Fall armyworm: impacts and implications for Africa

Evidence Note Update, October 2018

Rwomushana, I., Bateman, M., Beale, T., Beseh, P., Cameron, K., Chiluba, M., Clottey, V., Davis, T., Day, R., Early, R., Godwin, J., Gonzalez-Moreno, P., Kansiime, M., Kenis, M., Makale, F., Mugambi, I., Murphy, S., Nunda. W., Phiri, N., Pratt, C., Tambo, J.

KNOWLEDGE FOR LIFE

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Executive Summary

This Evidence Note provides new evidence on the distribution and impact of FAW in Africa, summarises research and development on control methods, and makes recommendations for sustainable management of the pest.

FAW biology

FAW populations in Africa include both the 'corn strain' and the 'rice strain'. In Africa almost all major damage has been recorded on maize. FAW has been reported from numerous other crops in Africa but usually there is little or no damage. At the moment managing the pest in maize remains the overriding priority.

In Africa FAW breeds continuously where host plants are available throughout the year, but is capable of migrating long distances so also causes damage in seasonally suitable environments. There is little evidence on the relative frequency of these two scenarios. Studies show that natural enemies (predators and parasitoids) in Africa have "discovered" FAW, and in some places high levels of parasitism have already been found.

Distribution and Spread

FAW in Africa

Rapid spread has continued and now 44 countries in Africa are affected. There are no reports from North Africa, but FAW has reached the Indian Ocean islands including Madagascar. Environmental suitability modelling suggests almost all areas suitable for FAW in sub-Saharan Africa are now infested. Spread directly across the Sahara is unlikely. But if FAW does establish in the small suitable areas in North Africa, it would become a risk to Europe through migration.

FAW in Asia

In 2018 it was found in Yemen and India. Large areas of Asia are highly suitable for FAW, some corresponding with major maize-producing zones. The pest can be expected to spread rapidly through Asia, so countries should prepare response plans immediately.

Impacts in Africa

Yield loss

In new household surveys in Ghana and Zambia, 98% of farmers reported maize to be affected, but only 2-4% reported damage to Napier grass, sorghum or millet. The average maize loss reported by farmers in Ghana was 26.6% and in Zambia 35%. This is much lower than reported in 2017. Yield loss could be lower due to climatic factors, build-up of natural enemies or improved management. Farmers may be getting better at estimating FAW damage.

Extrapolating these losses nationally gives an estimate of US$177m lost value of the annual maize crop in Ghana and US$159m in Zambia. Most parts of Ghana and Zambia are highly suitable for FAW so countries with maize growing in areas less suitable for the pest might be expected to suffer less damage. But the relationship between environmental suitability and damage has yet to be established.

Farmers' control practices

Applying pesticide is the most frequent control method used. More farmers use pesticide in Ghana than in Zambia, but fewer farmers used pesticides in 2018 than in 2017. In Zambia the proportion of farmers using traditional methods or not controlling FAW has increased since 2017. In Ghana the proportion of farmers using no control method has halved.

In Ghana a major change from 2017 is the increased use of biopesticides. This reflects a national policy to recommend and subsidise their use. The most common active ingredient used was Bacillus thuringiensis (Bt); over half the users had received it for free. Very few farmers use biopesticides in Zambia. A few farmers reported using very highly toxic pesticides, which is a serious concern.

Trade impacts

Following establishment of FAW in Africa, the EU instigated emergency measures requiring strict phytosanitary controls in exporting countries to reduce the risk of the pest reaching Europe. In 2017 two consignments from Africa containing FAW were intercepted in Europe, and 17 in 2018. This level of interceptions suggests African exporters are currently managing the situation adequately.

Controlling FAW

There is wide agreement that Integrated Pest Management (IPM) is the appropriate approach to controlling FAW.

Monitoring FAW provides information to support decision-making. Field scouting scores the percentage of plants affected and is used to decide whether treatment is worthwhile, but decision thresholds are yet to be determined in Africa. Pheromone traps are being used to monitor FAW, though the relationship between trap catch and population size for the different types of trap and pheromone being used is unclear. FAO has developed an Android app (FAMEWS) for recording field scouting and pheromone trap data. Research on remote sensing, automatic counting of trap catches, image analysis of insects and damage, and radar, will all improve monitoring and contribute to understanding FAW biology, as well as provide opportunities for forecasting.

Pesticides are being used by many farmers and are recommended by governments. Many are effective if applied correctly, but are often used without appropriate safety precautions. Some farmers are illegally using highly dangerous chemicals. Reports of pesticides being ineffective are probably due to inappropriate use rather than pesticide resistance. Seed treatment can protect the crop for up to several weeks in favourable conditions.

Biopesticides suitable for FAW control in Africa have been identified in a survey of registered biopesticides in 30 countries. Eight active ingredients have been prioritised, and field testing is in progress for several including insect viruses, *Bacillus thuringiensis* (Bt), neem products and mating disruption using pheromones.

Biological control offers immediate and longer term potential. Several indigenous natural enemies (predators and parasitoids) have been discovered, with up to 70% parasitism reported. Research on conservation, encouragement and augmentation of natural enemies is required. Research on natural enemies in Latin America for possible introduction to Africa is in progress.

Agronomic and cultural practices can reduce the likelihood or severity of FAW infestation. New evidence shows intercropping maize with legume crops (beans, soybean, groundnut) reduces damage. The use of companion plants (repellents and trap crops) has also been shown to reduce FAW damage in Africa. Work is required to ensure companion plants are not weedy and can be obtained and grown cost effectively.

Insect-resistant maize has been identified, and five promising hybrids may be available within two to three years. In trials of genetically modified maize, preliminary results show partial control of FAW. Few African countries have legalised the use of any genetically modified crops.

Farmers are experimenting with traditional pest control methods as well as trying new ones, including various repellent and insecticidal substances and plant extracts. Ways of encouraging natural enemies have been reported. Some organisations are conducting trials on these methods which have the benefit of being low cost and locally available.

FAW advice and information

Advising farmers

Many stakeholders are providing advice. Their different objectives, experience and knowledge results in them providing different advice to farmers. In principle, recommended control methods should be efficacious, safe, sustainable, practical, available and affordable. In practice many of these criteria are context specific, so any recommendation or advice is unlikely to suit all farmers in all situations.

Multiple communication channels are being tested and used for advising farmers on controlling FAW. These include traditional and innovative ICT-based systems. Each has advantages and disadvantages in relation to the quality and complexity of information that can be communicated, and the cost per recipient. A combination of approaches is likely to provide the most cost-effective outcomes.

Information for other stakeholders

Much information on FAW has been collated and published, including manuals produced by CIMMYT, USAID and FAO. These and many other materials for farmers, researchers and other stakeholders are available through CABI's fall armyworm portal (www.cabi.org/isc/fallarmyworm).

Recommendations

As envisaged in the FAO partnership framework and new R4D consortium, many stakeholders contribute to FAW management. Recommendations are made for four groups.

National FAW coordination task forces should:

- Ensure the voice of different stakeholders, especially smallholder farmers, is heard
- Monitor FAW crop loss and control practices, to provide evidence for national decisions
- Use any subsidies to encourage the use of low risk control methods
- Learn lessons from tackling FAW that can be applied to other invasives

Advisory Services should:

- Use a combination of both traditional and novel communication methods
- Tailor messaging to specific target audiences
- Consider efficacy, safety, sustainability, practicality, availability and cost effectiveness when recommending control practices
- Encourage farmers to:
    - Maintain plant diversity through intercropping and habitat management
    - Avoid practices which kill natural enemies of FAW
    - Observe and monitor fields regularly after germination
    - Experiment with different control practices
    - Refrain from intervening as soon as leaf damage is observed

Regulators should:

- Maintain regulatory credibility by providing emergency/temporary registration for government-recommended control products
- Work with industry associations to identify and stop companies selling unregistered and/or dangerous products
- Within the existing legal framework, expedite registration of lower risk products
- Continue efforts to regionally harmonise pest control product regulations

Researchers should:

- Test and validate control methods commonly used by farmers
- Develop simple and robust action thresholds based on FAW damage levels
- Determine why recommended control actions are sometimes not effective

- Monitor FAW natural enemies and identify practices that conserve and enhance the mortality they cause
- Identify opportunities for establishing local enterprises producing bio-inputs
- Continue research on the use of host plant resistance and classical biological control
- Continue research on FAW biology and ecology, with the aim of improving control decisions by farmers and other stakeholders
- When developing and introducing new control practices, consider efficacy, safety, sustainability, practicality, availability and cost effectiveness for smallholder farmers.

