The economic value of releasing parasitoid for the control of maize stemborers in East and Southern Africa

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Abstract

The braconid larval parasitoid *Cotesia flavipes* Cameron was introduced from Asia into East and Southern African region starting in 1993 to control the invasive exotic maize stemborer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae). A quasi-experiment was constructed using farmers that applied sublethal dosages of pesticide in assessing the counterfactual for the impact of the establishment of the introduced parasitoid in five countries in the region. Logistic regression method was used to estimate the probability that farmers' would inadvertently exclude parasitoids in their maize field. Thereafter the propensity score matching method was used to find corresponding farmers excluding parasitoids among those who did not for yield comparison. The geographical information system (GIS) application software with ecological, agricultural and land cover data bases was used to classify and select the ecological zones surveyed, to estimate the spread of the parasitoid. Results indicate a rampant use of pesticides at sublethal dosage across the countries. Intensifying maize production by is likely to improve the effectiveness of parasitoids. The annual value of the economic impact of the introduced parasitoid is estimated to range from US $ 43 m – 76 m. It is apparent that the appropriate matching algorithm depends on the distribution of yield data available. The study demonstrates the potential of using biological agents to improve yields among the poor households who can seldom afford purchased inputs.

Introduction

The invasion of the exotic stemborer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) to the African ecologies from Asia caused losses in maize output of up to 70% (Kfir 1994) depriving millions of adequate staple food while causing ecological harm by displacing indigenous stemborers (Kfir, 1997; Zhou et al., 2001). In an attempt to abate maize yield losses, the International Centre of Insect Physiology and Ecology (ICIPE) initiated a biological control (BC) program to reunite the exotic pest with its co-evolved natural enemies in the early 1990s. The larval parasitoid *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) was introduced from Asia into Kenya and was released at the coast in 1993. Since then, *C. flavipes* populations had decreased by around 70% (Jiang et al. 2006). An economic impact study in Kenya calculated a benefit-cost ratio of the project of 19:1 (Kipkoech et al., 2006), with forecasted economic benefits in the order of US $ 183 million for the 20 years following the release of *C. flavipes*. In the past six years, the parasitoid has been released and became permanently established in 9 more countries in the East and Southern Africa (ESA) region, namely Somali, Zimbabwe, Zambia, Madagascar, Malawi, Mozambique, Uganda, Ethiopia and Tanzania (Omwega et al, 2006).

The establishment of *C. flavipes* has been documented for several countries (Omwega et al., 2006), but with the exception of Kenya (Kipkoech et al., 2006) there has been no attempt to economically evaluate the impact of the establishment of the parasitoid. Economic impact assessment attempts to compare the situation 'with' the intervention program to a situation of 'without' the program (Baker 2000). Because the introduced parasitoid is highly specific to stemborers (Ngi-Song and Overholt 1997), non-target effects of the parasitoid in the African environment are minimal. Thus the main costs relate to the release of the parasitoid while the main benefits are the yield loss abated by the establishment of the pest's natural enemy.

The main problem encountered in impact assessments is the determination of the counterfactuals, namely 'What would be the maize output, if the parasitoid had not been introduced in the region?' For the present study, baseline data on yield losses and the temporal changes in maize yield loss abated attributable to the establishment of the parasitoids in the different countries are largely missing. Thus in this paper, we had to find a way to impute the value of the BC program among maize farmers in five countries of the ESA region (Malawi, Mozambique, Uganda, Ethiopia and Tanzania) by comparing the value of the maize output of farmers, who inadvertently exclude parasitoids in their maize fields by applying sublethal dosages of pesticides with that of farmers who do not use pesticides at all and thereby allow the parasitoids to survive and exert control of the pest.

Because of the 'public good' nature of BC, it is not easy to distinguish users of biological control from non-users. Low rates of pesticides have been shown to eliminate parasitoids without killing the pest (Neuenschwander et al., 1986; Cugala 2006). Thus, for this paper, farmers who use lower than the recommended rates of pesticides were identified and used as the control group. The propensity score matching (PSM) method (Rosenbaum & Rubin 1983) was then used to create counterfactuals by constructing a quasi exclusion experiment.

