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Economic impacts and management of fall armyworm (*Spodoptera frugiperda*) in smallholder agriculture: a panel data analysis for Ghana

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Abstract

Background Fall armyworm (*Spodoptera frugiperda*; FAW), a native pest of the Americas, invaded West Africa about 7 years ago and spread rapidly across the rest of sub-Saharan Africa (SSA) and several countries in Asia and Oceania. Early cross-sectional studies reported that the pest causes severe damage to maize, stimulating widespread use of synthetic pesticides in smallholder farming systems. Using panel data from Ghana, this paper assessed the impact of FAW on maize productivity and the changes in the strategies adopted by smallholder farmers for the management of the pest.

Methods Household data collected in two rounds (2018 and 2020) from 370 smallholder maize-growing households in Ghana were used. The dynamics of FAW infestation and the management practices applied by farmers were analysed descriptively, while panel data regression methods, such as fixed effects and correlated random effects models, were used to estimate the effect of FAW on maize productivity.

Results We found evidence of reduced intensity of pesticide use, increased use of protective equipment when spraying pesticides, increased adoption of biopesticides and cultural practices for FAW management, in line with recommended integrated pest management solutions. Results from panel data regression analysis showed that after controlling for other determinants of maize productivity and unobserved heterogeneity, the negative effect of FAW infestation on maize productivity is not statistically significant.

Conclusions Our findings suggest that with better knowledge of FAW and the use of more sustainable and environmentally-friendly solutions, the yield losses due to FAW are not as severe as initially reported.

Keywords Fall armyworm, Maize, Pesticides, Integrated pest management, Smallholder farmers, Ghana

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Introduction

Fall armyworm (FAW), *Spodoptera frugiperda*, is an agricultural pest of global importance. Native to the tropical and sub-tropical regions of North and South America, the pest was detected in Benin, Nigeria, Togo (West Africa) and São Tomé & Príncipe (Central Africa) in early 2016 (Goergen et al. 2016). Given high environmental suitability, increased global trade and the flight capacity of the pest, it quickly spread throughout sub-Saharan Africa (SSA) within a year and was later confirmed to be present in North Africa and Asia (CABI 2021). In 2020, FAW invaded several Oceania countries, including Australia, where it has been described as the 'coronavirus of agriculture' due to its devastating impacts (Sexton-McGrath 2021). Seasonal migrations into Europe are also possible in the near future (Early et al. 2018; Liu et al. 2020).

The FAW is a voracious pest that can feed on hundreds of plant species (Motezano et al. 2018), but it has a high preference for maize. It is estimated that the outbreak of FAW has the potential to cause maize production losses ranging from 4.1 to 17.7 million tonnes annually (valued at US$ 1.1–4.7 billion) in just 12 maize-producing countries in SSA (Rwomushana et al. 2018). Using nationally representative datasets, De Groote et al. (2020) and Abro et al. (2021) have also shown that the FAW invasion is causing average annual maize yield losses of 33% and 36% in Kenya and Ethiopia, respectively. Thus, without appropriate control actions, the pest could worsen the already precarious food security situation in SSA (FAO et al. 2020), where maize is an important staple food crop for many households (Erenstein et al. 2022). Moreover, FAW invasion has spurred increased use of pesticides (Kassie et al. 2020; Tambo et al. 2020a; Yang et al. 2021), which can have detrimental effects on animal, human and environmental health.

In this paper, we study the economic impacts and management of FAW in smallholder agriculture. Specifically, (1) we assess the impact of the incidence and degree of FAW infestation on maize yield and income; and (2) we investigate the dynamics of FAW management practices adopted by farm households, with particular emphasis on pesticide use patterns. We used panel data from 370 smallholder farmers across seven regions of Ghana, where the pest has been recorded attacking maize plants since 2016.

Our study mainly contributes to two strands of the growing literature on FAW invasion. Our first contribution relates to the literature on understanding the current strategies used by farmers for tackling FAW, so as to be able to identify gaps and provide recommendations for sustainable management of the pest (e.g., Kansiime et al. 2019; Kumela et al. 2019; Chimweta et al. 2020; Tambo et al. 2020a, b; Asare-Nuamah 2021; Makale et al. 2022; Kalyebi et al. 2023). These previous studies relied on cross-sectional data that do not capture the dynamics of FAW management. Here, we address this shortcoming using two rounds of panel data. For instance, the above studies found that the most widely used FAW control method in Africa is chemical pesticides, and the panel data will allow us to understand if this finding persists over time or if there has been a shift towards more reliance on non-chemical methods. The first wave of the panel data represents the early years of FAW invasion when farmers had limited knowledge about the pest, while the second wave reflects a period of increased awareness of and experience with the FAW pest.

Second, we contribute to the literature on the economic impacts of FAW. Previous studies have mostly focused on quantifying yield or revenue losses associated with FAW infestation, using data on farmers' estimates of actual and expected maize yields without controlling for potential confounding factors (Day et al. 2017; Rwomushana et al. 2018; Kumela et al. 2019; De Groote et al. 2020; Koffi et al. 2020). A few related studies have used cross-sectional survey data and regression methods to estimate the impacts of FAW by comparing FAW-affected and unaffected households (e.g., Tambo et al. 2021; Bannor et al. 2022). Unlike these previous studies, we used panel data, which have the advantage of properly accounting for unobserved farmer heterogeneity that might bias cross-sectional estimates. The study most related to our work is Kassie et al. (2020), who used a cross-sectional fixed effects model to provide a rigorous conomic analysis of FAW impacts in southern Ethiopia. Our panel data analysis adds to the limited rigorous evidence on the economic impacts of FAW. Insights from this study can be used to inform policies and interventions aimed at tackling the FAW invasion in smallholder agriculture.

