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**Productivity Effects of Biological Control of Maize Stemborer Pests in
Kenya: Damage Control Function Approach**

by Soul-kifouly G. Midingoyi, Hippolyte D. Affognon, Ibrahim Macharia, and
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Productivity effects of Biological Control of Maize Stemborer Pests in Kenya: Damage Control Function Approach

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Abstract

In this study, we evaluate the productivity impacts of the biological control program (BC) against stemborers in maize production in Kenya. We use production function with damage control function framework to clearly account for the difference in yield-effects of inputs that contribute to plant growth and factors that control damage to plant. The endogeneity concern with pesticide use was accounted for by employing a two-stage least square (2SLS) estimator that subsequently allows deriving the marginal physical product. Findings from the first stage show that the presence of BC agents is associated with a decrease in pesticide use, providing insights on the potential substitution of insecticide by the biological control and the hazard-reducing effect of BC on environment. The second stage analysis show significant and positive relationships between maize production and BC suggesting the positive impact of the BC on productivity. The marginal physical product shows that bio-control contributes to substantial increase in maize productivity as each percent point increase in BC level is associated with at least 12 kg/ha gain in maize. Biological control is an advantageous and sustainable policy tool to reduce food insecurity and the potential risks on environment and human health among farmers with poor socioeconomic status.

Key words: Biological control (BC), Damage abatement model, Environment, Maize Productivity, Stemborer, Kenya

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1. Introduction

In Eastern Africa, cereals, especially maize, are among the most important and widely grown field crops primarily for food subsistence and commerce purposes. In Kenya, Maize is the most important staple food which provides about 65% of staple food calorie intake and 35% of the daily dietary energy consumption and stands for an annual per capita consumption rate of 98 kilograms (Kang'ethe, 2011; Kirimi et al., 2011; Ariga et al., 2010). Ninety percent (90%) of rural households are engaged in its production which is dominated by small scale farmers with 75% of the overall production while the remaining 25% is grown by large scale farmers (Kang'ethe, 2011). Maize is grown in almost all the existing agro-ecological zones with the higher potential in Highland tropics, Moist transitional and Mid-Altitude which cover 30 % of the total country maize area but provide 80% of the total production with a 2.5 t/ha as yield average. The lower potential part groups the lowland tropics, the dry mid-altitude and dry-transitional zones which cover 29% of the country maize area but provide just 11% of the total national production in maize with an average in yield of less than 1.5 ton/ha (De Groot et al., 2005). The trends in maize production reveals that rates of growth in maize production have not kept pace with demand, in large part driven by population growth (estimated at 2.9% per annum). The country then relies on importation which, although low, has continually been rising during recent years (Kang'ethe, 2011; Kirimi et al. 2011). Maize production growth rate averages 1.71%, of which 58% is explained by an expansion of area under crop, and a smaller, though important component (42%), by growth in national average yields (Olwande and Smale 2012).

Like in most of the Eastern Africa countries, maize cropping in Kenya is constrained by biotic constraints including insect pests and mainly lepidopteran stemborers that stand for the major injurious pests causing losses estimated in the neighborhood of 20-70% of the potential yield (Youdeowei 1989; Seshu Reddy 1990). *Chilo partellus*, *Busseola fusca* and *Sesamia calamistis* were found to be the most economically important stemborer pest in the country (Ong'amo et al., 2006). The yield losses resulting from the destructive action of these pests was reported and varied in the literature. Seshu Reddy (1985) reported the yield losses to range from 74.4 to 87.7%. Cugala (2007) differentiates between losses in research station which average 20 to 40% and in smallholder's farms that range from 50% to 100%. Odendo et al. (2003) report total loss in maize due to stemborer attacks to average 14 %, ranging from 11% in the highlands to 21% in the dry areas.

Several strategies including cultural control, chemical control (pesticide use) were developed to control these stemborers to reduce damages on maize plants. Although these appear promising not many of the recommendations have been adopted by African farmers because they seem unpractical or unattractive due to the limited management capabilities of farmers and their lack of access to adequate advisory services (Seshu Reddy, 1998, Van denBerg *et al.*, 1998). The chemical control that entails the use of synthetic pesticides to manage stemborers pest was used by very few farmers, the majority being resource-poor farmers who cannot afford pesticides. The pesticide use is also associated to externalities such as resistance buildup by stemborers with its potentially costly management, soil contamination with decreasing soil biodiversity and water contamination with health risk for human and animal (Hajek, 2004, Macharia *et al.*, 2009).

In such contexts, biological control was the most suitable and sustainable pest management option for resource-poor farmers because of the non-requirement in additional cost for farmers and its self-perpetuating features. Biological control is a component of the integrated pest management which involves the release of natural enemies of pests to reduce pest population density below a level that has no economically significant consequences for producers. The International Centre of Insect Physiology and Ecology (icipe) in partnership with National Agricultural Research Organisations (NAROs) implemented biological control of stemborers through different projects by releasing biological control agents or parasitoids (*Cotesia flavipes*, *Telenomus isis*, *Xanthopimpla stemmator* and *Cotesia sesamiae*) which are the natural enemies of up-cited stemborers in the major maize producing area in East and Southern Africa. Following the releases, post-release surveys and many studies have been carried out, reporting establishment, acceptable level of parasitism and reduction of stemborer densities (Bonhof *et al.*, 2001; Zhou *et al.*, 2001; Odendo *et al.*, 2003; Jiang *et al.*, 2006, Omwega *et al.*, 2006; Jiang *et al.*, 2008). The impact study by Zhou *et al.*, (2001) revealed that the introduction of *C. flavipes* results in pest (*C. partellus*) population density reduction by 52.94% in the northern part and 33.07% in the southern part of the Kenyan Coastal region. Although studies demonstrated the successful establishment and effectiveness in pest density population reduction, little is known about the relationship between these biological successes and gain in maize yield. Success of BC should be differentiated from its impact or its effective contribution to economic outcomes (Cock *et al.* 2015). The present study aims at examining the productivity-effect of the biological control of maize stemborer in Kenya.

To our knowledge, very few studies so far provide evidences on whether BC that has been implemented to reduce stemborers infestation and damage to maize was able to help farmers to substantially increase yield. So far, one of the rare attempts is Cugala (2007) who determined the impact of BC on yield using the field-based exclusion⁶ experiments in Mozambique. Even though, the exclusion experiment seeks to determine the intrinsic yield gain from the biological control through the experimental partial removal of natural enemy, this method allows assessing effect at plot level and is restricted to very short environment. Variations in biological and physical features in release regions, variations in types and uses of inputs, variations in agroecological zones as well as variations in farmers' skill and experiences are also some confounding factors that might influence productivity. The existing empirical evidence on productivity-effect of similar pest management technologies, especially pesticide use (Widawsky et al., 1998; Campbell, 1976 and Headley 1968), accounted for these variations using production function. Nonetheless, there is a lack of considering pesticides as damage control input and these studies found that the derived marginal product in value from their production function was higher than the marginal cost, results that would have been different if this input were considered in its right nature. Van Ittersum et al. (2013) and Zhengfei et al. (2005) distinguished between two categories of inputs in production function modeling: yield-enhancing (or standard) inputs and damage-reducing inputs. Yield-enhancing inputs are different from the damage-reducing inputs as the former (fertilizers, seed for example) intervene directly in the biological process of the plant growth whereas the later (pesticide, Integrated Pest Management) increase the share of the potential output that producers realize by reducing damage from damaging pests. This asymmetry in inputs' influence on output should be accounted for in the production process (Zhengfei et al., 2005).