Strategies for pest control and their implication in maize production

Integrated pest management (IPM) programs for controlling crop pests' aim at using various control techniques in a compatible manner and at the same time minimizes the use of pesticides. However, without proper farmer training, the use of pesticides and natural control of pests are not compatible and are mutually exclusive. Studies have shown that farming households often do not adhere to label specifications and apply pesticides beyond or below the economic optimum around the world (Shankar and Thirtle 2005). While it may seem obvious that the lack of adequate cash limits farmers' ability to apply pesticides at required dosages, factors endogenous to the farming households such as the desired maize produce quality and farmers' socio-economic status may influence the household decisions to use pesticide and the rate of application. When stratifying farmers into those inadvertently excluding parasitoids and those who allow parasitoids to control the pest and comparing their yield difference directly we presume that all farmers produce under similar conditions, and as such the difference in yields is as a result of the parasitoid's action, which, however, may not be true. Because of endogeneity in the faming environment, it is possible that those who apply pesticides at lower than the recommended dosages are also likely to apply less of other inputs. Consequently, if those excluding the parasitoid experience lower maize yield, this may not only be due to increase in pest incidence resulting from the exclusion of the parasitoids, but could result from the combination of increased pest incidence and low input use.

The technological packages for pest control disseminated to farmers, though often similar, are adjusted to differences in the development of infrastructure (input and output marketing and farmers education services), human capital (education level, income sources, farming experience and technical skills) and their micro-environments the farmers experience. Factors such as household income, farmers' education and gender issues determine the pest control strategy. Consequently, farmers still obtain less than optimal yields because the pest control strategies work differently under different farm management.

The PSM technique accommodates the heterogenic nature of the faming environment and corrects for endogeneity in determining the match for the respective farmers who inadvertently exclude parasitoids in their farms among those who apply no pesticides and allow for maximum pest suppression by the parasitoids.

Materials and methods

Data sources

Two data sets were used in this study. The first set was obtained from a cross-sectional household surveys carried out between September 2007 and April 2008 in the five countries (Mozambique, Malawi, Uganda, Tanzania and Ethiopia). All the areas surveyed were below 1500 m above sea level, where *Ch. partellus* is the main maize pest (Ingram 1958, Nye 1960, Seshu Reddy 1983, Zhou et al., 2001) (Figure 1b). A multi-stage random sampling procedure using administrative divisions was used for selection of the sampling villages. The sampling units, i.e. maize producing households, were chosen using the systematic random sampling procedure from a list of farmers in the randomly selected village. Data collected included maize output, maize variety grown, input use level (inorganic fertilizers use, N and P), pesticide type and quantity used, labor use in maize production, the cropping system, proportion of land under maize, management of the pest habitat and the farmers' perception of the role of natural enemies. The data was used to characterize farming households and to implement the PSM to assess the yield loss abatement attributable to the introduction of *C. flavipes*.

The second set included data from previous surveys of maize fields that together with the spatially distributed rainfall and temperature data, was used to determine the *Ch. partellus* niches per country, the probability of establishment of *C. flavipes* (that correlates with the effectiveness of the parasitoid), and to estimate the maize area and production in each of the niches. The maize production information is necessary to quantify the impact of the parasitoid because the value of yield loss abated by the parasitoid is directly related to total maize production. Because maize production information is given per administrative divisions in national statistics, the information may not conform to the distribution of parasitoids and the pest maps. The effectiveness of the parasitoid in the present study was modeled to correlate with the probability of parasitoid establishment. The costs of the biological control in the region were obtained through analysis of the cost estimates of the BC program of ICIPE.