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Acronyms

AEZ	Agroecological Zone
AI	Active ingredient
Bt	Bacillus thuringiensis
CABI	CAB International (Centre for Agriculture & Biosciences International)
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Centre (Mexico)
DFID	Department for International Development (UK)
DGIS	Directorate-General for International Cooperation (Netherlands)
EPPO	European Plant Protection Organisation
EFSA	The European Food Safety Authority
EUROPHYT	European Union Notification System for Plant Health Interceptions
FAO	Food and Agricultural Organisation of the United Nations
FAOSTAT	FAO statistics service
FAW	Fall armyworm
FFS	Farmer field school
GDP	Gross Domestic Product
GIZ	Gesellschaft für Internationale Zusammerarbeit (Germany)
GM	Genetically Modified
HHP	Highly Hazardous Pesticide
ICIPE	International Centre for Insect Physiology and Ecology
IITA	International Institute of Tropical Agriculture
ISPM	International Standard for Phytosanitary Measures
NGO	Non-Governmental Organisation
NPPO	National Plant Protection Organisation
ODK	Open Data Kit
PPRSD	Plant Protection and Regulation Services Directorate (Ghana)
PRISE	Pest Risk Information Service
PMDG	Pest Management Decision Guide
PPE	Personal Protective Equipment
R4D	Research for Development
SfMNPV	Spodoptera frugiperda multiple nucleopolyhedrovirus
SIT	Sterile Insect Technique
SPS	Sanitary and Phytosanitary
SSA	Sub-Saharan Africa
TOT	Training of Trainers
USAID	United States Agency for international Development
USD	United States Dollar
USDA	United States Department of Agriculture
WEMA	Water Efficient Management for Africa
WHO	World Health Organisation
ZARI	Zambia Agricultural Research Institute

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Introduction

In 2016 the Fall Armyworm (FAW, *Spodoptera frugiperda*) was found in Africa for the first time (Goergen *et al.*, 2016). FAW is native to the Americas, where it is recognised as one of the most damaging crop pests. It prefers to feed on cereals, particularly maize which is a major food crop in Africa. The arrival and rapid spread of FAW was therefore seen as a major threat.

In view of this threat, the UK Department for International Development (DFID) commissioned CABI to produce an "evidence note" (Abrahams *et al.,* 2017). The document presented information on rapid field assessments in Africa, modelling of expected distribution and impact, as well as a review of control options based on information from the literature. The aim was to provide evidence and recommendations for decision makers in Africa responsible for the response to the threat, as well as for external organisations seeking to assist in the response.

As anticipated in the 2017 evidence note, FAW has continued to spread in Africa, and is now present in almost all countries of sub Saharan Africa except Djibouti and Lesotho. Recently it has reached Asia, where it can be expected to continue its rapid spread.

Much has been said and done to counter the FAW threat in Africa. FAO developed a Framework for Partnership for Sustainable Management of the Fall Armyworm in Africa, and recently an international Research for Development (R4D) consortium has been formed. Many national response efforts have been supported through funds from the FAO Technical Cooperation Programme. Various manuals have been produced, research is in progress in several of the priority areas, and a wide variety of advice has been disseminated through multiple channels. But although FAW has become a fact of life for many farmers in Africa, it is clearly still a serious threat. At FAO's recent Committee on Agriculture, the Africa group requested discussion on the problem, and emphasised the need for additional support.

In such a situation decision makers within and outside Africa need up-to-date evidence and information on the basis of which they can prioritise investment and interventions in responding to the continuing threat. This update to the evidence note therefore seeks to provide that information in the following ways:

- In **Section 1** we briefly review new information on the biology of FAW populations in Africa, highlighting the significance of the findings as well as important gaps in knowledge.
- In **Section 2** we report the current distribution of FAW, and provide an update on environmental suitability modelling. The spread of FAW to Asia, and the potential risks for Europe are also reported.
- In **Section 3** we summarise the results of farmer surveys conducted in Ghana and Zambia in 2018, repeating the surveys reported in the 2017 evidence note. Comparison of the 2017 and 2018 results highlights where changes have occurred, particularly in terms of farmers perceptions and responses. As before, the farmer reported loss data are used to extrapolate national maize yield losses for selected countries
- In **Section 4** we summarise ongoing and recent research on control methods, highlighting significant new findings.
- In **Section 5** we discuss the dissemination of information and advice to farmers and other stakeholders.
- In **Section 6** we conclude with some recommendations for key stakeholder groups, to which the participants at the international conference to be held in Ethiopia at the end of October 2018 can be expected to add.

Thus the aim is to provide an update on the status of FAW management in Africa, rather than to repeat the evidence presented in 2017. As well as the 2017 Evidence Note (Abrahams *et al.*, 2017) much information on FAW biology and management is also available in the excellent manuals produced by CIMMYT and USAID (Prasanna *et al.*, 2018) and by FAO (2018a). These and many other materials for farmers, researchers and other stakeholders are available through CABI's fall armyworm portal (www.cabi.org/isc/fallarmyworm).

1. FAW behaviour, biology and ecology

1.1 Host range of fall armyworm in Africa

The FAW larva (Figure 1) is known to feed on the leaves, stems and reproductive parts of many different plant species. A review of the host plants of FAW by Casmuz *et al*. (2010) provides a list of up to 186 host plants belonging to 42 different families as hosts in the Americas. But Montezano *et al.* (2018) have recently reported 353 host plant species based on a thorough literature review, and additional surveys in Brazil, from 76 plant families, principally Poaceae (106), Asteraceae (31) and Fabaceae (31).

Across Africa, maize is the most widely reported host on which FAW damage is encountered, with some reports from sorghum. This pattern was repeated in our recent surveys in Ghana and Zambia, with millet, napier grass and tomato also reported to be the affected by a few farmers (Table 1).

Table 1: Plants reported as attacked by FAW in Ghana and Zambia

Crop	% of farmers in Ghana (n=467)	Crop	% of farmers in Zambia (n=439)
Maize	98.1%	Maize	98.6%
Sorghum	3.9%	Napier grass	2.3%
Millet	2.6%	Tomato	2.0%

From field surveys, media reports and Plantwise plant clinics where farmers bring plant and larval material for diagnosis, the pest has been reported from at least 28 other crops[1]. However, although the majority of these crops are reported in the Americas to be hosts for FAW (Casmuz *et al*., 2010), there are few confirmed reports of FAW damage on these crops. Some reports are almost certainly misidentifications, but even where attack is due to FAW, the level of infestation may be too low to justify any control measures (although the host could serve as a reservoir of FAW that would attack the next maize crop). Validating records from various hosts is important, but should also be accompanied by an assessment of damage.

Rice is not being reported to be adversely affected by FAW, despite its wide cultivation in West Africa and many other countries in sub-Saharan Africa. This is despite the fact that the so-called "rice strain" is present. Further studies on what damage to host plants other than maize is occurring would be useful, but for the time being the main focus for control efforts should be in maize.

Figure 1: The fall armyworm larva

[1] African eggplant, beans, black nightshade, brinjals, cabbage, chinese cabbage, cashew nut, cassava, chillies, cocoa, cotton, groundnut, mango, okra, onion, orange, pearl millet, pigeon pea, rape, rice, sesame, soybean, sugarcane, sunflower, sweet pepper, sweet potato, wheat and yam.

