Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Environmental Sustainability

Fall armyworm invasion in Sub-Saharan Africa and impacts on community sustainability in the wake of Coronavirus Disease 2019: reviewing the evidence

Monica K Kansiime, Ivan Rwomushana and Idah Mugambi

Drawing on a synthesis of the recent empirical literature, we show that since its first report in 2016, fall armyworm has continued to spread rapidly posing severe threats to the food security of smallholders in Sub-Saharan Africa. Fall armyworm impacts have been more pronounced during 2020 due to Coronavirus Disease-2019 (COVID-19) restrictions that hampered labor availability and smallholder access to crop protection inputs. The agricultural system's vulnerability to COVID-19 underscores the need for a recovery effort that focuses on building back better for smallholder communities to overcome the impacts of the pandemic, and build resilience against similar threats in the future. Institutional strengthening, linkages to input and output markets, and microcredit support will address immediate production challenges in the wake of COVID-19. Enhancing the technical capacities of smallholders and regional collaboration for multirisk monitoring and early warning will inform coordinated actions for the sustainable management of fall armyworm and other emerging risks.

Address
Centre for Agriculture and Biosciences International (CABI), Canary Bird, 673 Limuru Road, Muthaiga, PO Box 633-00621, Nairobi, Kenya

Corresponding author: Kansiime, Monica K (m.kansiime@cabi.org)

Current Opinion in Environmental Sustainability 2023, **62**:101279

This review comes from a themed issue on **Emerging pests and pathogens**

Edited by **Peter Søgaard Jørgensen**

For complete overview of the section, please refer to the article collection, "Re-assessing the challenges of emerging pests and pathogens for sustainable development post-COVID"

Available online 8 April 2023

Received: 7 March 2022; Revised: 18 January 2023; Accepted: 8 March 2023

https://doi.org/10.1016/j.cosust.2023.101279

Introduction

Sustainable Development Goal 2 is hinged on achieving the zero-hunger target globally by 2030, and agricultural production is critical for achieving this target. However, agricultural systems and crop productivity across the continent are under threat due to climate change, the intensification of natural disasters, and upsurges in transboundary pests and diseases, in particular, invasive species [1]. Invasive pests cause a significant reduction in crop yield and quality, imposing a great effect on the livelihoods of smallholders, besides economic, ecological, and societal impacts. Pratt et al. [2] predicted that just five invasive species cause up to US$1.1 billion in economic losses to smallholders across six eastern African countries each year. This equates to around 2% of the total agricultural gross domestic product (GDP) for the region. Eschen et al. [3**] estimated the annual cost of invasive species to agriculture in Africa at US$ 65.58 billion.

First reported in Africa in 2016 [4], the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is arguably the most damaging invasive species to afflict all corners of the continent affecting major African crops, particularly maize, sorghum, millet, and legumes [5]. It is estimated that crops worth over USD 13 billion per annum are at risk of fall armyworm damage throughout Sub-Saharan Africa (SSA), thereby threatening the livelihoods of millions of smallholders [6]. For maize alone, yield losses ranging from 11% to 58% have been reported in various African farming systems [7–11*], translating into a revenue loss of up US $9.4 billion annually [3]. This is especially challenging for smallholder farmers, where yield declines result in loss of income and hunger. Smallholders also often lack the knowledge, tools, technologies, and management practices, or financial resources to recognize and respond to new pest species sustainably [12].

The consequences of fall armyworm invasions on food and nutrition security in Africa have been made even more pronounced during the 2020 global economic shutdown as a result of the Coronavirus Disease-2019 (COVID-19) pandemic. The containment measures for the disease created conditions for a major disruption to food system supply chains, giving rise to a dramatic increase in hunger. He and Krainer [13] report that while 7.4 million people were infected by COVID-19 in 2020, up to 811 million people were undernourished, almost 10% of the world's population, most of whom are in

Africa. Hunger-related fatalities reached four million in 2020, 10 times the number of COVID-19 fatalities. Unlike COVID-19, pathogen-related crop loss disproportionately affects food-insecure populations in developing countries [14], thus, the need for sustainable management solutions that are accessible to smallholders.