Propensity score matching

The counterfactual for the impact of establishment of *C. flavipes* is evaluated by considering the outcome of the possible, inadvertent exclusion of the parasitoid by each individual farmer. There are two possible outcomes in the treatment by individual *i,* D_i equals one if farmer *i* excluded the parasitoids in his maize field (participant) and D_i equals zero if the farmer did not use any pesticides in his farm (non participant), where $i = 1,2,\ldots,N$, N denotes the total sample population. The third group of farmers applying pesticides at recommended or more than the recommended rates (using the label instruction for pesticide concentration) was ignored because it comprised only about 2% of the farmers across the countries. Thus for the present study, a farmer *i* is either benefiting from the introduced parasitoid or not, the latter being the counterfactual. The effect of excluding parasitoids by farmer *i* is given as $T_i = Y_i(1) - Y_i(0)$, where $Y_i(0)$ and $Y_i(1)$ are the average yields of the farmers excluding parasitoids and those who do not, respectively. Taking the mean outcome of the yield differences between participants and non-participants as an approximation of yield gains of BC is not advisable, since participants and non-participants usually differ even when parasitoids are not excluded leading to a 'selection bias'. The propensity score matching technique that gives the difference in the yield over the common support[1] weighted by the propensity score distribution of farmers applying sub lethal pesticide rates ($D_i = 1$). Thus, the propensity score for subject *i*, is the conditional probability of being assigned to treatment $D_i = 1$ vs. control $D_i = 0$ given a vector x_i of observed covariates: $e(x_i) = pr(D_i = 1 \mid X_i = x_i)$, where it is assumed that, given the *X's* the D_i*'*s are independent. From the survey data, the propensity scores is estimated from observed data, using logistic regression as below: $\log[\frac{e(x_i)}{1-e(x_i)}] = \log[\frac{\Pr(D_i = 1 \mid X_i = x_i)}{1-\Pr(D_i = 1 \mid X_i = x_i)}]$. The nearest neighbor with replacement technique is used to match individual farmers excluding parasitoids with individual farmers who rely on the biological control.

The average difference in maize yield among farmers who excluded parasitoids and those who did not (y) was estimated as $y = (Y_p - Y_{wp})/Y_{wp}$, (where Y_p is the yield of farmers relying on biological control and Y_{wp} is the yield of farmers excluding parasitoids). Thus, for every country, the yield attributable to the release of parasitoids was computed as $(Q \times y)/(1+y)$; Q is the quantity

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[1] Two assumptions are made when implementing PSM; 1) the conditional independence assumption assumes that given a set of observable covariates X which are not affected by treatment, potential outcomes are independent of treatment assignment and 2) the common support (overlap condition) assumes perfect predictability of *D* given *X* such that persons with the same *X* values have positive probability of both being participants and non-participants (Heckman et al 1999).

of maize produced in the areas, where *Ch. partellus* is the important maize pest and the probability of parasitoid establishment exceeds 0.4 (Figure 2d).

Estimating maize production, stemborer and parasitoid distribution

GIS application software with databases for the climate, land elevation, agricultural production, and land cover of each country was used to classify and select the ecological zones surveyed, estimate the spread of the parasitoid, and to estimate the maize area under the spread of the parasitoid. The generalized additive model (Hastie & Tibshirani 1986) with a binomial distribution and logistic link function was used to relate the probability of occurrence as a function of climatic predictors (mean annual temperature, mean temperature of the coldest month, the annual precipitation and a moisture index (PET/mean annual rainfall). Model selection followed a stepwise algorithm based on Akaike's information criterion (AIC) that operates via backward stepwise elimination from an initial full model. We used splines as smoothers, with up to four degrees of freedom allowed in the stepwise procedure, as set by default in the program GRASP (Lehmann et al., 2002). The agreement between predictions and observations was assessed using the standard area-under-the-curve (AUC) measure of a receiver-operating characteristic (ROC) plot (Fielding & Bell 1997) and its cross-validated version (AUC_{cv}). Values of AUC vary between 0.5 for an uninformative, random model and 1 for a model with perfect discrimination. Cross-validation was performed by splitting the data set into five partitions (5-fold CV) and re-estimating the model coefficients at each loop that yielded AUC values of 0.79 and 0.80 for cross-validation.