In general, disease and pests management strategies have been considered as damage-abating variable in different studies (Fox and Weersink, 1995; Babcock et al., 1992, Pranetakvatakul et al., 2012). By reducing pests' densities and damage on plant, biological control is also used against plant-damaging agents and can be a perfect substitute for insecticide. This study developed a production function framework with damage abatement specification to account for the damage-

⁶ Field 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 activity occurs 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. The difference between the yield from unprotected and exclusion plot represent the yield gain due the biological control at plot level.

reducing characteristics of the biological control and then adds to the current literature on the impact of damage-reducing factors (Pranetakvatakul et al., 2012; Pemsil, 2005; Karagiannis et al., 2005; Qaim and Janvry, 2005; Shankar and Thirtle, 2005; Zhengfei et al., 2005; Norwood and Marra 2003; Huang et al., 2002)

The remainder of this paper is organized as follows. Section 2 presents the empirical framework of the production function including damage abatement models. In section 3, we present the data and area of research. Section 4 reports the results and finally, section 5 concludes.

2. Empirical approach and estimation procedure

2.1 Damage control function

When investigating productivity of production factors, the above-described difference in inputs consideration are seldom accounted for and this may be misleading because of the risks of overestimation of some types of factors and the underestimation of types of others (Lichtenberg and Zilberman, 1986; 1992; Ajayi, 2005; Pemsil, 2005; Asfaw et al., 2011). The alternative method proposed in the literature to correct this potential bias is the damage abatement framework also called damage control function framework. Following Lichtenberg and Zilberman (1986), this model is broadly expressed as follows:

$$Q = F[X, G(Z)] \quad (1)$$

This equation expresses that production (Q) can be characterized as a function of directly productive inputs (or yield-enhancing), X , and damage abatement factor $G(Z)$ defined on the interval $[0, 1]$ with extreme values $G(Z) = 0$ and $G(Z) = 1$ denoting respectively zero elimination and complete eradication of the destruction effect. Z is a vector of a variety of damage control inputs to use. Written in its simple linear form, the specification may yield:

$$q = f_1(x) + f_2(x).G(z) \quad (2)$$

The function $f_1(x)$ stands for the minimum output, and $f_1(x) + f_2(x)$ is considered as the maximum output (or the attainable output) free of the damaging pest effects. The minimum output is null in most cases and this allow to have the general expression of the function to be:

$$q = f(x).G(z) \quad (3)$$

From this equation, the marginal productivity of damage abating input can be expressed as:

$$\frac{\partial q}{\partial z} = \frac{q}{G(z)} * \frac{\partial G(z)}{\partial z} \quad (4)$$

2.2 Empirical model specification

2.2.1 Production function with damage control specification

Most of plant control strategies including pest control using the bio-agents contribute to the yield losses reduction unlike the growth-inducing input such as fertilizers, seeds, etc. Hence, assessing the productivity of biological control of maize stemborers requires the application of the damage control framework of Lichtenberg and Zilberman (1986) for which the reduced form is represented by the equation (3). Translating this equation in its empirical form requires different functional specifications for the productive input function ($f(x)$) and the damage control function ($G(z)$). The Cobb-Douglas function has traditionally and widely been used in the specification of the production function ($f(x)$) (Carpentier and Waiver, 1997; Pemsil, 2005; Asfaw et al, 2010). Under this specification, the equation (3) can be written as:

$$q = a \left[\prod_{i=1}^n (x_i)^{\beta_i} \right] * G(z_{BC}, z_{Ins}) \quad (5)$$

Or in its logarithmic form:

$$\ln q = a + \sum_i^n \beta_i \ln x_i + \ln(G(z_{BC}, z_{Ins})) \quad (6)$$

The Cobb-Douglas functional is however criticized for its lack of flexibility as it implicitly imposes some *a priori* restrictions on parameters estimation that appear untenable (Zhengfei *et al.*, 2005; Lyu *et al.*, 1984). It imposes all elasticity to be equal to one and does not allow the possibility of interaction between the input factors. The translog functional and other flexible forms have more attractive properties and do not deal with these *a priori* restrictions. We further performed Wald test that yields an F-stat statistically significant at 1% level (Table A1), confirming the selection of translog specification. For these reasons, the translog functional form has been considered in this study for the productive input function.

$$\ln q = a + \sum_i^n \beta_i \ln x_i + \frac{1}{2} \sum_i^n \sum_j^n \alpha_{ij} \ln x_i \ln x_j + \ln(G(z_{BC}, z_{Ins})) \quad (7)$$

With respect to the damage control function component ($G(z)$), different functional forms have been assumed in the literature. In the damage control framework as developed by Lichtenberg and Zilberman (1986), the damage reducing feature should be understood as a reduction proportion and then its value is imposed to lie between [0 1] interval. Number of functional forms has been cited to fit this imposition and include the exponential, logistic, Weibull and Pareto distributions (Lichtenberg and Zilberman, 1986) completed with Rectangular hyperbola, linear response plateau and Square root response plateau by Fox and Weersink (1995). The first three (exponential, logistic, Weibull) distributions are the most used in the literature (Praneetvatakul *et al.*, 2002; Pemsil 2006) and their mathematical expressions can be defined as follows:

$$\text{Exponential:} \quad G(z_{BC}, z_{Ins}) = 1 - \exp(-\gamma_1 z_{BC} - \gamma_2 z_{Ins} - \gamma_3 z_{BC} z_{Ins}) \quad (8)$$

$$\text{Logistic:} \quad G(z_{BC}, z_{Ins}) = [1 + \exp(\mu - \gamma_1 z_{BC} - \gamma_2 z_{Ins} - \gamma_3 z_{BC} z_{Ins})]^{-1} \quad (9)$$

$$\text{Weibull:} \quad G(z_{BC}, z_{Ins}) = 1 + \exp(-(z_{BC})^{\gamma_1} - (z_{Ins})^{\gamma_2} - (z_{BC} z_{Ins})^{\gamma_3}) \quad (10)$$

where z_{BC} stands for the biological control variable represented by biological control level or rate of parasitism, z_{Ins} the quantity of insecticide used in (kg/ha) and the term $z_{BC} z_{Ins}$, the interaction of the two damage control factors. $\mu, \gamma_1, \gamma_2, \gamma_3$ are the coefficients to be estimated for each of the specification.

