Economic Welfare Change Attributable to Biological Control of Lepidopteran Cereal Stemborer Pests in East and Southern Africa: Cases of Maize and Sorghum in Kenya, Mozambique and Zambia

Soul-kifouly Midingoyi [a,b], Affognon Hippolyte [a], Ong'amo Georges [a,d] and LeRu Bruno [a,e]*

[a]International Centre of Insect Physiology and Ecology (icipe), PO Box 30772-00100, Nairobi, Kenya; [b]Department of Agribusiness Management & Trade, Kenyatta University, Nairobi – Kenya; [d]School of Biological Sciences, University of Nairobi, Nairobi – Kenya; [e]Institut de Recherche pour le Developpement, France

[*]Corresponding author: Email: smidingoyi@icipe.org or zoulkm2000@yahoo.fr

Abstract

This study adopted the economic surplus model to evaluate the impact of the biological control program (BC), implemented by the International Centre of Insect Physiology and Ecology (icipe), on cereal crops production in Kenya, Mozambique and Zambia. The BC was implemented in East and Southern Africa between 1993 and 2008, with the aim of helping small scale farmers to reduce cereal yield losses due to stem-borers and improve their well-being. Findings show that BC-intervention substantially contributes to consumer and producer welfare in the three countries. The net present value of $US 271.76 million, the attractive Internal Rate of Return of 67%, as well as the estimated Benefit Cost Ratio of 33.47, imply the efficiency of investment in BC-program. Moreover, 0.35%, 0.25% and 0.20% of poor are yearly lifted out of poverty respectively in Kenya, Mozambique and Zambia. These findings underscore the need for increased investment in BC in the sub-region.

***Keywords**: Biological Control, Stemborers, Economic Surplus Model, Kenya, Mozambique, Zambia*

1. Introduction

In Eastern and Southern Africa, cereals, especially maize [*Zea mays* L.] and sorghum [*Sorghum bicolor* (L.)], are among the most important and widely grown field crops by commercial and small-scale farmers. Their production is, however, constrained by biotic and abiotic problems. Abiotic constraints included among others, climate change, soil fertility and low input use due to limited capital endowment. Among biotic constraints, insect pests represent an important challenge and lepidopteran stemborers are by far the major injurious pests that occur when maize and sorghum are cultivated (Omwega *et al.*, 2006, Kfir *et al.,* 2002; Polaszek, 1998; Kfir, 1998). Due to the economically important yield loss associated with stemborers infestation, many endogenous and introduced mitigation strategies have been developed and can be grouped in three categories: the Integrated Pest Management (IPM), chemical control and cultural control (Polaszek, 1998). Unfortunately, many recommendations on these strategies have not been adopted due to the constraints associated to their use that make them impracticable and unattractive to farmers (Van den berg and Nur, 1998).

The chemical control strategy is based on the use of synthetic insecticides to eliminate stemborers and then reduce the output losses. However, inconveniences are noted and include the resistance to insecticides, adverse effects on non-target species, hazards of insecticides residues, direct hazard from insecticides, non-guaranteed success in application, tendency in insecticides overusing and application of insecticides cocktails (Varela *et al.,* 2003; Van den berg and Nur, 1998). Moreover, even if insecticides are perceived to be important product against stemborers in commercial agriculture, the lower purchasing power due to the low-economic value of cereal crops seem to be a limiting factor and many resource-poor farmers cannot afford them. Considering these constraints and the potentially negative impact of chemical control on human health and environment, biological control is gaining attention. Classical biological control involves the introduction of an exotic natural enemy, such as predator and parasitoid, into a new environment where they did not formerly exist. Because of its self-perpetuating characteristic when definitely established and the no-requirement of recurrent additional investment, classical biological control remains an appropriate tool for pests control for resource-poor farmers (Hajek, 2004; Kipkoech, 2009).

As part of research program on the biological control, from the early 90s to date, the African Insect Science for Food and Health (icipe) made important progress in investigating on suitability and effectiveness of pests' control with numbers of natural enemies. *Icipe,* in partnership with National Agricultural Research Organisations (NAROs) and Universities, implemented biological control of stemborers through different projects[1] by releasing natural enemies in the major maize and sorghum producing area in East and Southern Africa. Following this introduction of natural enemies, post-release survey and a number of studies have been carried out, reporting establishment, acceptable level of parasitism, reduction of stemborer densities and reduction in yield losses (Omwega *et al.,* 2006; Odendo *et al.,* 2003, Emana *et al.,* 2001; Cugala and Omwega, 2001; Zhou *et al.,* 2001; Bonhof, 1997). The ultimate goal of research being the welfare improvement of poor population with little resource endowment, the direct effect of *icipe'* biological control of stemborers needs to be assessed in order to really appreciate its contributions to rural communities and general economy.

In this paper, we analyze the welfare effects of the release of natural enemies of maize and sorghum stemborers through different biological control programs initiated by *icipe* from the early 1990s to 2007. The objective of the study is to pinpoint the distribution of benefits among the economic agents in presence and, to appreciate the efficiency of investments in research on *icipe* implemented biological control programs in Kenya, Mozambique and Zambia.

2. Background on the biological control interventions

2.1 Biological control

The biological control can be defined as the deliberate use of living organisms (predators, parasitoids, nematodes, and pathogens) to maintain the population of a species (especially pests) at a lower density (Simmonds,1967; Debach and Rosen, 1991; Lazarovitz *et al.,* 2007) This type of control stems from natural ecosystem function principle by which populations of an organism

[1] Among these projects, we have "Biological control of insect pests in subsistence crops grown by small-scale farmers" within the period of 1993 to 1996, the aim was to minimize health risks, environmental pollution and damage to natural ecosystems through the development of a sustainable crop protection technology. Another project considered was "Biological control: a sustainable solution for smallholder maize and sorghum farmers in East and Southern Africa" that covered the period of 2002 to 2005. The objective here was the regulation of pest density through biological control implementation, capacity building and increasing awareness among farmers on biological control.

are regulated through the interaction of their lifecycle with another organism. This natural principle has then been applied to agriculture with the goal of effectively manage populations of beneficial organisms and their ability to reduce the pests' activities within environmental, legal and economic constraints (Lazarovitz *et al.,* 2007).

Using this principle, many pest management programs have been implemented in sub-Saharan Africa. Among the common examples were the control of the cabbage pest *Plutella xylostella* with the parasitoid *Diadegma semiclausum* on cabbage production in Kenya (Macharia *et al.,* 2005; Asfaw *et al.,* 2013), the use of *Cotesia flavipes* as an augmentative biological control agent for *Diatraea saccharilis* in rice production (Lv, 2010); the control of water hyacinth with the release of *Neochetina* species in Benin and East Africa (De Groote *et al.,* 2003), and the biological control of the cassava mealybug (*Phenacoccus manihoti*) using the control agent *Apoanagyrus (Epidinocarsis) lopezi* in 27 african countries (Zeddies *et al.,* 2001). In this study, we will consider the biological control as the use of parasitoids against stemborers with the expectation of significant reduction of pest population densities and abatement of damages to maize and sorghum crops.

2.2 Major targeted stemborer pests

Stemborers are insect pests that cause, during their larval stage, important physical and economical damages on cereal crops (Overholt *et al.,* 2001; Kfir *et al.,* 2002). Many studies revealed the presence and the high diversity of stemborer species in East and Southern Africa (Le Ru *et al.,* 2006; Moolman *et al.,* 2014) but the most economically important species are the crambid *Chilo partellus* (Swinhoe), and the noctuids *Busseola fusca* (Fuller) and *Sesamia calamistis* Hampson (Kfir *et al.,* 2002). The summary of their main characteristics is presented in table 1. Odendo *et al.* (2003) examined the economic value of loss due to stemborers and found the average loss in maize due to stemborer attacks to be at 14 %, ranging from 11% in the highlands to 21% in the dry areas. An extrapolation to the Kenyan national production in maize revealed that about 0.44 million tons valued at US$ 25-60 million and which is enough to feed 3.5 million[2] people per annum are lost.

[Table 1 about here]

[2] The per capita annual maize consumption is 125 kg

2.3 Released parasitoids of cereal stemborers

This study concerns the classical biological control as most of the released parasitoids are exotic. The exotic larval parasitoid *Cotesia flavipes* Cameron (Hymenoptera, Braconidae) has been imported from Asia in 1991 and released from 1993 in East and Southern Africa beginning by the coastal region of Kenya (Overholt *et al.,* 1994). The egg parasitoid *Telenomus isis* (Polaszek) (Hymenoptera, Scelionidae) is one of the most important stemborers' natural enemies found in West Africa (Schultess *et al.,* 2001; Bruce *et al.,* 2009) and introduced by *icipe* in East Africa in 2005. In addition to this last species released, the virulent strain of the indigenous larval parasitoid *Cotesia sesamiae* Cameron from Western Kenya has been introduced in Taita Hills in Kenya where it didn't formerly exist. But before this redistribution of *C. sesamiae*, the solitary pupal parasitoid *Xanthopimpla stemmator* Thunberg (Hymenoptera, Ichneumonidae) was released in the early 2000s in many East and Southern African countries including Mozambique and Zambia (Cugala, 2007). These four biological control agents are the focus of this economic evaluation which intends to appreciate the extent to which the biological control program contributes to the improvement of the community (consumer and producer) welfare.