The Geo-statistics program capitalizes on the correlation between observations to interpolate the attribute of interest and to delineate areas with high pest infestation in the areas where the introduced parasitoid established. Cross tabulation involving a cell-to-cell map comparison between parasitoid distribution and maize growing areas maps for each country was conducted to generate a table with areas of similarity, i.e., cells that have the same probability of occurrence class, and dissimilarity, i.e., cells that have different probability of occurrence classes in each of the maps. The area under maize in every region was obtained and multiplied by the average maize yield calculated from the survey data to obtain the country's maize output in the areas of interest i.e. where *Ch. partellus* is important and *C. flavipes* has a high probability of establishment.

Results and discussions

Farmers in all the five countries allocated large proportions of their land to maize production (Table 1). With the exception of Uganda, most farmers do not plant certified seeds. Hybrid seed was planted by 31.4 to 69.6% of the farmer. Compared to the other countries, a high proportion of farmers in Malawi applied pesticides and inorganic fertilizers. In all countries, farmers applied inorganic fertilizers to their maize crops with the highest percentage in in Malawi (55.6%). In Malawi, the high percentage of farmers (>43%) applying pesticides and fertilizers was attributed to the input subsidies implemented in that country, which allowed farmers to purchase inputs at subsidized rates. Most farmers growing maize in areas with cash crops such as cotton used the cash crop pesticides in maize. Farmers, who applied less that the recommended rate of pesticides, reported pest infestations even after applying the pesticides and thus were likely to have excluded the parasitoids or the pesticides did not work (Table 2). In all five countries, most households interviewed relied on agriculture for their income. The average age of the family household ranged between 43.4 and 49.7 with over 58% of the households headed by males. Across all countries, farmers who planted hybrid seed and/or applied inorganic fertilizers obtained significantly higher yields.

Between 33.8 and 48.5% of farmers in all the countries ranked soil fertility, pests and erratic rainfall as the main constraint to maize production, and the rankings followed the same trends in all countries. Farmers in the river basins along the Shire valley in Malawi reported that flooding was occasionally the main problem. Wild animals also destroyed farmers' crops in fields near forests. The main maize pests reported in the countries were rats, cutworms and stemborers. Like in Kenya (Kipkoech et al 2006), most farmers, could not correctly identity the symptoms of stemborer attack.

Logistic regression results

Table 3 shows the results of the logistic regression model run to determine the factors that influence farmers to use pesticides at sub-lethal rates. The significant factors vary among the countries. The coefficients from a logistic regression equation represent the change in log odds of the farmer excluding the parasitoids in their maize fields in response to per unit change in the independent variables. The independent variables with positive coefficients show that the log odds (and, therefore, the probability) of the variables increases with an increase in the value of the variable. The signs of the explanatory variables differed among the countries that signify the difference in the socio-economic conditions under which maize is produced. The proportion of land under food crops and the farmers' perception of pest attack during the preceding season (risk) were significant factors in all the countries and had a positive sign in all countries except for Mozambique. For the risk factor, the positive sign of the farmers' perception of the pest situation during the preceding season shows that when farmers perceived a high pest infestation, they are likely to apply pesticides in the following season. The increase in probability of pest exclusion could be a manifestation of lack of cash outlays and farmer education necessary for proper application of pesticide. The coefficients of availability of off-farm income and availability of farm employees had negative signs, which mean that farmers with off-farm income and farm employees were not likely to use pesticides at recommended rates. It is plausible that given low incomes in the region, availability of off-farm income and hired employees would partially mitigate the shortage of capital and labor. The education variable had a positive non-significant sign in all countries. Education is expected to reduce the risk aversion behavior of farmers thus increase use of pesticides but because of cash constraints faced by most African farmers they are likely to apply pesticides at rates lower than that recommended.