The overall model from the two above-described functional forms for the productive input function ($f(x)$) and the damage control function ($G(z)$) can be expressed as follows:

$$\ln q = a + \sum_i^n \beta_i \ln x_i + \frac{1}{2} \sum_i^n \sum_j^n \alpha_{ij} \ln x_i \ln x_j + \sum_k^m \lambda_k d_k + \ln [(1 - \exp(-\gamma_1 z_{BC} - \gamma_2 z_{Ins} - \gamma_3 z_{BC} z_{Ins}))] + \varepsilon$$

(11)

for the exponential functional form and

$$\begin{aligned} \ln q = & a + \sum_i^n \beta_i \ln x_i + \frac{1}{2} \sum_i^n \sum_j^n \alpha_{ij} \ln x_i \ln x_j + \sum_k^m \lambda_k d_k \\ & + \ln \left[(1 + \exp(\mu - \gamma_1 Z_{BC} - \gamma_2 Z_{Ins} - \gamma_3 Z_{BC} Z_{Ins}))^{-1} \right] + \varepsilon \end{aligned} \quad (12)$$

for the logistic functional form.

The parameters β , α_{ij} , λ_k , μ , γ_1 , γ_2 , γ_3 are to be estimated. The set of variables x_i are productive input use, with $i=1$ for labor, 2 for seed, 3 for mineral fertilizer, 4 for material cost. d_k is the set of farming characteristics, region dummy and socioeconomic characteristics of the farmer with $k=1$ for hybrid variety, 2 pest pressure, 3 for the agro-ecological zones, 4 access to extension services. Z_{BC} and Z_{Ins} represent respectively the bio-control of BC variable and the quantity of used insecticide. ε stands for the error term.

2.2.2 Marginal product of the damage control agent

The marginal productivity MPV_{BC} is the increase in output arising from a marginal increase of a certain input. It is obtained by considering the first derivative of the production function with respect to that input. The general expression of its calculation is given by the equation (4) and expressed as follows.

$$\frac{\partial q}{\partial Z_{BC}} = \frac{q}{G(Z_{BC}, Z_{Ins})} * \frac{\partial G(Z_{BC}, Z_{Ins})}{\partial Z_{BC}} \quad (13)$$

Substituting $G(Z_{BC}, Z_{Ins})$ with respect to the specification of the functional form of damage abatement allows having:

$$MPV_{BC} = \frac{\partial q}{\partial Z_{BC}} = q * \frac{(\gamma_1 + \gamma_3 Z_{Ins}) \exp(-\gamma_1 Z_{BC} - \gamma_2 Z_{Ins} - \gamma_3 Z_{BC} Z_{Ins})}{1 - \exp(-\gamma_1 Z_{BC} - \gamma_2 Z_{Ins} - \gamma_3 Z_{BC} Z_{Ins})}$$

(14)

for the exponential functional form and

$$\begin{aligned}MPV_{BC} &= \frac{\partial q}{\partial z_{BC}} \\ &= -q(-\gamma_1 - \gamma_3 z_{Ins})[(1 + \exp(\mu - \gamma_1 z_{BC} - \gamma_2 z_{Ins} - \gamma_3 z_{BC} z_{Ins}))^{-1}]\end{aligned}$$

(15)

for the logistic functional form

2.2.3 Estimation procedure

In our previous development on the empirical models, the specifications do not consider one of the critical problems in econometrics and statistics which is the endogeneity of regressors in production function. Indeed, the insecticide use by farmer in our case may be endogenous to production causing the existence of a relationship between plant pests, insecticide use and crop yield (Hang *et al.*, 2002, Pems1, 2005). This causes insecticide use variable to be correlated with the production function residuals. Not accounting for this problem could lead to biases in estimates and errors in the functions interpretation even for the coefficient of biological control. To overcome this possible bias, the two-stage least squares (2SLS), as suggested in econometrics literature, was adopted. The procedure consists in using valid instrumental variables (IV) to predict the value of insecticide use through an insecticide use function in a first stage. In this stage, instrument variables that are correlated with insecticide use but not with residuals need to be chosen. In a second stage, the predicted values of insecticide use can be inserted in lieu of the insecticide variable in the final estimation of the production functions. The defined specifications for the damage production function are nonlinear and this led to use non linear least square (NLS) regression for the parameters estimation.

3. Data and survey area

3.1 Data collection and survey area

This study was conducted by a multidisciplinary team involving entomologists and economists. The aim of this study was to integrate agronomic (entomological) characteristics and

socioeconomic features in analyzing the performance achieved by farmers. Data was thus collected in different phases and include biological-based and socio-economic data in five regions including Coast, Eastern, Western, Nyanza and Rift-valley regions. In a first step, insect sampling survey was conducted by the entomologist team and help in obtaining the biological control parameters including the pest density (the number of pests per plant), the infestation rate (the proportion of infested plants by the stemborer pest) and the parasitism rate (the biological level) which stands for the variable of interest in this economic impact study.

Figure 1 about here

Household survey was subsequently conducted in the same region using the entomologists sampling frame. A sample of 600 households in forty (40) villages distributed across five (05) regions were successfully interviewed (Figure 1). A structured questionnaire was developed and pre-tested before being used to collect the household and plot level data. The questionnaire was administered by a group of well-trained enumerators made of post-graduate students and experienced officers from the Ministry of Agriculture. The enumerators' selection was conditional on their understanding of the spoken local language and their knowledge of the farming system of the selected regions. The questionnaire contains questions regarding perception and knowledge of the stemborers and the released natural enemies, the socio-demographic, economic and farming backgrounds of the sampled households and plot-level characteristics which include inputs and outputs quantities and prices during the cropping season 2014-2015.

3.2 Overview on the variables used in the models

The quantitative and qualitative variables used for the estimation of insecticide use and damage control models are summarized in the table1. We use physical values for productive inputs and monetary value material cost. All the variables are presented with their description and quantitative variables are shown with their units, means and standard deviations. Maize yield is the dependent variable and represents the harvested quantity by the farmer per hectare. Maize yield was found to average approximately 1500 kg/ha for the sampled farms. Labor input is referred to as the number of man-days used to grow and harvest one hectare of maize land. The number of persons and duration of work of each farming operation were recorded and assuming eight hours for man-day

and using man converting factor, the total labor was calculated and averaged 136 man-days. The quantity of seed, fertilizers, insecticides used on maize field have reported and converted for one hectare. Cost variable stands the fixed cost obtained from the depreciation of all the material and tools used in maize farming during the cropping year of the surveyed period. Parasitism rate (or BC level) is biological control measure provided by the natural scientists and represented the proportion of parasitized pests at vegetative stage. Parasitism represents the biological control activity variable. Among other quantitative variables, we have experience that states the number of years the farmer has been practicing maize farming, age, number of years in schooling and insecticide price.