1.2 Lifecycle and biology

A key feature of FAW biology is that it does not diapause, so several generations can overlap within a single crop cycle when conditions are suitable. Indeed in several African countries FAW generations have been continuously observed throughout the year, wherever host plants are available, including off-season and irrigated crops (Prasanna *et al.*, 2018). In such areas build up of the population is more likely, and main season crops are more likely to be infested early. This contrasts with the Americas where in cooler climates populations die out, and damage is caused by migrating moths. Although the patterns of population persistence, dispersal, and migration in Africa are not yet well documented, conditions in many parts of Africa, especially where there is a bimodal rainfall pattern, suggest that FAW is resident in the crop fields and persists all year round. In areas where it cannot persist year round, crops will be susceptible to migration from permanent populations. However the relative importance of these two scenarios in Africa is not clear at the moment. Studies are commencing to examine migration using various approaches including radar.

On maize young FAW larvae usually feed on leaves, creating a characteristic windowing and holed effect. This and moist sawdust-like frass mostly in form of lumps, near the funnel and upper leaves, gives farmers easily spotted signs of larval feeding. Older larvae stay inside the funnel, feeding mostly during the night, and many farmers are now aware that the funnel can be opened to reveal the caterpillar for handpicking and crushing as a control method.

The 2018 survey in Ghana (see Section 3) showed that of the farmers who had experienced FAW in their fields, 57% and 43% reported attack occurring in the early and mid-stages of the crop, while in Zambia, the vegetative stage of the crop was reported to be most affected (84%) (Table 2). However, few farmers reported presence of FAW in the later stages of the crop. When finding ear damage after harvest, they tended to relate it to the earlier damage on the leaves, rather than to the FAW feeding on the ears themselves (Figure 2). This may be because fewer farming activities are undertaken after tasselling, so farmers are less frequently in the field making observations. While there is need for greater awareness that a maize plant can recover from some the foliar damage, there is also need for awareness that damage to the ear is irreversible so has an immediate influence on the yield.

In the 2017 evidence note we highlighted that in Latin America, large numbers of natural enemies (parasitoids, predators and pathogens) of FAW had been reported. Since then evidence is mounting that FAW is also being attacked by several different natural enemies in Africa. This is discussed further in section 4 on control.

An area of FAW ecology which has not yet been examined in Africa is the interaction between FAW and other maize pests, particularly the stem borers. Bentivenha *et al.* (2017) examined competition in laboratory arenas between caterpillars of FAW and other moths found on maize in the Americas, and showed FAW had a competitive advantage. One possibility therefore is that FAW attack in Africa could reduce damage caused by other pests.

Table 2: Crop stages most affected by fall armyworm in Ghana and Zambia

Crop stage most affected	Ghana	Zambia
Emergence/seedling/ early stage	57%	10%
Vegetative/ mid stage	43%	84%
Flowering	0%	5%
Post flowering/late stage	0%	1%
Total	100%	100%

Figure 2: Maize ear damage by FAW

Figure 3: The fall armyworm adult moth (Copyright, Goergen, IITA)

1.3 Taxonomy and genetic differentiation

FAW occurs in two races: a 'rice strain' (R strain) and a 'corn strain' (C strain); the former is thought to preferentially feed on rice and various pasture grasses and the latter on maize (corn), cotton and sorghum. The strains are morphologically identical (Figure 3), but can be distinguished by molecular techniques. Recent evidence shows that the diversity of FAW in Africa is greater than previously thought, including a haplotype that has not yet been observed in the Western Hemisphere (Nagoshi *et al*., 2018). Analyses of South African specimens of FAW indicate corn and rice strains are both present there (Jacobs *et al.*, 2018). In Uganda, FAW populations were found to consist of what the authors call two sympatric sister species of maize-preferred and rice-preferred strains (Otim *et al*., 2018). These results indicate that the two strains seem to be spreading more or less together in Africa. There have been some attempts to establish the origin of these strains, and evidence from Ghana (Cock *et al.,* 2017) and Togo (Nagoshi *et al*., 2018) suggests that the populations are most similar to that found in the Caribbean region and the eastern coast of the United States.

The practical implications for management of there being two strains remains to be seen. Some initial studies have shown that parasitoids do not necessarily discriminate between the two strains of FAW in maize crops. However, some researchers suggest C- female x R-male – incompatibility and R- female x C-male – compatibility does exist. In addition, the C-strain appears to be more responsive to some commercial pheromones that the R-strain. This has implications for pheromone-based monitoring systems, particularly as the different commercial pheromones lures do not all use the same blend of chemical components.

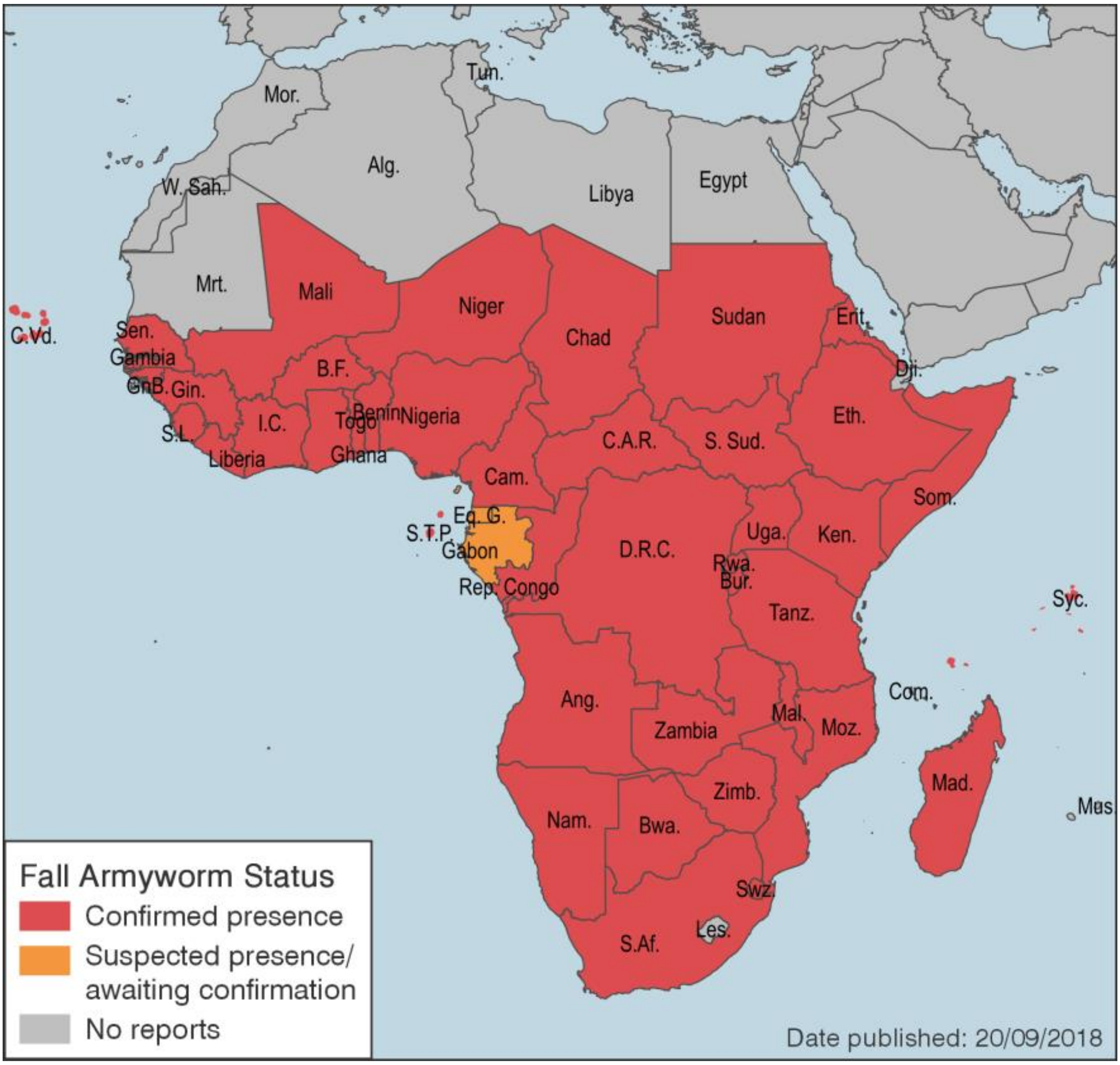
2. Distribution and spread

2.1 Current distribution of FAW in Africa

In the 2017 evidence note we reported that FAW was confirmed to be present in 28 countries, with confirmation awaited from several others. Since then FAW has continued to spread and as of September 2018, more or less the entire sub-Saharan Africa has been invaded (44 countries, see Figure 4). Confirmation of the pest's presence comes through a variety of sources, including IPPC official reports (only eight countries, no change since 2017), ministerial declarations, peer reviewed journals, and information from UN affiliated organisations. Equatorial Guinea and Gabon suspect its presence, but with no official confirmation, while Lesotho has indicated the absence of FAW.

