008 (James, 2008). While a larger proportion (57%) of the area is situated in developing countries, the large majority of farmers (90%) are located in developing countries. The Food and Agriculture Organization (FAO) review, citing several other reviews, concluded that the technology has high potential and that currently available transgenic crops and their derived foods have been judged safe for human and livestock consumption (FAO, 2004). Although scientists differ in their views on the potential risk to the environment, they agree that these risks should be assessed on a case-by-case basis and recommend post-release ecological monitoring to quantify environmental impacts (FAO, 2004).

Still, genetically modified crops have generally not been well received in Europe, mostly because of consumers' concerns about possible harm to human health,

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Abbreviations: GM, Genetically modified; **NGOs,** Non-Governmental Organizations; **IRMA,** Insect Resistant Maize For Africa; **CIMMYT,** International Maize and Wheat Improvement Centre; **KARI,** Kenya Agricultural Research Institute; ***S,*** supply; ***P,*** price; ***D,*** demand; ***P^**,** equilibrium price; ***Q^**,** equilibrium quantity; **DREAM,** distributed real-time embedded analysis method; **IFPRI,** International Food Policy Research Institute; **LT,** lowland tropics; **DM,** dry mid-altitudes; **DT,** dry transitional; **HT,** highland tropics; **MT,** moist transitional; **OPV,** open pollinated varieties; **IRR,** internal rate of return.

damage to the environment and uneasiness about the ‘unnatural’ status of the technology (Nuffield Council on Bioethics, 1999). Moreover, Europe already has surplus production, so yield enhancing technologies are not a priority and a strong farmers’ lobby would rather protect its markets from external competition. In addition, the expected benefits from the innovation to the European consumers are also small (Demont et al., 2004). Finally, Europe has accepted the precautionary principle (which is also included into the Cartagena protocol): where the possibility of harmful effects on human health is identified but scientific uncertainty persists, provisional risk management measures are necessary to ensure the desired high level of health protection adopted (McMahon, 2003). By 2007, eight European countries grew GM crops, although the area is limited to 100,000 less for each country. Moreover, the only crop is maize and no other GM food crops have so far been allowed (James, 2008).

Developing countries face a difficult choice. If Europe and North America cannot agree, with all the science and policy analysts available, how can African countries make a rational decision? Africa, where per capital food production is not keeping pace with population growth and millions facing serious food shortages, might not have the luxury of rejecting GM crops. All new technologies have potential risks, and it is up to African farmers, consumers and policy makers to weigh the risks against the benefits (Pinstrup-Andersen and Schøler, 2002).

The cultural turn against agricultural science among affluent societies, especially in Europe, is often adopted by African elites who have strong ties with them, which has led to the development of often stringent regulatory systems (Paarlberg, 2008). Supported by non-governmental organizations (NGOs), donors and international organizations, African countries are developing regulatory legislation reflecting the European legislation and the cautionary principle rather than the United States (US) system. As a result, it has been argued, Africa is denied the biotechnology it desperately needs to develop its agriculture and meet the demands of its rapidly growing population (Paarlberg, 2008).

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 assessment on both the economic and environmental impact.

Economic impact assessment of genetically modified crops

The first commercial GM varieties were planted in 1996 and by 2009, they covered 134 million ha, the fastest adoption of any crop technology ever (James, 2010). The technology is used on all continents, although six countries in the Americas and Asia grow 95% of the global area. Europe only grows GM crops on a small area, and Japan not at all.

The major GM crops are soybean (52% of GM area), maize (31%), cotton (12%) and canola (5%). Worldwide, three quarters of soybean area are now planted in GM varieties, half of the cotton area and a quarter of the maize. The two major traits are herbicide resistance and insect resistance. Herbicide resistance is the most important trait; crops with this single trait cover 62% of all GM area, mostly in the same four crops. Insect resistance as a single trait covers 15%, while the combination (double or triple traits) covers 21% of GM global area. While slightly more than half of the area in GM crops is found in developing countries, most of the 14 million farmers (90%) are small and resource-poor farmers in developing countries, mostly Bt cotton (7 million in China and 5.6 million in India). While no commercial GM rice has been planted, China approved Bt rice in 2009, and golden rice, biofortified with provitamin A maize, has been developed (James, 2010).