Context and methods

Fall armyworm in Ghana

As is typical in many SSA countries, maize is an important staple crop and a major source of livelihood for many farmers in Ghana. It is the most widely cultivated food crop, covering over a million hectares of land. Yet, maize yield remains very low, averaging about 1.9 tonnes per hectare in the country over the past decade (FAOSTAT 2021). The low productivity is caused by multiple abiotic and biotic stresses, including drought, poor soil conditions, insect pests, diseases and weeds (Ragasa et al. 2017; Scheiterle et al. 2019). In recent years, FAW has become the most important maize pest in the country. The pest was first detected in Yilo Krobo district in Eastern region in early 2016, and it quickly spread throughout the country by the end of 2016 (Cock et al. 2017; FAO 2020a).

Based on a survey of farmers' perceptions of FAW-induced yield losses, Day et al. (2017) estimated that the FAW outbreak could potentially reduce Ghana's maize production by about 45%, equivalent to a revenue loss of US$ 284.4 million. In a similar survey a year later, the national average maize yield loss due to FAW was reported to be 26.6%, valued at US$ 177 million (Rwomushana et al. 2018). Given concerns about the significant threats posed by the pest, the Government of Ghana reportedly allocated US$ 4 million to procure and distribute pesticides as an emergency response in 2017 (FAO 2020b). Subsequently, several actions have been taken to combat the pest, including the creation of a national multi-stakeholder task force to coordinate response efforts, and the implementation of public information campaigns to increase awareness of FAW and sustainable management practices (Kansiime et al. 2020). Findings from a study by Williams et al. (2019) suggest that these concerted actions have helped to reduce the economic losses due to FAW invasion in Ghana.

Some studies have examined the choice and effectiveness of FAW management measures in Ghana (Rwomushana et al. 2018; Tambo et al. 2020a, b; Asare-Nuamah 2021; Ansah et al. 2021). They found that farmers have been experimenting with different chemical and cultural control practices, such as spraying of synthetic pesticides or biopesticides, handpicking of caterpillars, use of detergents and regular weeding, with varying degree of success in controlling the pest. However, the use of synthetic pesticides is often the most preferred option, and this is largely driven by access to subsidised or free pesticides (Tambo et al. 2020b). Worryingly, Tambo et al. (2020b) further observed that nearly half of the pesticide users in their sample did not wear protective apparels while spraying pesticides to control FAW, resulting in reports of pesticide-related ill-health.

Fig. 1 Map of Ghana showing the survey locations

Data and sample characteristics

This article draws on two rounds of survey data from 370 smallholder maize-growing households in Ghana. Data for the first round were collected in 2018 with the aim of investigating the economic impacts of FAW and farmers' management strategies. These farm households were revisited in 2020 for a follow-up survey to understand the dynamics of FAW infestation and management. The 2018 and 2020 surveys covered the 2017 and 2020 main agricultural seasons, respectively.

The surveys were conducted in Ashanti, Brong Ahafo, Central, Eastern, Northern, Upper West, and Volta regions, which comprise seven of the ten administrative regions of Ghana (Fig. 1).[1] These regions constitute the major maize-growing areas of the country. Two districts with high maize production levels were selected from each region. Within each sampled district, three or four villages were randomly selected. Finally, we randomly sampled maize-producing households from the selected villages. The number of households interviewed per village ranged from 8 in smaller villages to 14 in relatively larger villages. It should be emphasised that while our data are useful for understanding FAW impacts and responses among a sample of smallholder farmers, they are not representative of maize-producing households in the study villages or regions in Ghana.

Data were collected through face-to-face interviews conducted by trained enumerators. The enumerators used tablet-based questionnaires that covered information on severity of FAW infestation, FAW management practices, household demographic characteristics, maize production activities, and access to information and other institutional support services.

Table 1 presents the summary statistics for the key variables in the two survey years. Our sample consists mostly of male-headed households, with middle-aged and low-educated household heads. In both survey years, more than two-thirds of the households did not have access to credit, with even an 8-percentage points reduction in 2020. Conversely, the number of households that accessed subsidized inputs nearly doubled over the two periods. The Ghana government provides subsidized

[1] Six new regions have since been carved out of the 10 regions, making a total of 16 regions in the country. We report the original 10 regions that were available during the first round of survey.

Table 1 Descriptive statistics for study variables

Variable	Description	2018	2020
Age	Age of household head (years)	44.73	46.60**
		(11.96)	(11.87)
Gender	Household head is male (1/0)	0.89	0.89
		(0.31)	(0.31)
Education	Household head secondary education or more (1/0)	0.28	0.25
		(0.45)	(0.43)
Household size	Number of household members	10.12	8.41**
		(7.55)	(4.51)
Accessed credit	Household accessed credit in the past year (1/0)	0.30	0.22**
		(0.46)	(0.42)
Subsidized inputs	Household received free or subsidized inputs (1/0)	0.35	0.69***
		(0.48)	(0.46)
Wealth index	Household asset index based on principal component analysis	0.07	0.14
		(1.43)	(1.43)
Distance to agro-dealer	Distance from household to the nearest agro-dealer (km)	6.74	3.57***
		(8.97)	(4.84)
Distance to extension	Distance from household to the nearest extension office (km)	8.25	5.02***
		(9.28)	(7.37)
FAW information	Household received information on fall armyworm (1/0)	0.79	0.68***
		(0.41)	(0.47)
Maize area	Total area under maize (hectares)	2.71	2.71
		(5.02)	(3.64)
No. of plots	Total number of maize plots cultivated by household	1.18	1.16
		(0.45)	(0.50)
Seed cost	Expenses on maize seed (GHC/ha)	28.15	30.50
		(80.50)	(63.07)
Fertilizer cost	Expenses on mineral fertilizer (GHC/ha)	51.30	329.10***
		(103.09)	(282.95)
Pesticide cost	Expenses on pesticides (GHC/ha)	106.41	24.68***
		(81.69)	(39.40)
Hired labour cost	Expenses on hired labour (GHC/ha)	273.78	250.19
		(299.12)	(355.01)
Maize yield	Quantity of maize harvested (kg/ha)	1744.27	1846.84
		(1865.28)	(1266.62)
Maize income	Gross maize income less production costs (GHC/ha)	1348.23	1506.29
		(1992.23)	(1520.23)
Observations	Number of observations	370	370