As anticipated, FAW has been able to cross the Indian Ocean to reach Madagascar (Chinwada, 2018) and other islands. It was commented that the climatic conditions and maize growing activities in Madagascar were conducive to FAW establishment, and that 80% of the country's maize production was grown in suitable agro-climatic conditions for FAW.

Figure 4: Presence of fall armyworm in Africa



2.2 Pathways of spread

The rapid spread of FAW in Africa can be attributed to the strong flight capacity of the insect, though it is possible that it was already more widespread than realised when first detected, and the apparent rapid spread was in part due to the spread of awareness. The rapid spread to the Indian Ocean Islands is harder to explain by natural flight, so it is possible that the frequent flights from the mainland to those countries could have played a part. Cock *et al*. (2017) concluded that potential pathways of spread included unaided dispersal by wind-assisted flight, as contaminants of traded commodities, and as stowaways on or in aircraft. Wind-assisted flight alone might not have been sufficient for FAW to cross the Atlantic, but once in Africa all the pathways listed could have occurred, including for the spread to the Indian Ocean Islands. It is still not clear whether there were multiple introduction events, or a single event involving multiple individuals from both strains.

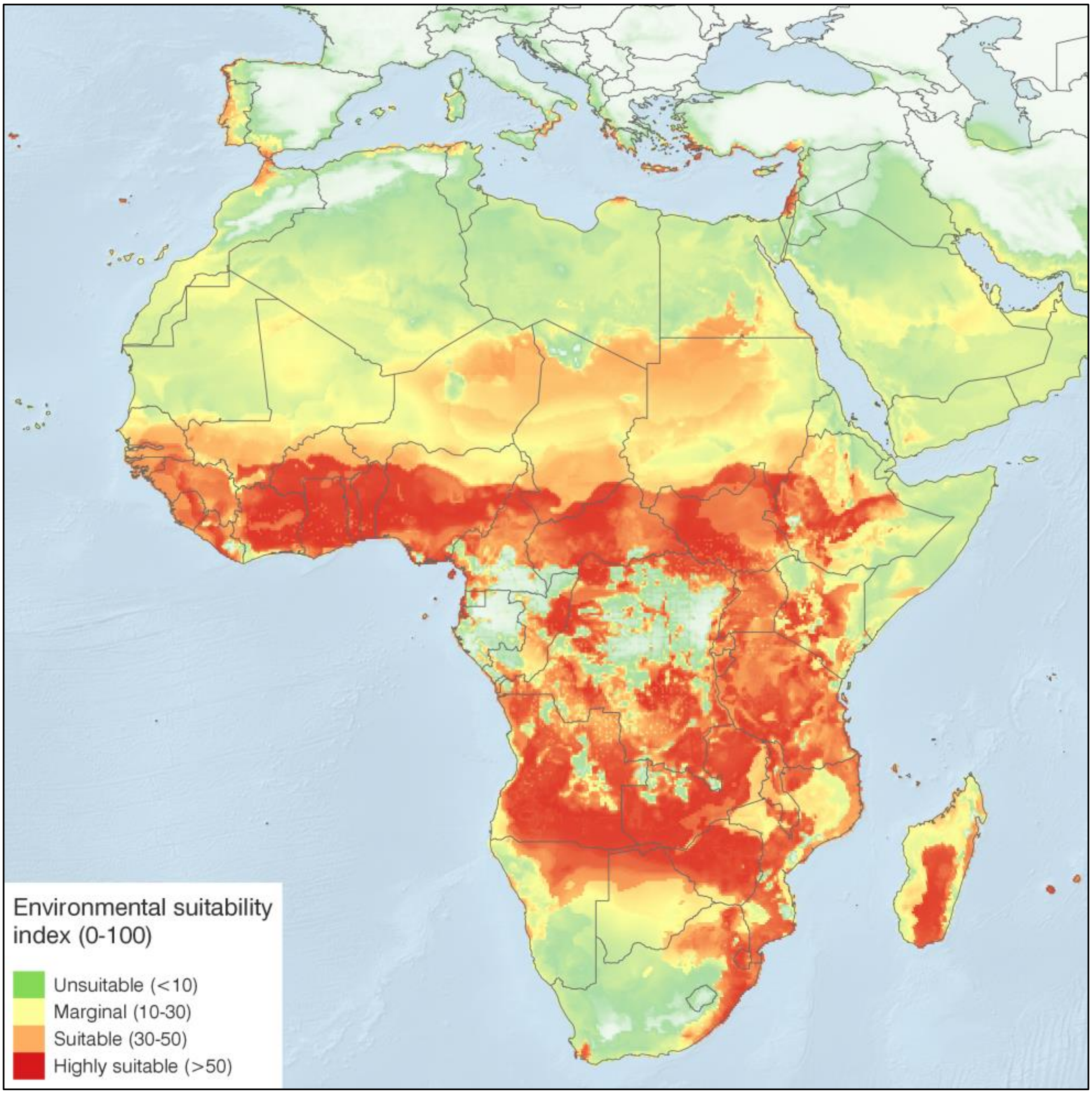
2.3 Environmental suitability for FAW in Africa

The map of modelled FAW environmental suitability has been updated with additional information (Figure 5). The variables contributing most to environmental suitability are the mean temperature of the coldest month of the year, and the intensity of the rainy season. Forest cover is also important. In Figure 5 a suitability index of 0.5 means a 50% probability that an area is suitable for FAW. Green shading represents low environmental suitability, and yellow moderate suitability. Orange and red signify the environment is suitable or very suitable for FAW to establish.

The model shows that large areas of sub-Saharan Africa are highly suitable year-round for FAW. However, some areas are clearly less suitable, such as parts of South Africa, Congo, DRC, Gabon and Cameroon. In these areas migration of FAW may be more important in determining the extent of crop damage. Much of Northwest and Northeast Africa has low suitability, so would not be expected to host year-round populations of FAW. However, the Nile Valley in Sudan and Egypt could provide a corridor allowing FAW to spread to Egypt from established populations in South Sudan and Ethiopia. USAID & Virginia Tech (undated) conducted a risk analysis for Egypt suggesting that introduction was quite likely.

There are also small portions of the North Africa coast and Israel with high suitability, but which are not yet invaded. Arrival there by migration across the Sahara is unlikely due to the long distances and harsh conditions, but if insects did reach there, establishment could be possible.