The major advantages of GM crops are grain yield increases and cost reduction through better pest control (Brookes and Barfoot, 2010). On-farm field trials carried out with Bt cotton in different states of India showed that the technology substantially reduces pest damage and contributes towards increases in grain yields (Qaim and Zilberman, 2003). In developing countries, the yield gains from pest-resistant varieties can be much higher than in other countries where GM crops are used mostly to replace and enhance chemical pest control (Qaim and Zilberman, 2003). GM crops may contribute towards reduced negative health effects of chemicals when they replace them (Zilberman et al., 2007), and allow widespread use of conservation agriculture (Brookes and Barfoot, 2010).

In 2006, the direct farm income benefit from GM crop was estimated at $9.4 billion (Brookes and Barfoot, 2010). This is equivalent to having added between 3.6% to the value of global production of the four main GM crops. From 1996 to 2006, it is estimated that farm global incomes have benefited by $30.3 billion (Brookes and Barfoot, 2010). Given a conducive institutional framework, GM crops can contribute significantly to global food security and poverty reduction (Qaim, 2009).

In Africa, the first GM crop was Bt cotton, introduced in 1997 in South Africa. In 2009, South Africa planted 2.1 million ha in GM crops, including maize, soybean and cotton. Kenya already experimented with virus resistant sweet potatoes in the early 1990s (Qaim, 2001), but the trait did not provide adequate control. Egypt tested with GM potatoes but ended the research fearing for its export markets (Paarlberg, 2006). Only in 2008, two more countries introduced commercial GM crops in Africa: Egypt with Bt maize and Burkina Faso with Bt cotton (James, 2010). Field trials with GM bananas are currently under way in Uganda (Dauwers, 2007).

While most of the world has now embraced GM crops, Europe and Japan are holding back. Europe already has a large agricultural surplus, and consumers' often hold negative perceptions towards the technology (Knight et al., 2008), so the European Union (EU) has adopted the precautionary principle, which imposes heavy regulatory barriers towards release of GM crops. Africa has been lagging in the development of its regulatory system, due to lack of human skills, facilities and resources. Currently, many countries are developing regulatory systems, largely following the European line. This development reflects more the cultural bias of the African political elite than a careful calibration of potential benefits versus their risks (Paarlberg, 2008). Regulatory delays in the release of new technologies can be very expensive (Kikulwe et al., 2008). Proper economic analysis of potential benefits of GM crops, together with a careful assessment of its environmental and other potential risks, is therefore most important.

The insect resistant maize for Africa (IRMA) project

The Insect Resistant Maize for Africa (IRMA) project, a collaborative effort between the International Maize and Wheat Improvement Centre (CIMMYT) and the Kenya Agricultural Research Institute (KARI), has been developing genetically modified maize varieties by incorporating modified genes with constitutive expression derived from the soil dwelling bacteria *B. thuringiensis* (Bt) (Mugo et al., 2005). The Bt genes code for crystal δ-endotoxins that control lepidopteran stem borer pest species of crops (for example, Bt rice, Bt cotton and Bt maize). So far, cut leaf tissue from maize transformed with different Bt events and genes were introduced in Kenya following stipulated 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 spotted stem borer (*C. 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 (*B. fusca*), which is mainly found in the highland ecologies.

At the same time, 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 to estimate the potential impact of Bt maize in Kenya. The specific model combines the economic surplus model with an interdisciplinary approach and the use of geo-referenced data.

