Measuring the economic value of redistributing parasitoids for the control of the maize stemborer *Busseola fusca* Fuller (Lepidoptera: Noctuidae) in Kenya

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Abstract

This study assesses the ex ante economic impact of the establishment of two parasitoids, the scelionid egg parasitoid *Telenomus isis* Polaszek from West Africa and a virulent strain of the braconid larval parasitoid *Cotesia sesamiae* Cameron from western Kenya, to control stemborer. Using a Cobb-Douglas production function, it was estimated that yields increased by 28.5% when pesticides were used to control stemborers. The benefit-cost ratio after the establishment of the parasitoids ranged from 1:1 to 777:1, with a net present value of up to US$192 million. The study demonstrates the potential of redistributing parasitoids indigenous to Africa for the control of African stemborers. Because the benefits of biological control are positively scale dependent, while the costs are generally scale irresponsive, biological control programs would accrue more benefits if parasitoids were released to a wider area.

Keywords: biological control; economic valuation; maize; stemborers

Cette étude évalue l'impact ex ante de l'établissement de deux parasitoïdes, le scelionide Telenomus isis Polaszek de l'Afrique de l'Ouest, qui parasite les oeufs, et une souche virulente de larves parasitoïdes Braconide Cotesia sesamiae Cameron de l'ouest du Kenya, pour contrôler les foreurs de tiges. Au moyen de la fonction de production de Cobb-Douglas,

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il a été estimé que les récoltes ont augmenté de 28.5% suite à l'utilisation de pesticides pour contrôler les foreurs de tiges. Le coefficient bénéfice-coût, après l'établissement des parasitoïdes, est passé de 1:1 à 777:1, avec une valeur actuelle nette allant jusque 192 millions US$. L'étude montre le potentiel de la redistribution des parasitoïdes indigènes en Afrique pour le contrôle des foreurs de tiges africains. Parce que les bénéfices du contrôle biologique dépendent positivement de l'échelle, alors que les coûts ne sont en général pas sensibles à l'échelle, les programmes de contrôle biologiques accumuleraient plus de bénéfices si les parasitoïdes étaient lâchés dans des zones plus vastes.

Mots-clés : *contrôle biologique ; évaluation économique ; maïs ; foreurs de tiges*

1. Introduction

In Kenya, lepidopteran stemborers are considered the most damaging insect pests, with reported yield losses of up to 78% (Seshu Reddy & Sum, 1992; Kfir, 1994). The invasive *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) and the indigenous *Busseola fusca* Fuller (Lepidoptera: Noctuidae) are the economically most damaging stemborers, accounting for 85% of the maize yield loss attributed to the stemborer attacking maize in the country (Zhou, Overholt & Mochiah, 2001; De Groote, Overholt et al., 2003). The geographic distribution of these two species depends on elevation, with *Ch. partellus* being a lowland and *B. fusca* a mid-altitude to highland species (Seshu Reddy, 1983; Harris & Nwanze, 1992; Zhou, Overholt & Mochiah, 2001).

Various control options have been researched in the past 20 years but none has provided a complete solution to the problem. Pesticides have been promoted as holding the key to transforming African agriculture and enabling it to reach levels such as those seen in East and South Asia during the green revolution. However, because of resource constraints and lack of training, pesticides are not a feasible option for most Kenyan farmers and less than 30% of these farmers use them for their maize crops (Hassan, 1998; Kipkoech et al., 2006). Besides this, if pesticides are applied incorrectly and at a sub-lethal dosage they may selectively kill the natural enemies of the pest, thereby aggravating pest infestations and increasing yield loss (Neuenschwander et al., 1986; Cugala et al., 2006). Thus, reported high gains from the use of pesticides could be the result of incomplete valuations that do not consider externalities. The appropriate pest control technology should focus on sustainability, by minimizing the negative impacts to users and the environment and requiring farmers to spend only a small fraction of their income, since for poor farmers the marginal opportunity cost of any expenditures is high.

Biological control can yield huge economic gains (Huffaker et al., 1976; Norgaard, 1988; Bokonon-Ganta et al., 2002; De Groote, Ajuonu et al., 2003; Macharia et al., 2005; Kipkoech et al., 2006). In fact, it was the success of the biological control of *Ch. partellus* in Kenya's low potential lowland areas (Hassan, 1998) through the introduction of the braconid endo-parasitoid *Cotesia flavipes* Cameron (Zhou, Baumgärtner & Overholt, 2001; Kipkoech et al., 2006), implemented by the International Centre of Insect Physiology and Ecology (ICIPE), that provided the motivation to explore the potential for extending biological control to the indigenous *B. fusca* in the high potential maize growing areas of Kenya. The success of the introduced *C. flavipes* was demonstrated by its establishment and spread from the release points (Omwega et al., 1997), increasing parasitism and decrease in stemborer density by up to 70% (Zhou & Overholt, 2001; Zhou, Baumgärtner & Overholt, 2001; Jiang et al., 2006), and by its positive economic impact (Kipkoech et al., 2006).