Figure 5. Environmental suitability for FAW in Africa (from Regan *et al.*, 2018)

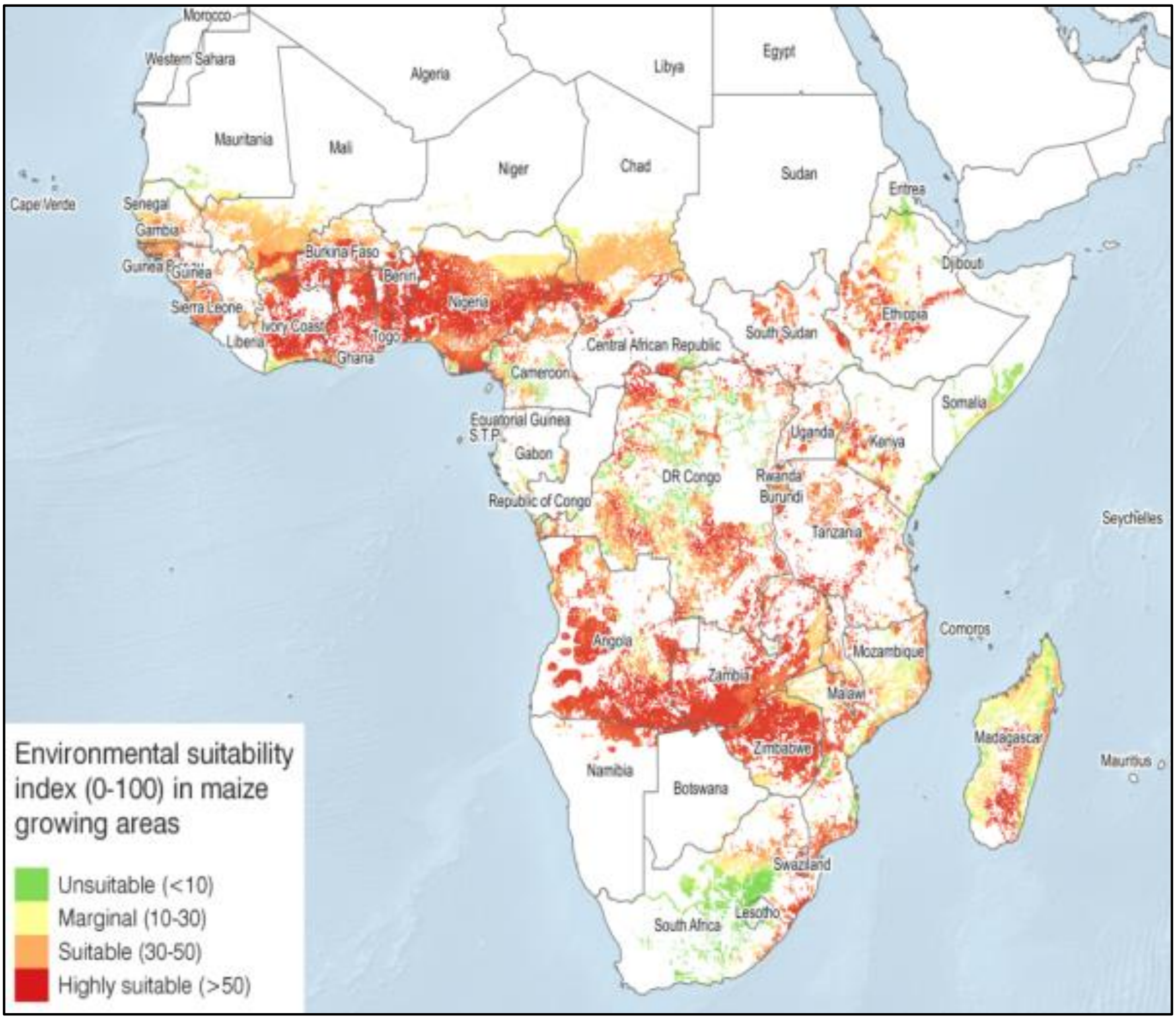


Further analysis of the data from Ghana and Zambia was undertaken to determine whether environmental suitability modelling could be used to understand within-country distribution at a greater level of detail. The analysis found that FAW does not seem to be associated with any particular climate type at this level, but coincides mostly with the locations where most maize is grown. Understanding the local abundance and impact of FAW would likely involve surveying not only FAW populations, but landscape features, alternative hosts, as well as control methods being used. It would also be important to study the local dispersal of FAW, as there could be meta-population or local dynamics influencing local abundances at landscape scale, including whether the populations may be migrant or resident. Such a study might be better conducted in countries where there is greater variation in suitability; a large proportion of both Ghana and Zambia is highly suitable for FAW.

2.5 Environmental suitability in maize growing areas

Although large areas of sub- Saharan Africa are highly suitable, not all those areas are major maize-growing zones. To further pinpoint where most serious economic losses might occur, Figure 6 shows the intersection between maize growing areas and the areas with a suitability index higher than 0.5. Although the relationship between environmental suitability and population size (and thus damage) has not been determined, it is reasonable to assume that areas of maize production with a high environmental suitability index are those where the risk of economic loss is greatest. Figure 5 shows that although there are areas of maize production with high suitability for FAW in many countries, West Africa and southern Africa appear to be particularly at risk. This "risk of exposure" constitutes one part of the food insecurity risk mapping described in Section 3.

Figure 6: Environmental suitability index in maize growing areas in Africa



2.6 FAW in Asia

In early 2018 FAW was found in Yemen and in July it was announced in India (Ganige *et al*., 2018; Sharanabasappa *et al*., 2018), prompting consideration of how it crossed the Indian Ocean. There appear to be three main possibilities. Through natural migration and taking several generations, FAW could have crossed the Arabian Peninsula from East Africa, and then entered South Asia. Its appearance in Yemen prior to its discovery in India lends support to this possibility. Another possible pathway for the invasion could have been wind-assisted migration directly from Africa to South Asia on the southwest monsoon that blows in that direction from about June. Rare examples of open-ocean migration of dragonflies from India to East Africa and back (Anderson 2009) show that this pathway is possible. The third route FAW could have reached India is as a stowaway or contaminant on planes and commodities moving from Africa to Asia (Regan *et al*., 2018).

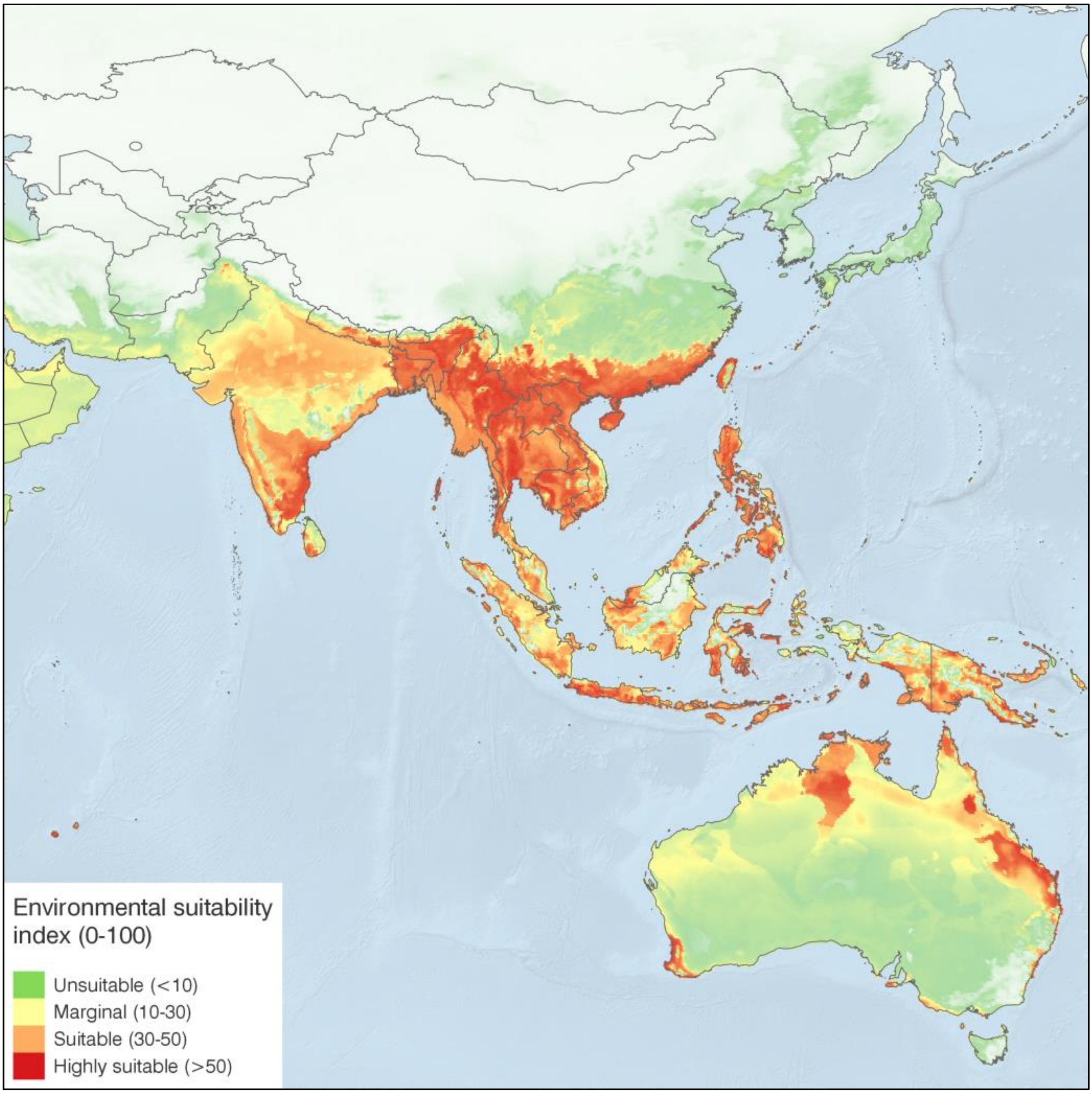
The rapid spread in Africa suggests that now that FAW has reached India, it is likely to spread rapidly to other neighbouring countries. Already it has spread to several states in India, and although first observed on maize, there are concerns that it has been found on sugar cane, another major crop in India.