Values in parentheses are standard deviations. All monetary values have been deflated to 2018 values

*, ** and *** denote that the mean difference between 2018 and 2020 is statistically significant at 10%, 5% and 1% respectively

inputs (improved seeds and fertilizers) and extension services to farmers through the 'Planting for Food and Jobs' flagship programme. It is possible that the 2020 Ghanaian general election influenced the surge in the supply of subsidized or free inputs. Political manipulation of input subsidies for electoral gains has been well documented in several African countries, including Ghana (Banful 2011; Mason and Ricker-Gilbert 2013; Takeshima and Liverpool-Tasie 2015).

On average, households cultivated maize on one plot of less than three hectares in size. Compared to 2018, the average household expenditure on fertilizer increased by more than six-fold, while that on pesticide decreased by four-fold in 2020, potentially pointing to a reallocation of household resources from pesticide to fertilizer. As we will show in the next section, lower levels of FAW infestation in 2020 and increased use of non-chemical control measures could probably explain the diversion of capital from pesticide to fertilizer. The average maize yield was about 1.7–1.8 tonnes per hectare, which is comparable to the national average yield of 1.9–2.0 tonnes per hectare in recent years (FAOSTAT 2021). The average maize yield and income were greater in 2020 compared to 2018, but the differences between the 2 years are not statistically significant.

Empirical approach

The panel data were analysed descriptively to explore the dynamics of FAW infestation and the management practices applied by farmers. The assumption is that given the extent of crop losses caused by FAW and the risks and costs associated with the intensive use of synthetic pesticides for its control, farmers will over time adopt a variety of sustainable FAW management practices, in line with the concept of integrated pest management (IPM). IPM involves the use of a combination of sustainable pest control techniques, including pest resistant varieties, biological control, cultural control and mechanical control, as well as judicious use of chemical control as a last recourse (Dhawan and Peshin 2009).

To understand the effects of FAW on maize productivity, we estimated the following panel equation:

$$\begin{aligned} \boldsymbol{Y_{it}} =& \alpha + \boldsymbol{\vartheta_1 H_{it}} + \boldsymbol{\vartheta}_2 \boldsymbol{P}_{it} + \boldsymbol{\vartheta_3 R} \\ &+ \vartheta_4 D + \boldsymbol{\vartheta}_5 \boldsymbol{FAW_{it}} + \mu_i + \varepsilon_{it} \end{aligned} \tag{1}$$

where $\boldsymbol{Y_{it}}$ denotes the maize productivity outcomes for household i at time t. We used maize yield and income as indicators of maize productivity. Maize yield is measured by the quantity of maize harvested in kg/hectare, while maize income consists of gross revenue from maize production minus production costs, such as expenses on seed, fertilizer, pesticide, mechanization and labour (expressed in GHC/hectare). $\boldsymbol{H_{it}}$ is a vector of household characteristics, including age, gender and education of household head, household size, asset wealth, and access to institutional services such as credit, input subsidies and information sources. $\boldsymbol{P_{it}}$ is a vector of plot-level variables, such as plot size, and investment in seed, fertilizer, herbicide and labour when the outcome variable is maize yield. D is a year dummy that accounts for heterogeneity between survey years, such as the Covid-19 shock in 2020, which was not an issue in 2018. $\boldsymbol{R}$ represents a vector of regional dummies to control for geographical differences, such as agro-climatic conditions. The choice of these covariates was inspired by related literature on the productivity and welfare effects of FAW in smallholder agriculture (e.g., Kassie et al. 2020; Tambo et al. 2021). A description of the covariates is presented in Table 1.

Our main variable of interest is $\boldsymbol{FAW_{it}}$, which captures FAW infestation. Thus, the associated parameter, $\boldsymbol{\vartheta_5}$, quantifies the effect of FAW infestation on maize productivity. We used two different measures of FAW infestation. The first is a dummy variable that takes a value of one if a household observed FAW infestation on their maize fields, and zero otherwise. This was determined by presenting photo sheets illustrating key features of FAW and symptoms of its damage to the sample households, who were then asked to confirm whether or not they observed the pest in their maize fields in the past cropping season. We are also interested in the differential effects of the intensity of FAW infestation on maize productivity. Hence, the second measure of FAW infestation is a vector of the severity of infestation, consisting of no, minor, moderate or major infestation, based on farmers' self-reported information, and following Tambo et al. (2021). Minor infestation refers to if FAW caused damage on less than half of the maize plants; moderate infestation means that about half of the maize plants were attacked by FAW; while major infestation implies that more than half of the maize plants were affected by the pest.[2] $\vartheta_1 - \vartheta_5$ are the parameters associated with the explanatory variables, μ_i captures unobserved household characteristics, and ε_{it} is the random error term.