2.4 Released points and establishment of the released bio-agents

Many ESA countries benefited from the *icipe* Biological Control (BC) program comprising Tanzania, Ethiopia, Zambia, Mozambique, Eritrea, Uganda and Kenya. The release sites of our study countries are depicted in figure 1. This figure presents the distribution of release sites in Kenya agricultural zone. In this country, bio-agents have been released in six provinces including the major cereal growing zones. The release species include *C. flavipes*, the first parasitoid released in 1993, *X. stemmator* in 2004, *T. isis* and *C. sesamiae* in 2007 released at Taita Taveta and Eldoret. In Mozambique, the first release has been realized at Maracuene and Moamba in 1996 with *C. flavipes*. The most recent release in this country is that of *X. stemmator* realized in 2003 and 2004. The majority of releases sites have been concentrated in Gaza and Maputo provinces. In Zambia, *C. flavipes* has first been released in Luangwa, Sinazongwe and Sesheke districts in 1999. It has been complemented by *X. stemmator* first released in 2004.

The establishment assessment is a pre-condition for any economic assessment as the effectiveness in yield reduction and contribution to revenues and food security is strongly conditioned by the effective presence and parasitism by the bio-agents. The presence and effective parasitism of the released parasitoid have been confirmed through many studies and surveys (Assefa *et al.,* 2008; Mailafiya, 2008; Moonga, 2007; Cugala, 2007; Omwega *et al.,* 2006; Getu *et al.,* 2003; Sallam *et al.,* 2000; Omwega *et al.,* 1997; Omwega *et al.,* 1995). However, during a recent sampling survey, the *T.isis* has been found just in the regions where it has been released and the *C.sesamiae* has not been recorded (Ongamo *et al. 2014*, unpublished data). The impact assessment will then mainly based on the other two species (*C. falvipes* and *X. stemmator*)

[Figure 1 about here]

2.5 Maize and sorghum areas and yields in Kenya, Mozambique and Zambia

The time-series data on maize and sorghum cropped area and yield for the three study countries were sourced from the FAO database (FAO, 2014) and compiled in graph forms (figure 2, figure 3, and figure 4) for the three countries. The situation of the two crops in Kenya the last three decades is depicted in figure 2. The total area under maize and sorghum generally depicted an increase with some fluctuations. The yield for both crops also depicted a fluctuation trends but remains globally stagnant for the three countries. The responsible factors for this stagnating trends in yield performance include climatic factors with poor rainfall (Smale *et al.,* 2011) declining soil fertility, lower adoption of best practices such as the use of hybrids and fertilizers (JAICAF, 2008) and the high prevalence of bird and pest damages (USAID, 2009; Denic *et al.,* 2001) and generally a lower uptake of new agricultural technologies (World Bank, 2006).

[Figure 2 about here]

[Figure 3 about here]

[Figure 4 about here]

3. Theoretical framework for economic welfare analysis

3.1 Economic surplus model

Since the introduction of the Economic Surplus Modeling (ESM) approach in agricultural technology impact assessment by Shultze (1953) and Grilitches (1958) and its improvement through applications by Akino et Hayami, (1975), Altson *et al.* (1995) and Zhao *et al.* (1997), there has been a growing interest in its application in agricultural research ex-post impact assessment. The ESM stems from partial equilibrium framework which is the most common approach for the evaluation of commodity-related technological progress in agriculture (Alston *et al.,* 1995; Norton and Davis, 1981). The economic surplus model consists in estimating the aggregate total monetary benefits for socio-economic agents entailed by the introduction of a research innovation of development intervention in a targeted social environment (Maredia *et al.,* 2014; Akino and Hayami, 1975). In other words, estimations through this model make it possible to appreciate the variation of consumer and producer surplus attributable to intervention.

The framework has been developed in the literature under many assumptions. In most of the East and Southern Africa countries, the locally produced maize and sorghum are commercialized within each country. Very small proportion of these crops is exported and this led to assume the close economy in the development of our framework. Under this assumption, and following the framework presented by Alston *et al.,* 1995, Maredia *et al.* 2000, Moore *et al.* (2000), Mensah et *al.* (2009) and assuming linear curves[3] of supply and demand, the determination of surplus change from the Biological Control (BC) intervention can be described as follows.

The maize or sorghum supply curve before the BC-intervention is given by: $q^s = \alpha + \beta p$ (1) where q^s is the initial quantity supplied, α the intercept of the supply curve, β the slope parameter of the supply curve and p the price level. The initial demand curve is given by: $q^d = \mu + \gamma p$ (2) where $\boldsymbol{q^d}$ represents the initial quantity demanded, μ the intercept of the demand curve and γ the slope of the demand curve. Following the economic theory, the initial market equilibrium is obtained by equating the total demand to the total supply equations, yielding the initial market equilibrium price p^* before the intervention:

$$\sum q^s = \sum q^d \iff p^* = (\mu - \alpha)/(\beta + \gamma) \qquad (3)$$

The BC intervention induces a parallel and downward shift of the supply curve giving a new supply curve $q_{BC}^s = \alpha + \beta(p + k) = (\alpha + \beta k) + \beta p$, where k stands for the shift factor treated as intercept change and q_{BC}^s represents the new quantity supplied with the intervention. New market equilibrium is derived from this technology-induced supply curve and the demand curve

[3] The question of which functional form of supply and demand curves is to be considered. Researchers assumed that in case of parallel supply shift, linear model provides a good approximation of any other non-linear model, and then the choice of the functional form is considered as irrelevant (Mensah *et al.,* 2009)

($q_T^d = \mu + \gamma p$), yielding a new market equilibrium price, considered as derived from the supply shift:

$$\sum q_{BC}^s = \sum q_{BC}^d \iff p_{BC}^* = (\mu - \alpha - K\beta)/(\beta + \gamma) \qquad (4)$$

The graphical illustration of the market equilibrium displacement provides a geometrical view of the economic surplus model (Figure 5). The initial supply curve S0 (algebraically described by the equation (1)) and the demand curve D (algebraically described by the equation (2)) intercept at the point A (p^*, q_0) which represents the initial market equilibrium as assumed in economic theory. The point A coordinates p^* and q_0 represent respectively the initial equilibrium price and quantity supplied or demanded.

[Figure 5 about here]

Hence, the initial surplus distribution is presented as follow:

Initial Consumer Surplus p^*AD_0
Initial Producer Surplus p^*AI_0
Initial Total Surplus D_0AI_0

With the BC intervention, the supply curve S_0 is expected to shift to S_1. This results in a new equilibrium point $B(q_{BC}, p_{BC})$ with the coordinates p_{BC} and q_{BC} representing respectively the new equilibrium price and quantity of maize or sorghum under the BC intervention. The resultant change in welfare (surplus) is then given as follow:

Change in Consumer Surplus: $\Delta SC = p^*ABp_{BC} = p^*q^*Z(1 + 0.5Z\eta)$
Chance in Producer Surplus: $\Delta SP = p_{BC}BCd = p^*q^*(K - Z)(1 + 0.5Z\eta)$
Change in Total Surplus: $\Delta TS = p^*ABp_{BC} + p_{BC}BCd = p^*q^*K(1 + 0.5Z\eta)$
with $K = k/p_0$ the supply shift factor, ε the supply elasticity and η the demand elasticity and $Z = -\frac{p_{BC}^* - p^*}{p^*} = (K\varepsilon)/(\varepsilon + \eta)$ relative reduction in price according to Alston et al. 1995

3.2 Return to investments and benefit-cost analysis

In general, the welfare benefits are compared to the monetary investments in order to appreciate the efficiency of the program or research through the measure of its return to investment. Economic benefit of the BC intervention will be extended to the estimation and analysis of the Net Present Value (NVP), the Internal Rate of Return (IRR) and Benefit-Cost Ratio (B/C) (Masters, 1996; Jones et al., 2006). NPV measures surplus from profit compared with costs of research and it is estimated based on a given interest rate. This must adequately reflect opportunity cost of funds invested i.e. the profitability rate of funds invested in the research. The NPV expression is given as:

$$NPV = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+r)^t} \quad (5)$$

Where B_t is benefits of the technology (the total surplus), C_t represents the total cost incurred in BC, r is the discount rate, and t is time periods for which the Biological Control (BC) occurs. A technology project is profitable and acceptable if the NPV exceeds zero.