Two parasitoids, the West African scelionid egg parasitoid *Telenomus isis* Polaszek (Hymenoptera: Scelionidae) and a virulent strain of the indigenous larval parasitoid *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae), were therefore released in a pilot site of the Taita Hills. *T. isis* and *T. busseolae* Gahan are the most important mortality factors for noctuid stemborers in West Africa, where they cause egg mortality of up to 95% (Schulthess et al., 2001). However, *T. isis* has never been reported from east and southern Africa. *Cotesia sesamiae*, on the other hand, is the most common larval parasitoid of *B. fusca* in these regions of Africa (Kfir, 1995). In Kenya, it exists as a virulent and an avirulent strain. The virulent strain occurs in the highlands of western Kenya, where it successfully develops in *B. fusca* and the noctuid *Sesamia calamistis* Hampson, a minor borer species, but not in the Taita Hills in southwestern Kenya. By contrast, the avirulent strain, which only develops in *S. calamistis* while it is encapsulated in *B. fusca*, exhibits a mosaic distribution throughout Kenya (Ngi-Song et al., 1998; Mochiah et al., 2002). ICIPE plans to release the virulent strains of *C. sesamiae* into other areas of the Kenyan moist transitional and highland zones, where either only the avirulent strain occurs or the parasitoid does not occur at all.

Using socioeconomic and maize fields survey data collected from Taita Hills, this study assesses the ex ante economic impact of introducing the two parasitoids by looking at the value of the maize output loss decrease based on various possible pest suppression scenarios. The results are then extrapolated to cover all the niches of the parasitoids in the moist mid-altitude and highland zones in Kenya. The production function approach is used to assess the initial output loss to stemborers. This is a departure from the traditional techniques used to compute the impact of introduced parasitoids, such as cage experiments (Debach, 1946) and exclusion experiments (Neuenschwander et al., 1986; Cugala et al., 2006; Neuenschwander, 1996), which are used to assess the impact of parasitoids on pest densities, and the direct yield loss assessment of the impact of the pest on yield (De Groote et al., 2002), which are time consuming and costly. Moreover, the results of those techniques cannot be extrapolated because they represent an oversimplification of the diverse field and farmer characteristics. The present approach takes into account the farming environment as a whole, thereby incorporating the impact of the diverse farming environments on assessing the productivity of pesticides, a proxy for assessing the impact of biological control.

2. Methodology

2.1 Study area

Kenya is divided into six agro-ecological zones: lowlands, dry mid-altitudes, moist mid-altitudes, dry transition zone, moist transition zone and highlands (Hassan, 1998). The high potential maize growing region is made up of the moist transition zone and the highlands (see Figure 1), which comprise 53.6% of Kenya’s maize growing area and produce 68.8% of the total output. There are some large-scale intensive and extensive maize farmers, but 89.3% of the maize farmers here are small-scale (Karanja et al., 2003). These zones experience a bimodal rainfall pattern with 2,000 mm precipitation per annum, with the long rains falling from April to June and the short rains from October to December. The fertile volcanic soils make the area highly productive.

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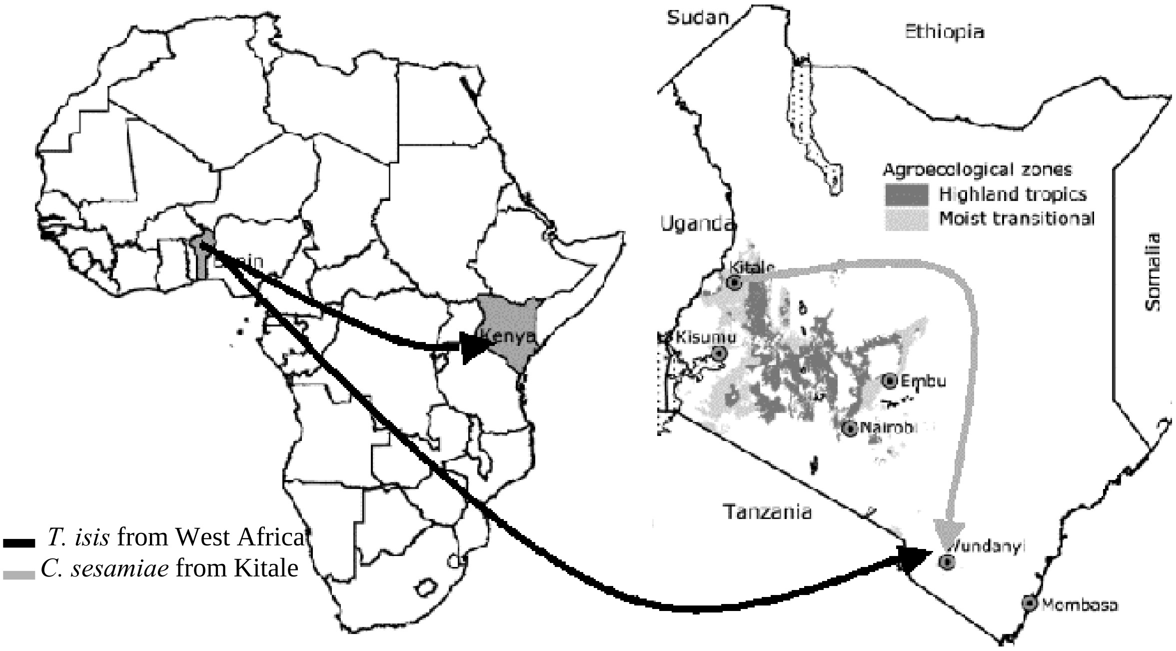