While Eq. 1 can be estimated using a simple pooled ordinary least squares (OLS) model, the parameter estimates will be inefficient with incorrect standard errors, as the pooled OLS estimator ignores the panel nature of the data. Consequently, we estimated the two equations using a panel fixed effects (FE) regression model, which controls for time-invariant household unobserved heterogeneity and offers more efficiency in estimation. A drawback of this standard FE model is the failure to recover the coefficients on variables with insufficient variation over time or time-constant variables, such as the regional dummies. To circumvent this limitation, we applied a variant of the standard FE model, as proposed by Mundlak (1978). The Mundlak FE estimator, which is also referred to as the correlated random effects (CRE) model, involves the inclusion of the mean of time-varying variables ($\bar{T}$) as additional regressors in Eq. (1) (Wooldridge 2010). Unlike the pooled OLS estimator, the CRE estimator accounts for unobserved household characteristics, as does the FE estimator. In the CRE approach, Eq. (1) can be re-specified as:

$$\begin{aligned} \boldsymbol{Y_{it}} &= \alpha + \boldsymbol{\vartheta_1 H_{it}} + \boldsymbol{\vartheta_2 P_{it}} + \boldsymbol{\vartheta_3 R} + \vartheta_4 D \\ &+ \vartheta_5 FAW_{it} + \boldsymbol{\vartheta_6 \bar{T}} + \mu_i + \varepsilon_{it} \end{aligned} \tag{2}$$

[2] It should be noted that a more appropriate approach to measuring the intensity of FAW infestation would have been to do field scouting during the agricultural season. This was not possible in the current study because we used data from household surveys conducted at the end of the cropping season.

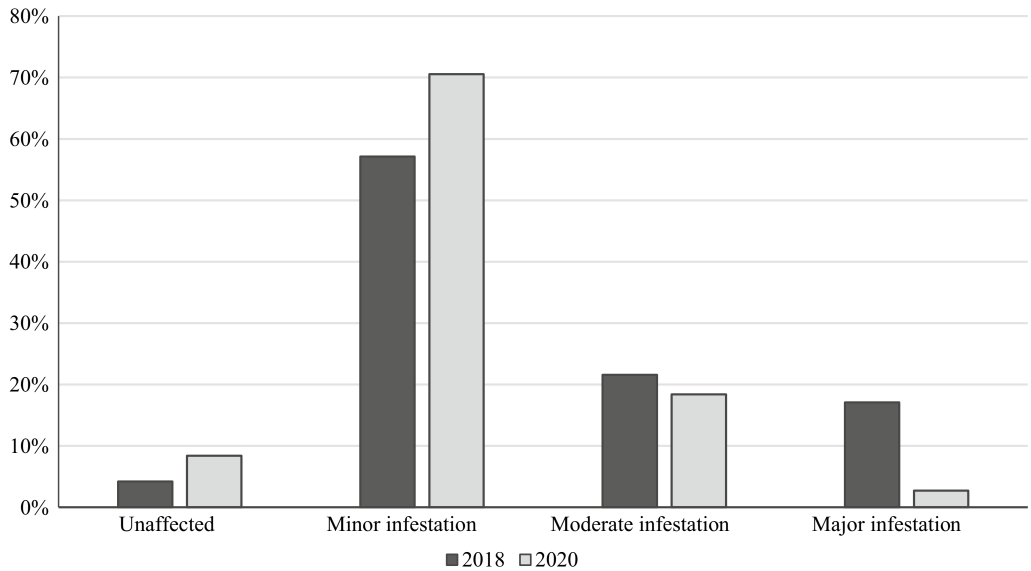

Fig. 2 Level of FAW infestations reported by sample farmers

The two panel models (CRE and FE) are the preferred estimators, but we also report results from pooled OLS estimators for comparison purposes.

Results and discussion

We begin this section by exploring the dynamics of FAW infestation and the management practices adopted by the sample households. We will focus particularly on pesticides, owing to their widespread use against FAW in SSA. We then present the regression results on the effect of FAW on maize productivity.

Dynamics of FAW infestation and management practices

Figure 2 shows the severity of FAW infestations, as self-reported by the sample farmers. In both years, more than half of the farmers reportedly recorded minor levels of FAW infestations in their maize fields. Proportionally more farmers were unaffected by FAW or suffered minor infestations in 2020 compared to 2018, while moderate and major infestations were more pronounced in 2018. These results, coupled with an earlier study showing that about a quarter of a sample of farmers in Ghana reported major infestations in 2017 (Tambo et al. 2020a), may be suggestive of a reduction in the severity of FAW infestation over the years. This is possibly due to increased years of experience in managing the pest, and thus reduced levels of infestations in more recent years.

The FAW management strategies implemented by the households are presented in Fig. 3. We find that the practices are similar in both survey years, and correspond with those reported by previous studies in Ghana and other SSA countries (e.g., Tambo et al. 2020a, b; Asare-Nuamah 2021; Njuguna et al. 2021). The management practices include: (1) insecticides, including synthetic pesticides and biopesticides; (2) mechanical methods, such as handpicking and crushing of caterpillars or destruction of infested plants; and (3) cultural methods, such as the avoidance of late or staggered planting, frequent weeding to remove alternative host plants, intercropping and rotation of maize with non-host crops, and fertilization to support healthy plant growth.

A comparison of the management practices between the two periods reveals some interesting insights. First, in most cases, the share of farmers who used the management practices in 2020 is significantly greater than those who did so in 2018. Second, the difference in the share of users of the various management is particularly greater in terms of preventive cultural practices, such as timely planting, fertilization, frequent weeding, as well as intercropping and rotation with non-host plants. This might partly explain why we observed reduced levels of infestation in 2020 (Fig. 2). A few (3%) of the households unaffected by FAW even claimed to have implemented cultural practices to prevent the pest infestation (see Additional file 1: Fig. S1). Third, there is a slight but statistically significant reduction in the share of farmers that used synthetic pesticides for FAW control between 2018 and 2020, and this translated into a statistically significant increase in the use of biopesticides during the same period. This is an encouraging finding, given that biopesticides are generally agreed to be lower risk options for FAW management in Africa (Bateman et al. 2021).