In this paper, we review the invasion and impact of fall armyworm on the livelihoods of smallholders in SSA and implications for community sustainability in the wake of COVID-19, drawing on a synthesis of peer-reviewed articles published between 2020 and 2022. We highlight new lessons learned since the fall armyworm invasion in Africa in 2016 and make recommendations for policy and practice for sustainable management of this pest, as well as preparedness to manage future threats.

Fall armyworm invasion and distribution

The fall armyworm is an agricultural pest native to the Americas. Since its first report in Africa in 2016 [4], the pest rapidly spread to more than 45 countries across the continent [15,16], and Africa is predicted to experience the greatest degree of fall armyworm threat in the future [14,17]. The spatial and temporal dynamics of the fall armyworm in Africa are influenced by several factors, including its high reproductive capacity, high migration ability, climate patterns, and cropping systems [18]. Given the variation in rainfall patterns, cropping seasons, and planting dates within and between countries and regions, there is a possibility of year-round breeding and infestation in Africa compared with the Americas where extended freezing temperatures affect fall armyworm survival [19]. Models show that fall armyworm can establish and persist in almost all countries in eastern and central Africa and a large part of western Africa under the current climate [19]. However, climatic barriers, such as heat and dry stresses, may limit the spread of the fall armyworm to North and South Africa. Future projections suggest that the fall armyworm invasive range will retract from both northern and southern regions toward the equator.

Impact of fall armyworm in Sub-Saharan Africa

Yield losses

While fall armyworm is reported to affect several crops, yield loss estimates in SSA have been mainly on maize, a key staple in the region. Recent socioeconomic surveys have estimated maize yield losses ranging from 11% to 58%, with variations across agroecological zones and cropping seasons [8,20**,21]. A systematic and countrywide study in Kenya using community surveys showed that the percentage of loss experienced by affected farmers decreased slightly, from 54% in 2017 to 42% in 2018 [8]. This is possibly due to varying climatic factors, a buildup of natural enemies, or improved pest management techniques [22,23]. In Ethiopia, a study combining agroecology-based community surveys and nationally representative data from an agricultural household survey estimated an average annual loss of 36% in maize production, reducing 0.67 million tonnes of maize (0.225 million tonnes per year) between 2017 and 2019 [24**]. Relatedly, a socioeconomic study in Southern Ethiopia using plot-level and household characteristics data showed an average maize yield loss of 10.8% [10]. In Benin, a national survey of maize farmers showed that farmer-perceived yield losses amounted to 797.2 kg/ha of maize, representing 49% of the average maize yield [25*]. Field scouting and farmer interviews in Zimbabwe estimated grain yield decreased by 58% [7].

Economic loss

Maize accounts for over 30% of SSA people's caloric intake. More than 300 million Africans depend on maize as their main food crop. Therefore, yield losses have significant negative impacts on the livelihoods of smallholder farmers, their income, and food security. A social economic survey in Zimbabwe showed significantly lower maize income and total household income per capita for fall armyworm-affected households than those not affected, with a mean difference of $59.19 and $258.84 per year, respectively [26**]. Bannor et al. [27] showed similar results of decreased farmers' income from maize production in Ghana, rendering them food-insecure. Another study further shows significant economic loss due to fall armyworm damage, and losses of up to $9.4 billion annually were estimated in 33 countries in Africa [3]. Management costs (comprising mainly labor costs associated with weeding and spraying) and crop yield losses constituted the majority of the estimated cost. In Ethiopia, the total economic loss due to fall armyworm was estimated at $200 million or 0.08% of GDP [24]. These estimates resonate with earlier studies that estimated economic damage of $2.48–6.19 million in 12 African countries [11], and national loss of $ 177 million and $159 million in Ghana and Zambia, respectively [22] due to fall armyworm. Fall armyworm also has had an impact on trade. Presently, it is classified as an A1 quarantine pest under the European and Mediterranean Plant Protection Organization regulations [11], resulting in global trade restrictions.