MATERIALS AND METHODS

The economic surplus model

In an open market, supply *S* increases with price *P* while demand *D* decrease. The changes of supply and demand in function of price are called price elasticities, expressed as a percentage change of quantity relative to a percen-tage change in price, either demand price elasticity ($\varepsilon_d = e_d\ P/D$) or supply elasticity ($\varepsilon_s = e_s\ P/S$). If we assume for simplicity that these relationships are linear, these functions can be represented mathematically by:

$$\begin{cases} S = a_s + e_s P \\ D = a_d + e_d P \end{cases} \qquad (1)$$

Reversely, the price changes in function of the demand or supply, and above set of equations can equally represented by:

$$\begin{cases} P = -\frac{a_s}{e_p} + \frac{1}{e_p} S \\ P = -\frac{a_d}{e_d} + \frac{1}{e_d} D \end{cases} \qquad (2)$$

This is the conventional way of presenting the demand and supply equations, and the equilibrium is found where the two lines cross, at point *B* with equilibrium price P^* and equilibrium quantity Q^* (Figure 1).

In an open market economy, all consumers pay the same equilibrium price P^* and all producers receive that same price, regardless of their willingness to pay or sell. This generates an economic surplus. The first eager producer would have been willing to sell the first unit of the product at P_1, the intercept of the supply curve (Figure 2), but receives P^*, surplus of P^*- P_1. Similarly, the first eager consumer would have been willing to pay P_2 for the first unit, but only pays P^*, a surplus of P_2- P^*. Adding up these surpluses for the producers, from the first unit to the equilibrium quantity, results in the producer surplus, and is equal to the area of the red triangle $P_1 P^* Q^*$. In a similar fashion, consumer surplus can be calculated by the area of the yellow triangle $P^* P_2 Q^*$.

When a new technology is introduced in the economy, which allows the production of a higher quantity, say an amount of *J*, at the same cost, producers can offer that extra amount at the same price. This causes the supply function (*S*) to shift to the right (*S'*), and a new equilibrium forms at B' (Figure 2). Note that the increase in quantity produced ($Q^{*'}$ - Q^*) is less than *J* since a higher production also reduces the price, which again reduces the supply. The change in economic surplus can be measured by the change in the triangle area, from the triangle $P_1 P_2 B$ to the triangle $P_1' P_2 B$, a change captured by the trapezium $P_1' P_1 B B'$ in Figure 2.

It is more convenient, however, to split the change in economic surplus over producer and consumer surplus. The change in consumer surplus is captured by the change from the original consumer surplus, the triangle $P^* P_2 Q$ to the new consumer surplus, the triangle $P^{*'} P_2 B'$, a change captured by the orange area in Figure 2. Similarly, the change in producer surplus is found by the diffe-

