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Economic impacts of fall armyworm and its management strategies: evidence from southern Ethiopia

Menale Kassie[†,*], **Tesfamicheal Wossen**[‡], **Hugo De Groote**[§], **Tadele Tefera****, **Subramanian Sevgan**[†] **and Solomon Balew**[††]

*[†]International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya; [‡]International Institute of Tropical Agriculture (IITA), Nairobi, Kenya; [§]International Maize and Wheat Improvement Centre (CIMMYT), Nairobi, Kenya; **International Centre of Insect Physiology and Ecology (icipe), Nairobi, Kenya; [††]Development Economics Group, Wageningen University and Research, the Netherlands*

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Abstract

This paper explores the economic implications of fall armyworm (FAW) and its management strategies by exploiting exogenous variation in FAW exposure amongst households in southern Ethiopia. We find that FAW exposure affects maize yield and sales negatively, but not consumption. Furthermore, we find evidence of crowding-in and intensification of insecticide use in response to FAW exposure. We also find suggestive evidence that existing extension service arrangements lack the capacity to deal with emerging threats such as FAW. Results imply that targeted interventions aimed at improving the effectiveness of control measures and institutional capacity would be key to reduce the adverse effects of FAW.

Highlights

- The economic impact of fall armyworm (FAW) in southern Ethiopia assessed
- Fall armyworm significantly reduces maize yields and maize sales
- A positive correlation observed between FAW exposure and intensity of insecticide use
- Existing individual FAW control strategies do not significantly abate losses from FAW
- Improving institutional capacity is essential to control FAW

*Corresponding Author: E-mail: mkassie@icipe.org

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JEL classification: I31, O13, Q12, Q16

1. Introduction

Agriculture remains the primary source of livelihoods for most households in sub-Saharan Africa (SSA) (Dercon and Gollin, 2014). However, the sector's contribution to food security and poverty reduction is limited by many, often interacting, biotic and abiotic factors. For example, the recent invasion of fall armyworm (*Spodoptera frugiperda* JE Smith) has become a major threat to food security in the region (Day *et al.*, 2017). The fall armyworm (FAW) is an invasive and damaging pest native to tropical and sub-tropical America, but it is spreading across Africa. The pest arrived in SSA during a time when the region is challenged to feed its rapidly growing populations – an on-going battle. Since its arrival in 2016, in West Africa, the pest has spread rapidly through the continent, currently affecting 44 countries (Rwomushana *et al.*, 2018). The outbreak of FAW is a major setback in SSA as it causes enormous damage to maize crops, the prime staple food for more than 300 million farmers in Africa (Day *et al.*, 2017; Wossen *et al.*, 2017; VIB, 2019). Current estimates from 12 African countries suggest an annual loss of 4.1 to a massive 17.7 million tons of maize due to FAW (Rwomushana *et al.*, 2018). Farm-level estimates from Ghana and Zambia suggest a yield loss of 22–67 per cent (Day *et al.*, 2017), 47 per cent in Kenya (Kumela *et al.*, 2018) and 9.4 per cent in Zimbabwe (Baudron *et al.*, 2019) due to FAW infestation. If appropriate and effective control strategies are not implemented, the pest will continue to cause massive destruction to maize and aggravate the already precarious food security and livelihood conditions of millions of smallholder farmers across many countries in SSA.

In Ethiopia, FAW poses a significant risk for 9.6 million maize-producing smallholders. Current reports suggest that a quarter of the 2.9 million ha of land planted with maize is infested by FAW, resulting in a loss of more than 134,000 tons of maize production (Beemer, 2018). Such losses could have fed about 1.1 million individuals.[1] In addition to yield reductions, the country has also incurred significant expenditures on insecticides and monitoring costs. For instance, in the 2017 cropping season, the country spent about US$4.6 million to purchase 277,000 litres of insecticides and equipment for surveillance work to trace and track pest infestations. Such emergency investment can hurt other development efforts by diverting resources from other productive investments. Furthermore, beyond yield losses and pest control costs, other FAW-induced economic impacts can include reduction of income due to reduced maize sales; reduced food consumption because of reduced food availability from both crops and livestock, as crop residues are a major livestock feed source in rural

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[1] The per-capita maize consumption is 127 kg per person per year in major maize-producing regions of Ethiopia, including our study area (Muricho *et al.*, 2017).

areas; higher medical treatment expenditure for people exposed to insecticides and environmental damage related to insecticides contamination (Denberg & Jiggins, 2007; Midingoyi *et al.*, 2018). Moreover, FAW infestation can affect the performance of other businesses, including food processing industries and suppliers of input, such as seeds and fertiliser along the maize value chain.

Nonetheless, despite the obvious and significant risks posed by the incidence of FAW, there is little rigorous empirical evidence to inform policymakers and ongoing agricultural research efforts by quantifying the impact of FAW on agricultural productivity and the welfare outcomes of smallholder farmers. Previous research on the link between FAW and yield as well as on pest control strategies such as grain/legume intercropping, frequent weeding, the application of chemicals and implementing push-pull technology[2] includes (Day *et al.*, 2017; Hailu *et al.*, 2018; Kumela *et al.*, 2018; Midega *et al.*, 2018; Baudron *et al.*, 2019). However, these studies are not based on rigorous impact estimation methods but on simple comparisons of means from household survey data and on-farm experiments, without taking into account other factors that influence yield and infestation levels. In addition, the studies mentioned do not examine the welfare implications of FAW incidence or the role played by institutions in minimising the risk of FAW. In this regard, we believe that quantifying the economic impact of FAW and the potential effectiveness of current control strategies can provide the necessary impetus to develop improved FAW management and control systems. It can also help policymakers prioritise their resource allocations for effective management of FAW and other pests.

This paper contributes to the literature by offering a rigorous economic analysis of the impacts of FAW and the role that pest control strategies and institutions play in reducing the adverse effects of FAW. For this analysis, we use comprehensive household- and plot-level data collected in southern Ethiopia. More specifically, we provide insights into (i) how maize yield, quantities of maize sales and per capita maize consumption are affected by exposure to FAW; (ii) the association between the incidence of FAW and insecticide use at farm level; (iii) the effectiveness of current FAW control strategies used by farmers in minimising the economic burdens of FAW and, finally, (iv) the role that institutional capacity and readiness play in reducing the adverse effects of FAW and how this is affected by farmers' access to – and trust in – the existing institutions, in particular agricultural extension.

The rest of the article is organised as follows: section 2 presents the study area and data, while section 3 reports descriptive statistics for treatment

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[2] Push-pull technology is a cropping system in which cereals such as maize are intercropped with perennial fodder legumes (*Desmodium*) that repel ('push') stemborers and suppress *Striga* species (witchweed). The cereal crops are also surrounded by a border of perennial fodder grass (e.g. *Pennisetum purpureum*/Napier grass or *Brachiaria* species) that attracts ('pulls') stemborers away from cereal plants (Khan *et al.*, 2014; Pickett *et al.*, 2014).

and outcome indicators and socio-economic and institutional characteristics. Section 4 describes the empirical strategy employed to estimate the impact of FAW. Section 5 presents our empirical results, and section 6 concludes the paper.