Environmental impacts

Smallholders in Africa rarely use pesticides in maize production. With the invasion of fall armyworm, extensive use of synthetic pesticides has been reported across the SSA region [20,28]. This situation is partly due to the emergency response strategy to fall armyworm invasion by most governments that included the procurement and free distribution of pesticides in efforts to curb the menace [11,20,22,28]. Although subsidized by governments, rapid responses such as those that were deployed for fall armyworm management can in most cases lead to the indiscriminate application of pesticides with little regard for safety. Besides, the use of synthetic pesticides as the sole control measure is unsustainable due to their high cost, risk of increased pesticide resistance, pest resurgence, and risk to human health, natural ecosystems, and biodiversity [6,29]. For example, the use of cheaper, less effective, and moderately hazardous pesticides by smallholders has been reported [9,12]. In Zambia, reports of the use of highly hazardous WHO class-II and -1b products were made, as well as farmers using untrialled cocktails of pesticides.

Health and social impacts

SSA is experiencing an epidemic of pesticide abuse. Smallholders often spray highly toxic chemicals without protective clothing or attention to other safety measures, such as appropriate dilution rates, field reentry periods, preharvest intervals, and safe disposal of used containers. A World Health Organization report estimated that in 2016, over 150 000 deaths and over seven million disability-adjusted life years from pesticide self-poisoning could have been avoided by sound pesticide management [30]. Tambo et al. [28**] reported some evidence that unsafe pesticide use is putting farmers' health at risk. Many formulae are known to impair development in children. Government donations of chemicals without appropriate safety equipment and training only serve to promote pesticide abuse.

Fall armyworm management practices

Following its first detection on the continent, various strategies have been employed to manage the fall armyworm. Smallholders have used a mix of physical and mechanical control measures such as handpicking of larvae and egg masses, adding soil/sand/ash to plant whorls, household soaps, drenching with tobacco extracts, destroying ratoon host crops and infested plant parts, early planting, and deep ploughing to kill pupae [31,32]. Use of agroecology-based practices such as maize rotation with nonhost crops, intercropping, 'push–pull', sowing multiple maize varieties, and in-field diversity to promote natural pest regulation have also been reported in some farming systems [32–35]. The use of synthetic pesticides, however, remains the most commonly used method for the management of the fall armyworm across Africa's farming systems [17,28,31,36]. Reliance on synthetic pesticides is often explained by the lack of suitable cost-effective alternative pest management options. Besides, smallholders often lack knowledge of pest identification, monitoring, and early detection and therefore resort to synthetic pesticides as curative measures once the pest occurs [12].

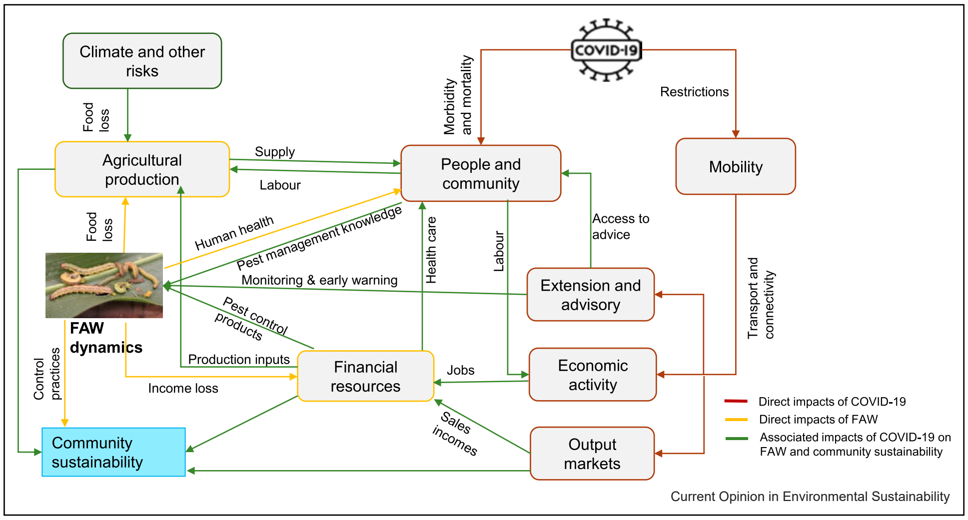
Many pesticides are known to be effective for fall armyworm control, though many have not been registered for use in several countries in SSA [37]. Besides, the associated health and environmental risks of insecticide use, continue to suggest the need for a safer and much more environmentally friendly approach to fall armyworm control. Biological control options using entomopathogenic microbes such as nuclear polyhedrosis virus, *Bacillus thuringiensis*, *Metarhizium anisopliae*, *Beauveria bassiana*, and Spinosad [17], and plant extracts with insecticidal properties such as neem (*Azadirachta indica*) and pyrethrum (*Tanacetum cinerariifolium*) [22,38], have been recommended as alternatives. There are also reports on locally prevalent indigenous natural enemies (predators and parasitoids) in Africa, with up to 70% fall armyworm parasitism [23,39,40].