Yield losses abatement, savings and the cost of the BC program

Results in the last section of Table 1 show that the per country yield loss abatement attributed to the establishment of the parasitoids ranged between 5.1 and 25.7 depending on the matching algorithm used. Overall, using Mahalibois with replacement matching algorithm gave higher yield loss abatement percentage than caliper method. This could be attributed to the lower number of farmers who excluded pesticides and obtained lower yields and because the algorithm could match one user of pesticides with several non-users that could lead to overestimation of the yield loss abatement attributable to the parasitoid. The total area under the spread of the parasitoid in the region (Figure 2c), the physical quantity and value of maize produced per country in areas overlapped by the spread of *C. flavipes* (Figure 2d) is given in Table 4. The total quantity of maize produced in the area during 2007 main season is estimated to be 6.7 million tones valued at US $ 1.5 billion using the maize average market price obtained from the survey of US $ 216/ton.

The total annual benefits of the biological control in the five countries ranged from US $ 43 m – 76 m. The present value of cost (compounded at a rate of 10% relative to the base year of 2007 when the program was economically evaluated) incurred in establishment of the parasitoid to date is US $ 17.7 million, all of which was incurred by donors through ICIPE. BC of *Ch. partellus* occurred at no costs to the farmers in the countries. The highest costs of BC incurred in Nairobi between 1993 and 1997 for the purchase of equipment, and during initial studies (e.g. non-target species effects) required to comply with the FAO code of conduct for release of exotic parasitoids, mass rearing and release of the parasitoids. Using the one-year value of yield loss abated the internal rate of return range from 10% to 16% while the benefit-cost ratio ranges from 2.4-4.3 depending on the matching algorithm used.

Discussion and conclusion

The area of establishment of the parasitoid varied across the countries and agroclimatic zone in a country. In Uganda and Malawi, the modeling of the parasitoid establishment showed that although the parasitoids spread across all the agro-ecological zones, there was no area with a high probability of parasitoid establishment. However, using PSM, these countries had the highest yield loss abatement compared to the other countries. The semi-intensive system of agriculture practiced in the two countries (for example along the Shire valley in Malawi) where maize is produced in more than season per year, would favor pest development and consequently high location efficiency of the pest by the parasitoid.

Basing the impact study solely on the effect of a natural enemy is a simplification of the real situation. For example, various studies have showed that soil fertility has a considerable effect on both the pest and plant yield. Thereby pest infestations increase, while yield losses decrease linearly with increasing soil fertility (Sétamou et al., 1995; Mgoo et al. 2006; Wale et al., 2006; Chabi-Olaye et al. 2008). Furthermore, in Africa, cereals are usually intercropped with others cereals or crops that are non-hosts to stemborers. Some mixed cropping arrangements have been found to drastically reduce borer densities on cereals (Schulthess et al. 2004; Chabi-Olaye et al., 2005; Wale et al., 2007; Songa et al., 2007).

The PSM method incorporates the observable socio-economic attributes of the household while all the natural factors and farm management practices are captured by the yield difference obtained by the farmers' categories. The CMA and MWR matching algorithms estimated average yield loss abatement by the parasitoid of 13.5 and 16.0% respectively. It is expected that by allowing replacement using the MWR, the average quality of matching increases and bias decrease (Caliendo and Kopeining 2005). In our case the two matching techniques overall had similar results but variable results across the countries. It seems therefore that the matching algorithm appropriate depends on the distribution of data at hand.

Complete economic impact assessment of BC programs is uncommon. This is because BC projects lead to numerous direct and indirect benefits and costs that affect many facets of the economy and, thus, to assess the impact only in terms of yield loss abated is an underestimation. In order to carry out a complete impact assessment, more data is required, which in our case was not available. In Africa, farmers seldom keep farming records and the impact of pests can only be measured qualitatively from information farmers can recall. Benefits of the biological control including the impact of increase of maize produced on the health of farming households, nations' savings on importation of maize and maintaining of health environment through minimizing use of chemical pesticides are difficult to measure.