2. Study area and data sources

The data used in this study come from the Hawassa Zuria District in Southern Ethiopia to assess the impact of integrated pest management options on maize and livestock productivity. This district was selected for this study because it is one of the country's main maize-producing areas. Maize is the second dominant crop next to teff (*Eragristis teff*) amongst the cereal that is grown in Ethiopia. The country cultivates over 2 million ha with an average maize yield of about 3 tons/hectare. More than 9 million smallholder farmers are involved in maize production in Ethiopia (Abate *et al.*, 2015). A study in major maize growing areas of the country shows that maize accounts for up to 61 per cent of all crop sales amongst male-headed households and 58 per cent amongst households led by women (Marenya *et al.*, 2016), implying that maize is a major food security and cash crop with important implications for household welfare.

The Southern Nations, Nationalities, and People's region (SNNPR), where this study is carried out, occupies 15 per cent of the country maize cultivated area (CSA (Central Statistical Agency), 2017/2018). The study district represents 5 per cent and 16 per cent maize area and production of the region, respectively (CSA (Central Statistical Agency), 2017/2018).

3. Descriptive statistics

3.1. Socio-economic and plot variables

Maize is the most important cash and staple food crop grown in the study area. The average farm size is about 1.16 ha, but more than 70 per cent of it is allocated to maize cultivation. The household survey data were collected for the 2017/2018 production season in May and June 2018 from 1,269 randomly selected maize farmers in 18 villages out of the 23 villages in the district (Figure 1).[3] The sample households grew maize on 1.8 plots on average (about 2,293 plots from 1,269 households), and 62 per cent of the surveyed households grew maize on more than one plot.

Table 1 summarises household-, plot- and village-level variables, based on data collected using Census and Survey Processing System (CSPro) software.

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[3] The plan was to cover all villages in the District, but the five villages planted maize before we implement a baseline survey.

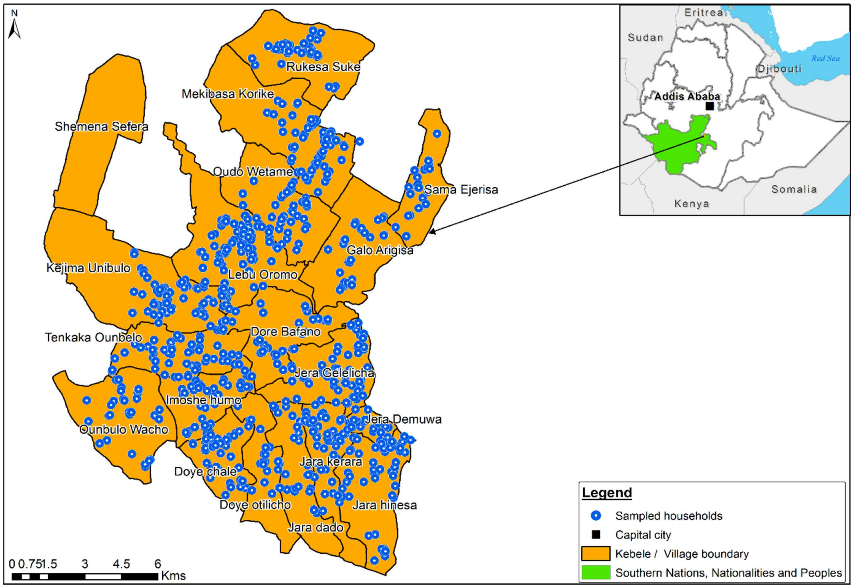

Fig. 1. Map of the study area.

The data comprise explicitly household and plot characteristics as well as data related to FAW and other plot-level shocks.

Plot characteristics data included maize yield, maize varieties, the distance of the plot to the farmer's residence and plot ownership (1 = *Owned*, 0 otherwise) and perception of plot fertility, plot slope and soil depth. Other plot-related data included farm investment, such as factor inputs (pesticide use, fertiliser, seed, labour, frequency of weeding and ploughing) and agricultural practices (maize–legume intercropping, irrigation and manure). Maize–legume intercropping was practised on 57 per cent of the total sample of maize plots. The haricot bean was the dominant legume intercropped with maize in the study area.

The institutional data captured included information on farmers' trust in extension officers, and the distance to the nearest extension service information centre and to the nearest main market. Information on socioeconomic characteristics includes self-reported quantities of maize sales and consumption, farm size and cell phone and livestock ownership, gender (1 = *Male*, 0 otherwise), number of years of education and the age of the household head. Finally, location-related variables denoted by dummies for *village* and *altitude* were included in the analysis to capture location-specific heterogeneities between affected and unaffected farmers.

3.2. Treatment and outcome indicators

In this section, we present the descriptive statistics of our main treatment and outcome indicators. The incidence of FAW as reported by the farmers is our

Table 1. Definition of variables and summary statistics

Variables	Mean	Standard deviation
Outcome variables		
Maize yield (kg/ha)	3,185	1,400
Maize quantity sold (kg)	885.3	956.7
Per capita maize consumption (kg/year)	142.7	77
Insecticide use (1/0)	0.334	0.472
Insecticide use (ℓ/ha)	0.729	1.55
Plot shocks		
Fall armyworm (1/0)	0.670	0.470
Stemborer (1/0)	0.592	0.492
Other shocks (1/0)	0.301	0.459
Fall armyworm control measures		
No control measure *(ref)*	0.087	0.282
Chemicals (1/0)	0.134	0.341
Handpicking (1/0)	0.294	0.456
Ash (1/0)	0.013	0.112
Chemicals + handpicking (1/0)	0.116	0.320
Chemicals + ash	0.008	0.091
Handpicking + ash	0.018	0.134
Plot investment		
Urea use (kg/ha)	141.3	284.56
DAP use (kg/ha)	139.70	229.40
Seed use (kg/ha)	21.08	9.07
Hired labour (1/0)	0.423	0.494
Ploughing frequency	3.142	0.423
Herbicide use (1/0)	0.022	0.148
Weeding frequency	2.86	0.527
Plot characteristics		
Good plot fertility *(ref)*	0.669	0.471
Medium plot fertility (1/0)	0.300	0.459
Poor plot fertility (1/0)	0.030	0.171
Flat plot *(ref)*	0.772	0.420
Medium slope plot (1/0)	0.205	0.403
Steep slope plot (1/0)	0.024	0.152
Shallow depth plot *(ref)*	0.316	0.465
Medium depth plot (1/0)	0.271	0.445
Deep depth plot (1/0)	0.413	0.492
Manure (1/0)	0.394	0.489
Irrigation (1/0)	0.023	0.149
Legume-maize intercropping (1/0)	0.570	0.495
Plot distance to residence (walking minutes)	37.1	101.6
Plot tenure (1 = owned, 0 otherwise)	0.938	0.241
Household characteristics		
Sex of household head (1 = male, 0 otherwise)	0.939	0.239
Age of household head (years)	42.8	11.797

(Continued)