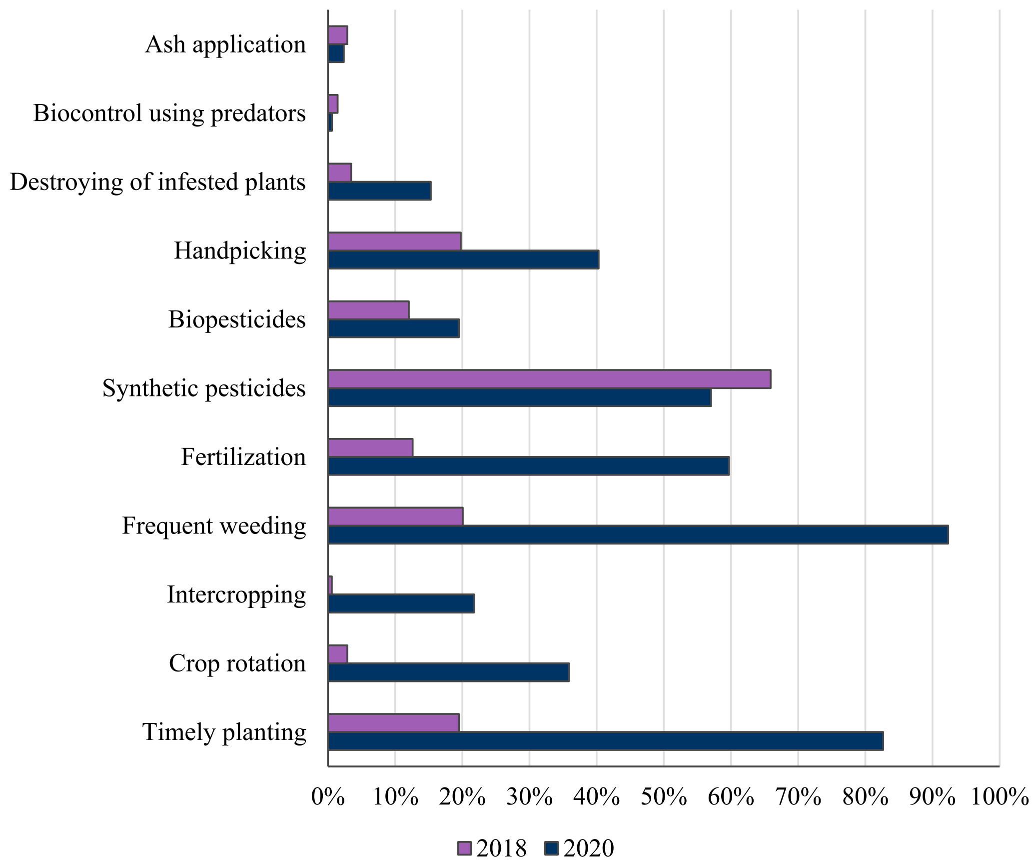

Fig. 3 Management practices adopted against FAW. Note: There are statistically significant differences ($p < 0.05$) between 2020 and 2018 for all the management practices, except the use of ash and predators.

Overall, the results in Fig. 3 suggest that farmers are using several management practices (particularly non-chemical options) for FAW management, in line with the tenets of integrated pest management (IPM) and recommended guidelines for FAW management in smallholder agriculture (Day et al. 2017; Hruska 2019). These findings depart from earlier studies that have shown that synthetic pesticide is the most widely used FAW management practice among African smallholders (e.g., Rwomushana et al. 2018; Kumela et al. 2019; Tambo et al. 2020b). In the wake of the FAW invasion, mass awareness campaigns have been rolled out to educate farmers on the identification and sustainable management of the pest, using complementary communication channels such as printed materials, radio, SMS, television broadcasts, and village-based video screenings (CABI 2019; Kansiime et al. 2020). This may have contributed to the increased use of management practices and a shift towards sustainable, non-chemical solutions in more recent years. However, the results also show that there is very little to no use of other important IPM components such as parasitoids and predators and host plant resistance, even in 2020, suggesting that more efforts are needed to research and promote these alternative, sustainable approaches to FAW management in the country.

Pesticide use dynamics

Table 2 indicates that the number of times that households sprayed pesticides against FAW in 2018 ranged from 1 to 12, with about 20% of the households spraying more than three times during the cropping season. By contrast, none of these same households sprayed pesticides more than three times in 2020, with more than half of them spraying only once throughout the cropping season. On average, the number of pesticide sprays per season was 2.45 in 2018, and this reduced significantly to 1.52 in 2020 ($\rho < 0.000$). Our data also show that the per hectare expenditure on pesticides reduced significantly by 56% (from 113.08 GHC/ha in 2018 to 49.64 GHC/ha in 2020) in real terms over the two survey periods. These results imply that the intensity of pesticide use (in terms of frequency of sprays and pesticide expenditure) against FAW has decreased since 2018. This is noteworthy because indiscriminate use of pesticides poses serious

Table 2 Frequency of pesticide use

No. of sprays per season	2018 (n = 256)	2020 (n = 237)
1	22.76	54.66
2	39.84	37.71
3	17.07	7.63
4	16.26	0
5	1.63	0
6	1.22	0
8	0.41	0
9	0.41	0
12	0.41	0

Values are percentages of pesticide users

risks to humans, the environment and beneficial insects, such as natural enemies and pollinators.