A question that ought to be answered in this analysis is whether biological control has had sufficient pest suppression for farmers to solely rely on. Conventionally, procedures for making decisions about use of chemical insecticides involve comparing an estimate of the density of insects in the field with a threshold density, where the threshold density is taken to be the density at which the value loss due to insect damage exactly equals the cost of applying the insecticide. This study has shown that, the decision to use chemical pesticides depends on farmers' expectation on the pest situation and availability of cash outlays. Although the threshold density is not known, the reduction in the stemborer density through parasitism is expected to influence farmers' perception on the expected impact of pest leading to a reduction in pesticide use.

Most impact assessments of pest control using parasitoids are based on parasitism rates and corresponding pest reductions. However, the present study involved a wide geographic area where data on parasitism rates and temporal changes in pest densities was absent. Thus, the yield loss abatement assessment was based on sublethal dosages of pesticides using a meta-analysis.

The PSM method is most appropriate for our analysis because it combines the observable attributes in getting a match for farmers excluding the parasitoids from those who allow parasitoids to control the pest in their maize fields. Interactions in the ecosystem particularly for pests attacking domesticated crops could be influenced by other factors such as onset of rains and farming household factors that are remotely linked to ecosystem functions. The rate of parasitism and the quantity of maize output lost to stemborers remains a probabilistic factor and fluctuate depending on natural factors and household activities. Use of fertilizers in maize production for example would increase stemborer density but the yield losses to the pest will be low because the plant vigor could compensate the effect of the pest (Wale et al 2006). Analyzing the impact of BC using PSM on annual basis provides the most accurate estimate of the impact since no assumptions are made on factors that influence maize yield such as the environmental factors and pest densities by using the actual, though indirectly. The input use rates and the farming household characteristics are factored in to the analysis through the matching procedure.

The results are expected to vary with annual loss levels conditioned on the seasonal fluctuation of stemborer density. If the pest density increases, the yield loss to stemborer increases but the benefits of BC will increase because of the efficiency of the parasitoid locating the pest and the proliferation of the parasitoid population. Under these circumstances, the percentage of yield saved reported in table 1 will change.

The establishment and effectiveness of parasitoid seem to be influenced by the scale of maize production. Countries that produce more maize have higher impact of the parasitoid. With no effective pest control measures, pest density is expected to increase with increase in maize production because of the abundance of food for the pest that leads to enhanced pest location efficiency by the parasitoid. This finding strengthens the classical notion of comparative advantage and economies of scale the lead to optimization of benefits. The study demonstrates the potential of using biological agents to improve yields among the poor households who seldom afford purchased inputs. Because the model used exhibit linear model feature, benefits of the BC are expected to vary linearly with changes in parameters such as changes in maize prices and quantity of maize produced.

The economic impact of biological control of stemborers using *Ch. partellus* had been analyzed before for Kenya (Kipkoech et al 2006) that estimated benefits of up to US $ 187 million over a 20-year period. This result roughly gives an average of about US $ 9.4 million per year, which compares well with the current results given the size of the area currently under consideration. The value is expected to trickle in perpetuity given that now, the parasitoid is permanently established in the countries.

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Table 1: Household characteristics and use of farming inputs and maize yield