IRR measures the interest rate at which, current value of investments in BC is equal to current value of BC benefits. IRR can then be compared to any other rate of interest; in particular the one charged by commercial banks or interest rates of private investments. If IRR is greater than those rates mentioned, one should conclude that investments in BC in the studied countries are relevant. The benefit-cost ratio (BCR) measures the relative value of benefit generated per investment unit. It is expressed as a ratio of the sum of a BC intervention's discounted benefits to the sum of discounted costs of research and releases. A ratio greater than one, will justify the relevancy of investment in BC program in the selected countries.

$$BCR = \frac{\sum_{t=0}^{T} B_t / (1+r)^t}{\sum_{t=0}^{T} C_t / (1+r)^t} \quad (6)$$

3.3 Effects on poverty reduction

The welfare effects have been calculated as total monetary value associated with the BC of maize and sorghum stemborers. This total generated social benefit can also be seen as accrued surplus that allow households to escape poverty. Indeed, the BC intervention can reduce poverty by raising the income of farmers' households, by reducing purchasing price for consumers' households or by creating new employment in the maize or sorghum value chains. Alene *et al.*, (2009) provides a formula that allows deriving the number of poor people lifted out of poverty from the change in surplus due to new technology. Hence for each country, the increase in number of persons that shifted from the group of poor (under the poverty line) to the group of non-poor (above the poverty line) due to the *icipe'* biological control program is given by:

$$\Delta P = \left(\frac{\Delta TS}{AgGDP} * 100\%\right) * \frac{\partial ln(N)}{\partial ln(AgGDP)} * N \qquad (7)$$

Where ΔP is the number of poor lifted out of poverty, ΔTS is the change in economic surplus due to the biological control program, $AgGDP$ is agricultural gross domestic production in year t and N is the total number of poor. The term $\frac{\partial ln(N)}{\partial ln(AgGDP)}$ represents the poverty elasticity that stands for percentage reduction of total number of poor due to 1% increase in agricultural productivity. This term is fund to be equal to 0.72 for Sub-Saharan Africa (Thirtle, 2003) and will be used for this study.

4. Parameters and data sources

4.1 Biological control induced supply shift parameter

While referring to the theoretical framework and the formula obtained for the producers, consumers and total surplus in equation (08), the K_t parameter representing the BC research-induced supply shift parameter is found to be critical in determining the benefits from the BC spread. The supply shift parameter is estimated by Alston *et al.* (1995) to be equal to:

$$K_t = \left(\frac{j_t}{\varepsilon}\right) - c_t \qquad (08)$$

where j_t is the proportionate change in production due to BC intervention at time t, ε the price supply elasticity of the product and C_t, the cost increase incurred by the presence of the BC agent. Biological control is a self-spreading and self-sustained technology that prevents farmers from spending any additional cost in insecticides use. This imply that the total cost of production remains unchanged and rending the parameter c_t in Equation (08) to be equaled to zero. Therefore the expression of the supply shift equation is reduced to the ratio ($\frac{j_t}{\varepsilon}$).

While ε is provided by the literature on maize and sorghum supply studies, the parameter j_t still need to be estimated. The parameter represents the total increase in production attributable to the BC intervention. It's given by the following equation:

$$J_t = \sum_i^n (\Delta BC_{it} * S_{it} * A_t) \qquad (09)$$

With ΔBC accounting for yield increase due to the presence of a biological control agent or combination of agents, i the released and established species of the bio-agents and their combination. *C. flavipes* (Cf), *and X. stemmator* (Xs) as well as their combination (Cf, Xs). S is the rate of BC area coverage which is the ratio of the total area covered by a released BC agent (or combination of agents) i and the total acreage under considered crop (maize or sorghum), A is the total acreage under considered crop and t represents the time. The parameter j_t is then derived from the equation (10) as proportion of total production at the year t as ($j_t = J_t/Y_t$) where Y_t stands for the total production of maize or sorghum at the defined year t. Therefore the overall formula for estimating the BC-research supply shift becomes:

$$K_t = \frac{1}{\varepsilon * Y_t}\left(\sum_{i}^{n}(\Delta BC_{it} * S_{it} * A_t)\right) \qquad (11)$$

4.2 Yield gains attributable to the BC intervention (ΔBC)

The yield gains due to each of the released bio-agents have been sourced from results on exclusion experiments conducted by entomologists. Researchers conduct the so-called exclusion experiments to determine the intrinsic gain due to the parasitism by the bio-agents (Kfir, 2002; Cugala, 2007). These trials have consisted in setting plots in fully protected, unprotected and exclusion plots as treatments. The unprotected plots are those let without any plant protection and then represent where the BC activities occurred naturally. The exclusion plots were sprayed with selected insecticide to partially eliminate the natural enemies and then were referred to as the non-BC plots. On the fully protected plots, natural enemies and stemborers pests have been totally removed. Yield losses due to the stemborers attack in the absence of the natural enemies were obtained from the difference between the expected yield from the fully protected and exclusion plots. The difference between the yield from unprotected and exclusion plots is of high interest for the present study and represent the yield gain due the biological control at plot level. Hence, the yield gain due to BC was 26.1% in Chokwe, 11.2% in Machipanda and 7.6% in Lichinga in Mozambique (Cugala, 2007). The mean of these three percentages (14.96%) has been considered in this study for *X. stemmator*. Zhou *et al.* (2001) estimated the yield gain due to *C. flavipes* at 10% and this proportion has been considered for *C. flavipes* in the present study. In addition, based on the findings from Zhou *et al.* (2001) on the impact of bio-agent pests parasitism[4] over time, we assumed the BC-induced gain not be constant along the timeframe of our analysis. Following the parasitism rate trends, we consider 5% of the above-found yield-gain for the first three years, 18% for the fourth year, 50% for the fifth year and the constant 100% from the sixth year.

4.3 Evolution of the BC-covered area

The biological control is a self-spreading technology and consequently the evaluation of its impact largely depends on the extent to which the released natural enemies really spread. The measurement of the area covered by BC in this impact evaluation constitutes a challenge as data on the follow-up and yearly monitoring of the spread are missing and mostly for the most recent releases. However, models on the organism spreading are available in the literature: Waage's function $A_t = 4D\pi r_m t^2$ where A_t is the area occupied at time t, D is the population diffusion coefficient and r_m the intrinsic rate of the population growth; Chock's exponential function $A_t = f * e^{gt}$ where A_t is the proportion of acreage where the biocontrol agent is established in year t after release, f is the intercept coefficient, g is a constant specific to the dispersal rate, and e is the base of the natural logarithm (≈ 2.718).

These functions do not integrate the complexity that can imply a time-variant and multiple agents-based BC program. In other words, the possibilities of multiple points of release, the possibility of diversity in the released bio-agents and the overlapping probability of the spread of two or more different bio-agents are of high importance in spread modeling. Hence, to approximate the annually covered area by the BC-spread, spatial analysis using geo-processing tools of GIS software has been used. We first checked and documented all the GIS coordinates of the release points. We then modeled the spread around each release benchmark site in the four encompass directions using the method of concentric circles respecting the year of release and the appropriate specific dispersal rate.

In this assessment, the annual spread rates were taken from various sources (**Error! Reference source not found.**). In fact, the literature on the dispersal rate provides many figures for the first

[4] Based on host-parasite interaction model, the impact study by Zhou *et al* (2001) demonstrated the trends of stemborer-pest parasitism by bio-agent to show a latent period (first three year) an uptake period (three years) and a plateau (maximum) during the remaining period. And then, higher impact from BC-agent is really effective after several years following the release.

released species *C. flavipes.* Base on this species' recovery in Northern Tanzania where no release has been made before, Omwega *et al.* (1997), assuming the origin to be the inadvertent escape from Mbita, estimated the spread rate of *Cotesia* to be 60 $km.year^{-1}$. In another study conducted by Assefa *et al.* (2008) in Ethiopia, the dispersal rate of *Cotesia* was found to be higher than 200 $km.year^{-1}$. Another recent study estimates the spread distance at 11.23 $km.year^{-1}$. The principle of the "least favorable assumption case" led us to select the minimum distance found in the literature. The dispersal rate was estimated at 8.3 km per year for *X. stemmator* (from Cugala, 2007).

Based on these spread distances, the BC covered area has been modeled for all of release points for each year and the area under BC spread (6) has been calculated using the GIS software functions. For Kenya case, the spread modeling has been made using the agricultural land map whereas for the Mozambique and Zambia cases, the modeling has been made on all land as agricultural land maps were not available. The appropriate coefficients[5] were then used to calculate the annual maize and sorghum cultivated area under BC and we finally derived the proportions of maize and sorghum cultivated land under BC (Figure 7). The trends in these proportions show a higher BC cover for Kenya comparatively to Zambia and Mozambique (Figure 6 and Figure 7).

[Figure 6, 7 about here]

4.4 Price elasticity of supply and demand and prices data for maize and sorghum

As previously demonstrated in the section on the economic surplus model, price elasticity of supply and demand (ε and ŋ) are key determinants in the estimation of consumer, producer and the overall social benefits. The estimates of price supply elasticities are found to equal 0.11 in Olwande *et al.* (2009), 0.36 in Onono *et al.* (2010), 0.53 (short run) and 0.76 (long run) in Mose *et al.* (2007). According to Alston *et al.* (1995), when data on supply elasticities is lacking, it becomes expedient to rely on the unit price elasticity of supply. The most closed figure to the unit elasticity supply, that is 0.76, has been referred to in this assessment for Kenya case. For the remaining countries, the literature on recent estimates on supply elasticity is short and the figures

[5] In Kenya, maize occupies over 22% of total farmed land (Mbithi and Huylenbroeck, 2000). For Mozambique and Zambia, the yearly proportions of acreage under maize and sorghum compared to the entire land have been used.

found from various sources (Table 2) have been considered. On the other hand, all the price elasticities of demand found in the literature with value lower than one have been considered in the assessment as they confirmed the necessity nature of maize and sorghum in East and Southern Africa.