Table 3 reports the types of pesticide used by farmers for FAW control in Ghana. Consistent with Kansiime et al. (2019); Tambo et al. (2020b), we find that a wide range of pesticides are used by smallholder farmers in attempts to fight the devastating FAW pest in Africa. The number of different synthetic pesticide and biopesticide products applied slightly increased over the two study periods. In both years, Bacillus thuringiensis (Bt) + Monosultap was the most widely used pesticide against FAW. Most of the types of pesticides used are moderately hazardous (WHO class II), and there is no record of the use of highly hazardous pesticides in both

Table 3 Pesticides used for FAW control (%)

Trade name(s)	Active ingredients	WHO toxicity class*	2018 (n = 256)	2020 (n = 237)
Buffalo Supa or Golan	Acetamiprid	II	0.00	2.11
Viper 46 EC	Acetamiprid + Indoxacarb	II + II	1.17	0.00
Stricker Super	Acetamiprid + Emamectin–Benzoate	II + II	0.00	2.11
Neemazal	**Azadirachtin**	N	0.00	0.42
Agoo	**Bacillus thuringiensis (Bt)** + Monosultap	III + N	25.00	19.41
Acetastar	Bifenthrin + Acetamiprid	II + II	0.39	0.00
Bypel	**Bt + Pieris rapae granulosis virus**	III + N	7.03	12.66
Klopar	Chlorfenapyr	II	0.39	0.00
Dursban or Sunpyrifos	Chlorpyrifos–ethyl	II	5.86	4.22
KD 215EC	Chlorpyrifos + Lambda-cyhalothrin	II + II	1.56	0.00
Pyrinex	Chlorpyrifos + Deltamethrin	II + II	0.78	0.00
Cydim Super or Cymethoate Super	Dimethoate + Cypermethrin	II + II	0.39	0.42
Attack or Ataka Super	Emamectin Benzoate	II	15.23	13.92
Emastar	Emamectin Benzoate + Acetamiprid	II + II	9.77	16.46
Altimec Super	Emamectin Benzoate + Cypermethrin	II + II	0.00	1.27
Dean	Emamectin Benzoate + Imidacloprid	II + II	1.95	0.84
Adepa	Ethyl palmitate	N	8.98	7.17
Belt Expert	Flubendiamide + Thiacloprid	II + II	0.00	0.42
Confidor	Imidacloprid	II	2.34	0.00
Karate, Lambda or Pawa	Lambda–cyhalothrin	II	11.33	1.27
Eforia 45 ZC	Lambda–cyhalothrin + Thiamethoxam	II + II	3.91	1.69
K-Optimal	Lambda–cyhalothrin + Acetamiprid	II + II	10.55	5.91
Eradicoat T	**Maltodextrin**	III	3.91	10.55
Actelic Super	Pirimiphos–methyl	II	0.00	0.42
Agroblaster	**Pyrethrins**	II	0.00	2.95
Warrior Super	**Sophora flavescent plant extract** + Emamectin–Benzoate	N + II	0.00	10.13

The bold ones are biopesticides. Values are percentages of pesticide users

* WHO recommended classification of pesticides (WHO 2020)

Ia = extremely hazardous; *Ib* = highly hazardous; *II* = moderately hazardous; *III* = lightly hazardous; *U* = unlikely to present acute hazard; *N* = not classified

Table 4 Use of PPE items

PPE use	2018 (n = 256)	2020 (n = 237)
None	56.64	17.03
Mask	22.18	42.97
Coverall	29.18	51.89
Gloves	16.02	28.92
Gum boots	37.35	71.08
Cap/Helmet	13.28	10.54

Values are percentages of pesticide users

Table 5 Pesticide-related illness

Symptom	2018 (n = 256)	2020 (n = 237)
None	65.23	70.27
Headache	24.22	17.84
Stomach ache	5.07	7.02
Dizziness	16.02	11.62
Skin irritation	13.67	11.89

Values are percentages of pesticide users

survey years. Noticeably, there is a decrease in the use of Lambda-cyhalothrin-based pesticides. Conversely, there is a slight increase in the use of Bt + Pieris rapae granulosis virus and Maltodextrin, which are biopesticides. We also see that certain pesticide products (mostly biorationals and biopesticides) were used only in 2020. These include Sophora flavescent plant extract + Emamectin–Benzoate and Pyrethrins. This may reflect farmers' awareness of low-risk options, as well as efforts of the government of Ghana to promote biopesticides for FAW management (Rwomushana et al. 2018; Kansiime et al. 2020). Results from recent field experiments in Ghana have also shown that biopesticides are as effective as synthetic pesticides in controlling FAW (Nboyine et al. 2022; Agboyi et al. 2023).

Table 4 shows that more than half of the pesticide users in 2018 did not wear any standard PPE item while working with pesticides. This number reduced significantly to 17% in 2020. In particular, we find that the percentage of users of mask, coverall, gloves and gum boots nearly doubled over the two survey periods. The lack of use of PPE among Ghanaian farmers is a well-known concern (Ntow et al. 2006; Kwakye et al. 2019; Tambo et al. 2020b). Hence, the recent surge in the use of PPE items could be influenced by access to information on pesticide safety, as part of the intensive awareness campaigns on FAW management. Given the reduction in the intensity of pesticide use, as well as the increase in the percentage of users of PPE items, it is unsurprising to see that a slightly lower percentage of farmers reportedly experienced acute pesticide-related illness in 2020, compared to 2018 (Table 5).