The models also used various qualitative variables including among others, improved varieties and agro-ecology dummy variables which were included as proxy for rainfall, temperature and altitude distribution. The highland tropical and moist mid-altitude zones are expected to be significantly positively correlated to maize productivity because of their highest rainfall level and best soil quality compared to the reference which is the lowland tropical zone. The relevance of considering agro-ecological zones as influencing factor of agricultural productivity was demonstrated in Kassie et al. (2009). Participation to training in maize, contact with extension agents, farmers' group membership as well as the perceptions of farmers on infestation level were also considered in the models.

Table 1 about here

4. Empirical results

4.1 Insecticide use function and biological control

As previously indicated, this study used two-stage least-square (2SLS) estimation because of the possible endogeneity of the insecticide use. However, verifying the necessity of sound utilization of this procedure seems important because when endogeneity is not a significant problem, the least squares estimator is more efficient than the two stages-least square (Wooldridge, 2003). To check the endogeneity suspicion about the insecticide use, we conducted a Hausman test (Hausman, 1978). This test assumes the null hypothesis of no endogeneity. The results are presented in Table A1 in appendix. Wu-Hausman F-test and the Durbin-Wu-Hausman Chi-square test gave the same

results for the test on insecticide use. Both tests yield scores that are significantly different from zero at 1% level and this suggests the strong rejection of the null hypothesis of no endogeneity. This statistically justifies the use of the 2SLS estimator.

As a first step in this BC productivity effect assessment, insecticide use function have been established through the OLS regression of the applied amount of insecticide on maize (dependent variable) over some explanatory variables such as household socio-economic characteristics (Age, schooling, experience in maize production, membership to association), the BC parasitism, the level of pest infestation (medium and high), insecticide price and the agro-ecology regions dummies.

Both linear and log-log functional specifications were estimated and the corresponding results summarized in Table 2. The log-log form shows a good explanatory power as the adjusted R square equal 0.87. Both models presenting significant *Fstat* at 1% level are globally significant and can give right to interpretation. Most of the coefficients show their expected signs in both models. According to the results, labor use is statistically significant at 5% and this means, the more labor intensive the production, the more amount of insecticide is applied. Rotation coefficient was found to be positive and significant at least at 10% denoting that the use of insecticide is higher if maize is plant on the same plot for longer period. This is in line with the disadvantage known for the monoculture practice which favor pest development which triggers the excessive use pesticide. The medium to higher infestation level is associated to higher use of insecticide. Farmers in the Agro-ecological zones 1, 2 and 3 were found to use much insecticide on maize production compare to the others.

Most importantly, in both models, the coefficient of the parasitism is found to be negative and significant at 10% level at least, illustrating an important role of the Biological Control in insecticide use reduction. This suggests that the higher the parasitism or biological control activity, the less insecticide is applied to maize. This translates that farmers who are likely to be aware of the existence of the natural bio-agents, set the use of insecticide accordingly. This is in line with the results by Asfaw *et al.*, (2011) who found a negative relationship between biological control and pesticide use in cabbage production in Kenya. These findings have many implications with respect to the role of the biological control in environment protection.

This substitutability of pesticide use with Biology control agent may entail a significant reduction in quantity of chemical used and then substantially lower the direct costs associated to plant protection. When referring to the indirect costs associated with pesticide use as human health impairments, livestock product losses, loss of beneficial arthropods and birds, pesticide resistance of pests (Macharia et al., 2011), the BC as alternative to pesticide use offers possibilities of lowering these detrimental effects on the environment and human health.

Table 2 about here

4.2 Production function with damage abatement specification

In a second stage estimation, production function with maize yield as dependent variable and the independent variables including the predicted values of insecticide use and biological control, was estimated. Results for models of conventional (no damage-reducing consideration) specifications of production function as well as for models of production function with damage abatement specifications are presented in Table 3. The most often used specification for production function in the literature is Cobb-Douglas (CD) but alternatively, we use translog for its flexibility and best comparative advantages. To ascertain this, a test was performed to find out whether translog form was appropriate than the Cobb-Douglas form. Wald test of the joint significance of interaction terms in the translog (α_{ij} in equation 7) form shows that the null hypothesis is rejected ($p=0.0042$, see Table A2 appendix) indicating that translog specifications were better than Cobb-Douglas ones in fitting the collected data. Furthermore, the results of the two types of specifications of production function show a slight improvement of the adjusted R-square⁷ for translog meaning that it best fitted the empirical data. Further, translog and CD function showed the expected signs for some productive inputs (Mineral fertilizer and seed). Most of the variables related to the farm characteristics and biological parameters are found to be statistically significant. The level of pest pressure represented by the infestation level is negative and significant at 5% level and then indicates that higher pest presence is associated with reduction in maize yield. BC variable is positive and significantly different from zero. Hence, even with the conventional production

⁷ Gayawan and Ipinoyomi (2009) empirically demonstrated adjusted R-square to the best criteria (comparatively to AIC and SIC) in the selection model based on goodness of fit

function models, maize productivity increases with the level of biological control, showing a potential positive impact of the biological control on production.

As for the production functions including damage control functions, several specifications were tested but only two (Exponential and logistic) were reported, the other not converging or yielding weird results after thousands of iterations. For both specifications, the form with and without interaction terms (respectively exponential1, exponential2, logistic1 and logistic2) have been reported. The adjusted R-square ranges from 0.5349 to 0.5575 with the higher coefficients for the exponential functional forms. However, neither exponential1 nor exponential2 present positively statistically significant coefficients for the BC and insecticide variables in the damage function and then favor the symmetric model (conventional models). Hence, only both logistic models (logistic1 and logistic2) yielded statistically significant coefficient for damage-abatement variables confirmed the theory on asymmetry in input use in production process.

Both models depict many significant coefficients with signs in concordance with prior expectations. With respect to the variables of farming characteristics, hybrid variety was revealed as an important influencing factor in maize production as its coefficient is positively and statistically significant at 1% level. This indicates that farmers performed well in term of maize productivity with hybrid varieties compared to the traditional varieties. Environment with pest pressure above the medium is associated with reduction in productivity as the coefficient of the higher pest pressure variable is negative and statistically different from zero at 5% level. Agro-ecological zones dummies display positive and significant at 1% level coefficients for Agro-ecology 6 and 3 (highland tropical and moist-mid altitude) confirming the higher potential in maize production of these regions compared to the reference which is here the agro-ecology 1 (the lowland tropics). Having been in contact with extension service is statistically significant at 1% level indicating that farmers who benefit from services of extension agents from the Ministry of Agriculture have higher productivity compared to their counterparts without access to such services.