Table 1. Continued

Variables	Mean	Standard deviation
Family size (number)	5.766	1.695
Education of household head (years)	5.084	4.554
Distance to extension services (walking minutes)	30.5	25.37
Household confidence in extension service officers (1/0)	0.824	0.381
Cellphone ownership (1/0)	0.161	0.367
Value of livestock ownership (‘000 s)	29.170	29.915
Distance to main market (walking minutes)	69.986	55.108
Altitude (metres above sea level)	1733.105	68.151
Plot (household) observations		2,292 (1,269)

key variable of interest collected at plot level (1 = *plot suffers from FAW*, 0 otherwise). To measure the incidence of FAW, respondents were asked the following two related questions: (1) *Are you or your household aware of FAW?* and (2) *Can you identify the FAW from these pictures?* The second question was asked to verify farmers’ knowledge of FAW and to eliminate the possibility of some farmers mixing up FAW with other pests such as stemborer. In addition to FAW, we also collected plot-level data on the incidence of other types of pests as reported by the farmers, such as stemborer (1 = *plot affected by stemborer*, 0 otherwise), as well as other incidents such as disease infections and adverse climatic events (1 = *plot suffered from other incidents*, 0 otherwise). In addition, the survey captured self-reported maize yield losses due to FAW, stemborer, diseases and adverse climatic events (drought and flood) that affected the plot. Data on FAW control measures were also collected for each plot. Of the total sample households, 84 per cent were aware of FAW, and amongst those, 97 per cent correctly identified it from the pictures presented to them. Based on the data from the picture verification exercise on the incidence of FAW, we found that about 74 per cent of the interviewees were affected by FAW.

On FAW control measures, out of the 1,536 (67 per cent of the total maize plots) maize plots infested by FAW, 13 per cent received no control measures; 20 per cent, 44 per cent and 2 per cent of the plots, respectively, were managed using chemicals, handpicking and ash and 17 per cent, 1 per cent and 3 per cent of maize plots, respectively, were treated with a combination of either chemicals and handpicking, chemicals and ash, and handpicking and ash. On institutional factors, FAW-affected households resided a 32-minute walk away from sources of extension services, while unaffected households were only a 25-minute walk away. Nonetheless, in terms of relying on institutional information, the figures are roughly equal: about 82 per cent of the affected households trusted the advice offered by extension officers in their villages, compared with 84 per cent for households unaffected by FAW.

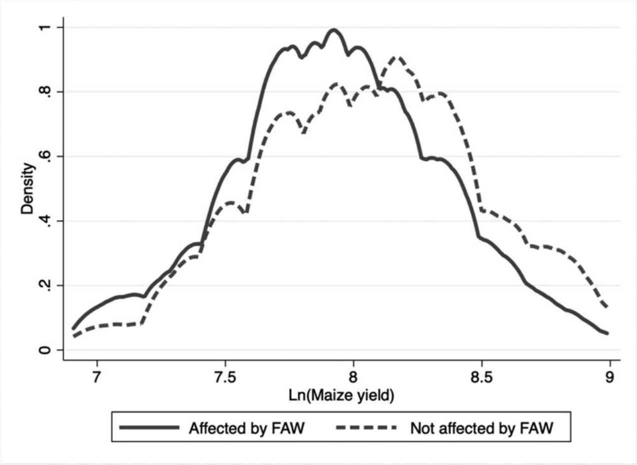

Fig. 2. Non-parametric estimation of maize yield (kg/ha).

The first outcome variable is maize yield (kg/ha). The pooled plot average maize yield (kg/ha) in our sample is 3.19 t/ha.[4] Hybrid maize varieties were planted in about 97 per cent of the maize plots during the current production season (the dominant maize variety is the pioneer hybrid, P3812W). Self-reported FAW maize production damage ranged from the lowest (1 per cent) to the highest (100 per cent) loss. The average loss in the sample was recorded as 10.8 per cent. The average maize yield on FAW-affected plots is 3.04 t/ha, while it is 3.48 t/ha on unaffected plots (the difference is statistically significant at the 1 per cent level). The difference in maize yields between plots affected or unaffected by FAW is further illustrated in Figure 2, which depicts non-parametric (kernel) estimates of the density of yields for the two types of plot. The graph suggests a negative correlation between FAW infestation and maize yields. Even though the relationship is not causal, the distribution suggests that FAW may have an adverse consequence on food consumption as farmers' food availability – and, to some extent, accessibility of food – is determined by own production (Kassie *et al.*, 2015).

Our next outcome indicators are per-capita consumption of maize (kg per year) and quantities of maize sales (kg). The difference in the above outcome indicators between households affected or unaffected by FAW is reported in Figures 3 and 4. In all cases, the distributions suggest lower outcomes (in terms of consumption and quantities of maize sales) for FAW-affected households compared with those that were unaffected. Furthermore, the Kolmogorov–Smirnov equality-of-distributions test reveals that the difference is statistically

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[4] To account for potential outliers, for all outcomes (yield, quantities of maize sales, the quantity of insecticides use, income and per-capita consumption), we trimmed the bottom and top 2 per cent values.

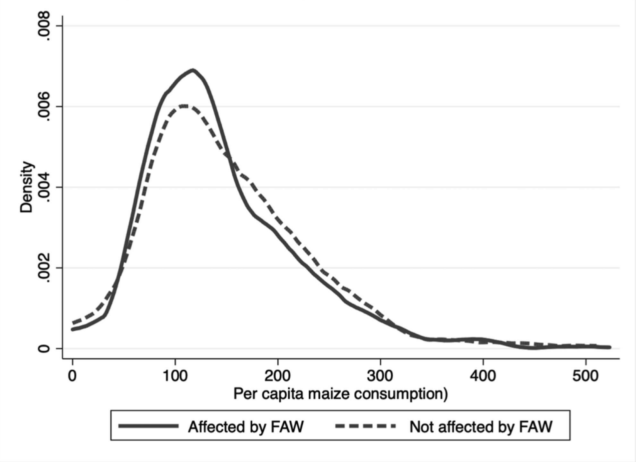

Fig. 3. Non-parametric estimation of per capita maize consumption.

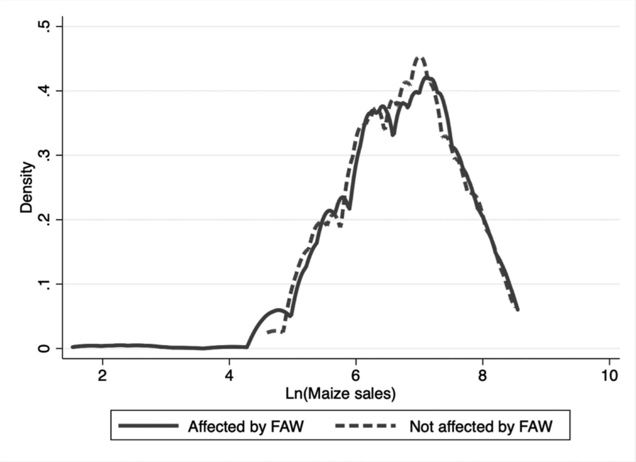

Fig. 4. Non-parametric estimation of quantities of maize sales.

significant for all outcomes. However, these differences cannot be attributed to FAW infestation without controlling for other confounding factors.

The final outcome indicator is the use of insecticides. According to our data, insecticides were applied in about 33 per cent of the maize plots, the average application rate being 0.73 ℓ/ha. Farmers applied more insecticides on FAW-affected plots (1.0 ℓ/ha) compared with unaffected ones (0.59 ℓ/ha). Figure 5 displays a higher insecticide application rate in FAW-affected plots compared with unaffected plots across the entire rank distribution.