Fall armyworm management practice varies across countries, regions, and places, and factors affecting smallholder decisions to manage the pest included financial resources or asset base, farmer perceptions, and access to subsidized farm inputs and extension information [28,41]. Constantine et al. [42] reported that limited availability, high cost, and farmer perception about the efficacy of biopesticides limit their use in Kenya. Further efficacy research into low-cost and smallholder-friendly solutions should be done building on local knowledge and ecological principles to enhance sustainable management of fall armyworm.

Impacts of the Coronavirus Disease-2019 pandemic on fall armyworm management

Since the declaration of COVID-19 as a global pandemic in January 2020, there has been a massive disruption of livelihoods due to the disease itself but also occasioned by the stringent measures put in place to curb the spread of the disease. Agricultural workers in low- and middle-income countries that have labor-intensive farming systems suffered disruptions in their supply chains and outputs were compromised due to labor shortages [43,44]. There were also disruptions in the supply and availability of critical production inputs such as fertilizers, plant protection products, and seeds. This contributed to limited crop protection interventions by farmers, including monitoring for the pest, weeding, and timely pesticide sprays, which have direct effects on both preventive and curative pest management actions. According to Food and Agriculture Organisation, in many fall armyworm-affected countries, pest management activities reduced or even stopped due to COVID-19 restrictions [45]. Also, capacity-building initiatives for farmers and extension workers were reduced. As the fall armyworm continues to ravage crops and invade new areas, innovative ways of delivering the needed fall armyworm management information and new technologies are needed to recover from current COVID-19 impact and preparedness for the future. Figure 1 shows the characteristics of the COVID-19 disruption on fall

Figure 1



Characteristics of the COVID-19 disruption on fall armyworm management and impacts on community sustainability.

armyworm management and impacts on community sustainability.

Prospects for sustainable fall armyworm management and community sustainability

Recent research indicates continued negative impacts of fall armyworm and other threats on the food security of smallholders in Africa. While farmers rely on pesticides for the control of fall armyworm, this presents sustainability challenges as most smallholders in Africa cannot afford the repeated spraying required to achieve effective pest control, without government support. This situation has been worsened by COVID-19 restrictions as many farmers could not access the pest control products due to distractions in mobility, supply chains, and income earning ability. Importantly, many potential low-cost smallholder-friendly solutions building on biological control, agroecology practice, and farmer local knowledge have been tested and can be promoted as part of the fall armyworm area-wide integrated pest management (IPM) strategy. Area-wide IPM is defined as the long-term planned campaign against an insect pest population in a relatively large predefined area to reduce the insect population to below economic injury levels [46]. If properly coordinated, the approach can achieve more sustainable and longer-lasting suppression of mobile pests such as fall armyworm. Strategic communication — harnessing the strengths of digital tools — in pest identification and management is key for esnsuring continuous farmer and extension worker education and sustainability.

COVID-19 revealed how agricultural systems are extremely vulnerable to crises underscoring the need for a recovery effort that focuses on building back better for smallholder communities to overcome the impacts of the pandemic, and build resilience against similar threats in the future. Institutional strengthening and smallholder linkages to input and output markets, and microcredit support will address immediate production challenges in the wake of COVID-19. Enhancing the technical capacities of smallholders to use IPM measures, and regional collaboration for multirisk monitoring and early warning will inform prevention, preparedness, and coordinated actions for the sustainable management of emerging risks.