For the damage-abatement input, in the logistic2 model, both are positive and significantly different from zero at 10% level for BC coefficient and 1% level for the insecticide. This indicates that the presence of the released BC agents is playing an important role in maize production. In other words, biological control of stemborers pests has positive impact on maize yield. This result is in line with Asfaw *et al.*, (2011) who found the same significant relationship between the reliance

on Biological control on cabbage production in Kenya and Tanzania. Evidence of increase productivity using biological control was demonstrated in many other studies on other crops (Lv *et al.*, 2010; Bauer *et al.*, 2003).

The other damage-abating input that significantly contributes to maize yield increase is insecticide use. In summary, the two damage reducing factors effectively contribute to reduction of yield loss in the studied region. But the extent of their contribution is also important to be specified in order to appreciate their *Ceteris paribus* intrinsic values and this involves the determination of marginal effect of the damage-abating inputs.

4.3 Marginal physical product of abatement inputs and damage function value

Marginal physical product (MPP) of BC and insecticide can be derived from the estimated models through equations 14 and 15. Marginal effect of a targeted variable measure the product instantaneous rate of change and will provide a good approximation to the amount of change in productivity response that will be produced by a 1-unit change in the target variables. Table 4 shows the marginal physical product for the two damage controlling agents (BC and insecticide). The MPP varies with the specification as found in many previous studies using damage abatement methodology (Pemsl, 2005; Praneetvatakul *et al.*, 2002). But when referring to the logistic1 and logistic2 models for which coefficients are significant, the MPP for BC is found equal to 12 kg/ha and 16 kg/ha respectively. This means that each change of 1% in BC level results in adding 12 or 16 kg/ha to maize yield, holding all other input unchanged or constant. Furthermore, result for the insecticide show that an increase of 1 kg results in 1201 kg/ha or 1170 kg/ha, showing the higher efficiency of insecticide use. When including the adverse effects and risks of insecticide use on environment and human health and the difficulty in affordability for small scale farmers, the cost-less BC for farmer remains the best option.

The predicted value of $G(z_{BC}, z_{Ins})$ based on the average values of the damage-abatement variables yields the damage control function term. This factor represents the proportion of the attainable production due to the use of the damage abating factors. The factor has its value bound between [0, 1]. For instance, a term of 0.94 means that the abatement factors succeed in preserving

86% of the attainable yield and the remaining 14.3% represents the uncontrolled damage. Values on this factor from different specifications are summarized in Table 4. The damage function value varies from 0.86 for logistic model to 0.94 for the exponential model. For the logistic (for which the two damage control variables were significantly different from 0), the remaining unabated yield or the actual output loss is still relatively higher (14.3%) and call for either the improvement of the BC level or other additional integrated management which should involve complementary safe control strategies.

Table 4 about here

Based on the econometric estimates of damage control function, the evolution of the damage control coefficient at different insecticide use level with and without BC was plotted (See Figure 2) to estimate the relationship between insecticide, BC and damage control. The curves were obtained holding the BC level at its average and maximum rates as shown in the figure for two logistic functional forms. The curves show an increasing trend of the damage control with the insecticide use level. The with-BC curve displays this tendency as well and thus confirms the role of intensity of insecticide and BC in yield loss reduction in maize farming. The figure also helps establish that the distance between the curves (with and without BC) reduce gradually with increasing insecticide use, translating that the yield effects would be higher with less applied insecticide. Moreover, the highest distance between the curves is at zero insecticide level, suggesting that those benefiting mostly from the BC program are farmers who do not use insecticides. This confirms the BC intervention to be mostly for small and resource-poor households. In addition, the gap is higher for the maximum BC level than the mean, meaning that higher presence of the natural enemies (higher level of biological control) is associated to higher benefit in term of yield effect.

Figure 2 about here

5. Conclusion

This study investigates on the impact on productivity to shed light on the real advantages of the biological control to resource-poor smallholders. Due to the damage-reducing feature of the biological control, the study applies damage-abatement function framework to account for asymmetry in input contribution to production function. Moreover, the analysis has consisted in combining biological, socioeconomic and farming characteristics to identify the intrinsic effect on yield due to the BC program implementation. The estimation of insecticide use function illustrated that the presence of BC agents led to reduction in pesticide use. The indirect effect associated to this advantage of BC is the potential diminution of environmental pollution risks as well as expenditures on human health. Moreover, estimation of production functions using different damage function specifications indicates that BC has had positive impact on maize output. The marginal product resulting from the models demonstrate that each augmentation of 1% in biological control level, results in abating maize losses by 12 kg/ha. These economic benefits from the BC may be higher with level of parasitism (more presence of bio-agents). This costless and self-sustain control represents the best alternative for poor farmers when referring to the expensiveness of pesticides cost. The indirect cost of the negative externalities from pesticides (potential hazards on environment and the expenditure in human health) also add to the advantages of the BC.

The actual output loss given by the high unabated proportion of 14.3% of the attainable yield confirms the incapacity of two considered damage-reducing inputs to completely abate losses in maize production. This may be explained by the fact that the objective of BC and natural enemies has never been the total elimination of pests but the regulation of density that translate into substantial yield increase. Overall, BC is an effective and environmentally friendly tool to tackle pest problems in maize production. Our suggestion is the up-scaling to other countries where stemborer pests remain major problem for maize production. Action can also be taken to increase the parasitism rate for higher impact on food security.

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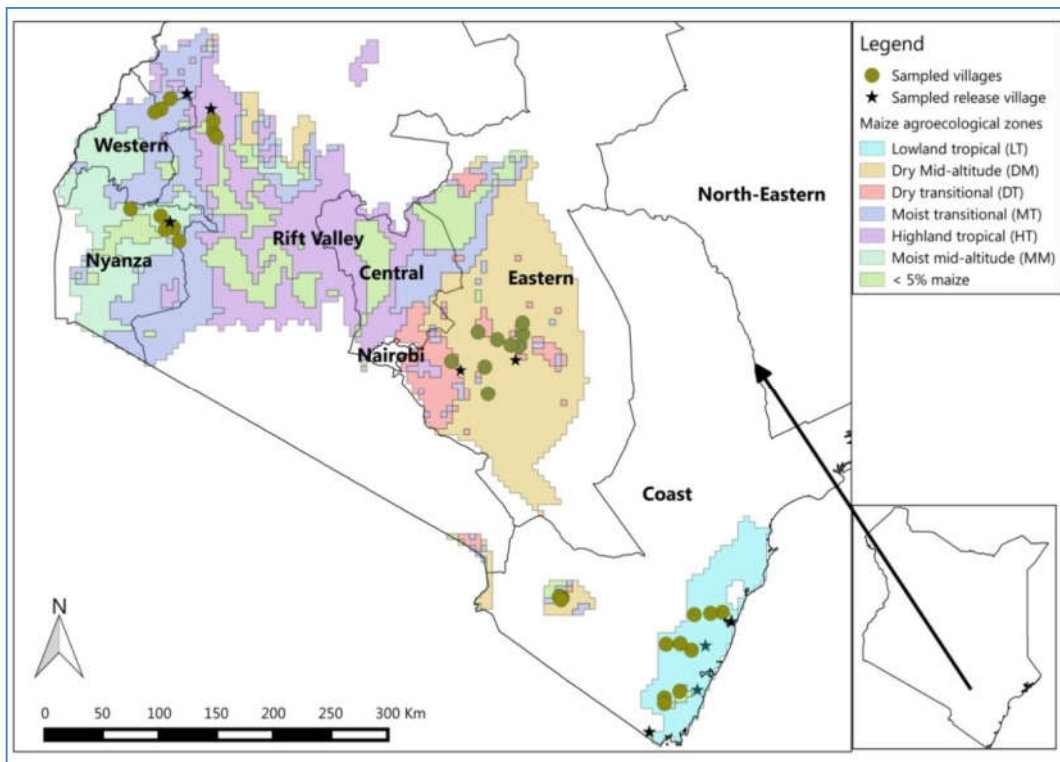