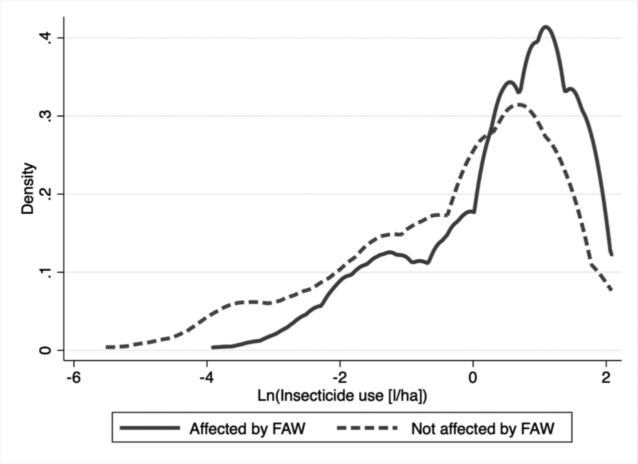

Fig. 5. Non-parametric estimation of insecticide use.

By and large, the descriptive analysis suggests that farm households affected by FAW have experienced more negative economic outcomes than their unaffected counterparts. However, this is an unconditional comparison. Outcome variables are not only influenced by FAW incidence: they are affected by many other factors too. In the next section, therefore, we evaluate the effects of FAW that are conditional on other covariates.

4. Econometric framework for estimating FAW impacts

In this section, we present our primary empirical strategy to identify the effect of FAW exposure on maize yield, quantities of maize sales, insecticide use and maize consumption. Since the incidence of FAW is an exogenous shock to the farming communities, its effect on the above-mentioned outcomes is evaluated using an exogenous treatment framework. In particular, we employ the following function specification for our key outcome indicators:

$$Y_{ip} = \beta F_{ip} + \vartheta X_{ip} + \varphi V_j + \varepsilon_{ip} \tag{1}$$

where the indices i and p denote household and plot, respectively, and Y_{ip} denotes outcome variables (maize yield per ha, quantities of maize sales, probability and litres of insecticide used and per-capita maize consumption). While maize yield and insecticide use are measured at the plot level, quantities of maize sales and per-capita consumption are measured at the household level. F_{ip} is a FAW dummy variable equal to 1 if plot p is affected by FAW; it is otherwise 0. X_{ip} denotes vectors of observable plot and household level covariates, while V_j captures village fixed effects to control for varying agro-climatic conditions, general market and economic conditions and soil quality across the village. Finally, ε_{ip} is a plot- and household-specific error term, and the parameters to be estimated are β, ϑ and φ. The primary interest here is to estimate the size and sign of FAW impact, β.

Even though exposure to FAW is reasonably exogenous, we also exploited the variation in FAW exposure at the plot level and estimated a fixed-effect model by introducing household fixed effects. Our plot data are cross-sectional, but about 62 per cent of the households in our sample produce maize on more than one maize plot. This enabled us to estimate differences in productivity and insecticide use on plots cultivated by the same farmer that were either affected or unaffected by FAW (Kassie and Holden, 2007, 2018). The inclusion of household fixed effects would presumably account for unobserved household-level heterogeneity. While controlling for household fixed effects, we also controlled for a battery of plot characteristics as well as factor inputs in estimating yield and insecticide use function to control for plot-specific observed and unobserved characteristics.[5]

Next, we examined the effectiveness of control measure strategies, since some farmers who are affected by FAW use chemicals, handpicking, ash or some combination of these strategies. To explicitly quantify the effectiveness of available FAW control measures, we introduced a categorical variable, C_{ip}, which assumes the following values depending on the different strategies that the farmers implement:[6]

$$C_{ip} = \begin{cases} 1, \text{No prevention strategy (none)} \\ 2, \text{Chemicals} \\ 3, \text{Handpicking} \\ 4, \text{Ash} \\ 5, \text{Chemicals and handpick} \\ 6, \text{Chemicals and ash} \\ 7, \text{Handpicking and ash} \end{cases}$$

$$Y_{ip} = \alpha_0 + \gamma C_{ip} + \vartheta X_{ip} + \varphi V_j + \varepsilon_{ip} \tag{2}$$

The effectiveness of available strategies is evaluated by estimating their effectiveness in protecting yield (Y_{ip}). Letting $C_{ip} = 1$ be the base category (i.e. no prevention strategy), then $\gamma_{c2} = \gamma_{c3} \cdots = \gamma_{c8} = 0$ implies that the control strategies currently being implemented by farmers do not reduce the loss caused by FAW. However, if $\gamma_{c2} = \gamma_{c3} = \ldots \gamma_{c8} > 0$ and significant, then implementing these control strategies is important as it prevents yield losses due to FAW infestation.

In addition, using the following specification, we examined whether, and to what extent, agricultural extension institution capacity proxied by farmers'

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[5] For example, if farmers access private information, such as how good the soil on their plot is or *what the shocks on the plot have been*, they might adjust their factor input decisions accordingly (Fafchamps, 1993; Levinsohn and Petrin, 2003; Assunção & Braido, 2004).

[6] There are no farmers using a combination of the three measures.

access to extension services, farmers' trust in extension officers, which can measure their capacity and maize–legume intercropping[7], helped reduce the yield loss inflicted by FAW:

$$Y_{ip} = \alpha_0 + \beta F_{ip} + \gamma L_{ip} + \delta I_i + \rho \left(F_{ip} * L_{ip}\right) + \theta \left(F_{ip} * I_i\right) + \vartheta X_{ip} + \varphi V_j + \varepsilon_{ip} \quad (3)$$

In the above specification, L_{ip} measures maize–legume intercropping, while I_i measures the institutional capacity – which, in our case, is access to extension services. In addition to simple access, we also captured farmers' trust in extension officers as a proxy for their capacity. The roles of intercropping, on the one hand, and of access to extension services, and trust in extension officers in protecting yield losses, on the other, are both captured by the interaction term between FAW infestation (F_{ip}) with access in extension services/trust in extension officers (I_i) and intercropping (L_{ip}). If $\theta, \rho \geq 0$, then intercropping, access to extension services and trust in such extension officers are all important in reducing the adverse effects of FAW. However, if $\theta < 0$, it would imply either that access to extension services is not important in alleviating the negative effects of FAW infestation, or that such institutional (extension service) capacity is needed, but it is lacking.

The choices of explanatory variables in all functions are governed by the economic theory and previous similar empirical studies (Di Falco *et al.*, 2011; Teklewolde *et al.*, 2013; Kassie *et al.*, 2018; Wossen *et al.*, 2019). Finally, we considered within-group dependence while estimating standard errors. However, the usual cluster-robust standard errors that permit heteroskedasticity and within-cluster error correlation assume a large number of clusters (Cameron *et al.*, 2008; Wossen *et al.*, 2019). When there are too few clusters, the usual cluster-robust standard errors are unreliable (Cameron *et al.*, 2008). In our case, standard errors were clustered at the village level, but we only had 18 villages. Therefore, we follow the approach adopted by Cameron *et al.* (2008) in such cases and report standard errors that are wild bootstrapped at the village level.