Maize and sorghum time-series data on prices have been assessed from FAO database and other documents and compiled in curves shown in Figure 8. Maize and sorghum prices steadily increased from 1990 to 2013. The highest price for each curve is observed in 2008 or 2009 and this confirms the rise in price following the 2008 world food crisis. In the estimation of the total product value, these prices have been converted to real using the food consumer price indexes assessed from the FAO and African Development Bank databases.

[Table 2 about here]

[Figure 8 about here]

4.5 BC – research investments

The set of activities (Identification of pests, importation and quarantine of natural enemies, field-releases, follow-up and evaluation) implemented by the *Icipe* as part of its BC program implied investments in personal including scientists, administratives, technicians and dissertation scholars. This program also invested in laboratory equipments and vehicles for the projects, importation and mass rear natural enemies, basic surveys, studies and consultations, training of national scientists, extensionists and farmers. Data on the annual total cost of these activities have been assessed from project documents and evaluations reports. Basically the Biological Control program is made of a series of four projects that have been implemented from 1990 to 2005: the first from 1990 to 1992 with a cost of USD 0.6 millions, the second from 1993 to 1996 with a total cost of DFI[6] 3.87 millions, the third from 1997 to 2001 with a total cost of DFI 7.5 millions and the fourth from 2002 to 2005 with a total cost of USD 5.52 millions. The total annual expenses have been partitioned base on the 10 countries (Kenya, Eritrea, Madagascar, Malawi, Mozambique, Somalia, Tanzania, Uganda, Zambia, and Zimbabwe) that benefited from the program and the shares of our three study countries have been considered.

[6] DFI is the "Dutch Guilders", former currency of the Netherlands (1 unit worth 0.56 USD, value of 23.02.2015)

5. Results and discussions

5.1 Welfare change due to biological control of stemborers

The results on the welfare gain from the economic surplus model are presented in the table 3. The Biological control intervention has contributed to an aggregate value of $US 1,358.46 million to the economy of the three countries with 84.25% ($US 1,144.57 million) from maize production and the remaining 15.75% ($US 213.89 million) from sorghum production. These results show that the Biological Control program of *icipe* has globally induced a highly positive impact on welfare in the three countries. The value is however lower than that obtained for the biological control of the cassava mealybug in Africa that was estimated at $US 2,205 million (Norgaard, 1988). Producers got the larger share of welfare by gaining 57.70 % of the total surplus generated by the *icipe'* BC program.

At country level, results show that Kenyan maize farmers gained an average of $US 14 million annually from 1993 to 2013 whereas sorghum producers gained an average of $US 5.31 million per year during the same period. The annual gains were $US 6.44 and 14.72 million for maize production, $US 0.98 and 0.30 million for sorghum production, respectively for Mozambique (from 1996 to 2013) and Zambia (from 1999 to 2013). Maize and sorghum consumers gained as well from the decrease in price due to the higher supply induced by the biological control of stemborers. Annual surplus gains were 11.82, 5.48 and 9.40 $US million for maize consumers and 3.58, 0.93 and 0.17 $US millions for sorghum consumers in Kenya, Mozambique and Zambia respectively. Although these country results are positive, they are lower than the average annual gain of $US 50 million estimated by Bokonon-Ganta *et al.* (2002) for the Biological Control program of mango mealybug in Benin.

[Table 3 about here]

5.2 Net benefits and rates of return to investments in BC program

The results of estimation of the net present value of benefits, the rates of return on investments in BC-program and the benefit-cost ratios are reported in Table 3. The total net present value of *icipe'* biological control program over the period of 1990-2013 was estimated at $US 175.66 million for maize, $US 46.56 million for sorghum cumulating at $US 271.76 for both crops. At country level, the NPVs were found to reach $US 141.52, $US 33.02 and $US 38.98 million for both crops in Kenya, Mozambique and Zambia respectively. The higher results for Kenya compared to the other two countries can be explained by the higher number of natural enemies released in the country with the synergy of their effect leading to high parasitism translating into high loss reduction. The other explanation is the seemingly best distribution of the released sites that allow the natural enemies to spread and cover more extended agricultural areas in the country. The spread started from the coastal region and Western (with the Mbita inadvertent escape), and has been followed by spread from other well-distributed released sites in the Central, Eastern and Rift-valley. In Mozambique, the majority of the release points are concentrated in the south region and in Zambia, most releases were done closer to the border entailing the large share of spread to occur out of the country territory. Moreover, the earlier start of the BC-program in Kenya may explain the higher value of the BC-derived social benefits.

The net present values derived from BC-program are however lower than estimates from impact of other Biological control program in Africa. For example, De Groote *et al.* (2003) found a net present value of the biological control of water hyacinth in southern Benin to be US$260 million.

One important step in this evaluation was to appreciate the efficiency of investment in the BC-research by calculating the internal rate to return on the investments. The overall internal rate of return of 44% obtained for the aggregate three countries is attractive because the return is above the prevailing discount rate considered of 10%. In addition, for all countries and both crops, the internal rate of return, ranging from 69.84% for maize in Kenya to 23.39% for sorghum in Zambia, is higher than current prevailing interest rate of 10%. This result justifies that the investment in *icipe'* biological control research was a highly worthwhile investments in the three countries.

The other efficiency measure for funds use in research is the Benefit-Cost Ratio (BCR) which was found to equal 15.60 meaning that each dollar invested in the biological control program generates an additional higher value of 33.47 dollars for the aggregate countries. For each country, the BCRs are much higher than 1, confirming the high profitability of investing in *icipe'* biological control research and release of natural enemies in these countries. However, the figures found are lower than that obtained in many other BC program impact assessments for instance De Groote *et al.* (2003) estimated a BCR of 124:1 for the biological control program of water hyacinth in Southern Benin, Bokonon-Ganta *et al.* (2002) found a BCR of 145:1 for the biological control program of mango mealybug in Benin and Norgaard (1988) estimated a BCR of 149:1 for the biological program against the cassava mealybug in Africa.

5.3 *Impact of biological control of stemborers on poverty reduction*

Poverty reduction expressed here as the proportion of poor lifted out of poverty[7] ranges from 0.01% in 1996 to 0.56% in 2013 for Kenya, 0.04% in 2001 to 0.49% in 2013 for Mozambique; and 0.03% in 2003 to 0.79% in 2013 for Zambia. For each country, the reduction in poverty reached 0.1% after 6 to 7 years confirming the finding that the period before the expectation of impact from BC program is about 6 years (Zhou *et al.,* 2001). The average annual poverty reduction is presented in the table 4. Estimated impact on poverty was in average 0.35% per year in Kenya, 0.25% in Mozambique and 0.20% in Zambia. The relatively higher impacts for Kenya and for maize in term of poverty reduction are consistent with the broader spread of BC and the importance of maize as crop produced and consumed by the higher share of populations who are in majority the resource-poor people. Poverty impacts from BC-program have steadily increased with time confirming the BC intervention as a sustainable policy for promoting poverty reduction.

[Table 4 about here]

5.4 *Sensitivity analysis*

To determine the robustness of the findings to change in yield-gain from the released natural enemies, sensitivity analysis was undertaken. Results show that the welfare change, the efficiency of investment in BC-research and the poverty reduction are sensitive to change in proportional yield gain (or BC-agents aptitude to parasitism) and price elasticity. Reducing the yield gain attributable to the parasitism by the bio-agent *Cotesia flavipes* by 50%, results in reduction of 47%; 37% and 34% of the total social benefits; 48%, 41% and 46% of the net present value of benefits for both crops and respectively for Kenya, Mozambique and Zambia. Reduction is also observed with the internal rate on return that drops from 113%, 29% and 19%

[7] Poor were defined as people living below international poverty line of US$ 1.25 per day.

to 93%, 25% and 16% respectively for each country. The poverty change also reduced in percentage by 48%, 38% and 34% respectively for Kenya, Mozambique and Zambia. Changes in yield gain due to *X.stemmator* also present variations but in a lesser extent and this may be due to the late release and shorter spread in comparison to the release of *C.flavipes*. With the reduction/augmentation in parameters, results still keep positive and high figures denoting that the higher profitability of the *icipe* BC program is verified.

[Table 5 about here]

6. Conclusion and implications

Using market and production data from various sources and GIS modeling, this study provides an ex-post evaluation of the impacts of *icipe'* biological control program on welfare and the efficiency in investments in biological control research. We applied the economic surplus model to assess the impact of the biological control of stemborers in Kenya, Mozambique and Zambia. The releases of *Cotesia flavipes, Cotesia sesamiae, Telenomus Isis and Xanthopimpla stemmator* over the period of 1993 to 2008 to control stemborers result in an auto-spread of the biological control that covers up to 90% of sorghum and maize in Kenya and just 20% in Zambia and Mozambique. The resulting welfare in term of monetary surplus for both producers and consumers were $US 1358.46 million for the three countries with 84.25% from maize and the remaining 15.75% from sorghum. In the three countries, the estimation of the internal rate of return and the benefit-cost ratios revealed the high efficiency of funds invested in BC research. The net present value also confirmed the high profitability of this investment. Moreover, the results showed a yearly increasing number of persons lifted out of poverty with the spread of BC and this justify that the BC intervention remains an important policy and self-sustain tool to promote and contribute to poverty reduction in the region.