Figure 1: Distribution of sampled villages in the maize agro-ecological zones

Table 1: Overview of the variables used in the models

Variable	Variable description	Unit	Mean	Std.Dev
Output variable				
Maize productivity	Maize yield	kg/ha	1.482	1.607
Household characteristics				
Age	Age of the household head	years	48.40	14.11
Gender	Gender of the household head (1=male; 0=female)		0.72	
Education	Number of years of schooling		7.73	4.36
Experience in maize	Experience in maize production	years	20.79	13.30
Household size	Total household size (number)		6.05	2.55
Main activity crop	Crop production as main activity (1=yes, 0=no)		0.61	
Standard inputs				
Labor	Total labor used for maize production	man-day/ha	136.18	118.69
Seed	Quantity of seed used	kg/ha	21.48	17.47
Mineral fertilizer	Quantity of mineral fertilizer used	kg/ha	43.33	84.63
Capital	Production equipment	Ksh/ha	1410.14	2460.17
Damage abatement inputs				
Insecticide	Quantity of insecticide use	kg/ha	1.58	3.86
BC level	Biological control rate of parasitism	percent	23.49	18.35
Plot characteristics				
Low fertility	low soil fertility level (1=yes, 0=no)		0.18	
High pest pressure	High pest pressure level (1=yes, 0=no)		0.24	
Improved variety	Used improved maize varieties (1=yes, 0=no)		0.64	
Traditional variety	Used traditional maize varieties (1=yes, 0=no)		0.29	
Rotation	Duration of rotation on the plot (years)		1.67	2.28
Access to development services				
Extension	Distance to the extension office	km	5.62	4.68
Training	Participated in training on maize farming (1=yes, 0=no)		0.38	0.49
Association	Belong to farmers 'association (1=yes, 0=no)		0.29	

Location characteristics

Agroecology1	Lowland tropical (LT) agroecology (1=yes, 0=no)	0.30
Agroecology2	Dry Mild altitude (DM) agroecology (1=yes, 0=no)	0.27
Agroecology3	Moist Mild altitude (MM) agroecology (1=yes, 0=no)	0.13
Agroecology4	Dry Transitional (DT) agroecology (1=yes, 0=no)	0.06
Agroecology5	Moist Transitional (MT) agroecology (1=yes, 0=no)	0.15
Agroecology6	Highland Tropical (HT) agroecology (1=yes, 0=no)	0.10

Table 2: Insecticide use function

	Linear		Log-log	
	Coefficient	Std. error	Coefficient	Std. error
Age	-0.0141	0.0173	-0.0022	0.0034
Education	-0.0039	0.0430	0.0054	0.0077
Association	0.0485	0.3590	-0.0673	0.0687
Main activity crop	0.3935	0.3701	0.0584	0.0699
Experience in maize	-0.0202	0.0146	-0.0041	0.0033
Improved variety	0.1089	0.3334	-0.0034	0.0762
Labor	0.3620 **	0.1492	0.0691 **	0.0338
Rotation	0.2013	0.1225	0.0400 *	0.0216
Yield	0.8116 ***	0.2408	0.1414 ***	0.0369
Low fertility level	-0.3153	0.4052	-0.1275 *	0.0663
High infestation level	0.6999 *	0.4072	0.2270 **	0.0989
Agroecology1	3.1847 ***	0.6686	0.4458 ***	0.1655
Agroecology4	0.4150	0.4477	-0.0565	0.1129
Agroecology3	1.4048 **	0.6390	0.3660 ***	0.1135
Agroecology2	2.0244 ***	0.7224	0.2441 **	0.0979
BC level	-0.0306 ***	0.0086	-0.0034 *	0.0019
Insecticide price	0.0022 **	0.0010	0.5190 ***	0.0191
Intercept	-6.8314 ***	2.4614	-3.6621 ***	0.3317
<i>Number of obs</i>	589		589	

<i>F Stat for joint significance of the coefficients</i>	8.22 ***	157.27 ***
<i>R-squared</i>	0.21	0.8686

*Significant at 10%; **Significant at 5%; ***significant at 1%

Table 3: Production functions with and without damage-abatement functions

Inyieldha	Conventional functions		Production function with damage-abatement function			
	Cobb-Douglas	Translog	Exponential 1	Exponential 2	Logistic 1	Logistic 2
Intercept	5.4350 *** (0.2321)	5.7362 *** (0.8907)	14.3054 (75.2756)	14.8302 (15234)	7.1295 *** (0.7862)	7.0972 *** (0.7783)
Labor	-0.0364 (0.0419)	0.0215 (0.2616)	-0.0718 (0.2136)	-0.1470 (0.2220)	-0.1975 (0.2338)	-0.1929 (0.2325)
Seed	0.3482 *** (0.0520)	-0.2037 (0.3349)	-0.1496 (0.2763)	-0.1825 (0.2892)	-0.2828 (0.3028)	-0.2719 (0.3020)
Min. fertilizer	0.1065 *** (0.0210)	0.1371 (0.1320)	0.1689 (0.1112)	0.1528 (0.1166)	0.1702 (0.1226)	0.1757 (0.1218)
Cost	-0.0082 (0.0173)	-0.0304 (0.1072)	-0.0259 (0.0884)	-0.0403 (0.0928)	0.0001 (0.0973)	0.0016 (0.0970)
Training	-0.0265 (0.0863)	-0.0306 (0.0859)	-0.0019 (0.0723)	0.0227 (0.0755)	0.0263 (0.0793)	0.0242 (0.0790)
Extension	0.1800 ** (0.0894)	0.2178 ** (0.0892)	0.2035 *** (0.0753)	0.2057 *** (0.0786)	0.2255 *** (0.0823)	0.2247 *** (0.0823)
Improved variety	0.0732 (0.0822)	0.0847 (0.0821)	1.3508 *** (0.1703)	1.2161 *** (0.1520)	0.7562 *** (0.1516)	0.7543 *** (0.1514)
Agroecology6	0.7690 *** (0.1818)	0.5820 *** (0.1868)	1.5134 *** (0.1441)	1.4515 *** (0.1163)	1.0679 *** (0.1212)	1.0666 *** (0.1206)
Agroecology5	0.6422 *** (0.1464)	0.5766 *** (0.1474)	0.1769 * (0.1038)	0.1334 (0.0840)	-0.1380 (0.0917)	-0.1359 (0.0911)
Agroecology2	-0.3032 *** (0.1082)	-0.3354 *** (0.1107)	0.7128 *** (0.1388)	0.5775 *** (0.1103)	0.1365 (0.1076)	0.1421 (0.1060)
Agroecology3	-0.1189 (0.1388)	-0.2290 (0.1447)	1.1618 *** (0.1666)	1.1841 *** (0.1413)	0.9124 *** (0.1618)	0.9112 *** (0.1597)