5. Results and discussions

This section discusses the impact of FAW on maize yield (t/ha), insecticide use measured as a binary variable (1/0), quantity of insecticide used (ℓ/ha), quantities of maize sold and per-capita maize consumption. In our estimation, we transformed maize yield and per-capita maize consumption into a logarithmic scale. For quantities of maize sold and quantity of insecticide use, we used an inverse hyperbolic sine (IHS) transformation, as some farmers have zero values for these indicators (Burbidge *et al.*, 1988).

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[7] Agronomic practices represent alternative measures to mitigate the effect of FAW (Hailu *et al.*, 2018; Midega *et al.*, 2018; Baudron *et al.*, 2019). Though the use of legume-maize intercropping is common in our study area it was not mentioned by farmers during the household survey and focus group discussions as FAW management strategies. However, we tested its effects following (Hailu *et al.*, 2018; Midega *et al.*, 2018; Baudron *et al.*, 2019).

Table 2. Maize yield estimation (kg/ha)

Variable	Pooled ordinary least squares regression (OLS)	Pooled ordinary least squares regression	Fixed effects regression model	Fixed effects regression model
Fall armyworm	-0.124^{***} (0.019)	-0.123^{**} (0.049)	-0.095^{***} (0.035)	-0.122^{**} (0.053)
Household characteristics	No	Yes	No	No
Plot investment	No	Yes	No	Yes
Plot characteristics	No	Yes	No	Yes
Household fixed effects	No	No	Yes	Yes
Village fixed effects	No	Yes	No	NA
R^2	0.019	0.313	0.79	0.838
N	2,219	2,219	2,219	2,219

Notes: Standard errors, wild-bootstrapped at the kebele level, are reported in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 2 reports results on the effect of FAW on maize yield.[8] The size and sign of the estimated coefficients across the different specification are similar and robust. Specifically, we find that FAW has a negative and statistically significant effect on maize yield. Our result suggests that, on average, FAW causes a yield loss of 11.5 per cent[9] after controlling for household fixed effects and other covariates that influence yield. This estimate is close to the self-reported yield losses (10.8 per cent) reported in section 3.2.

In Table 3, we present results on farmers' insecticide use behaviour in response to FAW infestation. In our estimation, we considered effects both at the extensive (probability to use) and intensive (application rate) margins. The results show a significant positive association between exposure to FAW and the use of insecticides, both at the extensive and intensive margins. Based on the fixed effects estimate, exposure to FAW is associated with an increase in the probability and intensity of insecticide use by 13 per cent and 38 per cent[10], respectively. The estimated results suggest that farmers not only crowd-in insecticides, they also intensify the use of insecticides in response to FAW exposure. In the next section, we discuss whether such crowding-in and intensification of insecticides by farmers are effective in minimising the adverse effects of FAW on maize yield.

Tables 4 and 5, respectively, report results on the effectiveness of control strategies, the role of extension institution and the role of maize–legume intercropping in preventing yield losses due to FAW. Concerning FAW control strategies, the results indicate that individual measures, including insecticides, are ineffective in protecting yield loses due to FAW. This result deserves further

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[8] Tables with full regression results for all outcome indicators are presented in Annex A.

[9] Note that the effect is computed as $100(\exp^{\beta} - 1)$ since we use the log-level regression model.

[10] Note that the effect is computed as $100(\exp^{\beta} - 1)$ since we use the log-level regression model.

Table 3. FAW infestation and the use of insecticides

Variable	Pooled linear regression model (	Fixed effects regression model	Pooled ordinary least squares regression model	Fixed effects regression model
	Insecticide use (1/0)	Insecticide use (1/0)	Quantity of insecticides used (litres per ha)	Quantity of insecticides used (litres per ha)
Fall armyworm	0.334*** (0.037)	0.125* (0.066)	0.509*** (0.064)	0.321* (0.159)
Household characteristics	Yes	Yes	No	No
Plot characteristics	Yes	Yes	Yes	Yes
Household fixed effects	No	Yes	No	Yes
Village fixed effects	Yes	NA	Yes	NA
R^2	0.212	0.843	0.192	0.847
N	2,219	2,219	2,219	2,219

Notes: Standard errors, wild-bootstrapped at the kebele level, are reported in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

attention because the measures applied were either not useful for controlling FAW, or they were not applied at the right stage of the insect's growth or farmers did not properly target the pest during spray. This result, i.e. that individual measures are not effective, is consistent with Baudron *et al.* (2019) and Kumela *et al.* (2018), who find that pesticides lacked efficacy in controlling FAW infestation[11].

However, our results also show that combining strategies, e.g. using chemicals and handpicking insect from the crop as well as handpicking and ash, seem to be effective in protecting yield loss from FAW: farmers who employed a combined strategy managed to protect their yield after a FAW infestation in comparison with those who failed to employ any strategy at all. A probable reason for the relative success of combining strategies is that, if the insect skips one strategy, it can be overcome by another.

Furthermore, the insignificant coefficient on the interaction between FAW control and maize–legume intercropping indicates that this agronomic practice is ineffective in reducing the risk posed by FAW. Although this result contradicts the findings by Hailu *et al.* (2018), it corroborates those of Baudron *et al.* (2019), who revealed that maize–legume intercropping was not effective in reducing the damage caused by the pest. In view of the danger of applying a 'one size fits all' approach, these conflicting results highlight the importance of understanding how and where control measures can perform well.

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[11] Given the low percentage of plots with some of the control measure combinations applied, we also estimated a separate specification where the control measures chemical, handpicking and ash were considered separately. Results remain consistent (Table 4, column 1).

Table 4. Effectiveness of existing control strategies-ordinary least squares regression [dependent variable: ln (maize yield, kg/ha)]

Variable	Full sample	Full sample	FAW-affected sub-sample
None	-	−0.123***	-
		(0.046)	
Ash	−0.157***	−0.200***	−0.086
	(0.033)	(0.034)	(0.056)
Chemicals	−0.110***	−0.154***	0.001
	(0.041)	(0.049)	(0.055)
Handpicking	−0.085***	−0.131***	0.004
	(0.027)	(0.031)	(0.047)
Chemicals + handpicking	-	−0.062**	0.095**
	-	(0.031)	(0.043)
Chemicals + ash	-	−0.124*	0.038
		(0.073)	(0.060)
Ash + handpicking	-	−0.041	0.086***
		(0.058)	(0.008)
Household characteristics	Yes	Yes	Yes
Plot investment	Yes	Yes	Yes
Plot characteristics	Yes	Yes	Yes
Household fixed effects	No	No	No
Village fixed effects	Yes	Yes	Yes
Base category	-	No FAW infestation	Only FAW affected plots (No control strategy used)
R^2	0.308	0.313	0.292
N	2,219	2,219	1,496

In terms of the role that institution plays in ensuring farming success, namely whether farmers have access to and trust the advice of bodies that provide extension services, we gained some interesting insights. While the interaction between access to extension services and FAW control was found to be insignificant, the interaction between FAW control and confidence in extension officers' advice was positive and significant. The absence of a significant interaction effect between FAW control and extension services implies either that access to such services is not important in the control of this pest, or that existing agricultural extension institution is not sufficiently prepared or equipped to tackle the invasive species. From the results reported in Table 3, one can deduce that the use of appropriate control strategies (the combination of chemicals and handpicking, ash and handpicking, etc.) appears to have been the key moderating factor in respect of the positive and significant effect found in the interaction between FAW control and confidence in extension officers' advice.