However, the findings on BC advantages can be considered as a lower boundary, since the calculation used conservative assumptions through the reasonable least favorable case principle (the lower dispersal rate of the released bio-agents for instance). The benefits would have increased if the advantages due to the spillover effect (spreads to the neighboring countries) were considered. The major implication of this assessment is that more funds could be advantageously invested in Biological program in East and Southern Africa.

Acknowledgment

The authors would wish to acknowledge Department for International Development (DFID) for financial support. We are grateful to the International Centre of Insect Physiology and Ecology (ICIPE) and the Institut de Recherche pour le Development (IRD) for the advice and research support. Our deepest thanks to Gerphas Okuku, Esther Abonyo and Kabiro Macharia for their effort in provision of data.

7. References

Akino, M., Hayami, Y., 1975. Efficiency and equity in public research: Rice breeding in Japan's economic development. American Journal of Agricultural Economics 57(1): 1-10.

Alene, A. D., Menkir, A., Ajala, S. O., Badu-Apraku, B., Olanrewaju, A. S., Manyong, V. M., Ndiaye, A., 2009. The Economic and Poverty Impacts of Maize Research in West and Central Africa. Agricultural Economics 40 (5): 535 –550.

Alston, J.M., Norton, G.W., Pardey, P.G., 1995. Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting. Cornell University Press, Ithaca, New York.

Asfaw, A., Mithöfer, D., Löhr, B., Waibel, H., 2013. Challenges for Economic impact assessment of classical biological control in Kenya and Tanzania. In Mithöfer, D., Waibel, H., 2013. Vegetable production and Marketing in Africa: Socio-economic research. Icipe-CABI

Assefa, Y., Mitchell, A., Conlong, D.E., Muirhead, K.A., 2008. The establishment of *Cotesia flavipes* (Hymenoptera: Braconidae) in sugarcane fields of Ethiopia and the origin of the founding population. Journal of Economic Entomology 101, 686-691.

Bokonon-Ganta, A.H., De Groote H., Neuenschwander, P., 2002. Socio-economic impact of biological control of mango mealybug in Benin. Agriculture, Ecosystems and Environment 93 (2002) 367–378

Bonhof, M. J., Overholt, W. A., Van Huis, A. Polaszek, A., 1997. Natural Enemies of Cereal Stemborers in East Africa: a Review. International Journal of Tropical Insect Science, 17, pp 19-35. doi:10.1017/S1742758400022141.

Bruce, Y. A., Schulthess, F., Mueke, J., Gohole, L., 2009.'Egg parasitoids of noctuid stemborers on maize in Kenya',International Journal of Biodiversity Science & Management,5:3,174 — 180

Cugala, D. R., 2007. Impact assessment of natural enemies on stem borer populations and maize yield in three agroecological zones in Mozambique. PhD thesis, Kenyata University. Nairobi, Kenya.

Cugala, D., Omwega, C. O., 2001. Cereal stemborer distribution and abundance, and introduction and establishment of Cotesia flavipes Cameron (Hymenoptera: Braconidae) in Mozambique. International Journal of Tropical Insect Science, 21, pp 281-287.

De Groote, H., Ajuonu, O., Attignon, S., Djessou, R., Neuenschwander, P., 2003. Economic impact of biological control of water hyacinth in Southern Benin. Ecological Economics 45: 105-117.

DeBach, P., Rosen, D., 1991. Biological control by natural enemies, 2nd edn. Cambridge: Cambridge University Press.

Denic, M., Chauque, P., Fato, P., Haag, W., Mariote, D., Langa, M., Jose, C., 2001. Maize screening for multiple stress tolerance and agronomic traits. Seventh Eastern and Southern Africa Regional Maize Conference.

Diao, X., Fan, S., Headey, D., Johnson, M., Pratt, A. N., Yu, B., 2008. Accelerating Africa's Food production in Response to Rising Food Prices Impacts and Requisite Actions. IFPRI Discussion Paper 00825.

Emana, G., Overholt, W.A., Kairu, E., MacOpiyo, L., Zhou, G., 2002. Predicting the Distribution of *Chilo partellus* (Swinhoe) and Its Parasitoid *Cotesia flavipes* Cameron in Ethiopia using Correlation, Step-wise Regression and Geographic Information Systems.

FAOSTAT., 2014. FAOSTAT. (Available from http://faostat.fao.org) (Accessed on June 2014)

Getu, E., Overholt, W.A., Kairu, E., Omwega, C.O., 2003. Evidence of the establishment of *Cotesia flavipes* (Hymenoptera: Braconidae), a parasitoid of cereal stem borers, and its host range expansion in Ethiopia. Bulletin of Entomological Research 93: 125-129.

Griliches, Z., 1958. "Research Costs and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy, 66 (5), pp. 419-431.

Hajek, A., 2004. Natural Enemies: An Introduction to Biological Control. Cambridge: Cambridge University Press.

JAICAF., 2008. The maize in Zambia and Malawi. Japan Association for International Collaboration for Agriculture and Forestry

Jones, R., Saunders, G. & Balogh, R., 2006. An Economic Evaluation of a Pest Management Control Program: 'Outfox the Fox'. Economic Research Report No. 29

Kfir R., 1998. Maize and Grain Sorghum: Southern Africa. In Polaszek., A., 1998. (Ed.) African cereal stem borers: economic importance, taxonomy, natural enemies and control. CAB International, Wallingford, Oxon, UK, 530 pp.

Kfir, R., 2002. Increase in cereal stem borer populations through partial elimination of natural enemies. Entomologia Experimentalis et Applicata 104: 299–306, 2002.

Kfir, R., Overholt, W. A., Khan, Z. R. and Polaszek, A., 2002. Biology and management of economically important lepidopteran cereal stemborers in Africa. Annu. Rev. Entomol. 2002. 47:701–31

Kipkoech, A., Schulthess, F., Yabann, W., Maritim, H., Mithöfer, D., 2006. Biological control of cereal stem borers in Kenya: A cost benefit approach. Ann. soc. entomol. Fr. (n.s.), 2006, 42 (3-4) : 519-528

Kipkoech, A., Schulthess, F., Yabann, W., Maritim, H., Erick, M., Mithöfer, D., 2009. The economic value of releasing parasitoid for the control of maize stemborers in East and Southern Africa. Contributed paper prepared for presentation at the International Association of Agricultural Economics Conference, Beijing, China, August 16-22, 2009

Lazarovitz, G., Goettel, S., Vincent, C., 2007. Adventures in Biological Control. In Vincent C, Goettel S and Lazarovitz G (2007) Biological Control, a global perspectives: Case studies from around the world, CABI

Le Rü, B., Ong'amo, G., Moyal, P., Muchugu, E., Ngala, L., Musyoka, B., Abdullah, Z., Matama-Kauma, T., Yahya Lada, V., Pallangyo, B., Omwega, C., Schulthess, F., Calatayud, P., Silvain, J., 2013. Geographic distribution and host plant ranges of East African noctuid stem borers. International Journal of Entomology, 42:3-4, 353-361

Lv, J., Wilson, L.T., Beuzelin, J.M., White, W.H., Reagan., T.E. Way, M.O., 2010. Impact of *Cotesia flavipes* (Hymenoptera: Braconidae) as an augmentative biocontrol agent for the sugarcane borer (Lepidoptera: Crambidae) on rice. Biological Control 56 (2011) 159–169

Machariaa, I., Lohra, B., De Groote, H., 2005. Assessing the potential impact of biological control of *Plutella xylostella* (diamondback moth) in cabbage production in Kenya. Crop Protection 24 (2005) 981-989

Mailafiya, D., Le Ru, B., Kairu, W., Calatayud, P., Dupas, S., 2008. Species diversity of lepidopteran stem borer parasitoids in cultivated and natural habitats in Kenya. J. Appl. Entomol. 133 (2009) 416–429

Maredia, M., Byerlee, D. Anderson., J. R., 2000. Ex-post evaluation of Economic impacts of agricultural Research Programs: A tour of good practice. Proceedings of a workshop organized by the Standing Panel on Impact Assessment of the Technical Advisory Committee CGIAR-TAC: "The Future of Impact Assessment in the CGIAR", 3-5- May 2000, Rome, Italy.

Maredia, M. K., Shankar, B., Kelley, T. G., Stevenson, J. R., 2014. Impact assessment of agricultural research, institutional innovation, and technology adoption: Introduction to the special section. Food Policy, 44, 214-217.

Masters, A.W., Coulibaly, B., Sanogo, D., Sidibé, M., Williams, A., 1996. The economic impact of agricultural research:a practical guide. Department of Agricultural Economics, Purdue University

Mbithi, L., Huylenbrock, V.G., 2000. A comparaison of maize production in Kenya before and after liberalization, tropicultura 2000, pp 191-186

Mensah, E.C., Clifford, E., Wohlgenant, K., 2009. A market impact analysis of soybean technology adoption. Research in Business and Economics Journal.