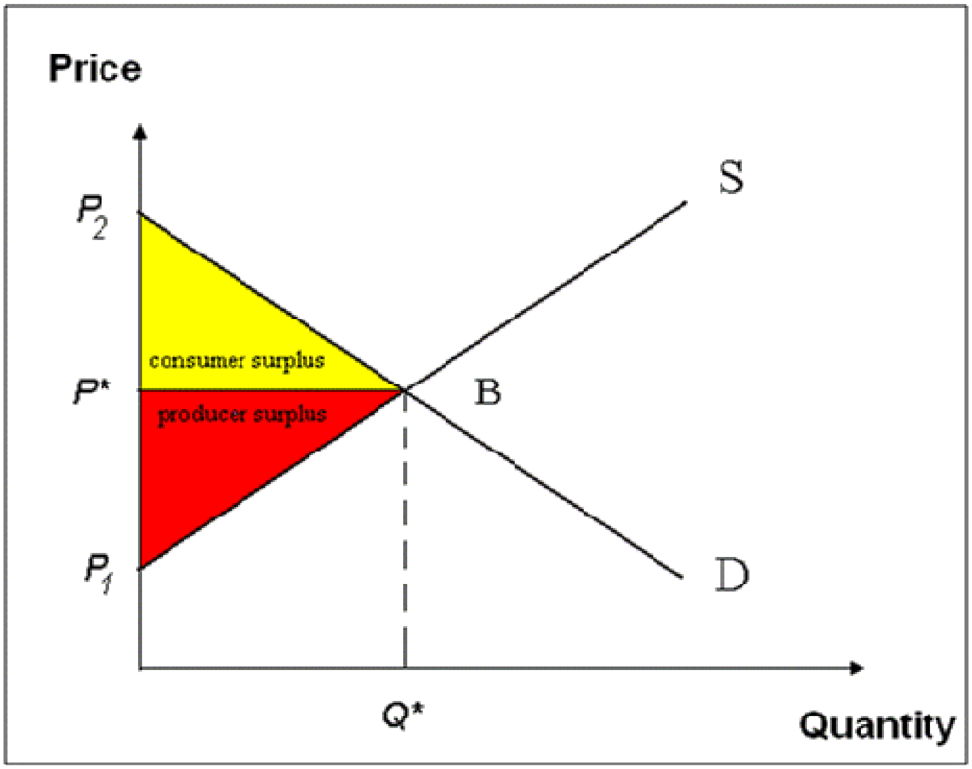

Figure 1. Economic equilibrium and economic surplus.

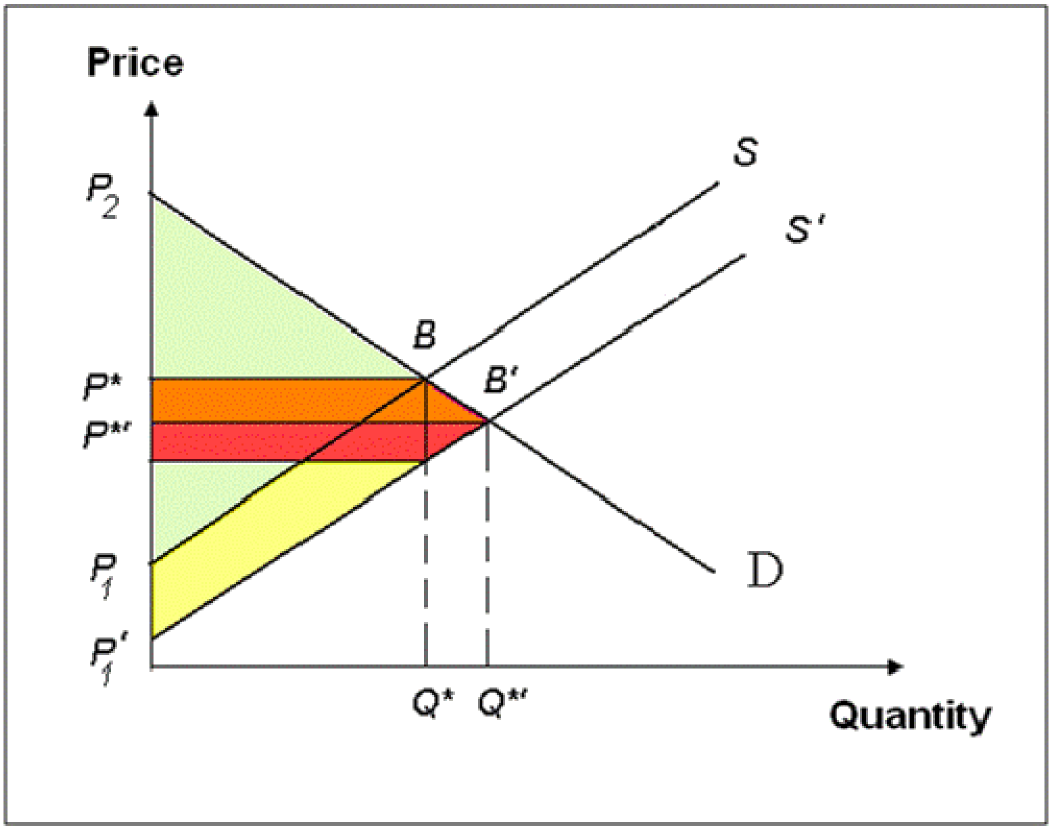

Figure 2. Shift in the supply function causing a change in economic surplus.

rence between the new producer surplus $P_1{}' P^{*'} B'$ and the original producer surplus $P_1{}' P^{*'} B'$, a change graphically represented by the red area in Figure 2.

Without going through the mathematical details, it is clear that if the initial P and Q are known, as well as the supply and demand elasticities to calculate the slopes, the change in producer and consumer surplus can be calculated from the red and orange areas in Figure 2. While the exact formulas can be found in the literature (Alston et al., 1998; Masters et al., 1998), it is more convenient to use the special software, Distributed Real-time Embedded Analysis Method (DREAM), developed by the International Food Policy Research Institute (IFPRI), which was also used for this paper.