Finally, we provide effects on maize sales and consumption of maize in Table 6. As expected, we find a negative and statistically significant association

Table 5. Mitigating FAW risk – the role played by intercropping as well as access to, and trust in, institutions-ordinary least squares regression

Variable	ln (maize yield, kg/ha)	ln (maize yield, kg/ha)
Fall armyworm	-0.265^{**}	-0.251^{***}
	(0.120)	(0.093)
Distance to extension services	0.001	-
	(0.017)	
Fall armyworm X distance to extension services	0.011	-
	(0.019)	
Trust in extension services	-0.074^{*}	-0.077^{*}
	(0.042)	(0.045)
Fall armyworm X trust in extension services	0.134^{*}	0.144^{*}
	(0.078)	(0.083)
Legume-maize intercropping	0.067^{***}	-
	(0.020)	
Fall armyworm X legume-maize intercropping	-0.021	-
	(0.035)	
Household characteristics	Yes	Yes
Plot characteristics	Yes	Yes
Plot investment	Yes	Yes
Household fixed effects	No	No
Village fixed effects	Yes	No
R^2	0.320	0.316
N	2,214	2,214

Notes: Standard errors, wild-bootstrapped at the kebele level, are reported in parentheses, $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

between FAW infestation and maize sales. Specifically, it reduces maize sales by 25 per cent. However, the reduction in maize yield did not translate into a reduction in consumption for the period considered in this study. This has two implications: either the yield loss caused by FAW is not large enough to reduce existing maize consumption patterns, or some consumption-smoothing behaviour has occurred amongst the sampled households, e.g. these households have reduced the quantity of maize they supply to the market. However, such consumption smoothing behaviour may lead to cash shortages to make productive investment.

6. Conclusions

In this article, we estimated the economic impact of FAW infestations and the role of control measures in mitigating the risks they entail. The analysis was carried out using econometric methods applied to comprehensive cross-sectional household and plot-level data collected from 1,269 maize farmers.

Table 6. Effect of FAW on maize sales and consumption-ordinary least squares regression model (dependent variable: ln (maize sales, kg) and ln (per capita maize consumption, kg/person/year)

Variable	ln (maize sales)	ln (maize consumption)
Fall armyworm	−0.239***	0.034
	(0.066)	(0.062)
Household characteristics	Yes	Yes
Household fixed effects	No	No
Village fixed effects	Yes	Yes
R^2	0.42	0.124
N	1,034	1,222

Notes: Standard errors, wild-bootstrapped at the kebele level, are reported in parentheses, $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

This is the first comprehensive study undertaken in Ethiopia to evaluate the welfare damage caused by FAW. Quantifying the impacts of FAW in this way provides the evidence required to prioritise resource allocation and develop improved FAW management systems.

We find that exposure to FAW had a significant negative impact on maize yield. Our results suggest a yield loss of 11.5 per cent even after controlling for the pest management strategies that farmers use. However, the reduction in maize yield did not translate into a reduction in consumption for the period considered in this study. This has two implications: either the yield loss caused by FAW is not significant enough to reduce existing maize consumption patterns, or some consumption-smoothing behaviour has occurred amongst the sampled households, e.g. these households have reduced the quantity of maize they supply to the market.

The findings also indicate that the share of maize supplied to the market is significantly lower amongst FAW-affected households compared with their unaffected counterparts. Thus, if the infestation of the pest is not minimised through appropriate pest management systems, the negative association between FAW exposure and quantities of maize sales will have long-term impacts on food security and poverty reduction, as liquidity constraints affect farmers' capacity to invest in productivity-enhancing technologies.

Furthermore, farmers who experienced FAW on their maize plots crowded-in and intensified the use of insecticides. This is an additional cost to farmers in addition to maize yield loss indicated above. They increase the quantity of insecticide use by about 38 per cent, although such measures have been shown to be ineffective in minimising the adverse effects of FAW on maize yield. According to our results, FAW control measures, when applied individually – including the application of chemicals – are not effective. However, the adoption of a combination of chemical and manual treatments (handpicking and killing) as well as ash and manual treatments by individual farmers played a mitigating role in combatting an infestation compared with employing no control strategy at all. This highlights the importance of understanding how and where FAW control measures applied by the individual farmer can perform well. In terms of the role that institution plays in ensuring farming success, namely farmers have access to the advice of bodies that provide extension services, we find insignificant effects. This result suggests either that access to such services is not important in the control of this pest, or that existing agricultural extension institution in the study area is not sufficiently prepared or equipped to tackle the invasive species. However, it became clear that farmers' trust in extension officers' advice, particularly on the use of FAW control strategies, played a key role in abating yield losses due to FAW.

The current study has some limitations, however. First, we only use cross-sectional data. Such data do not capture the dynamics of FAW infestation or its impact over time. Cross-sectional data also do not measure any change in the pest management practices exercised by farmers, institutions and the government over time through learning by doing and by accessing information on best practice. The extent of economic damage brought by the impact of FAW infestations may decrease over time as knowledge about controlling the pest increases. It is also worth mentioning that the data used for this study were collected shortly after FAW first appeared in Ethiopia: institutions, the government, and farmers alike were not ready to cope with its impact, nor were they adequately informed about the pest's behaviour or about what measures to use to address the problem.

A second limitation of the study relates to respondents having been asked about the type of control measure they had employed, but not about when – i.e. at what stage of the insect's growth – they had employed such measures or how they used them. These aspects have repercussions on our estimates regarding the effectiveness of control measures.

Third, although our estimates demonstrate the risk that FAW poses to Ethiopia's agriculture, the data presented in this study are not nationally representative. A fourth limitation is that the study only considers the binary incidence of FAW infestation: it ignores the intensity of infestation that can result in heterogeneity impacts. Future studies aimed at closing these and other gaps would assist in the more effective allocation of scarce resources to control the pest.