Moolman, J., Van Den Berg, J., Conlong, D., Cugala, D., Siebert, S., Le Ru, B., 2014. Species diversity and distribution of lepidopteran stem borers in South Africa and Mozambique. Journal of Applied Entomology 138: 52–66

Moonga, M.N., 2007. Assessment of infestation level of Chilo partelus swinhoe (Lepidoptera:crambidae) o maize and the impact of its parasitoid Cotesia flavipes Cameron (Hymenoptera:Braconide) in Sinazongwe District of Zambia. Master thesis, University of Zambia

Moore, R.M., Gollehon, N.R.& Hellerstein, D.M., 2000. Estimating Producer's Surplus with the Censored Regression Model: An Application to Producers Affected by Columbia River Basin Salmon Recovery. Journal of Agricultural and Resource Economics 25(2):325-346

Mose, L., Burger, K., Kuvyenhoven, A., 2007. Agregate supply response to price incentives: the case of smallholder of maize production in Kenya. African Crop Sciences Conference proceedings, vol. 8 pp. 1271-1275.

Norgaard, R. B., 1988. The Biological Control of Cassava Mealybug in Africa. American Journal of Agricultural Economics. 70(2):366-71.

Norton, G., Davis, J., 1981. Evaluating Returns to Agricultural Research: A Review. American Journal of Agricultural Economics 63(4):685-699.

Odendo, M., Ouma, J., Wachira, S., Wanyama, J., 2003. Economic assessment of maize yield loss due to stem borer in major maize agro-ecological zones of Kenya. African Crop Science Conference Proceedings, Vol. 6. 683-687

Olwande, J., Ngigi, M., Nguyo, W., 2009. Supply responsiveness of maize farmers in kenya: a farm-level analysis. Contributed Paper prepared for presentation at the IAAE 2009 Conference, Beijing, China, August 16-22, 2009.

Omwega, C., Muchugu, E., Overholt, W., Schulthess, F., 2006. Release and establishment of *C flavipes*, an exotic parasitoid of *C partellus* in East and Southern Africa, Annales de la Societe entomologique de France (NS). 42:3-4, 511-517

Omwega, C.O., Kimani, S.W., Overholt, W.A., Ogol, C.K.P.O., 1995. Evidence of the establishment of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) in continental Africa. Bulletin of Entomological Research 85 : 525-530.

Omwega, C.O., Overholt, W.A., Mbapila J.C. & Kimani-Njogu, S.W., 1997 . Establishment and dispersal of *Cotesia flavipes* (Cameron), an exotic endoparasitoid of *Chilo partellus* Swinhoe in northern Tanzania. African Entomology 5: 71-75.

Onono, P.A., Wawire, N.W.H., Ombuki, C., 2013. “The response of maize production in Kenya to economic incentives”, International Journal of Development and Sustainability, Vol. 2 No. 2, pp. 530-543.

Overholt, W. A., Ochieng J. O., Lammers, P. M., Ogedah, K., 1994 Rearing and field release methods for Cotesia flavipes Cameron (Hymenoptera: Braconidae), a parasitoid of tropical gramineous stemborers. Insect Sci. Applic. 15, 253-259.

Overholt, W.A., Maes, K.V.N., Goebel, F.R., 2001. Field Guide to the Stem Borer larvae of Maize, Sorghum and Sugarcane in Eastern and Southern Africa. ICIPE Science Press, Nairobi, Kenya.

Polaszek, A., 1998. (Ed.) African cereal stem borers: economic importance, taxonomy, natural enemies and control. CAB International, Wallingford, Oxon, UK, 530 pp.

Sallam, M.N., Overholt, W.A., Kairu, E., 2000. Dispersal of the exotic parasitoid *Cotesia flavipes* in a new ecosystem. Entomologia Experimentalis et Applicata 98: 211–217

Schulthess, F., Chabi-Olaye, A., Goergen, G., 2001. Seasonal fluctuations of noctuid stemborer egg parasitism in southern Benin with special reference to Sesamia calamistis Hampson

(Lepidoptera: Noctuidae) and Telenomus spp Hymenoptera: Scelionidae) on maize. Biocontrol Science and Technology 11, 765–77.

Schultz, T. W., 1953. *The Economic Organization of Agriculture*, McGraw-Hill, 1953.

Simatele, M. C. H., 2006. Food production in Zambia: The impact of selected structural adjustment policies. African Economic Research Consortium (AERC)

Simmonds, F.J., 1967. The economics of biological control. Journal of the Royal Society of Arts, Vol. 115, No. 5135 (OCTOBER 1967), pp. 880-898

Smale, M., Byerlee, D., Jayne, T., 2011. Maize evolutions in Sub-Saharan Africa. The World Bank Development Research Group, Policy Research Working Paper 5659

Thirtle, C., Lin, L., Piesse, J., 2003. The Impact of Research-Led Agricultural Productivity Growth on Poverty Reduction in Africa, Asia and Latin America. World Development, 31(12), 1959 -1975. doi: 10.1016/j.worlddev.2003.07.001

USAID, 2009. Staple foods value-chain - country report: Zambia. USAID

Van den Berg, J., Nur, A.F., 1998. Chemical Control. In Polaszek., A., 1998. (Ed.) African cereal stem borers: economic importance, taxonomy, natural enemies and control. CAB International, Wallingford, Oxon, UK, 530 pp.

Varela, A. M., Seif, A., Löhr, B., 2003. A Guide to IPM in Brassicas production in Eastern and Southern Africa. ICIPE Science Press.

World Bank, 2006. Mozambique, Agricultural Development Strategy: Stimulating Smallholder Agricultural Growth. Report No. 32416 MZ

Zeddies, J., Schaab, P., Neuenschwander, P., Herren, H., 2001. Economics of biological control of cassava mealybug in Africa. Agricultural Economics 24 (2001) 209–219

Zhao, X., Mullen, J.D., Griffith, G., 1997. Functional Forms, Exogenous Shifts, and Economic Surplus Changes. Amer. J. Agr. Econ. 79 (November 1997): 1243-1251

Zhou, G., Baumgartner, J., Overholt, W.A., 2001. Impact of an exotic parasitoid on stemborer (Lepidoptera) populations dynamics in Kenya. Ecol. Appl. 11: 1554–62