Economic impacts of FAW

The estimation results of the impact of FAW invasion on maize yield and income are presented in Table 6. While FAW infestation leads to a reduction in maize yield, the effect is not statistically significant, irrespective of the estimation method employed. For instance, the results from the CRE model suggest that compared to unaffected households, the households affected by FAW obtained about 14% lower (but statistically insignificant) maize yield.[3] Similarly, Table 6 indicates that FAW infestation is associated with a 4–10% decrease in maize income (depending on the estimation method), but these effects are not statistically significant. This implies that after controlling for household characteristics, inputs used and time-invariant unobserved heterogeneity, FAW infestation does not exert a significant effect on maize productivity. These results are consistent with a recent evidence from southern Africa showing low impact of FAW on smallholder maize farms (Harrison et al. 2022).

In Table 7, we examine the effects of the intensity of FAW infestation on the two maize productivity outcomes. Specifically, we estimate differential yield and income effects of minor, moderate and major levels of FAW infestation, based on self-reported information on severity of FAW infestation (see Fig. 2). The pooled OLS results suggest that minor infestation had no significant effect on maize yield and income, but household that experienced moderate and major levels of FAW infestation achieved respectively 19% and 23% lower maize yields, compared to unaffected households. However, it should be remembered that the pooled OLS model is neither efficient nor consistent, as it does not account for the panel nature of the data and unobserved heterogeneity. Results from the more rigorous FE and CRE estimators show that the different levels of FAW infestation had negative but insignificant effects on maize yield and income. Overall, Table 7 confirms that FAW infestation did not result in a significant reduction in maize productivity, regardless of the self-reported severity of infestation.

One could argue that our estimates above may be limited by lack of statistical power (imprecise parameter estimates), considering that the comparison group (no FAW infestation) were reported by less than 10% of the sample in both years. Hence, as a robustness check, we re-estimated the productivity effects of FAW by restricting the analysis to only the households that have suffered

[3] Percentage effect of dummy coefficients in models with a log-dependent variable is computed as100* exp {c− 0.5 V(c)} − 1, where c represents the dummy coefficients and V(c) denotes the variance of c (Kennedy 1981).

Table 6 Effect of FAW on maize productivity

	ln[Maize yield (kg/ha)]			ln[Maize income (GHC/ha)]		
	Pooled OLS	FE[b]	CRE	Pooled OLS	FE	CRE
Fall armyworm[a]	– 0.116	– 0.053	– 0.148	– 0.859	– 0.470	– 0.788
	(0.081)	(0.125)	(0.163)	(0.680)	(0.587)	(0.673)
Control variables included	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	No	Yes	Yes	No	Yes
Mean of time varying variables included	No	No	Yes	No	No	Yes
R-squared	0.3092	0.0076	0.3312	0.1413	0.0087	0.1564
F / Wald chi2	13.00***	2.75***	314.65***	5.78***	2.09**	149.28***
Hausman test chi2[b]		26.65*			24.74*	
F test that all u_i = 0[c]		1.92***			1.38***	
Observations	740	740	740	740	740	740

Values in parentheses are robust standard errors

The full regression results are presented in Additional file 1: Table S1

[a] Comparison group is no FAW infestation

[b] Hausman test of fixed versus random effects specification

[c] The statistically significant F test means that panel data models (rather than pooled OLS) are appropriate for our data

*$p < 0.1$

** $p < 0.05$

***$p < 0.01$

Table 7 Effect of levels of FAW infestation on maize productivity

	ln[Maize yield (kg/ha)]			ln[Maize income (GHC/ha)]		
	Pooled OLS	FE	CRE	Pooled OLS	FE	CRE
Minor FAW infestation[a]	– 0.071	– 0.031	– 0.128	– 0.837	– 0.476	– 0.811
	(0.084)	(0.128)	(0.168)	(0.691)	(0.610)	(0.704)
Moderate FAW infestation[a]	– 0.211**	– 0.107	– 0.214	– 0.861	– 0.599	– 0.872
	(0.098)	(0.182)	(0.208)	(0.780)	(0.973)	(1.024)
Major FAW infestation[a]	– 0.263*	– 0.108	– 0.202	– 1.036	– 0.386	– 0.700
	(0.142)	(0.175)	(0.200)	(0.887)	– 0.888	(0.942)
Control variables included	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	No	Yes	Yes	No	Yes
Mean of time varying variables included	No	No	Yes	No	No	Yes
R-squared	0.3134	0.0136	0.3348	0.1414	0.0094	0.1581
F / Wald chi2	12.20***	2.50***	526.58***	5.24***	1.86**	150.68***
Hausman test chi2[b]		27.15*			26.01*	
F test that all u_i = 0[c]		1.84***			1.36***	
Observations	740	740	740	740	740	740

Values in parentheses are robust standard errors

The full regression results are presented in Additional file 1: Table S2

[a] Comparison group is no FAW infestation

[b] Hausman test of fixed versus random effects specification

[c] The statistically significant F test means that panel data models (rather than pooled OLS) are appropriate for our data

*$p < 0.1$

** $p < 0.05$

***$p < 0.01$

Table 8 Effect of levels of FAW infestation on maize productivity (FAW-affected sample)

	ln[Maize yield (kg/ha)]			ln[Maize income (GHC/ha)]		
	Pooled OLS	**FE**	**CRE**	**Pooled OLS**	**FE**	**CRE**
Moderate FAW infestation[a]	− 0.155*	− 0.039	− 0.050	− 0.003	0.298	0.291
	(0.090)	(0.127)	(0.127)	(0.503)	(0.787)	(0.797)
Major FAW infestation[a]	− 0.204*	− 0.087	− 0.103	− 0.253	0.211	0.099
	(0.120)	(0.187)	(0.185)	(0.631)	− 0.989	(0.987)
Control variables included	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	No	Yes	Yes	No	Yes
Mean of time varying variables included	No	No	Yes	No	No	Yes
R-squared	0.3038	0.0193	0.3238	0.1384	0.0055	0.1561
F / Wald chi2	11.38***	3.22***	476.93***	4.43***	1.66*	138.84***
Hausman test chi2[b]		21.54*			21.50*	
F test that all u_i = 0[c]		1.68***			1.25**	
Observations	694	694	694	694	694	694