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Annex A: Tables with full regression results for all outcome indicators

Table 1A. Maize yield estimation, kg/ha

	Pooled OLS	Pooled OLS	Fixed effects (FE)	Fixed effects (FE)
Fall armyworm	−0.124***	−0.123**	−0.095***	−0.122**
	(0.019)	(0.049)	(0.035)	(0.053)
Use of ash		−0.035		0.018
		(0.051)		(0.062)
Use of chemicals		−0.008		−0.100*
		(0.048)		(0.059)
Handpicking		0.056		−0.006
		(0.044)		(0.067)
Chemical + handpicking		−0.076		−0.107
		(0.054)		(0.110)
Chemical + ash		−0.005		0.024
		(0.077)		(0.120)
Handpicking + ash		0.083		0.068
		(0.077)		(0.097)
Stemborer infestation		−0.012		0.051
		(0.027)		(0.041)
Other shocks		−0.117***		−0.117***
		(0.024)		(0.030)
Urea use		0.018**		−0.004
		(0.008)		(0.014)
DAP use		0.031**		0.023
		(0.015)		(0.017)
Seed quantity		0.364***		0.492***
		(0.037)		(0.036)
Ploughing frequency		0.007		0.064*
		(0.020)		(0.034)
Weed frequency		0.012		−0.031
		(0.017)		(0.033)
Labour use		0.044**		−0.006
		(0.018)		(0.035)
Herbicide use		−0.053		0.087
		(0.058)		(0.100)
Manure use		0.017		0.005
		(0.021)		(0.022)
Irrigation		0.042		0.015
		(0.074)		(0.066)
Maize–legume intercropping		0.052***		0.021
		(0.016)		(0.020)
Medium soil fertility		0.012		−0.046*
		(0.015)		(0.027)

(Continued)

Table 1A. Continued

	Pooled OLS	Pooled OLS	Fixed effects (FE)	Fixed effects (FE)
Poor soil fertility		−0.147*		−0.234***
		(0.076)		(0.062)
Medium slope		−0.003		−0.048*
		(0.020)		(0.028)
Steep slope		−0.047		0.055
		(0.081)		(0.068)
Medium depth		0.034		−0.047
		(0.028)		(0.039)
Deep depth		0.091***		−0.080*
		(0.025)		(0.044)
Plot distance from homestead		−0.000**		−0.000*
		(0.000)		(0.000)
Tenure security		0.079**		0.065**
		(0.032)		(0.032)
Sex		0.089**		0.000
		(0.040)		
Age		−0.024		
		(0.048)		
Household size		0.011*		
		(0.007)		
Education		0.010***		
		(0.002)		
Distance to extension		0.011		
		(0.015)		
Mobile phone ownership		0.071**		
		(0.032)		
Farm size		−0.080***		
		(0.020)		
Livestock ownership		0.033***		
		(0.011)		
Distance from market		−0.009		
		(0.020)		
Altitude		−0.118		
		(0.089)		
Location dummies	No	Yes	NA	NA
R^2	0.019	0.313	0.79	0.838
N	2,219	2,219	2,219	2,219

Notes: standard errors, wild bootstrapped at the kebele level are reported in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 2A. FAW infestation and the use of insecticides

	Pooled linear regression model	Fixed effect (FE)	Pooled OLS	Fixed effect (FE)
	Insecticide use (1/0)	Insecticide use (1/0)	Quantity of insecticides used (litres per ha)	Quantity of insecticides used (litres per ha)
Fall armyworm	0.334***	0.125*	0.509***	0.321*
	(0.037)	(0.066)	(0.064)	(0.159)
Use of ash	−0.384***	−0.009	−0.419***	−0.033
	(0.052)	(0.068)	(0.064)	(0.097)
Handpicking	−0.450***	0.045	−0.536***	−0.064
	(0.048)	(0.173)	(0.070)	(0.303)
Stemborer infestation	0.037	0.068	−0.009	0.087
	(0.028)	(0.050)	(0.043)	(0.074)
Other shocks	0.037	−0.044	−0.007	−0.073
	(0.030)	(0.045)	(0.035)	(0.089)
Irrigation	0.005	−0.046	0.001	−0.028
	(0.072)	(0.105)	(0.100)	(0.305)
Legume-maize intercropping	0.014	0.015	0.020	0.047
	(0.014)	(0.028)	(0.018)	(0.034)
Medium soil fertility	−0.077**	0.031	−0.174***	0.058
	(0.036)	(0.026)	(0.040)	(0.048)
Poor soil fertility	−0.113**	0.102	−0.069	0.260*
	(0.052)	(0.094)	(0.098)	(0.133)
Medium slope	−0.046	−0.070	−0.150***	−0.083
	(0.029)	(0.042)	(0.045)	(0.064)
Steep slope	−0.075	−0.022	−0.114	−0.143
	(0.046)	(0.096)	(0.102)	(0.186)
Medium depth	0.002	0.027	0.102	0.047
	(0.053)	(0.067)	(0.067)	(0.122)
Deep depth	0.019	0.035	0.125**	0.032
	(0.036)	(0.055)	(0.059)	(0.063)
Plot distance from homestead	−0.000*	−0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Tenure security	−0.022	0.002	−0.048	−0.019
	(0.048)	(0.038)	(0.079)	(0.070)
Sex	−0.025		−0.006	
	(0.066)		(0.096)	
Age	−0.008		0.011	
	(0.046)		(0.066)	
Household size	−0.006		−0.012	
	(0.007)		(0.010)	
Education	0.006**		0.003	
	(0.003)		(0.004)	

(Continued)

Table 2A. Continued

	Pooled linear regression model	Fixed effect (FE)	Pooled OLS	Fixed effect (FE)
	Insecticide use (1/0)	Insecticide use (1/0)	Quantity of insecticides used (litres per ha)	Quantity of insecticides used (litres per ha)
Distance to extension	0.013		−0.018	
	(0.011)		(0.026)	
Mobile phone ownership	−0.068		−0.168**	
	(0.049)		(0.072)	
Farm size	−0.067***		−0.140***	
	(0.025)		(0.048)	
Livestock ownership	0.031**		0.041*	
	(0.015)		(0.024)	
Distance from market	−0.028		−0.017	
	(0.027)		(0.037)	
Altitude	0.046		0.213*	
	(0.037)		(0.112)	
Location dummies	Yes	NA	Yes	NA
*R*2	0.212	0.843	0.192	0.847
N	2,219	2,219	2,219	2,219

Notes: Standard errors, wild bootstrapped at the kebele level are reported in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 3A. Effectiveness of existing control strategies (OLS regression) (dependent variable-maize yield (kg/ha)

	Full sample	Full sample	Only farmers experiencing fall armyworm infestation
None		−0.123**	
		(0.049)	
Ash	−0.157***	−0.199***	−0.087
	(0.033)	(0.034)	(0.055)
Chemicals	−0.110***	−0.158***	−0.038
	(0.041)	(0.039)	(0.053)
Handpicking	−0.085***	−0.130***	0.001
	(0.027)	(0.032)	(0.047)
Chemicals + handpicking		−0.066***	0.054
		(0.025)	(0.044)
Chemicals + ash		−0.128*	−0.002
		(0.069)	(0.069)
Ash + handpicking		−0.040	0.090
		(0.059)	−0.087
Stemborer infestation	−0.034	−0.012	−0.012
	(0.027)	(0.027)	(0.029)
Other shocks	−0.121***	−0.117***	−0.109***
	(0.023)	(0.024)	(0.029)
Urea use	0.016*	0.018**	0.030***
	(0.009)	(0.008)	(0.005)
DAP use	0.034**	0.031**	0.057***
	(0.015)	(0.014)	(0.015)
Seed quantity	0.361***	0.363***	0.337***
	(0.037)	(0.036)	(0.044)
Ploughing frequency	0.004	0.007	0.066***
	(0.02)	(0.020)	(0.024)
Weed frequency	0.012	0.012	−0.002
	(0.017)	(0.017)	(0.017)
Labour use	0.047**	0.044**	0.067***
	(0.019)	(0.019)	(0.022)
Insecticide use	−0.011	−0.053	−0.110
	(0.031)	(0.058)	(0.068)
Herbicide use	−0.054	−0.053	−0.110
	(0.057)	(0.058)	(0.068)
Medium soil fertility	0.016	0.011	0.013
	(0.015)	(0.015)	(0.030)
Poor soil fertility	−0.141*	−0.148*	−0.099*
	(0.078)	(0.077)	(0.059)
Medium slope	−0.009	−0.003	0.015
	(0.019)	(0.019)	(0.024)
Steep slope	−0.046	−0.048	−0.006