Figure 1: Introduction of *T. isis* and *C. sesamiae* to Taita Hills

Kenya's provinces are divided into districts. The districts are subdivided into divisions, which are further subdivided into locations and finally sub-locations, the lowest administrative unit. The Taita Hills (Latitude 3°25 and longitude 38°20), with their highest peak at 2,230 m above sea level, are part of Taita-Taveta District, which is surrounded by lowlands at an elevation of about 700 m above sea level. The area receives annual rainfall of about 1,500 mm and has good soils and an extensive network of rivers originating from the numerous hills. Maize is produced during the rainy seasons since farming in the area is predominantly rain-fed. However, farmers whose farms extend to the river valley grow maize throughout the year, using irrigation, and practice semi-intensive agriculture.

2.2 Sampling procedure

Taita-Taveta District is divided into six administrative divisions: Wundanyi, Mwatate, Voi, Tausa, Taveta and Mwambiri. Voi, Tausa and parts of Mwatate are in the low altitude zones, where *B. fusca* does not occur, and they were therefore excluded from this study. Two locations were randomly selected from each of the remaining three divisions, Wundanyi, Taveta and Mwambiri, and two sub-locations per location. From each of these sub-locations, 25 farmers were randomly selected, giving a sample of 300.The data on maize output and the use of inputs, farm and farmer characteristics and the farming system were collected by means of a questionnaire in November 2005.

The initial stemborer density was obtained through random sampling of plants at grain filling stages during three farm surveys conducted in July and December 2004 and July 2005 – referred to in this paper as seasons 1, 2 and 3 respectively. During the surveys, 10 to 15 plants were chosen at random from farms one kilometer away from each other in all four directions of the compass from Wundanyi urban center. After the numbers of borers per plant had been counted according to species, borers were reared on an artificial diet as described in Onyango & Ochieng-Odero (1994) until they pupated, reached adulthood, died or yielded parasitoids. The mean numbers of the different stemborer species were compared using the t-test statistic. To determine the initial output loss to stemborers, the production function incorporating pesticides as a damage control variable was evaluated to assess the increase in maize output at recommended rates of pesticide application.

2.3 Using the production function with an integrated damage control variable to assess the initial maize output losses due to stemborers

Pesticides were included in the production function as a conventional yield increasing input (Thirtle & Beyers, 2003; Qaim & Zilberman, 2003; Qaim et al., 2003), or rather, yield loss reduction input (Huang et al., 2002; Shankar & Thirtle, 2005). By including pesticide as a yield increasing input in a production function, one commits specification errors that lead to biased estimates as the marginal product of the damage control agents is overestimated (Lichtenberg & Zilberman, 1986). In contrast to productive resources that contribute directly to increasing yields, such as land, fertilizer and labor, the use of chemical pesticides does not increase yields per se; rather, its primary role is to reduce maize yield losses due to crop pests. The rest of this paper thus uses the terms 'yield loss reduction' and 'damage reduction' interchangeably in referring to the impact of the establishment of parasitoids on maize production.

Following the works by Lichtenberg and Zilberman (1986), a damage reduction function can be incorporated into the traditional models of agricultural production. The nature of damage control suggests that the observed maize output (Y) can be specified as a function of both standard inputs (X) and damage control measure (Z) as: $Y= f(X)G(Z)$. In this study, the vector X represents maize production area in hectares, labor in man-days used to produce maize, a dummy variable for use of hybrid seed (1= yes, 0= no), organic fertilizer used, in kg, and inorganic fertilizer used, in kg. The term, $G(Z)$, is a damage reduction function that is a function of the cost of pesticide (Z) used. This function has the properties of a cumulative probability distribution, defined on the interval of [0, 1]. When $G(Z) = 1$, the pesticides completely eliminated stemborers, so there were zero crop yield losses to stemborers, while when $G(Z) = 0$ the maize crop was completely destroyed by stemborers. The proportion of the potential yield reduction will depend on the effectiveness of the pesticide used and the quantity applied. In estimating the yield loss reduction function, logistic Weibull and exponential functional forms are often used. In the present study, the exponential functional form of the damage reduction function is chosen because it is most appropriate for pesticides (Carrasco-Tauber & Moffitt, 1992), allow for an easy interpretation of the results and satisfactorily fit the data.

$$Y_j = \alpha \prod_1^n X_{ij}^{\beta_i} . \exp(Z_j^m) \quad (1)$$

Y is output, X the vector of input used, α is the intercept, $\beta_i s$ are slopes of the X inputs, m is the slope of Z (damage reduction variable). j refers to the subscript of j^{th} farm, i is the subscript of i^{th} input, for all inputs $i=1,2,\ldots,n$. $exp(Z^m)$ is the damage reduction function with Z being quantity of pesticide and m being the coefficient of pesticides. Taking natural logarithms on both sides of equation (2) gives:

$$Ln\ Y_j = Ln\ \alpha_j + \sum_{i=1}^{n} \beta_i \ln X_{ij} + mZ_j + e \quad (2)$$

where e is the random disturbance term.