Tables and Figures

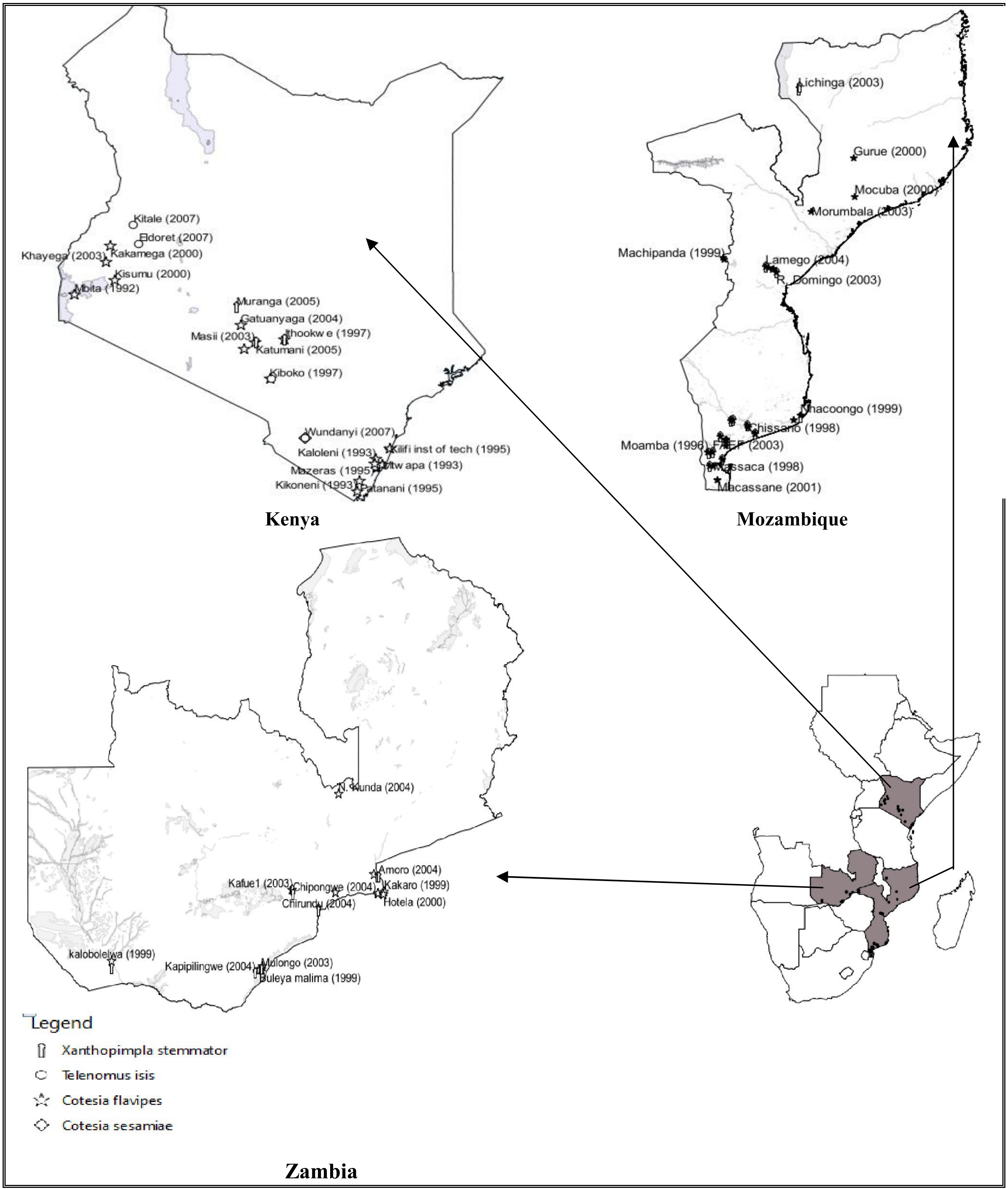

Figure 1. Points of released of parasitoids in the study countries

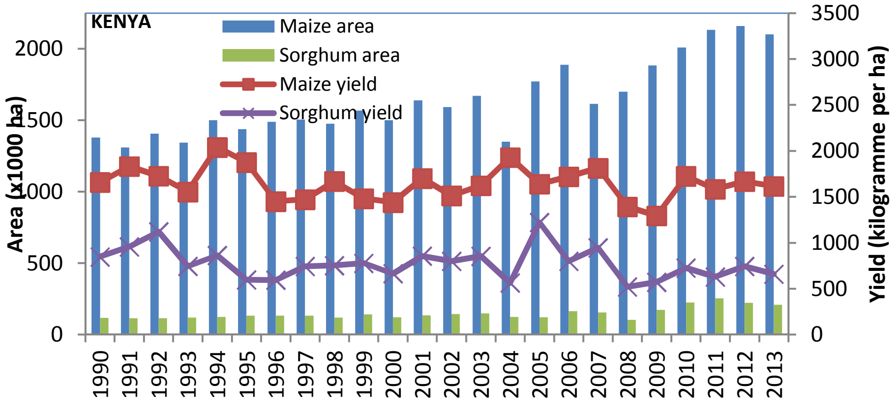

Figure 2. Trends in maize and sorghum area and yield in Kenya

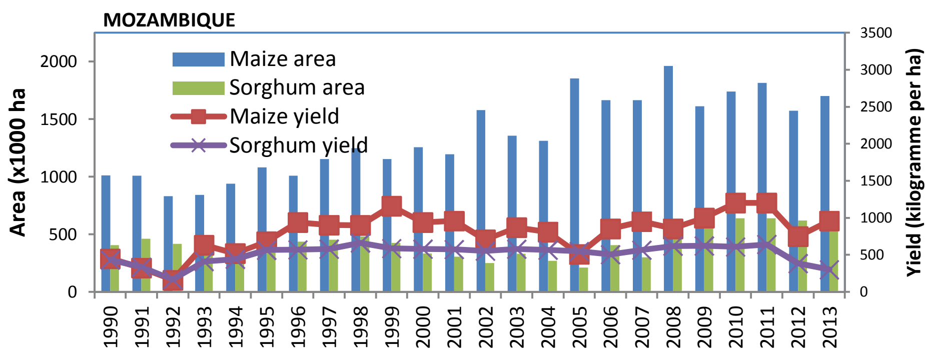

Figure 3. Trends in maize and sorghum area and yield in Mozambique

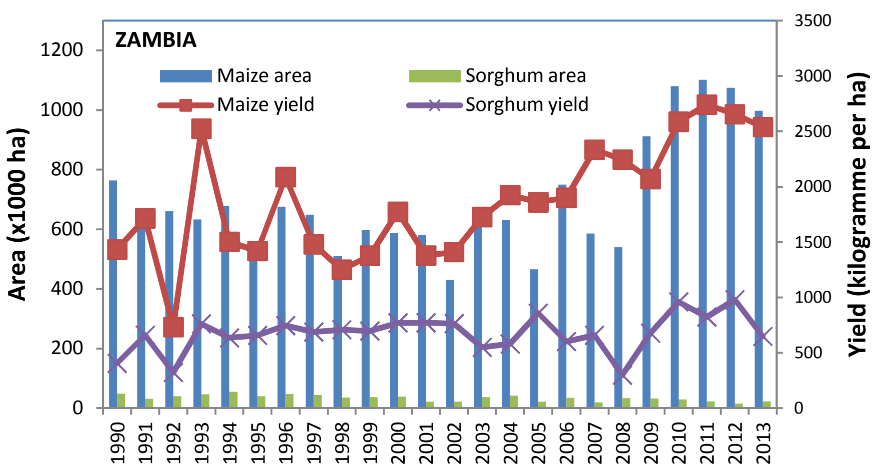

Figure.4: Trends in maize and sorghum area and yield in Zambia

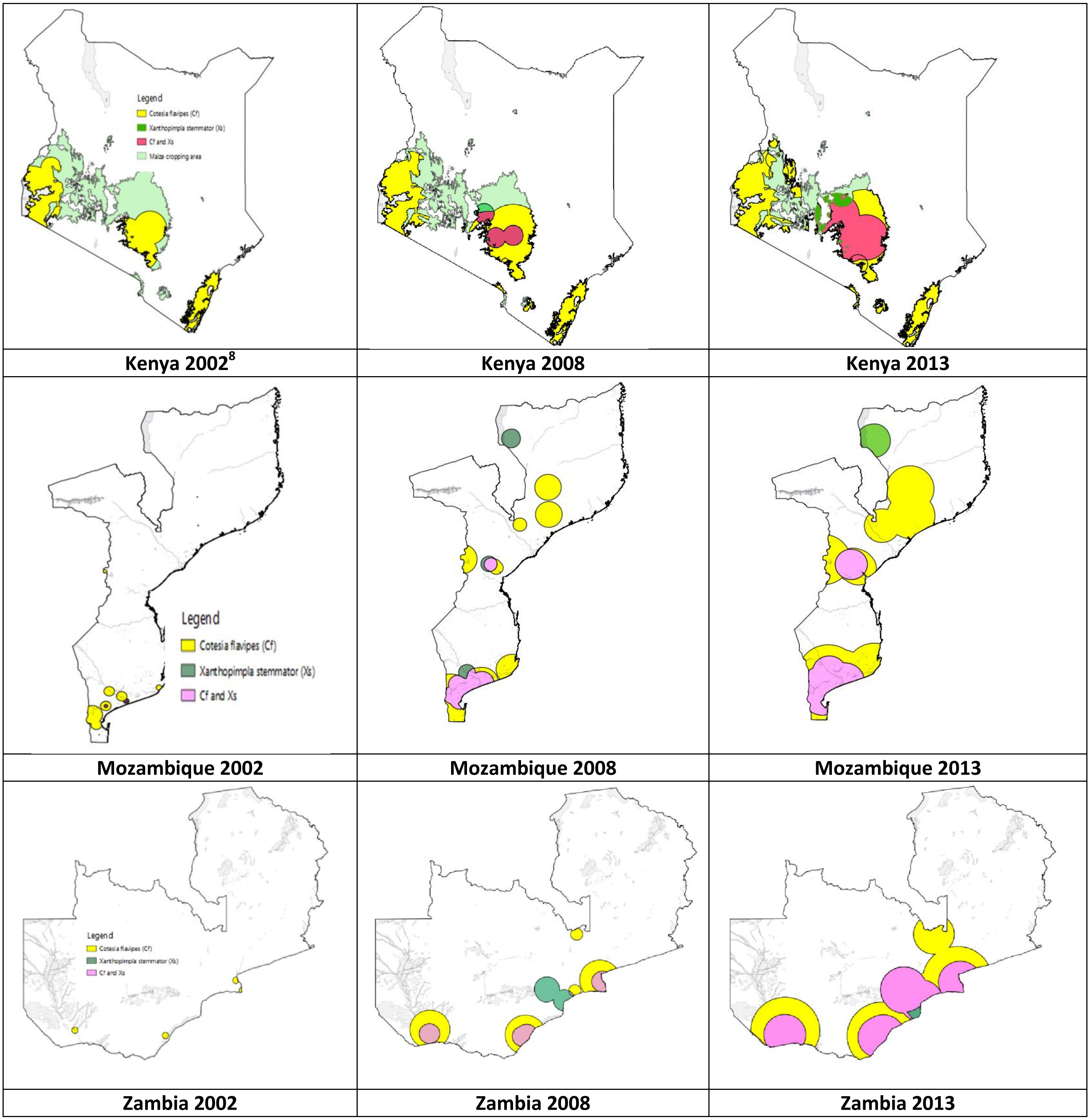

Figure 6. Evolution of BC spread in the study countries

[8] Spread modeled considering the lower spread rate found in the literature (11.2 $km.year^{-1}$ – Omwega et al (2006)