Extending the environmental suitability mapping from Africa shows that large areas of Asia are highly suitable for FAW (Figure 7), spanning many countries including India and China, the world's second largest producer of maize. The crop is produced in many parts of China including the southern areas with high environmental suitability. However, north-east China is a major maize production region, which Figure 7 shows is unsuitable for year-round persistence of FAW. It is therefore possible that FAW will make seasonal migrations to those areas in the same way that it moves north through US each year. In China the Oriental armyworm (*Mythimna separate*) already makes a similar migration, with much research focusing on migration triggers and processes, and how it can be monitored and forecast using various tools including radar (Jiang *et al.,* 2014).

2.3 Potential spread to Europe

Before FAW invaded Africa, Europe had already identified the species as a risk, directive 2000/29/EC specifying it as a harmful organism whose introduction should be prohibited. Following its introduction to Africa, FAW was categorised as a 'Union quarantine pest' (Jeger *et al.,* 2017), and subsequently the European Food Safety Authority conducted a partial pest risk assessment, focussing on sweet corn and the commodities on which FAW was most frequently intercepted in consignments from the Americas (Jeger *et al.,* 2018). The assessment estimated that tens of thousands to over a million individual larvae could enter the EU annually on commodities. Risk reduction measures on sweetcorn could reduce the entry on that pathway 100-fold, though sweet corn represents only a small proportion of all FAW host imports. Migration to Europe from current populations in sub-Saharan Africa was adjudged unlikely, but if FAW became established in North Africa, up to two million or more adults could seasonally migrate into the southern EU, and reach the small areas of Spain, Italy and Greece that provide climatic conditions suitable for establishment. Thus the likelihood of entry via natural dispersal could only be mitigated via control of the pest in Africa.

Figure 7: Environmental suitability for FAW in Asia (Regan *et al*., 2018)



3. Impacts of FAW on maize yield and other socio-economic variables

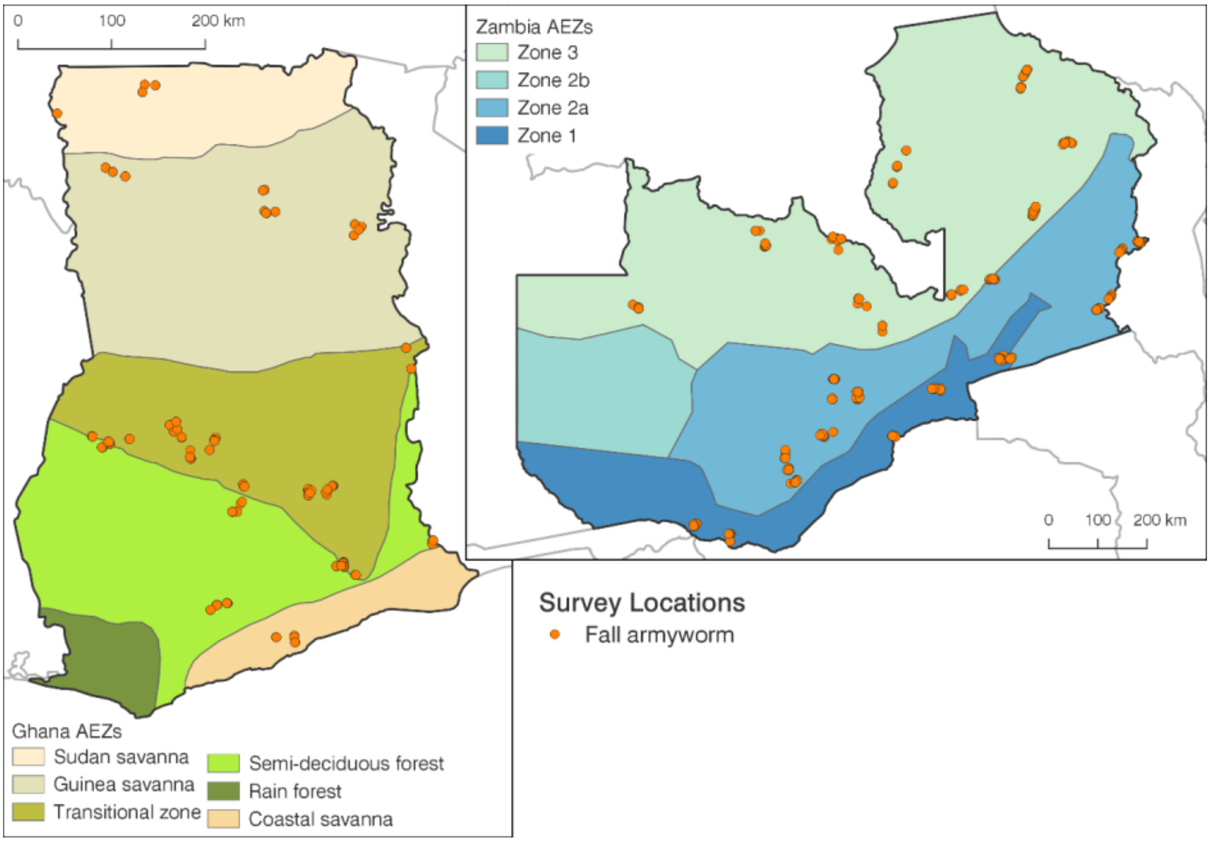
3.1 Household survey methodology

In order to understand the impacts of FAW on maize yield and farmers' livelihoods, and to obtain data that could be extrapolated to national level, household surveys were conducted in Ghana and Zambia using an Open Data Kit (ODK) data collection tool on tablets. The surveys were conducted by CABI with Ghana's Plant Protection and Regulatory Services Directorate (PPRSD), and the Zambia Agricultural Research Institute (ZARI). Householdheads were interviewed face-to-face by 12 officers in each country who were trained prior to the surveys. The survey tool captured information on household composition and farming activities, FAW control practices, perceptions of FAW impacts, and information resources. The sample consisted of 942 (504 in Ghana and 438 in Zambia) farm households that planted maize during the 2016/2017 and 2017/2018 cropping season (Figure 8). It also included follow-up phone calls to 166 farmers in Zambia and 132 in Ghana. Since the surveyed households were sampled using a multi-stage random selection process, farmers who did not plant maize in 2017/2018 cropping season were not discarded, but were asked only about the last cropping season in which they had grown maize.

3.2 Household characteristics

The majority of households surveyed in Ghana (87.4%) and Zambia (77.6%) were male headed, with an average age of 46-47 years. The average household size comprised around 8 or 9 individuals in Ghana and Zambia respectively. 37.7% of farmers in Ghana had no formal education, compared with only 4.2% in Zambia. In Ghana, 94.3% of the households had grown maize the previous season, and in Zambia, a higher proportion of those interviewed (99.0%) reported growing maize.