The reactive use of pest control measures by farmers in response to a high pest infestation suggests there is a systematic relationship between stemborer attack, pesticide use and maize output. Although fewer than 30% of the farmers apply pesticides (Kipkoech et al., 2006), those who do so are also likely to apply more of other inputs and manage their farms better, thus obtaining better yields. Thus if pesticide users experience higher productivity, this may be not only because of pesticide use but also because of the synergy created by their use of a combination of inputs. The covariance of damage variables, pesticide and the residual of the maize output function and use of other inputs is thus not zero, which poses the problem of endogeneity.

The instrumental variable (IV) approach is used to correct for endogeneity by developing an instrument for pesticide application that is correlated with actual pesticide use but does not affect output except through its impact on pesticides. To compute the IV, we hypothesized that age of the farmer, education (measured in years of schooling attained), availability of off-farm income and the farmer’s perception of the severity of the pest problem (measured as the percentage of the crop that the farmer believed would have been lost if he had not applied pesticides) influence use of pesticides. The predicted value of the pesticide use (IV) by each farmer is then used in the estimation of equation (2), incorporating pesticides as a damage control variable.

2.4 Pest control scenarios

Various yield loss assessment studies exist for cereal stemborers in Africa (e.g., Sétamou & Schulthess, 1995; Songa, 1999; Songa et al., 2001; Ndemah & Schulthess, 2002; Chabi-Olaye et al., 2005a,b: Mgoo et al., 2006) but few of them (Sétamou & Schulthess, 1995; Ndemah et al., 2003) have studied the link between parasitism, pest reduction and the resulting yield loss reduction. Maize grain yields are linearly and negatively related to numbers of stemborer larvae per plant (Usua, 1968; Bosque-Pérez & Mareck, 1991; Gounou et al., 1994; Sétamou et al., 1995; Ndemah & Schulthess, 2002; Wale et al., 2006). Thus, holding other factors constant, a reduction in stemborer density as a result of parasitism by the two parasitoids would lead to a linear reduction in the quantity of maize lost to stemborers.

The two parasitoids attack two different stages of the stemborer life cycle and thus create a complex synergistic pest control environment. The egg parasitoid, *T. isis* causes yield loss reduction by reducing the number of larvae before they can damage the crop (Temerak, 1981). Young *B. fusca* larvae migrate to the whorl (the growing tip of the maize plant) where they feed on the leaves or disperse to other plants by ballooning off (Kaufmann, 1983). As dispersal is positively density dependent, reducing the number of larvae through egg parasitism would also reduce the number of plants infested, allowing more plants to achieve their potential output. *Cotesia sesamiae*, on the other hand, attacks larger larval stages, which are already causing damage to the plant (Hailemichael et al., 2008). Thus, larval parasitoids are important in the long-term reduction in stemborer densities by reducing carry-over populations from one season to the next.

Two biotypes of *C. sesamiae* occur in Kenya. The avirulent biotype is encapsulated by haemocytes and hindered from development in the host, while the virulent biotype is able to overcome the immune defenses and successfully produce offspring in *B. fusca* (Ngi Song et al., 1998; Gitau et al., 2006). Two factors, the environment and the availability of the host, determine whether the *T. isis* will establish itself and achieve significant pest suppression in Kenya. Spatial models (Muchugu, ICIPE, unpublished data) have predicted that *T. isis* will achieve a higher pest suppression in the moist transitional zones than in the highland tropics because of the relatively higher number of parasitoid generations per cropping season. Thus, in order to estimate the impact of the two parasitoids, six pest suppression scenarios were chosen on the basis of the outcome of the climatic model and the plausible stemborer suppression levels reported in related studies (Sétamou & Schulthess, 1995; Omwega et al., 1997; Schulthess et al., 2001; Zhou, Baumgärtner & Overholt, 2001; Ndemah et al., 2003; Jiang et al., 2006). The scenarios over a 10-year period were: i) the two parasitoids do not achieve significant pest suppression, ii) either *T. isis* or *C. sesamiae* establishes itself and achieves a pest suppression of 10%, iii) one parasitoid establishes itself and achieves 20% pest suppression, iv) both parasitoids establish themselves and each achieves 20% suppression, v) one parasitoid establishes itself and achieves 40% suppression, and vi) both parasitoids establish themselves, with *T. isis* and *C. sesamiae* achieving a pest suppression of 20% and 10%, respectively.

By simulating stemborer densities over time using the projected suppression levels for each scenario, the net reduction in stemborer density from the initial average density is obtained. The output loss per stemborer is obtained by constructing a linear relationship of the effective stemborer density with the output lost. The output loss reduction is calculated on the basis of the proportion of the effective stemborer density suppressed by the parasitoids. The results from Taita Hills are extrapolated for the moist transitional zones and later to the maize growing zones of both the moist transitional zone and the highlands.