Estimating the parameters of the model

The parameters of the economic surplus model include production and price statistics, which were derived from secondary data, and include, maize production in the six agro-ecological maize production zones, the effectiveness of different Bt genes, population data, adoption levels of improved maize varieties, and maize prices. An overview of these data and references for their sources are presented in the following background section.

For Kenya, we assume supply elasticity equal to 0.8 and demand elasticity of -0.4, based on previous quantitative work (Bezuneh et al., 1988; Jayne et al., 1995; Kiori and Gitu, 1991). We use a discount equal to 10% and assume a small closed economy. Further, we assume the adoption is linear and starts after 5 years of developing the technology. The average maize price over the five years preceding this analysis was estimated at $193/ton.

Crop loss assessment

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, trials were set up in selected locations, details of which are presented elsewhere (De Groote et al., 2004). In each of the six maize growing agroecological zones, 4-5 villages were selected randomly (27 in total), and in each village, 5 farmers were randomly selected and one field from each farmer, which totals to 135 fields. In each selected field, two adjacent plots of 100 m^2 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 six-leaf stage. If necessary, the treatment was repeated in the protected plot later in the season. Otherwise, there was no interference with farmers' normal prac-tices. Yields were measured in both the short and long and short rainy season of 2000, and the long rainy season of 2001, 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).

Distribution of stem borer species in Kenya

The distribution of different stem borer species was calculated using data from the International Centre of Insect Physiology and Ecology (ICIPE) collected between 1996 and 2000 (Overholt, 1999; Zhou et al., 2001; Zhou et al., 2003). A total of 269 maize fields spread out over the different maize productions zone through the southern arable part of Kenya were sampled (Table 1). Fields were sampled on 392 occasions in the long and short rainy seasons, so several fields were sampled more than once. In each field on each sampling occasion, 20 plants were randomly selected, excised at ground level and split along the length. All stem borers found in the plants were identified to species level.

Maize and stem borers in Kenya

Maize production

Maize is the most important food crop in Kenya, which produces on average, 2.4 million tons of maize per year (Hassan et al., 1998c). Production is, however, unevenly distributed over the country. A study by CIMMYT and KARI defined six major agroecological zones for maize production in Kenya (Hassan et al., 1998b). 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 (Figure 3). 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 2). 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 are characterized by high yields (more than 2.5 t/ha) and produce 80% of the maize in Kenya on 30% of the area (Table 2). Finally, around Lake Victoria, we find 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 diversity of Kenya's geography has also brought a very uneven distribution of the population. By superposing the population census data on the agro-ecological map, each division can be assigned, with its population, to a particular zone. Similarly, maize production data in 1998 from the Ministry of Agriculture were linked to the population map, and combining these with the population census of 1999 (CBS, 2001), the food security situation in each zone can be assessed (Table 2).

The average maize food consumption in Kenya is estimated at 94 kg/person (Pingali, 2001). The average maize production per person is, however, only 80 kg per capita. Only the high potential zones (MT and HL), have a surplus, with a higher per capita production than the average consumption. 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

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 or farmers' assessment of loss in a representative way or over a large geographic area. During a survey in 1992, farmers were asked to estimate the extent of the stem borer problem, and the damage they cause (Hassan et al., 1998a). Extrapolating from the survey results, an aggregate crop loss of 12.9% was obtained (De Groote, 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.

RESULTS AND DISCUSSION

Crop loss measurement

To verify farmers' estimates, crop losses were assessed

Table 1. Number of sites and plants sampled for stemborers, by agroecological zone adapted to the maize agroecological zone from Overholt (1999), Zhou et al. (2001), Zhou et al. (2003).