Data Availability

No data were used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The study was funded under CABI's PlantwisePlus program. CABI is an international intergovernmental organization and we gratefully acknowledge the core financial support from our member countries (and lead agencies) including the United Kingdom Foreign, Commonwealth, and Development Office (FDCO), European Union, China (Chinese Ministry of Agriculture), Australia (Australian Centre for International Agricultural Research), Canada (Agriculture and Agri-Food Canada), Netherlands (Directorate-General for International Cooperation-DGIS), Switzerland (Swiss Agency for Development and Cooperation) and Ireland (Irish Aid, International Fund for Agricultural Development-IFAD). See https://www.cabi.org/about -cabi/who-we-work-with/key-donors/ for details.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Sundström JF, Albihn A, Boqvist S, Ljungvall K, Marstorp H, Martiin C, *et al*.: **Future threats to agricultural food production posed by environmental degradation, climate change, and animal and plant diseases — a risk analysis in three economic and climate settings**. *Food Secur* 2014, **6**:201-215.

2. Pratt CF, Constantine KL, Murphy ST: **Economic impacts of invasive alien species on African smallholder livelihoods**. *Food Secur Gov Lat Am* 2017, **14**:31-37.

3. Eschen R, Beale T, Bonnin JM, Constantine KL, Duah S, Finch EA, •• *et al*.: **Towards estimating the economic cost of invasive alien species to African crop and livestock production**. *CABI Agric Biosci* 2021, **2**:18.

The study estimated the cost of invasive alien species to agriculture in Africa. Data collected via online survey and literature review, and from publicly available sources. Among all the Invasive Alien Species (IAS) considered in this study, Fall armyworm (FAW) caused the highest yield losses (USD 9.4 Bn annually). The online survey however attracted a rather low response rate (n = 110 from 33 countries), and there are possibilities that some respondents may have unintentionally over-estimated costs.

4. Goergen G, Kumar PL, Sankung SB, Togola A, Tamò M: **First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (J E Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa**. *PLoS One* 2016, **11**:e0165632.

5. Overton K, Maino JL, Day R, Umina PA, Bett B, Carnovale D, *et al*.: **Global crop impacts, yield losses and action thresholds for fall armyworm (Spodoptera frugiperda): a review**. *Crop Prot* 2021, **145**:105641.

6. Harrison RD, Thierfelder C, Baudron F, Chinwada P, Midega C, Schaffner U, *et al*.: **Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: providing low-cost, smallholder friendly solutions to an invasive pest**. *J Environ Manag* 2019, **243**:318-330.

7. Chimweta M, Nyakudya IW, Jimu L, Bray Mashingaidze A: **Fall armyworm [*Spodoptera frugiperda* (J.E. Smith)] damage in maize: management options for flood-recession cropping smallholder farmers**. *Int J Pest Manag* 2020, **66**:142-154.

8. De Groote H, Kimenju SC, Munyua B, Palmas S, Kassie M, Bruce A: •• **Spread and impact of fall armyworm (*Spodoptera frugiperda* J.E. Smith) in maize production areas of Kenya**. *Agric Ecosyst Environ* 2020, **292**:106804.

The study used community interviews to assess impact of fall armyworm across cropping seasons and agro-ecologies in Kenya. Maize yield loss of about 1/3 of Kenya's maize production, estimated at about one million tonnes was reported. Substantial differences between the maize production zones were observed — low- and medium-potential areas were most affected compared to high-potential areas (highlands and moist transitional).

9. Kansiime MK, Mugambi I, Rwomushana I, Nunda W, Lamontagne-Godwin J, Rware H, *et al*.: **Farmer perception of fall armyworm (*Spodoptera frugiperda* J.E. Smith) and farm-level management practices in Zambia**. *Pest Manag Sci* 2019, **75**:2840-2850.

10. Kassie M, Wossen T, De Groote H, Tefera T, Sevgan S, Balew S: **Economic impacts of fall armyworm and its management strategies: evidence from southern Ethiopia**. *Eur Rev Agric Econ* 2020, **47**:1473-1501.