3. Results and discussion

3.1 Farming systems, pests and parasitism in the Taita Hills

Maize was ranked first in importance in meeting household food and income needs by 97.5% of the farmers. Legumes and other vegetables were ranked second, with most families intercropping maize with haricot beans. Vegetables were important crops grown by 70.6% of all farmers, as monocrops or mixed with other crops by 34.6% and 70.4% of the farmers, respectively. Most vegetable farmers used chemical pesticides to control vegetable pests and diseases.

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Table 1: Farming households' response on the importance of farming crops for food and income

	% of farmers				
		Rank[a] of crops by importance			
Crops	Crops grown	1	2	3	Use pesticides
Maize	99.4	97.5	1.2	0.6	54.6
Legumes	58.9	-	55.2	3.7	-
Fruits	11.0	-	2.5	8.6	-
Tubers	17.8	1.2	3.7	8.6	13.8
Vegetables	70.6	1.3	24.5	44.5	69.6
Sugarcane	8.0	-	-	3.7	-

Source: Survey data
[a] 1 = very important, 2 = moderately important, 3 = not very important

About half of the farmers used pesticides in maize production. Because dosages sub-lethal to the pest may kill natural enemies and thereby aggravate the pest problem (Kfir, 2002; Cugala et al., 2006), the availability of farmers who do not use pesticides provides an environment conducive to the proliferation of parasitoid populations. Applying insecticides at an appropriate dosage and better timing of applications are possible ways to mitigate their negative impact. Optimally, sprays should target the first and second larval stages, which are feeding on leaves. Once the larvae feed inside the stem they are difficult to treat, and insecticides are not effective against borers feeding inside the ear (Ndemah & Schulthess, 2002).

Three stemborer species, *B. fusca*, *S. calamistis* and *Ch. partellus*, were collected from Taita Hills. The stemborer incidence ranged from 23.4 to 41.4%, with an average stemborer density at the flowering stage of 0.5 to 0.7 stemborers per plant. The dominant species was *B. fusca*, which accounted for up to 90% of the total borers collected. The occurrence of *S. calamistis* in the area and its suitability for parasitism to *C. sesamiae* and *T. isis* (Ngi Song et al., 1998; Chabi-Olaye et al., 2001) is promising since, unlike the other species, it does not diapause during the off-season. Thus it will help to perennate the two parasitoids introduced to the area. Two parasitoid species, the indigenous pupal parasitoid eulophid *Pediobius furvus* Gahan and *C. flavipes*, were found to attack stemborers (Table 2). There was no parasitism recorded in July 2004 and only low total parasitism of 5.1 and 2.4% in December 2004 and July 2005, respectively.

Table 2: The percentage composition and parasitism of stemborer per species in the Taita Hills

	% composition according to season		
Stemborer species	July 2004 (Season 1)	December 2004 (Season 2)	July 2005 (Season 3)
B. fusca	92.1	65.4	90.2
C. partellus	0.0	17.9	1.2
S. calamistis	7.9	16.7	8.5
% plants infested	41.4	23.4	32.4
Average no. stemborers/plant	0.7b	0.5a	0.5a
	Parasitism		
Host		*Cotesia flavipes*	
B. fusca	0.0	0.0	0.0
C. partellus	0.0	7.1	0.0
S. calamistis	0.0	15.4	28.6
		Pediobius furvus	
B. fusca	0.0	0.0	0.0
C. partellus	0.0	0.0	0.0
S. calamistis	0.0	7.7	0.0
		% parasitism of all stemborers	
C. flavipes	0.0	3.8	2.4
P. furvus	0.0	1.3	0.0
Total parasitism by both	0.0	5.1	2.4

Source: Survey data

3.2 Costs of the project

The costs included in this study were those incurred by ICIPE for carrying out the necessary baseline studies, including the pre-release studies of the effects on possible non-target species attacked by the exotic parasitoid, to comply with international standards such as the FAO Code of Conduct for Biological Control (FAO, 1997). The cost of the project was shared among several biological control projects ongoing at ICIPE involving the same insect species. The administrative costs were shared among the different insect species that were reared by the staff of the institution. Activities associated with biological control using *T. isis* and *C. sesamiae* accounted for 22 and 20% of the administrative and insect rearing cost, respectively. Using a 10% interest rate, the present cost of biological control is estimated at US$167,245. A high proportion of the total cost (76%) was incurred in the laboratory studies. The administrative cost accounted for 12.4%, while insect rearing and shipping, field release and monitoring, and evaluation each accounted for 5.8% of the total cost.

3.3 The production function

The results of the estimation of the Cobb-Douglas production function are given in Table 3. The coefficients of the model are interpreted as the proportional change in maize output resulting from a percentage change in input. The fractional exponentials that measure the proportional change in output when all inputs included in the model changed at the same rate was 0.65, indicating a decreasing return to scale. The coefficients of land (0.344), quantity of organic manure (0.084) and inorganic fertilizers (0.123) and use of pesticides (0.002) all significantly affected maize outputs ($P<0.05$). The coefficient of land in maize production was higher than that of all the other variables, which suggests that maize production could be increased by putting more land under maize, to benefit from economies of scale. The significant positive effect of size of land on maize production may have been because of the financial constraints faced by smaller farmers (Kevane, 1996), the benefits of training by extension workers, who often favored larger farms, and the lower input intensity and higher relative cost of farming for farmers with small farms compared to those with larger farms (Qaim, 1999).