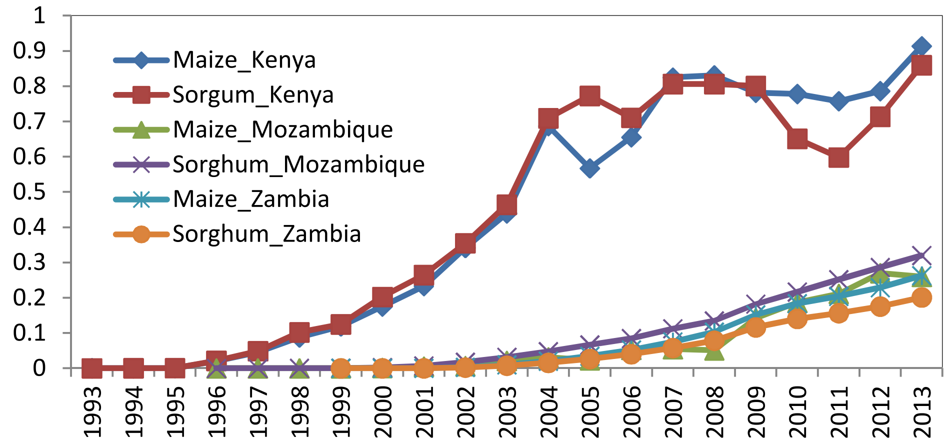

Figure 7. Trends in estimated proportions of area under crop covered by BC-agents

Table 1. Targeted stemborers and their characteristics

Stem borers	Origin	Common name	Crop infested	Damage on crops	Distribution	Reported yield loss
Chilo partellus (Swinhoe) (Lepidoptera: Crambidae)	Exotic (Introduced in Africa through Malawi in 1935)	Spotted borer	maize, sorghum, rice sugarcane	Leaf damage, dead-heart, direct damage to grain, increase susceptibility to stalk rot and lodging	East and Southern Africa in warm and low altitude	14-40% on maize (De Groote *et al.,* 2003) 12-30% (Polaszek, 1998)
Busseola fusca (Fuller) (Lepidoptera: Noctuidae)	Indigenous to Africa	African maize borer	maize, sorghum, millet,	Feed on stem and leaves	Sub-Saharan Africa, in cool high altitude area in Eastern	20-80% (Kfir *et al.,* 2002) 26 – 28% (Harris, 1962)
Sesamia calamistis Hampson. (Lepidoptera: Noctuidae)	Indigenous to Africa	Pink borer	maize, sorghum, finger millet, rice sugarcane	Attack a number of young stems, feed on stem	Sub-Saharan Africa, prevalent in medium and low altitude areas	20-40% (Nsami *et al,* 2002)

Table 2: Prices elasticity values used in the surplus calculation

Parameter	Value	Crop	Country	Source
Supply elasticity	0,76	Maize	Kenya	Mose *et al.* (2007)
	0,2	Sorghum	Kenya	Diao *et al.* (2008)
	0,4	Maize	Mozambique	Diao *et al.* (2008)
	0,4	Sorghum	Mozambique	Diao *et al.* (2008)
	0,3	Maize	Zambia	Doroch *et al.* (2009)
	0,24	Sorghum	Zambia	Simatele (2006)
Demand elasticity	0,8	Maize	Kenya	Nzuma and Sarker (2008)
	0,42	Sorghum	Kenya	Diao *et al.* (2008)
	0,47	Maize	Mozambique	Diao *et al.* (2008)
	0,424	Sorghum	Mozambique	Diao *et al.* (2008)
	0,47	Maize	Zambia	Doroch *et al* (2009)
	0,424	Sorghum	Zambia	Diao *et al.* (2008)

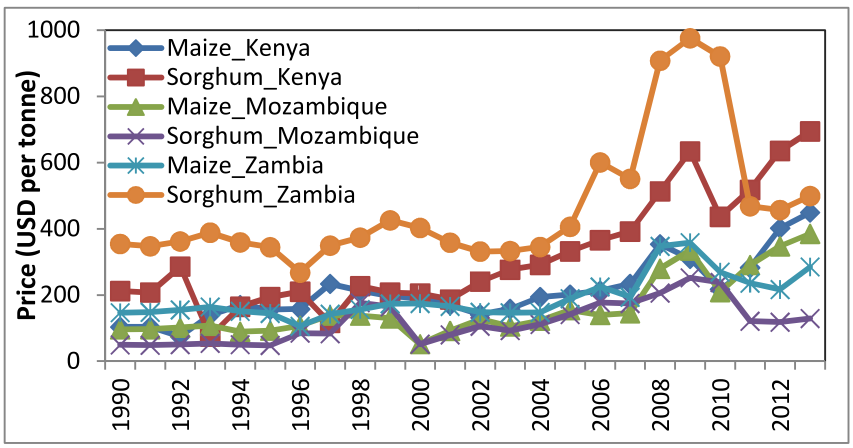

Figure 8: Trends in maize and sorghum prices in Zambia, Kenya and Mozambique

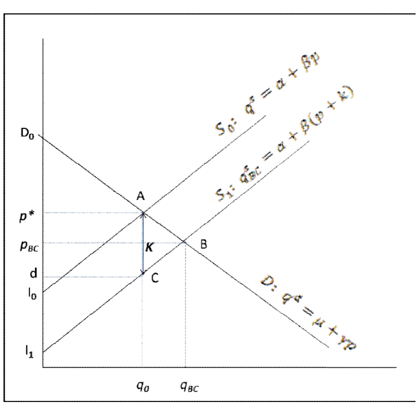

Figure 5: Change in economic surplus from a supply parallel shift induced by the BC program

Table 3: Welfare change, benefits and return to investment

Country	BC-induced change in			Net Present value (NPV) (USD millions)	Internal rate of return (IRR) (%)	Benefit-Cost Ratio (BCR)
	Producer surplus (USD millions)	Consumer surplus (USD millions)	Total surplus (USD millions)			
Kenya						
Maize	307.98	260.08	568.06	108.80	108.23	238.80
Sorghum	116.82	55.63	172.45	32.65	118.99	584.52
Total	424.80	315.70	740.50	141.52	113.08	276.45
Mozambique						
Maize	115.95	98.68	214.63	28.52	30.66	20.71
Sorghum	17.73	16.72	34.45	4.50	24.25	8.36
Total	133.68	115.40	249.08	33.02	29	11.57
Zambia						
Maize	220.89	140.99	361.88	38.34	18.76	8.08
Sorghum	4.47	2.53	7.00	0.64	16.11	5.18
Total	225.36	143.52	368.88	38.98	18.69	4.51
Aggregate						
Maize	644.82	499.75	1,144.57	175.66	31	11.60
Sorghum	139.01	74.88	213.89	46.56	81	49.57
Total	783.83	574.63	1,358.46	271.76	67	33.47

Table 4: Poverty reduction due to BC

Countries	Average annual (x 1000)	Average Percentage
Kenya		
Maize	43.98	0.27%
Sorghum	13.42	0.08%
Total	57.40	0.35%
Mozambique		
Maize	37.24	0.22%
Sorghum	6.88	0.05%
Total	44.12	0.25%
Zambia		
Maize	35.46	0.37%
Sorghum	0.71	0.01%
Total	36.17	0.20%

Table 5: Sensitivity analysis of the impact of Biological Control on maize and sorghum stemborers to yield gain

Parameter	Country	Parameter			Surplus		NPV		IRR		BC ratio		Poverty	
		Base	Change (%)	Value	Value	Change (%)	Value	Change (%)	Value	Change (%)	Value	Change (%)	Value	Change (%)
Cotesia flavipes (yield gain)														
	Kenya	10	-50	5.0	395.6	-46.6	73.1	-48.3	93%	-17.3	143.4	-48.1	0.18%	-48.2
		10	50	15.0	1112.5	50.2	214.9	51.9	126%	11.2	419.2	51.7	0.54%	51.7
	Mozambique	10	-50	5.0	157.9	-36.6	19.6	-40.6	25%	-13.6	7.3	-37.1	0.16%	-37.7
		10	50	15.0	341.8	37.2	46.6	41.2	32%	9.7	15.9	37.7	0.35%	38.2
	Zambia	10	-50	5.0	245.2	-33.5	21.2	-46.1	16%	-15.1	3.0	-34	0.13%	-37.3
		10	50	15.0	494.4	34.0	57.6	46.7	21%	11.0	6.2	34.4	0.27%	37.8
Xanthopimpla stemmator (Yield gain)														
	Kenya	15	-50	7.5	703.0	-5.1	136.8	-3.3	113%	0.0	267.3	-3.3	0.34%	-3.2
		15	50	22.5	778.6	5.1	146.3	3.4	113%	0.0	285.7	3.3	0.36%	3.3
	Mozambique	15	-50	7.5	213.6	-14.2	28.1	-15.0	28%	-3.6	10.0	-13.7	0.22%	-13.0
		15	50	22.5	284.8	14.3	38.0	15.1	30%	3.2	13.2	13.8	0.28%	13.1
	Zambia	15	-50	7.5	305.2	-17.3	30.4	-22.7	18%	-6.4	3.8	-16.8	0.17%	-16.7
		15	50	22.5	433.1	17.4	48.3	22.9	20%	5.5	5.4	16.9	0.24%	16.9