Zone	No. of sites	No. of plants/site sampled	Year and season
Lowland tropical	75	56	98 LR, 99 LR, 99 SR
Dry midaltitude	30	56	98 LR, 99 LR, 99 SR
Dry transitional	1	20	99 LR, 99 LR, 99 SR
Moist transitional	12	21	99 LR, 99 SR, 2000 LR
Highland tropics	8	23	99 LR, 99 SR, 2000 LR
Moist midaltitude	8	22	96 LR, 99 SR, 2000 LR
Total	134	198	

Table 2. Agro ecological zones and food security in Kenya.

Zone	Area (1992) [a]		Production (1992) [a]		Population (1999) [b]		Maize production (1998) [c]	
	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
Total	1,244	100	2,671	100	28,579	100	2,424	85

Source: [a]Hassan (1998); [b]Central Bureau of Statistics (2001); [c] Ministry of Agriculture (unpublished data).

Table 3. 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.

Zone	Production[a] (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
Total	2,395	276	2671	14.1	8.4	13.5	75.9	4.9	80.5

Source: [a] Hassan (1998) ; [b]De Groote et al. (2002); [c] estimated at $193/ton.

directly in farmers' fields, in a representative sample of all regions. Crop losses were thus estimated at 13.5%, with a value of $80 million (Table 3), very close to the farmers' estimates. Crop losses range from 9% in the highlands to 20% in the dry transitional zone. The distribution of the value of the losses over the regions is quite revealing. Almost half of the losses (US$ 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 agroecological zone

Since Bt genes can be very specific, it is important to assign maize losses to different species of stem borers.

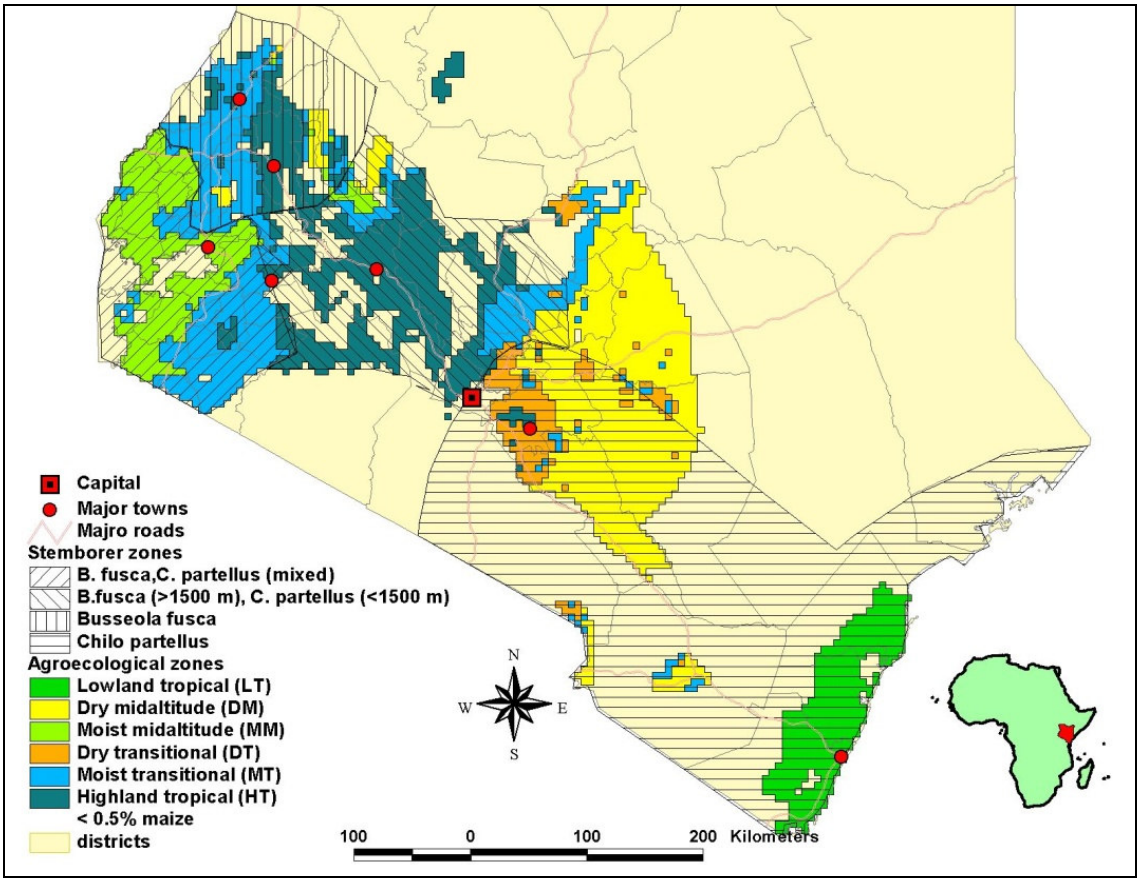

Figure 3. Maize agroecological zones and stemborer distribution.