The coefficients of conventional inputs in the area were low as a result of the low levels of organic manure (113.8 kg/ha) and inorganic fertilizer used (37.7 kg/ha) when compared to the recommended rates of 5 tons/ha and 110 kg/ha, respectively. There was a high variability in the application of these inputs, ranging from zero for both inputs to a maximum of 1235 kg/ha and 370.5 kg/ha for organic and inorganic fertilizers, respectively. This shows that although on average farmers applied organic and inorganic fertilizers in low quantities, some applied them in excess of the recommended rates. This was also in the case with pesticides, where the highest cost incurred by a farmer was Kshs 6422 (equivalent to 10 l/ha of standard recommended pesticides), which is far above the recommended rates, corroborating the observation by Shankar & Thirtle (2005) that some households apply pesticides above the international economic optimum.

Table 3: The Cobb-Douglas production function

Variable	Mean/ha[a]	Parameter	Coefficient	SE
Land in acres	n/a	β_1	0.344*	0.142
Labor in man-days	253.4 (19.9)	β_2	0.033	0.056
Planting of hybrid maize seed (D[b])	0.8 (0.03)	β_3	0.063	0.168
Quantity of organic manure (kg)	113.8 (17.6)	β_4	0.084*	0.038
Quantity of inorganic fertilizer (kg)	37.7 (4.6)	β_5	0.123*	0.046
Cost of pesticide application (Kshs)	653.4 (85.6)	β_6	0.002*	0.001

Source: Survey data
* significant at $P < 0.05$; [a] values in brackets are the standard errors; [b] dummy variable with values 1 for yes and 0 for no; n/a = not applicable because land is used in computing the rate of use of other inputs as rate per ha; N = 163, F = 58.1, R^2 = 69.0%

The regression coefficient of the damage control variable pesticide (β_6) shows that a 1% change in investments to control stemborers would lead to a 0.2% yield loss reduction. Current maize yields in the survey area are 1 ton/ha, with a total maize production of 5039 tons (MoA, 2005). The survey data shows that the average pesticide application rate in the area was Kshs 138.7/ha (Kshs 0.7 million for the whole area). Using the recommended rate, the total cost of pesticides required to control stemborers in the area was Kshs 1.7 million (Kshs 337 × 5039 ha). Investment of another Kshs 1 million (142.5%) in pesticides would lead to an increase in maize production of 28.5%, which is equivalent to the yield lost to stemborers in the area.

3.4 Evaluating the pest situation under different pest suppression scenarios

The present study's lag period of one year before the impact of introducing the parasitoids could be measured was considerably shorter than that reported by Zhou, Baumgärtner & Overholt (2001) and Zeddies et al. (2001). Bruce (ICIPE, unpublished data) recovered *T. isis* during the season following the first releases of the parasitoid at Taita Hills. However, Zhou, Baumgärtner and Overholt (2001) and Zeddies et al. (2001) worked with invasive pests and exotic parasitoid species and it is assumed that both require more time to adapt to the new ecologies than indigenous species (Jiang et al., 2006).

Table 4: Temporal reduction of stemborer density and the economic indicators under different pest suppression scenarios at Taita Hills

Year	No significant pest suppression	One parasitoid, pest reduction 10%	One parasitoid, pest reduction 20%	Both parasitoids, reduction by *T. isis* 20% and by *C. sesamiae* 10%	Both parasitoids, pest reduction 20%	One parasitoid, pest reduction 40%
0	0.60 (0.0)	0.60 (0.0)	0.60 (0.0)	0.60 (0.0)	0.60 (0.0)	0.60 (0.0)
1	0.60 (0.0	0.60(0.1)	0.60 (0.0)	0.60 (0.0)	0.60 (0.0)	0.60 (0.0)
2	0.60 (0.0)	0.60 (0.2)	0.60 (0.4)	0.59 (0.7)	0.59 (1.3)	0.59 (0.9)
3	0.60 (0.0)	0.59 (0.9)	0.59 (1.8)	0.58 (2.6)	0.57 (5.2)	0.58 (3.5)
4	0.60 (0.0	0.59 (2.2)	0.57 (4.3)	0.55 (6.4)	0.52 (12.6)	0.55 (8.6)
5	0.60 (0.0)	0.57 (4.3)	0.55 (8.6)	0.50 (12.5)	0.46 (23.8)	0.50 (16.6)
6	0.60 (0.0)	0.56 (7.5)	0.51 (14.6)	0.44 (21.0)	0.37 (38.2)	0.43 (27.6)
7	0.60 (0.0	0.53 (11.8)	0.47 (22.5)	0.36 (31.6)	0.27 (54.3)	0.35 (41.0)
8	0.60 (0.0)	0.50 (17.2)	0.41 (32.0)	0.28 (43.7)	0.18 (69.8)	0.27 (55.5)
9	0.60 (0.0)	0.46 (23.8)	0.34 (42.8)	0.20 (56.4)	0.10 (82.6)	0.18 (69.6)
10	0.60 (0.0)	0.41 (31.3)	0.28 (54.1)	0.13 (68.5)	0.05 (91.6)	0.11 (81.7)
Taita Hills						
NPV (million US$)	-0.16	0.1	0.14	0.25	0.35	0.36
B/C ratio	0	1	2	3	3	3
IRR (%)	0.0	0.1	7.2	11.1	13.9	14.3
Moist mid-altitude zones only						
NPV (million US$)	-0.2	45	60	73	86	89
B/C ratio	0	240	318	386	456	474
IRR (%)	0.0	101.3	128.3	147.0	161.9	162.8
All areas						
NPV (million US$)	-0.2	74	98	119	141	146
B/C ratio	0	393	520	633	746	777
IRR (%)	0.0	120.4	152.2	173.9	191.0	192.0