Figure 8: Map of survey areas in Ghana and Zambia

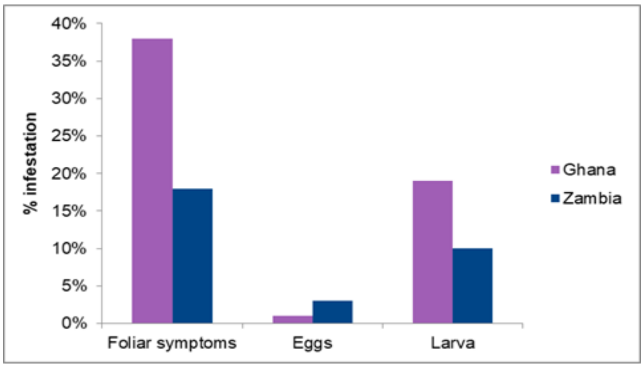


3.3 Field Infestation levels

At the time of the survey, 71 and 300 farmers in Zambia and Ghana respectively had a maize crop in the field and this was subjected to field scouting to determine the percentage infestation on 100 plants. The majority of farmers in both countries were able to distinguish the FAW features from other maize pests (97.2% in Ghana and 89.9% in Zambia). Foliar symptoms were the most recognisable of the infested plants, with 38% of plants in Ghana and 18% of plants in Zambia exhibiting foliar damage. Larvae were seen on 19% of plants in Ghana and 10% in Zambia (Figure 9).

Maize was by far the most affected host plant for FAW in both countries, which compares closely with the results of the previous survey. Low numbers of farmers reported infestation on cereals and grasses including napier grass, sorghum and millet (Table 1 in Section 2).

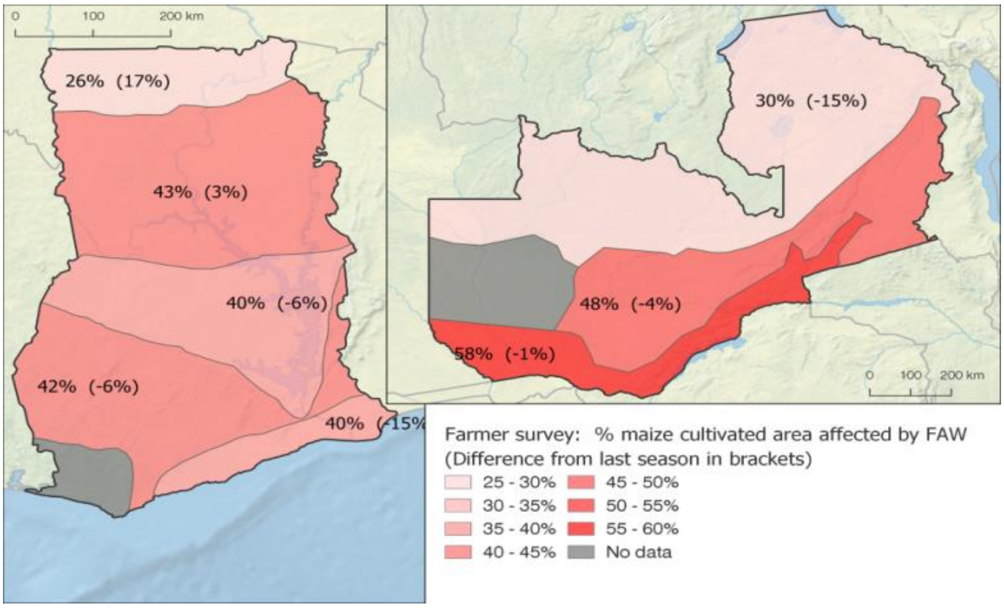
Figure 9: Field infestation levels due to fall armyworm in Ghana and Zambia



3.4 Maize area affected by FAW

Figure 10 shows farmer estimations of the percentage of maize growing area that was affected by FAW. This data was aggregated within agro-ecological zones in order to compare responses in 2017 and 2018. In Ghana, similar levels of infestation are reported on maize across the country. The area affected was reduced in the South compared to 2017 but increased in the north, which reported lower levels of infestation in 2017. In Zambia, there has been little change in the reported percentage of maize area affected in the South and it remains high. The North experienced a lower infestation than in 2017.

Figure 10: Percentage of maize cultivated area affected by FAW

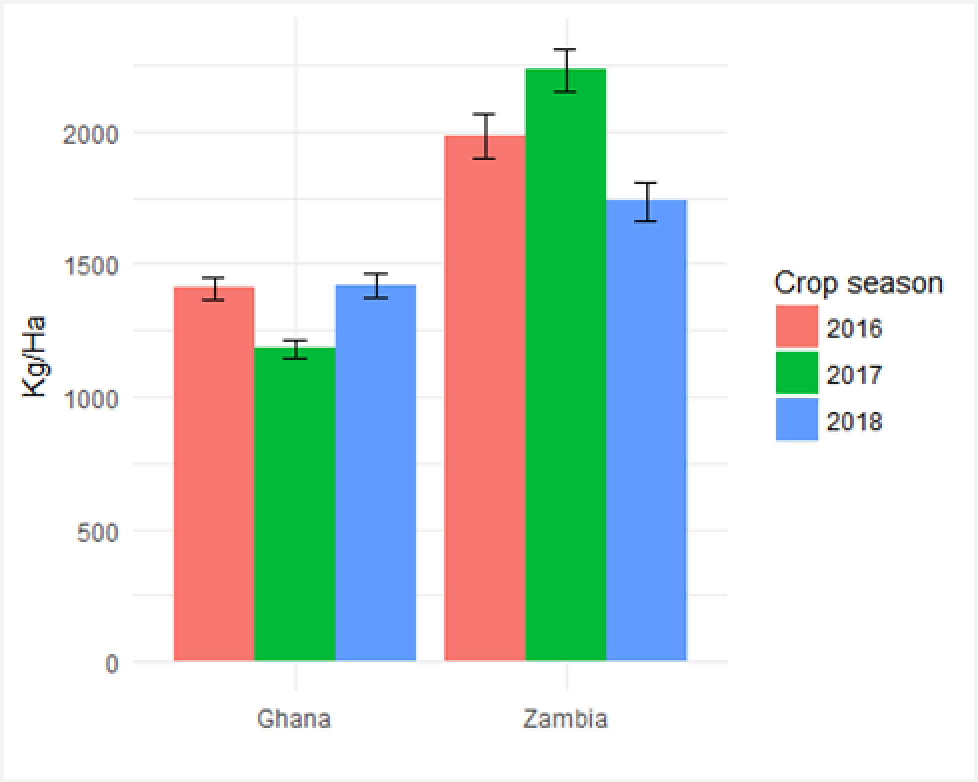


3.5 Maize yield in Ghana and Zambia

For Zambia, the 2015-16 maize harvest was determined to be prior to the widespread outbreak of FAW. No indication of a decline in yield in the year following the arrival of FAW was apparent from the 2017 survey data, despite widespread reports of impact. However, in 2016-17 there was a La Niña weather event leading to high yields and surplus national production (Chapoto *et al.,* 2017). 2017-18 maize production suffered a mid-season dry spell which impacted on yield and overall production levels in various maize regions in Zambia (FAO, 2018c), as reflected in the survey findings. Despite the importance of climate in determining maize yields and the annual variability that can result from differing environmental conditions (Figure 11), farmers in Zambia still classify FAW as one of the major drivers of change in maize yield, on a par with drought (Figure 12). This is despite the survey being undertaken following a production season badly affected by drought conditions. These farmer perceptions suggest, therefore, that the high yield rates in Zambia in 2016-17 would have been higher still in the absence of FAW, and the poor yields of 2017-18 were driven by both drought and losses to FAW.

In Ghana, 37% of farmers reported first observing FAW in 2016 (or earlier), 58% in 2017, and only 5% in 2018. The scale of infestation and losses to FAW in Ghana in 2016 was relatively limited and brought under control with generally good harvests, but the 2017 FAW infestations were more significant and widespread (USDA FAS, 2018). The farmer maize yield data from the survey indicates a reduction in yield from 2016 to 2017, although cereal production in 2017 was reported to be positive following government fertilizer subsidies (FAO, 2018d). As previously mentioned, various biotic and abiotic factors and inputs can influence yield, but FAW was the most frequently reported perceived driver of maize yield change (Figure 12).