11. Abrahams P, Bateman M, Beale T, Clottey V, Cock M, Colmenarez • Y, et al.: **Fall armyworm: impacts and implications for Africa**. *Evid Note*; 2017. Available from: ⟨https://www.invasive-species.org/fawevidencenote⟩.

This was the first estimate of the impacts of fall armyworm in 2017, a year after its report in African continent. The data were extrapolated to 12 maize-producing countries in SSA. Without control measures, the pest could cause maize losses of up to 17.7 million tonnes, translating into revenue loss of up to almost US$5 billion a year. This has potential to significantly impact food security and livelihoods of smallholders.

12. Day R, Abrahams P, Bateman M, Beale T, Clottey V, Cock M, *et al*.: **Fall armyworm: impacts and implications for Africa**. *Outlooks Pest Manag* 2017, **28**:196-201.

13. He S, Krainer KMC: **Pandemics of people and plants: which is the greater threat to food security?** *Mol Plant* 2020, **13**:933-934.

14. Savary S, Willocquet L, Pethybridge SJ, Esker P, McRoberts N, Nelson A: **The global burden of pathogens and pests on major food crops**. *Nat Ecol Evol* 2019, **3**:430-439.

15. Nagoshi RN, Goergen G, Tounou KA, Agboka K, Koffi D, Meagher RL: **Analysis of strain distribution, migratory potential, and invasion history of fall armyworm populations in northern Sub-Saharan Africa**. *Sci Rep* 2018, **8**:3710.

16. Nagoshi RN, Goergen G, Plessis HD, van den Berg J, Meagher R: **Genetic comparisons of fall armyworm populations from 11 countries spanning sub-Saharan Africa provide insights into strain composition and migratory behaviors**. *Sci Rep* 2019, **9**:8311.

17. Niassy S, Agbodzavu MK, Kimathi E, Mutune B, Abdel-Rahman EFM, Salifu D, *et al*.: **Bioecology of fall armyworm *Spodoptera frugiperda* (J. E. Smith), its management and potential patterns of seasonal spread in Africa**. *PLoS One* 2021, **16**:e0249042.

18. Guimapi RA, Niassy S, Mudereri BT, Abdel-Rahman EM, Tepa-Yotto GT, Subramanian S, *et al*.: **Harnessing data science to improve integrated management of invasive pest species across Africa: an application to fall armyworm (*Spodoptera frugiperda*) (J.E. Smith) (Lepidoptera: Noctuidae)**. *Glob Ecol Conserv* 2022, **35**:e02056.

19. Timilsena PB, Niassy S, Kimathi E, Abdel-Rahman EM, Seidl-Adams I, Wamalwa M, *et al*.: **Potential distribution of fall armyworm in Africa and beyond, considering climate change and irrigation patterns**. *Sci Rep* 2022, **12**:539.

20. Koffi D, Agboka K, Adenka DK, Osae M, Tounou AK, Anani Adjevi •• MK, *et al*.: **Maize infestation of fall armyworm (Lepidoptera: Noctuidae) within agro-ecological zones of Togo and Ghana in West Africa 3 yr after its invasion**. *Environ Entomol* 2020, **49**:645-650.

Socio-economic survey coupled with farm inspection of infestation levels of FAW in Togo and Ghana. Agro-ecology differences in infestation levels and observed reduced infestation in 2018 compared to 2017. 2017 had the highest yield loss, one year after the FAW invasion. Two rounds of interviews were done at farm level to quantify maize yield which may provide a better estimate as opposed to long recall periods. This also helps to make comparison across years with various infestation levels and management practices applied

21. Koffi D, Kyerematen R, Eziah VY, Osei-Mensah YO, Afreh-Nuamah K, Aboagye E, *et al*.: **Assessment of impacts of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on maize production in Ghana**. *J Integr Pest Manag* 2020, **11**:20.