Country	Mozambique	Malawi	Uganda	Tanzania	Ethiopia
% farmers planting certified varieties	31.2	43.0	70.1	59.8	4.9
% farmers applying pesticides	13.6	38.1	5.8	12.1	9.9
% farmers using organic fertilizers	13.0	86.6	35.8	24.9	23.1
% farmers using inorganic fertilizers	1.0	55.0	16.1	1.2	3.2
% farmers with off-farm income	30.8	40.5	46.4	41.4	18.8
Proportion of male headed households	59.1	63.6	86.5	60.3	98.4
% area under maize to total crop area	64.9(28.5)	30.0(10.2)	33.8(16.4)	72.9(27.1)	13.7(6.6)
Average age of household head	49.7(15.1)	42.7(16.2)	40.5(13.9)	47.3(15.4)	41.5(13.9)
Farmers' category	Average maize yield (tons/ha)				
No pesticides (biological control)	1.03(1.24) [265]	1.67(1.41) [180]	1.36(0.83) [265]	1.29(1.22) [271]	1.33(1.83) [279]
Sub lethal rates (exclude parasitoids)	0.65(0.49) [42]	1.17(0.85) [111]	1.15(0.61) [42]	1.18(1.25) [36]	1.12(0.93) [30]
Apply pesticides at recommended rates	1.06(0.34) [5]	1.30(0.91) [6]	1.37(0.51) [7]	1.36(0.29) [5]	- [0]
Avarage for all farmers	0.98 (1.17) [312]	1.48(1.24) [297]	1.33(0.80) [314]	1.28 (1.21) [312]	1.31(1.76) [309]

Values in the parentheses are the standard errors; Values in the box brackets are the sample sizes;
- Non of the farmers applied pesticides at recommended rate

Table 2: Percentage of farmers reporting pest attack after application of pesticides

Farmers' category Country	Sub lethal rates (exclude parasitoids)	Apply pesticides at recommended rates
Mozambique	86.4	20.0
Malawi	74.2	16.7
Uganda	63.2	14.3
Tanzania	66.4	20.0
Ethiopia	71.1	-

- Non of the farmers applied pesticides at recommended rate

Table 3: Factors influencing use of pesticides at pest sub-lethal rates

Variable	Mozambique	Malawi	Uganda	Tanzania	Ethiopia
Intercept	5.35*	-0.56	15.19*	6.92*	0.44
	(1.46)	(0.94)	(10.50)	(1.76)	(1.53)
Proportion of crop area under maize	-0.73	-0.03	-5.40*	0.37	1.36*
	(0.83)	(0.66)	(2.06)	(0.84)	(0.90)
Area allocated to food crops (ha)	-0.09	0.19*	-0.09	0.03	-0.01
	(0.06)	(0.09)	(0.17)	(0.13)	(0.01)
Farmers perception on pest infestation in season t-1[a]	-0.99*	0.10	1.22*	0.01	-1.93*
	(0.27)	(0.13)	(0.46)	(0.17)	(0.41)
Maize taste quality preference (taste influence by stemborer affected grains)	-1.83*	-0.27	-0.70	0.92*	0.36
	(0.43)	(0.41)	(0.67)	(0.56)	(0.83)
Physical appearance of maize produce (color influence by rotten grains)	-0.78	0.50*	-1.09*	1.58*	0.06
	(0.54)	(0.31)	(0.65)	(0.59)	(0.73)
Age of the household head	0.02*	-0.01	0.02	0.001	0.01
	(0.01)	(0.01)	(0.04)	(0.01)	(0.02)
Sex of household head	0.34	0.89*	1.77*	-0.84*	0.58
	(0.40)	(0.30)	(0.94)	(0.45)	(1.17)
Education of household head	0.06	-0.02	-0.26	-1.93*	0.44
	(0.32)	(0.21)	(0.44)	(0.52)	(0.34)
Households with off-farm income	-0.36	-0.16	-3.35	-1.17*	-0.80
	(0.43)	(0.08)	(180.50)	(0.37)	(0.65)
% output attributable to release of *C. flavipes* under different matching algorithms					
Caliper (0.4)	5.1	25.7	15.8	5.5	15.3
Mahalibois with replacement	14.2	20.4	16.5	18.8	9.9