Values in brackets are the % pest density reduction; NPV = net present value, B/C ratio = benefit-cost ratio, IRR = internal rate of return

Pest suppression would increase over time as stemborer density decreased. The simulation results (Figure 2) are based on the initial stemborer situation (Table 2). When each parasitoid species achieves pest suppression of at least 20% or one parasitoid achieves pest suppression of 40%, the yield loss to stemborers will be reduced to 7% and 6%, respectively. Significant yield losses of 23% still occur if only one parasitoid establishes itself and pest suppression increases to 10% in 10 years. In general, with at least 20% pest suppression by *T. isis* and 10% pest suppression by *C. sesamiae*, or vice versa, the output loss to stemborers in the area will be under 10% after 10 years. This emphasizes the presence of synergisms when both parasitoids are released.

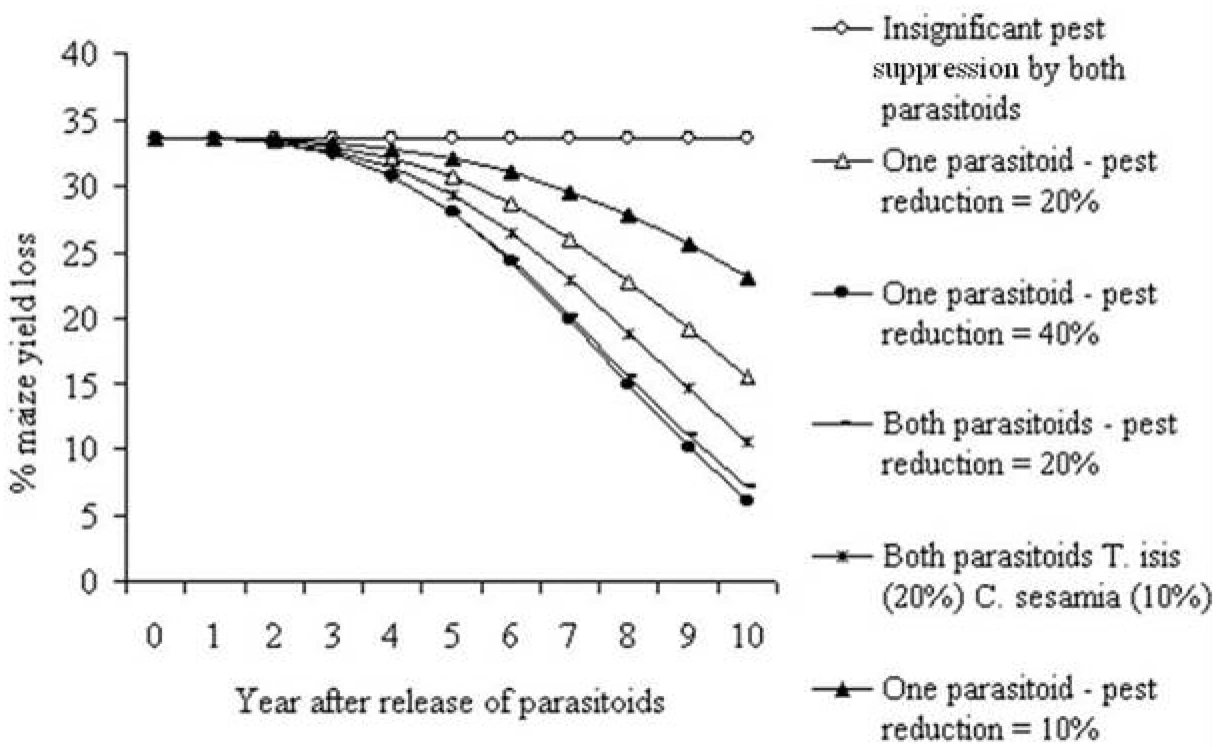

Figure 2: Reduction in the maize output loss resulting from suppression of stemborers