22. Rwomushana I, Bateman M, Beale T, Beseh PK, Cameron K, Chiluba M, *et al*.: **Fall Armyworm: Impacts and Implication for Africa**. CAB International; 2019, ⟨https://www.invasive-species.org/wp-content/uploads/sites/2/2019/02/FAW-Evidence-Note-October-2018.pdf⟩.

23. Agboyi LK, Goergen G, Beseh P, Mensah SA, Clottey VA, Glikpo R, *et al*.: **Parasitoid complex of fall armyworm, *Spodoptera frugiperda*, in Ghana and Benin**. *Insects* (2) 2020, **11**:68, https://doi.org/10.3390/insects11020068

24. Abro Z, Kimathi E, De Groote H, Tefera T, Sevgan S, Niassy S, •• *et al*.: **Socioeconomic and health impacts of fall armyworm in Ethiopia**. *PLoS One* 2021, **16**:e0257736.

Presents evidence on the impacts of FAW on maize production, food security, and human and environmental health. The study used a combination of an agroecology-based community survey and nationally representative data from an agricultural household survey. The study provides an array of FAW management practices and their perceived effectiveness, which differs across agro-ecologies.

25. Houngbo S, Zannou A, Aoudji A, Sossou HC, Sinzogan A, Sikirou • R, *et al*.: **Farmers' knowledge and management practices of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) in Benin, West

Africa. *Agriculture* (10) 2020, **10**:430, https://doi.org/10.3390/agriculture10100430.
The study assessed farmers' knowledge of FAW, their perceptions, and management practices. The severity of pest attacks was significantly associated with cropping practices and type of maize variety grown. Results further highlight farmers' dependency on chemical pesticides for FAW control, as over 90% used chemical pesticides.

26. •• Tambo JA, Kansiime MK, Rwomushana I, Mugambi I, Nunda W, Mloza Banda C, *et al*.: **Impact of fall armyworm invasion on household income and food security in Zimbabwe**. *Food Energy Secur* 2021, **10**:e281.
The study used regression to model food security and income, comparing households that had FAW and those that did not, based on farmers' self-reported information. maize income and total household income per capita for FAW affected households were significantly lower than those not affected by FAW, and those affected by FAW were likely to be more food insecure that those not affected. using a regression model indicates a possible relationship and not necessarily causality, though it gives a useful indication of the situation at household level due to FAW invasion.

27. Bannor RK, Oppong-Kyeremeh H, Aguah DA, Kyire SKC: **An analysis of the effect of fall armyworm on the food security status of maize-producing households in Ghana**. *Int J Soc Econ* (4) 2022, **49**:562-580, https://doi.org/10.1108/IJSE-07-2021-0418

28. •• Tambo JA, Kansiime MK, Mugambi I, Rwomushana I, Kenis M, Day RK, *et al*.: **Understanding smallholders' responses to fall armyworm (*Spodoptera frugiperda*) invasion: evidence from five African countries**. *Sci Total Environ* 2020, **740**:140015.
The study used unique survey data from 2356 maize-growing households in Ghana, Rwanda, Uganda, Zambia, and Zimbabwe, to examine how smallholder farmers are fighting fall armyworm. Results showed that smallholder farm households have adopted a variety of cultural, physical, chemical, and local options to mitigate the effects of FAW, but the use of synthetic pesticides remains the most popular option.

29. Kumela T, Simiyu J, Sisay B, Likhayo P, Mendesil E, Gohole L, *et al*.: **Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (*Spodoptera frugiperda*) in Ethiopia and Kenya**. *Int J Pest Manag* 2019, **65**:1-9.

30. World Health Organization: **World Health Statistics 2016: Monitoring Health for the SDGs Sustainable Development Goals**. World Health Organization; 2016.

31. Tambo JA, Day RK, Lamontagne-Godwin J, Silvestri S, Beseh PK, Oppong-Mensah B, *et al*.: **Tackling fall armyworm (*Spodoptera frugiperda*) outbreak in Africa: an analysis of farmers' control actions**. *Int J Pest Manag* 2020, **66**:298-310.