In Kenya, a complex of five stem borer species that cause damage to maize *(B. fusca, C. partellus, S. calamistis, C. orichalcociliellus* and *E. saccharina)* have been identified , and the geographic distribution of these species determined (Zhou et al., 2001). These geo-referenced data were superimposed on the map of the agroecological zones, and average distributions were calculated for each zone (Figure 4). A clear pattern emerges: two species, *B. fusca* and *C. partellus*, account for 85% of all stem borers found in any of the zones. *C. partellus* accounts for more than 60% of borers in the lowland and mid-altitude areas, but is almost absent in the high potential areas (transitional zone and highlands). *B. fusca,* on the other hand, shows the opposite pattern, and is dominant in the high potential transitional and highland areas. The other three borers are less important, with *C. orichalcociliellus* restricted to the lowland coastal area, while *S. calamistis* is widely distributed but at low densities, and *E. saccharina* is found at low densities in western Kenya near Lake Victoria (Zhou et al., 2001).

Assuming crop damage due to stem borers of different species is proportionate to their frequency, crop losses can be attributed to the different species by combining Table 3 and Figure 3. The results show that four stem borer species cause crop losses higher than 10% in at least one region, but 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 3 (proportion of crop loss by zone and species) 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 5).

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.

Efficiency of the Bt technology

In the beginning of the project, IRMA scientists imported different Bt genes from Mexico into Kenya, in the form of cut leaves from transformed maize inbred lines (Mugo et

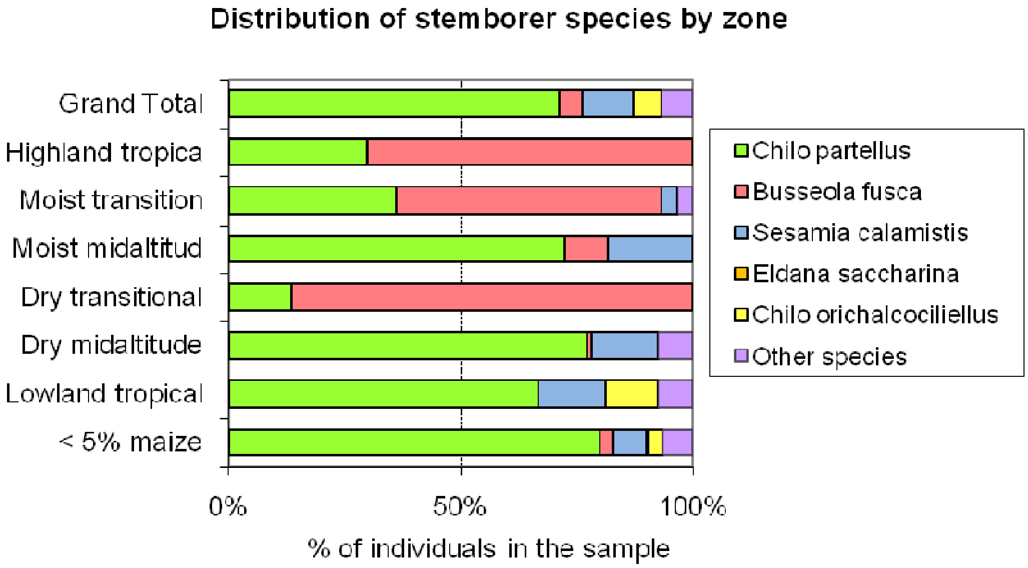

Figure 4. Distribution of different stem borer species by agroecological zone in Kenya. Source: overlapping maize agroecological zones (Hassan, 1998) with georeferenced data from the International centre of Insect physiology and ecology.

al., 2005). Seven Bt gene events were tested on 5 different species using insect bioassays (Mugo et al., 2004). 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, but unfortunately, no Cry genes was completely effective against *B. fusca*. Cross combinations were found to be more effective than straight events but still fell short of complete control.