3.5 Economic value of the biological control

The net present value (NPV) of the introduction of the two parasitoids for the control of *B. fusca* based on six parasitoid introduction scenarios and a maize output price of US$205/ton is presented in Table 4. Each of the scenarios assumed different pest reduction regimes. The NPV of the release of the parasitoids was negative, equal to the cost of the project, if both parasitoids failed to achieve significant pest suppression. The NPVs for Taita Hills ranged from US$-0.16 million, if none of the parasitoids achieved significant pest suppression, to a maximum of US$0.36 million, if one parasitoid achieved a pest reduction of 40% in 10 years. The benefit-cost ratio under all the scenarios ranged from 0:1 to 3:1 for the Taita Hills area. However, if the entire region in the moist transitional zone and the highlands was included, considering the niche for each parasitoid, the ratio increased to 777:1 and the NPV to US$147 million. The NPV was less than that obtained from the comparable biological control program using *C. flavipes* in the low potential areas of Kenya, which reported an NPV of US$180 million (Kipkoech et al., 2006). This is because the present study considered the high-potential areas, which have lower crop loss levels than the low-potential areas (De Groote, 2002). Unlike the former project (the program that targeted control of *Ch. Partellus*, which introduced only one larval parasitoid, *C. flavipes*, and had a five-year lag before the parasitoids significantly reduced pest densities), the present project released two species. *T. isis* was recovered in two subsequent seasons following the first release at Taita Hills, indicating that it had established itself (Bruce, ICIPE, unpublished data), while for *C. sesamiae* additional monitoring is required. A 10-year period was therefore considered, by the end of which the parasitoid was projected to have reduced output losses to insignificant levels.

The benefit-cost ratio calculated for this program was larger than that obtained by other biological control programs in Africa, for example the coffee mealybug program, with a ratio of 202:1 (Huffaker et al., 1976); the cassava mealybug program, with a ratio of 149:1 (Norgaard, 1988); the mango mealybug program in Benin, with a ratio of 145:1 (Bokonon-Ganta et al., 2002); the program for the control of water hyacinth in southern Benin, with a ratio of 124:1 (De Groote, Ajuonu et al., 2003); the cabbage diamondback moth program in Kenya, with a ratio of 24:1 (Macharia et al., 2005); and the control of stemborers using *C. flavipes* in the low potential maize growing areas of Kenya (Kipkoech et al., 2006). Worldwide, the highest benefit-cost ratios of biological control programs were 12,698:1 and 11,464:1 for the control of Citrophilus mealybug (*Pseudococcus fragilis*) and Klamath weed (*Hypericum perforatum*), respectively, in the US (Gutierrez et al., 1999).

Because maize is a staple crop in Kenya grown by almost all households, its cumulative production volume in the high potential areas is high, at 1.7 million tons compared to, for example, 265,000 tons for cabbages (Macharia et al., 2005). Furthermore, the farm gate price of maize (US$219/ton) is also higher than that of cabbage (US$66.3/ton). It is thus not surprising – given the high maize production volume and price, and the way the present project has maximized research capacity by using infrastructure and personnel already in place in other related programs in order to share costs – that the benefit-cost ratio of biological control of maize pests is high. The high benefit-cost ratio, if the entire region where the parasitoids could be established is considered, shows that the benefits of the biological control are positively scale dependent, while the cost is generally scale irresponsive. When the entire country was included in the analysis, the costs of biological control increased by 12.8%, while the benefits increased on average by over 3,000%. The same trend was found with the internal rate of return (IRR), where, with the limited area of analysis, rates of 0 to 14.3% were obtained compared to the IRR of 120.4 to 192.0% obtained when the entire moist transitional and highland area of Kenya was included in the analysis. The IRR, which is over 10 times higher than returns to many public or private investments in Kenya, shows that the results are expected to be positive under all likely economic situations. These results corroborate results by Karanja et al. (2003), who observed that technologies in high potential areas are likely to have substantially greater positive impacts on aggregate farm profits and incomes.

4. Conclusion

The main objective of this study was to determine the economic returns to biological control of cereal stemborers in the moist transitional and highland zones of Kenyan. It was only in conditions where the parasitoids would not establish themselves that the project would realize a negative NPV. With a pessimistic assumption that only one parasitoid will establish itself in a limited area of Taita Hills and achieve 10% pest suppression after 10 years, the biological control program still gives positive returns to investment.

The estimated benefit-cost ratio, IRR and NPV demonstrate the high value of just a few of a string of benefits attached to biological control. The importance of maize to small-scale farmers in the area means that the loss of maize output to stemborers has severe economic and social effects on the local community, such as reduced revenue and household food per capita. This importance is underlined by the fact that most farmers plant maize during all the cropping seasons, regardless of the availability of higher value crops such as vegetables. This study indicated the potential of biological control for contributing to the welfare of the local community, with no investment on the part of the farmers. It also showed that there are occasional cases where farmers overuse pesticides. Because insects often develop insecticide resistance (Brattsten et al., 1986) and because of the health risks of improper use of pesticides, biological control is expected to mitigate various costs accruing from use of pesticides.

The technology is particularly attractive for solving the classic policy objective of equitable distribution of income. Kenya has a mixture of large-scale farmers who are resource endowed and poor small-scale farmers who use low levels of purchased inputs, including pesticides. Since most of the technologies developed in the market require farmers to incur a cost in order to benefit from the technology, they thus benefit only the well-endowed farmers who have the means to buy the technologies. The biological control program, however, is expected to first benefit the small-scale farmers who do not use pesticides, and the benefits accruing to them will narrow the gap between the rich and the poor. Moreover, the ongoing reduction in stemborer damage will motivate large-scale farmers to reduce their pesticide use, which will lead to an increase in the benefits of the program in this regard.

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