32. •• Yigezu G, Mulatu W: **Local and indigenous knowledge of farmers management practice against fall armyworm (*Spodoptera frugiperda*) (J. E. Smith) (Lepidoptera: Noctuidae): a review**. *J Entomol Zool Stud* 2020, **8**:765-770.
A review of indigenous/cultural methods used in FAW management in Africa. Highlights various nonchemical methods used by farmers to manage FAW, although the efficacy of some of these methods has not been adequately researched. It is important to understand farmers' indigenous knowledge and practices and focus research efforts around such methods to increase probability of uptake.

33. Akeme CN, Ngosong C, Sumbele SA, Aslan A, Tening AS, Krah CY, *et al*.: **Different controlling methods of fall armyworm (*Spodoptera frugiperda*) in maize farms of small-scale producers in Cameroon**. *IOP Conf Ser Earth Environ Sci* 2021, **911**:012053.

34. Murray K, Jepson P, Chaola M : **Fall Armyworm Management by Maize Smallholders in Malawi: An Integrated Pest Management Strategic Plan**; 2019.

35. Scheidegger L, Niassy S, Midega C, Chiriboga X, Delabays N, Lefort F, *et al*.: **The role of *Desmodium intortum*, *Brachiaria* sp. and *Phaseolus vulgaris* in the management of fall armyworm *Spodoptera frugiperda* (J. E. Smith) in maize cropping systems in Africa**. *Pest Manag Sci* 2021, **77**:2350-2357.

36. Njuguna E, Nethononda PD, Maredia K, Mbabazi R, Kachapulula PW, Rowe A, *et al*.: **Experiences and perspectives on *Spodoptera frugiperda* (Lepidoptera: Noctuidae) management in Sub-Saharan Africa**. *J Integr Pest Manag* 2021, **12**:1-9.

37. Tepa-Yotto GT, Chinwada P, Rwomushana I, Goergen G, Subramanian S: **Integrated management of *Spodoptera frugiperda* 6 years post detection in Africa: a review**. *Curr Opin Insect Sci* 2022, **52**:100928.

38. Phambala K, Tembo Y, Kasambala T, Kabambe VH, Stevenson PC, Belmain SR: **Bioactivity of common pesticidal plants on fall armyworm larvae (*Spodoptera frugiperda*)**. *Plants* (1) 2020, **9**:112, https://doi.org/10.3390/plants9010112

39. Durocher-Granger L, Mfune T, Musesha M, Lowry A, Reynolds K, Buddie A, *et al*.: **Correction to: factors influencing the occurrence of fall armyworm parasitoids in Zambia**. *J Pest Sci* 2022, **95**:539-540.

40. Otim MH, Adumo Aropet S, Opio M, Kanyesigye D, Nakelet Opolot H, Tek Tay W: **Parasitoid distribution and parasitism of the fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in different maize producing regions of Uganda**. *Insects* (2) 2021, **12**:121, https://doi.org/10.3390/insects12020121

41. Caniço A, Mexia A, Santos L: **Farmers' knowledge, perception and management practices of fall armyworm (*Spodoptera frugiperda* Smith) in Manica province, Mozambique**. *NeoBiota* 2021, **68**:127-143.

42. Constantine KL, Kansiime MK, Mugambi I, Nunda W, Chacha D, Rware H, *et al*.: **Why don't smallholder farmers in Kenya use more biopesticides?** *Pest Manag Sci* 2020, **76**:3615-3625.

43. Lamichhane JR, Reay-Jones FP: **Editorial: impacts of COVID-19 on global plant health and crop protection and the resulting effect on global food security and safety**. *Crop Prot Guildf Surrey* 2021, **139**:105383.

44. Schmidhuber J, Pound J, Qiao B: **COVID-19: Channels of Transmission to Food and Agriculture**. FAO; 2020.

45. FAO: **Addressing the Impact of COVID-19 on the Global Action for Fall Armyworm Control**. FAO — Food and Agriculture Organisation of the United Nations; 2020 Guidance Note 7.

46. In *Area-wide Control of Insect Pests: from Research to Field Implementation*. Edited by Vreysen MJB, Robinson AS, Hendrichs J. Springer; 2007, https://doi.org/10.1007/978-1-4020-6059-5