In a second trial, maize plants with Bt genes, Cry1Ab and Cry1Ba, were infested with *C. partellus* and *B. fusca* and evaluated in the biosafety greenhouse of KARI in Nairobi. Both Bt Cry proteins expressed in maize leaves controlled *C. partellus* but neither toxin provided complete control of *B. fusca* (Tende et al., 2010). Partial control is not acceptable in stemborer control by Bt genes, since stemborers would be likely to develop resistance to the toxins quickly.

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. Adoption rates of improved maize varieties vary from 40 to 95% (Hassan et al., 1998a) (Table 4). We can now consider two scenarios. 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 equal to 0.8, demand elasticity equal to -0.4, discount equal to 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 this 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

Table 4. Impact assessment – annual potential gain.

Impact	Production (1000 ton)	Crop loss			Adoption (%)			Potential gain ($ m)		Potential gain (tons)	
		(1000 ton)	Value ($)	B. *fusca* (%)	Improved maize vars (%)	*Bt* maize (Scenario A, full resistance)	Bt maize (Scenario B, no *B. fusca* 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 (years)	Discount rate	Elasticities		Economic surplus (benefits)			Costs	B/C	IIR
			Supply	Demand	Producer	Consumer	Total	(discounted)		
A	1	10	0.8	-0.4	16.3	32.7	49			
	25	10	0.8	-0.4	69.5	139	208.5	6.76	31	83
B	1	10	0.8	-0.4	1.9	3.8	5.7			
	25	10	0.8	-0.4	8.1	16.1	24.2	6.76	3.6	30

B/C, Benefit/cost ratio; IIR, internal rate of return.

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 back-grounds 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 Insect Resistant Maize for Africa project succeeds in identifying 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

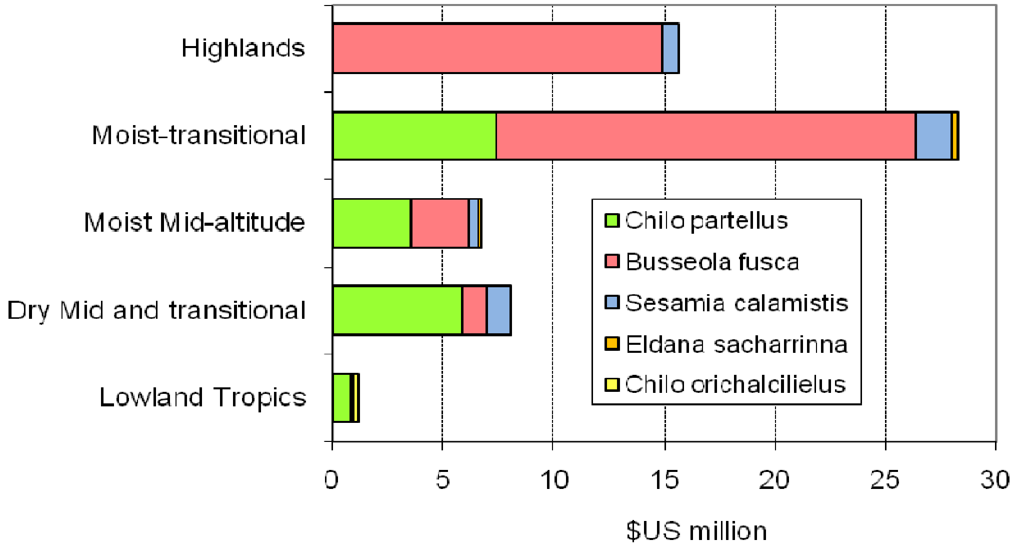

Figure 5. Value of crop losses due to different stemborers by agroecological zone.

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, 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 scenario's 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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