Values in parentheses are robust standard errors

The full regression results are presented in Additional file 1: Table S3

[a] Comparison group is minor FAW infestation

[b] Hausman test of fixed versus random effects specification

[c] The statistically significant F test means that panel data models (rather than pooled OLS) are appropriate for our data

*p < 0.1

** p < 0.05

***p < 0.01

from FAW infestation. In this case, we compare moderate and major levels of FAW infestations to minor level of infestation. We find that in the naïve pooled OLS model, moderate and major levels of FAW infestation are significantly (albeit weakly) associated with roughly 14% and 18% reduction in maize yields respectively, relative to minor FAW infestation. Once again, the results from the panel data regression models show no significant effect of FAW infestation on maize yield or income. This further confirms the above findings that FAW attack did not cause a statistically significant reduction in maize productivity, after controlling for household unobserved heterogeneity and other key determinants of productivity (Table 8).

Based on farmers' estimates and without controlling for potential confounding factors, several studies have reported high yield losses due to FAW invasion in SSA, ranging from 45% Ghana and 40% in Zambia (Day et al. 2017); 38% in Kenya and 47% in Ethiopia (Kumela et al. 2019); 26% in Ghana and 35% in Zambia (Rwomushana et al. 2018); 33% in Kenya (De Groote et al. 2020); 36% in Ethiopia (Abro et al. 2021); to 58% in Zimbabwe (Chimweta et al. 2020). Our findings support arguments by Baudron et al. (2019), Overton et al. (2021) and Harrison et al. (2022) that these previous farmers' estimates of FAW-induced yield losses in SSA may have been over-estimated. It is also possible that better knowledge of and response to FAW may have contributed to reduced pest severity and yield loss, given that most of the previous studies were based on data collected during the early years of FAW outbreak in Africa. In addition, a build-up of natural enemies could have contributed to FAW suppression (Agboyi et al. 2020), and consequently reduce potential yield loss. Our findings also lend support to the conclusions of Williams et al. (2019) that the various actions taken to tackle the FAW menace in Ghana led to a marked reduction in the economic losses incurred.

Conclusion

Fall armyworm (FAW), a native pest of the Americas, invaded West Africa about 7 years ago, and spread rapidly across the rest of Africa and several countries in Asia and Oceania. The pest is reportedly causing severe damage to maize, which is an important food security crop in Africa. In this article, we assess the productivity effects of FAW infestation, and the strategies adopted by smallholders for the management of the pest. We also analyse the dynamics of pesticide use against FAW, considering that the outbreak of this pest has stimulated widespread use of pesticides. Previous related studies employed cross-sectional data and failed to capture the dynamics of FAW management decisions or account for household unobserved heterogeneity when assessing the economic impacts of FAW. We fill this gap using two rounds of panel data from smallholder farmers in Ghana.

Results show the severity of infestation on farmers' fields is lower in 2020 compared to 2018. Farmers continue to use a wide range of cultural, physical and chemical methods for FAW management. However, there is increased adoption of preventive cultural measures, such as timely planting, regular weeding and fertilizer application. We also found evidence of a slight shift from the use synthetic pesticides to biopesticides, as well as reduced intensity of pesticide use and increased use of PPE items when spraying pesticides. Regression results indicate that FAW infestation exerts negatives effect on maize yield and net maize income, but the effects are not statistically significant.

We conclude that the smallholder farmers are resorting to IPM and agroecological approaches for combating FAW, in line with recommended practices (Day et al. 2017; Hruska 2019). Our evidence also suggests that early reports of FAW-induced yield losses (ranging from 20 to 60%) in Africa based on farmers' self-perception could have been overestimated or the potential build-up of natural enemies, coupled with better knowledge and experience of farmers in using IPM practices for FAW management may have contributed to the non-significant maize productivity losses observed in the current study.

Given that the problem of FAW persists and cannot be eradicated, there is a need to strengthen the promotion of sustainable and environmentally-friendly solutions to mitigate its impacts. For instance, considering that the use of pesticides is still a popular FAW control option among smallholder farmers, and the resulting risks to human health and natural enemies, it is necessary to improve farmers' knowledge of safe pesticide use practices (including the use of PPE) and incentivise the adoption of safer alternatives to synthetic pesticides, such as biopesticides and IPM. Another strategy to provide long-term control of FAW is for governments to invest in the development and promotion of FAW resistant varieties and biological control agents, which can help reduce the reliance on pesticides. For future research, it would be important to evaluate the effectiveness and costs and benefits of the different combinations of FAW management practices used by the smallholder farmers.

Abbreviations

CRE	Correlated Random Effects
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
FAW	Fall armyworm
FE	Fixed effects
GHC	Ghana Cedis
IPM	Integrated Pest Management
OLS	Ordinary Least Squares
PPE	Personal Protective Equipment
SMS	Short Messaging Service
SSA	Sub-Saharan Africa
WHO	World Health Organization

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43170-023-00181-3.

Additional file 1: Figure S1. Management practices adopted against FAW, disaggregated by level of FAW infestations. **Table S1.** Effect of FAW on maize productivity. **Table S2.** Effect of levels of FAW infestation on maize productivity. **Table S3.** Effect of levels of FAW infestation on maize productivity (FAW-affected sample).

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Declarations

Ethics approval and consent to participate

Before starting an interview, a consent statement was read to each respondent. Only those who gave their consent were interviewed.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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