Values in brackets are the standard errors

* Significant P<0.1

[a] Refer to the maize production season preceding the present season

Table 4: Estimated maize production statistics and value

	Estimated total area ('000 ha) under maize per country				
C. flavipes establishment probability	Mozambique	Malawi	Uganda	Tanzania	Ethiopia
0.0 – 0.2	131	339	133	664	584
0.2 – 0.4	137	177	685	538	111
0.4 – 0.6	221	41	306	400	108
0.6 – 0.8	291	17	6	265	62
0.8 – 1.0	17	0	0	17	22
Total area ('000 Ha)	797	573	1130	1884	886
Total production ('000 tons)	797	860	1469	2449	1152
Production in areas with probability of parasitoid establishment > 0.4					
Total area ('000 ha)	529	57	312	682	192
Total maize production ('000 tons)	529	86	406	887	249
	Value of yield loss abatement (US $ '000)				
CMA	5,828	4,800	13,853	10,533	8,229
MWR	16,226	3,810	14,467	36,004	5,325

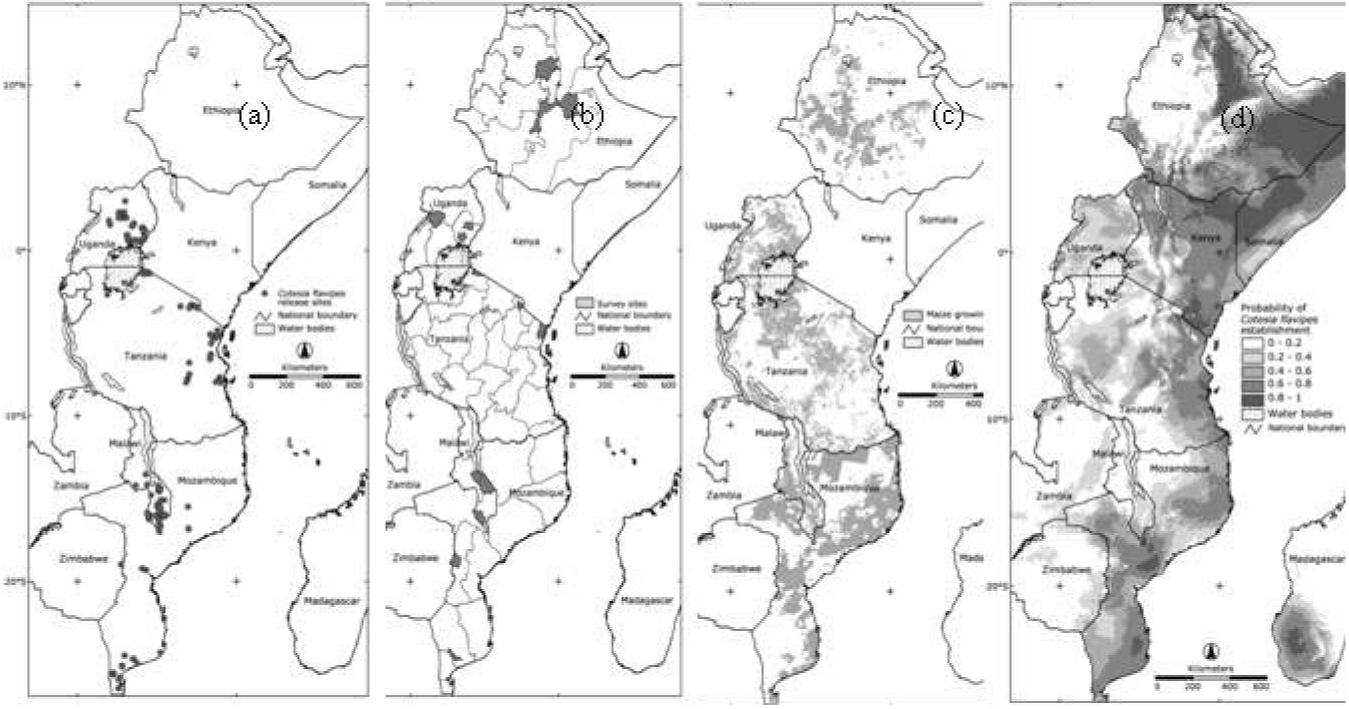

Figure 1: a) Parasitoid release sites; b) Sampling sites; c) maize growing areas; d) modeling of the spread of *C. flavipes*