Agroecology4	0.2195 (0.1683)	0.1836 (0.1690)	0.0022 (0.0700)	0.0136 (0.0728)	0.0482 (0.0762)	0.0484 (0.0761)
High pest pressure	-0.2045 ** (0.0808)	-0.1645 ** (0.0808)	-0.1779 *** (0.0677)	-0.1737 *** (0.0709)	-0.1882 ** (0.0742)	-0.1897 ** (0.0741)
Squared labor		0.0097 (0.0221)	0.0086 (0.0181)	0.0141 (0.0189)	0.0184 (0.0199)	0.0176 (0.0198)
Squared seed		0.1439 *** (0.0494)	0.1184 *** (0.0416)	0.1162 *** (0.0434)	0.1251 *** (0.0456)	0.1241 *** (0.0455)
Squared Min.fertilizer		0.0067 (0.0161)	-0.0013 (0.0135)	-0.0035 (0.0141)	-0.0044 (0.0148)	-0.0041 (0.0148)
Squared Cost		0.0097 (0.0061)	0.0050 (0.0051)	0.0055 (0.0054)	0.0044 (0.0056)	0.0044 (0.0056)
Labor X Seed		-0.0404 (0.0524)	-0.0359 (0.0442)	-0.0275 (0.0462)	-0.0039 (0.0484)	-0.0035 (0.0484)
Labor X Min.fert		-0.0282 (0.0179)	-0.0195 (0.0149)	-0.0169 (0.0156)	-0.0207 (0.0163)	-0.0213 (0.0163)
Labor X Cost		0.0004 (0.0227)	0.0009 (0.0184)	0.0015 (0.0193)	-0.0017 (0.0202)	-0.0014 (0.0202)
Seed X Min.fert		-0.0061 (0.0248)	-0.0192 (0.0205)	-0.0146 (0.0214)	-0.0085 (0.0225)	-0.0092 (0.0224)
Seed X Cost		-0.0231 (0.0253)	-0.0128 (0.0209)	-0.0135 (0.0219)	-0.0217 (0.0228)	-0.0224 (0.0228)
Min. fert X Cost		0.0126 (0.0092)	0.0087 (0.0077)	0.0097 (0.0080)	0.0107 (0.0084)	0.0106 (0.0084)
Labor X Insecticide		-0.0178 (0.0250)				
Seed Insecticide		-0.0079 (0.0292)				
Min.fert X Insecticide		-0.0027				

		(0.0085)	
Cost X insecticide		0.0102	
		(0.0094)	
Squared Insecticide		0.0575 ***	
		(0.0180)	
Insecticide (predicted)	0.0035	0.1292	
	0.0207)	(0.1486)	
BC level	0.0119 ***	0.0113 ***	
	(0.0021)	(0.0022)	

Damage abatement input

Intercept		0.0001	0.0001		
		(0.0965)	(0.0001)		
BC level		0.0000	0.0000	0.0129 **	0.0128 **
		(0.0024)	(0.0000)	(0.1602)	(0.0063)
Insecticide (predicted)		0.0001	0.0001	0.9958 ***	0.9256 ***
		(0.0389)	(0.0000)	(0.0059)	(0.1180)
BC level X Insecticide		0.0000		-0.0023	
		(0.0005)			
Number of obs	589	589	589	589	589
R-squared	0.4549	0.4861	0.5848	0.5931	0.5554
Adj R-squared	0.4406	0.4585	0.5648	0.575	0.5354

Table 4: Marginal physical product of abatement inputs and damage function value

	Conventional		With damage abatement specification			
	<i>Cobb-Douglas</i>	<i>Translog</i>	<i>Exponential1</i>	<i>Exponential2</i>	<i>Logistic1</i>	<i>Logistic2</i>
Marginal physical product (Kg/ha)						
<i>Parasitism (BC)</i>	0.755	0.714	3.689	3.742	11.77	16.17
<i>Insecticide</i>	3.336	121.443	4.505	5.370	1201.41	1170.10
Damage function						
<i>Value</i>			0.939	0.940	0.857	0.854
<i>Actual output loss</i>			0.061	0.060	0.143	0.146