(Continued)

Table 3A. Continued

	Full sample	Full sample	Only farmers experiencing fall armyworm infestation
	(0.080)	(0.081)	(0.074)
Medium depth	0.035	0.033	−0.007
	(0.028)	(0.028)	(0.041)
Deep depth	0.091***	0.090***	0.069*
	(0.026)	(0.025)	(0.041)
Manure use	0.019	0.018	0.053**
	(0.021)	(0.021)	(0.026)
Irrigation	0.036	0.042	0.077
	(0.071)	(0.074)	(0.077)
Legume–maize intercropping	0.052***	0.052***	0.052**
	(0.016)	(0.016)	(0.025)
Plot distance from homestead	−0.000**	−0.000**	−0.000
	(0.000)	(0.000)	(0.000)
Tenure security	0.077**	0.079**	0.096***
	(0.031)	(0.032)	(0.035)
Sex	0.094**	0.089**	0.101**
	(0.042)	(0.040)	(0.048)
Age	−0.027	−0.023	−0.013
	(0.048)	(0.048)	(0.054)
Household size	0.011*	0.011*	0.009
	(0.006)	(0.007)	(0.009)
Education	0.011***	0.010***	0.010***
	(0.002)	(0.002)	(0.003)
Distance to extension	0.008	0.011	0.008
	(0.015)	(0.015)	(0.017)
Mobile phone ownership	0.072**	0.071**	0.088**
	(0.034)	(0.032)	(0.043)
Farm size	−0.078***	−0.081***	−0.057**
	(0.019)	(0.019)	(0.028)
Livestock ownership	0.034***	0.033***	0.016*
	(0.010)	(0.010)	(0.009)
Distance from market	−0.012	−0.009	−0.016
	(0.020)	(0.020)	(0.018)
Altitude	−0.114	−0.117	−0.053
	(0.089)	(0.089)	(0.062)
Location dummies		No	Yes
Base category		No fall armyworm infestation	No strategy implemented
R^2	0.308	0.313	0.292
N	2,219	2,219	1,496

Notes: standard errors, wild bootstrapped at the kebele level are reported in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 4A. The role of access and trust in institution and intercropping on mitigating FAW risk-dependent variable (ln (maize yield, kg/ha))

	Pooled OLS	Pooled OLS
Fall armyworm	−0.265**	−0.251***
	(0.120)	(0.093)
Distance to extension	0.001	
	(0.017)	
Fall armyworm X distance to extension	0.011	
	(0.019)	
Trust in extension	−0.074*	−0.077*
	(0.042)	(0.045)
Fall armyworm X trust in extension	0.134*	0.144*
	(0.078)	(0.083)
Legume–maize intercropping	0.067***	
	(0.020)	
Fall armyworm X intercropping	−0.021	
	(0.035)	
Use of ash	−0.080	−0.074
	(0.076)	(0.073)
Use of chemicals	−0.119*	−0.114*
	(0.066)	(0.064)
Handpicking	−0.099*	−0.090*
	(0.053)	(0.051)
Chemical + handpicking	−0.024	−0.019
	(0.072)	(0.070)
Chemical + ash	−0.162***	−0.142**
	(0.062)	(0.059)
Handpicking + ash	−0.079	−0.071
	(0.088)	(0.083)
Stemborer infestation	−0.010	−0.007
	(0.028)	(0.028)
Other shocks	−0.116***	−0.118***
	(0.024)	(0.026)
Urea use	0.018**	0.018**
	(0.008)	(0.008)
DAP use	0.031**	0.030**
	(0.014)	(0.013)
Seed quantity	0.365***	0.363***
	(0.036)	(0.035)
Ploughing frequency	0.002	0.005
	(0.020)	(0.019)
Weed frequency	0.011	0.012
	(0.016)	(0.017)
Labour use	0.047***	0.046***
	(0.016)	(0.018)
Insecticide use	−0.007	−0.007

(Continued)

Table 4A. Continued

	Pooled OLS	Pooled OLS
	(0.033)	(0.033)
Herbicide use	−0.052	−0.051
	(0.058)	(0.058)
Medium soil fertility	0.009	0.010
	(0.015)	(0.015)
Poor soil fertility	−0.149**	−0.151**
	(0.076)	(0.075)
Medium slope	−0.003	−0.001
	(0.020)	(0.019)
Steep slope	−0.042	−0.045
	(0.080)	(0.079)
Medium depth	0.037	0.033
	(0.031)	(0.031)
Deep depth	0.093***	0.093***
	(0.027)	(0.027)
Manure use	0.017	0.020
	(0.023)	(0.022)
Irrigation	−0.002	0.005
	(0.041)	(0.039)
Plot distance from homestead	−0.000*	−0.000**
	(0.000)	(0.000)
Tenure security	0.074**	0.092***
	(0.032)	(0.030)
Sex	0.103***	0.102***
	(0.036)	(0.035)
Age	−0.035	−0.039
	(0.048)	(0.048)
Household size	0.012*	0.012*
	(0.007)	(0.007)
Education	0.010***	0.010***
	(0.003)	(0.003)
Mobile phone ownership	0.067**	0.064**
	(0.031)	(0.030)
Farm size	−0.083***	−0.089***
	(0.019)	(0.019)
Livestock ownership	0.031***	0.032***
	(0.010)	(0.010)
Distance from market	−0.012	−0.006
	(0.020)	(0.022)
Altitude	−0.108	−0.101
	(0.083)	(0.088)
Location dummies	Yes	Yes
R^2	0.320	0.316
N	2,219	2,219

Notes: standard errors, wild bootstrapped at the kebele level are reported in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 5A. Effect of FAW on maize sales and per capita maize consumption (pooled OLS regression)

Variables	ln (maize sales (kg))	ln (per capita maize consumption) (kg/person/year)
Fall armyworm	−0.239***	0.034
	(0.066)	(0.062)
Maize production	0.213***	0.108***
	(0.074)	(0.023)
Sex	0.025	0.178***
	(0.030)	(0.057)
Age	0.229*	0.041
	(0.127)	(0.057)
Household size	−0.096	−0.103***
	(0.143)	(0.010)
Education	0.004	−0.007**
	(0.017)	(0.003)
Distance to extension	0.008	0.018
	(0.006)	(0.018)
Mobile phone ownership	0.068*	0.110***
	(0.035)	(0.031)
Farm size	0.189***	0.132***
	(0.067)	(0.027)
Livestock ownership	0.476***	0.018
	(0.060)	(0.018)
Distance from market	0.125***	−0.017
	(0.030)	(0.021)
Location dummies	Yes	Yes
R^2	0.42	0.124
N	1,034	1,222

Notes: standard errors, wild bootstrapped at the kebele level are reported in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$