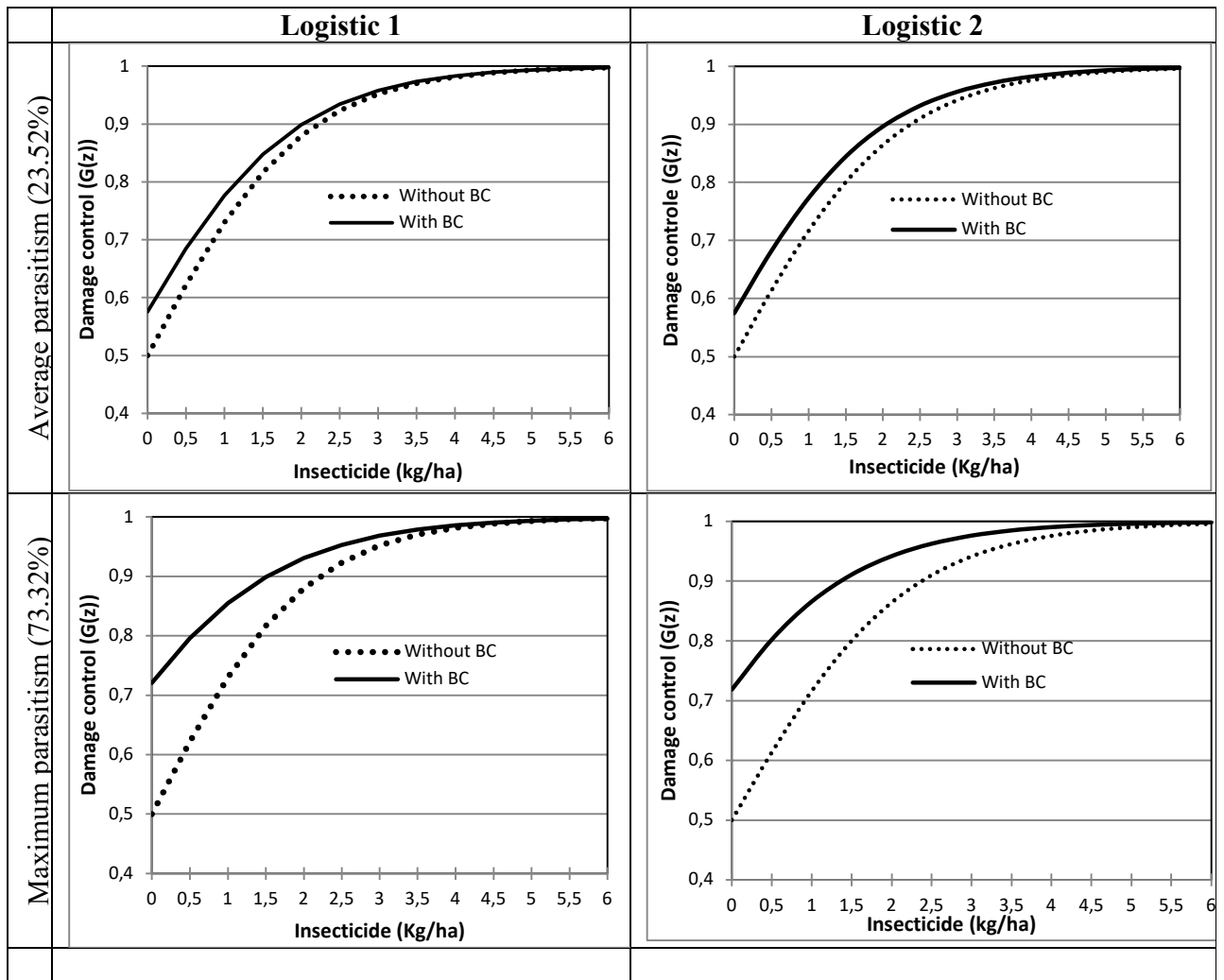


Figure 3 : Estimated relationship between insecticide use and damage control with and without Biological control

Appendix

Table A1: Endogeneity test of insecticide use

Instrumental variables (2SLS) regression

Inyieldha	Coef.	Std.Err
lnqinsecticimha1	-0.1691***	0.0492
lnlabormha1	0.0757	0.2635
lnqseedmha1	-0.1849	0.3413
lnqminfertmha1	0.1831	0.1376
lnmaterialcostha	0.0039	0.1095
training	-0.0775	0.0902
extension	0.2744***	0.0942
parasitism2	0.0082***	0.0025
varietyhybrid	0.1129	0.0861
Agroecology6	0.0253	0.2448
Agroecology5	0.0390	0.2145
Agroecology2	-0.7487***	0.1587
Agroecology3	-0.7274***	0.2077
Agroecology4	-0.3297	0.2233
pestpresurm3	-0.2065**	0.0838
lnlab2	-0.0103	0.0229
lnseedmha2	0.1651***	0.0514
lnminf2	0.0011	0.0168
lnmat2	0.0045	0.0064
lnlabxlnseed	-0.0211	0.0547
lnlabxlnminf	-0.0155	0.0187
lnlabxlnmate	0.0088	0.0231
lnseedxlnminf	-0.0198	0.0254
lnseedxlnmate	-0.0370	0.0261
lnminfxlnmate	0.0108	0.0095
cons	5.7830***	0.8888
Number of obs	586	
Wald chi2(25)	479.240	
Prob > chi2	0.000	
R-squared	0.407	
Root MSE	0.801	

Tests of endogeneity

Ho: variables are exogenous

Durbin (score) $\chi^2(1) = 18.181$ ($p = 0.0000$)
Wu-Hausman $F(1,559) = 17.8986$ ($p = 0.0000$)

Tests of overidentifying restrictions:

Sargan (score) $\chi^2(8) = 13.8886$ ($p = 0.0847$)
Basmann $\chi^2(8) = 13.4004$ ($p = 0.0988$)

Table A2: Wald test for choice between translog and Cobb-Douglas specifications

Inyieldha	Coef,		Std, Err,	Coef,		Std, Err,
_cons	5.4350	***	0.2321	5.7362	***	0.8907
lnlabormha1	-0.0364		0.0419	0.0215		0.2616
lnqseedmha1	0.3482	***	0.0520	-0.2037		0.3349
lnqminfertmha1	0.1065	***	0.0210	0.1371		0.1320
lnmaterialcostha	-0.0082		0.0173	-0.0304		0.1072
lnqinsecticimha1	0.0035		0.0207	0.1292		0.1486
training	-0.0265		0.0863	-0.0306		0.0859
extension	0.1800	**	0.0894	0.2178	**	0.0892
parasitism2	0.0119	***	0.0021	0.0113	***	0.0022
varietyhybrid	0.0732		0.0822	0.0847		0.0821
Agroecology6	0.7690	***	0.1818	0.5820	***	0.1868
Agroecology5	0.6422	***	0.1464	0.5766	***	0.1474
Agroecology2	-0.3032	***	0.1082	-0.3354	***	0.1107
Agroecology3	-0.1189		0.1388	-0.2290		0.1447
Agroecology4	0.2195		0.1683	0.1836		0.1690
pestpresurm3	-0.2045	**	0.0808	-0.1645	**	0.0808
lnlab2				0.0097		0.0221
lnseedmha2				0.1439	***	0.0494
lnminf2				0.0067		0.0161
lnmat2				0.0097		0.0061
lninsec2				0.0575	***	0.0180
lnlabxlnseed				-0.0404		0.0524
lnlabxlnminf				-0.0282		0.0179
lnlabxlnmate				0.0004		0.0227
lnlabxlnqinsec				-0.0178		0.0250
lnseedxlnminf				-0.0061		0.0248
lnseedxlnmate				-0.0231		0.0253
lnseedxlnqinsec				-0.0079		0.0292
lnminfxlnmate				0.0126		0.0092
lnminfxlnqinsec				-0.0027		0.0085
lnmatxlnqinsec				0.0102		0.0094
Number of obs	589			589		
F(15, 573)	31.88	***		17.6	***	
R-squared	0.4549			0.4861		

Adj R-squared 0.4406 0.4585

test lnlab2 - lnmatxlnqinsec

- (1) lnlab2 = 0
- (2) lnseedmha2 = 0
- (3) lnminf2 = 0
- (4) lnmat2 = 0
- (5) lninsec2 = 0
- (6) lnlabxlnseed = 0
- (7) lnlabxlnminf = 0
- (8) lnlabxlnmate = 0
- (9) lnlabxlnqinsec = 0
- (10) lnseedxlnminf = 0
- (11) lnseedxlnmate = 0
- (12) lnseedxlnqinsec = 0
- (13) lnminfxlnmate = 0
- (14) lnminfxlnqinsec = 0
- (15) lnmatxlnqinsec = 0

F(15, 523) = 2.26

Prob > F = 0.0042