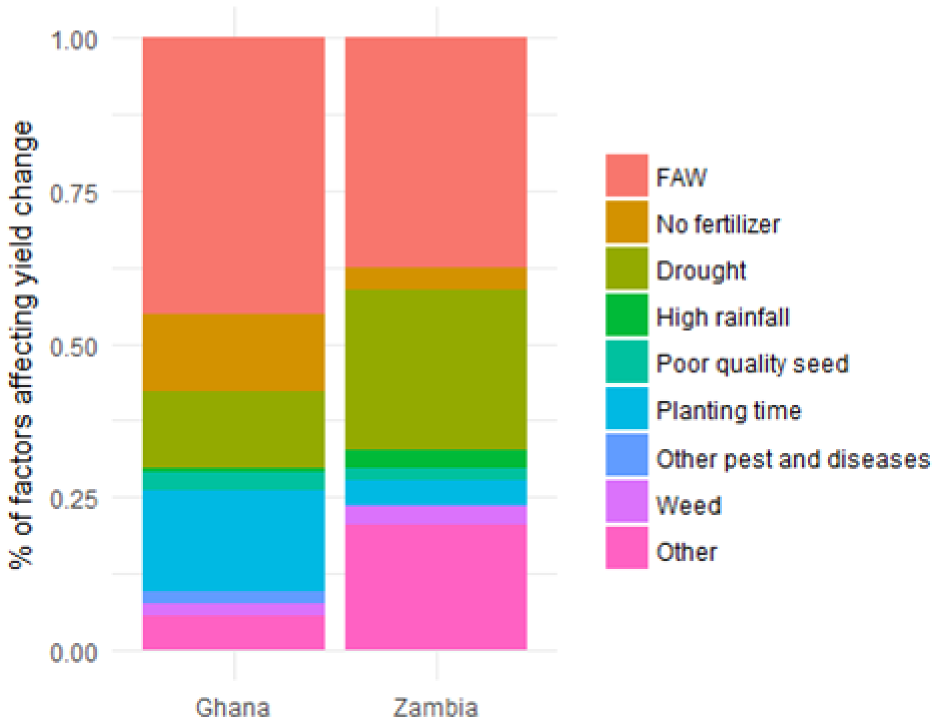
Figure 11: Average maize yield (Kg/ha) per household in Ghana (n=234) and Zambia (n=366) from 2016 to 2018 seasons. Only households with maize in the three seasons and which had identified FAW in their fields were considered in the calculations. Note: only 3% of the households did not identify FAW and thus were excluded from this analysis.



3.6 Factors affecting maize yield

FAW was the most common factor perceived to be affecting yield changes in both Zambia and Ghana (Figure 12). The second most important factor for Ghana was planting time while in Zambia it was drought. Planting time could impact maize production in two interacting ways. First, an earlier planting time before rains are stable (dry planting) could have negative effects on production due to drought. Second, late planting could benefit from better rain patterns but these fields might suffer from higher incidence of pests that have been building up in crops planted earlier.

Figure 12: Factors affecting maize yield change between 2016 and 2018 according to farmer's perception. Calculations are based on each farmer indicating the three most important factors affecting changes in maize yield in the studied period.

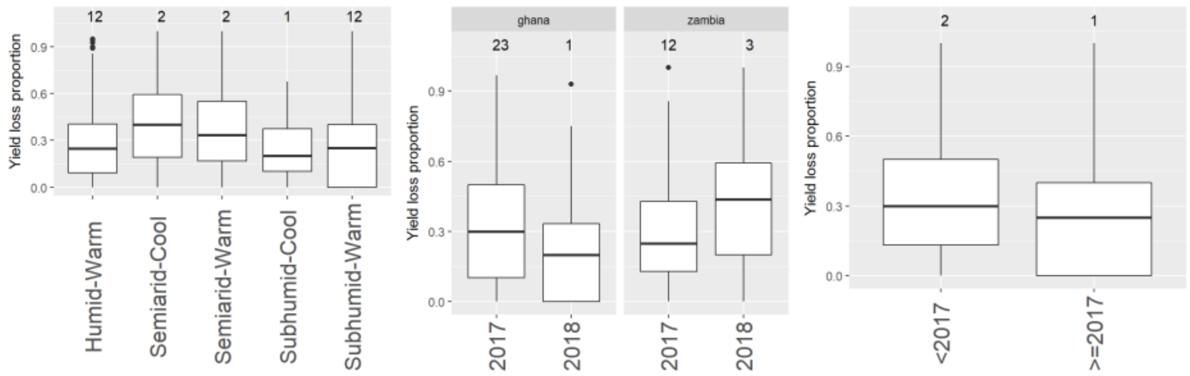


3.7 Yield loss estimation due to FAW

In order to determine the yield loss, farmers were asked to provide an estimate of their current production (farmer recall), as well as the potential production had they not had FAW (farmer prediction) for the current (2018) and previous season (2017). The yield loss (%) was then estimated as the different between actual and expected production value. From our study, 97% of farmers in Ghana and 99% in Zambia were affected by FAW, so an alternative yield loss estimation method based on comparing yield from affected and non-affected farmers in the same area and crop season (FAO, 2018b) was not generally feasible. We were able to use this method for Ghana in the crop season 2016, as in that year there was an adequate number of both groups of farmers with yield information (40 farmers with FAW and 53 without).

Using the recall method, differences in estimated yield loss were compared across agro-ecological zones (AEZs), years and time since FAW was first seen (before 2017 or after 2017). Comparisons were made in a full regression model pooling data from Ghana and Zambia. Including all factors in a single model we were able to compare yield loss across AEZs taking into account country and season differences.

Figure 13: Boxplot comparison of yield loss proportion in Zambia and Ghana; across agro-ecological zones (left), countries and seasons (centre) and time since FAW was first seen at farm level (right). For each level, the boxes indicate the lower quartile (bottom horizontal line), median (central horizontal line) and upper quartile (top horizontal line). Same numbers above levels indicates that yield loss values are not significantly different



On average, farmers reported a yield loss due to FAW of 26% (max 40%) in Ghana and 35% (max 50%) in Zambia. These values were lower than the estimates reported in 2017, particularly for Ghana. In general, these percentages are comparable to maize yield losses estimated in an experimental setting, with 15% to 73% losses when 55% to 100% percent of plants were infested with FAW (Hruska & Gould, 1997). In a similar study in Namibia, yield loss estimated by the recall method was even higher than our estimates, 57% (FAO, 2018b). However, the recall method might result in bias as farmers tend to overestimate their yield loss. Using the second method of comparing affected and non-affected farmers in Ghana for season 2016, the average yield loss estimation was reduced up to 17% (0.6% in humid region and 31% in subhumid AEZs). These values are slightly higher than those estimated for Namibia using the same method (13%). These differences between methods highlight the large spatio-temporal variability of yield loss estimations and the complexities in disentangling FAW from other factors.

Yield loss estimated by the recall method was significantly higher in semi-arid AEZs compared to the other zones present in Zambia and Ghana, but not by a wide margin (Figure 13). The countries showed different temporal patterns. In Ghana, farmers reported higher yield loss in 2017 than in 2018, while the opposite was observed for Zambia. This corresponds with the yield estimates in Figure 11. Farmers that had identified FAW in their fields in 2016 or earlier estimated a higher yield loss than farmers with a more recent invasion. Although the estimation of yield loss by farmers is not always accurate, this finding could be explained by higher population levels of FAW arising from the longer presence of the pest.

3.8 Estimates of national yield loss due to FAW

For Ghana, the estimated expected maize production (5 year average pre-FAW) and estimated lower and upper production and economic losses are given in Table 3, and the equivalent data for Zambia in Table 4. For each of these countries, loss estimates are grouped according to national AEZ definitions, with losses across different AEZs aggregated where statistically similar. In Ghana, the weighted average value of annual yield loss is US$ 177.3m, while in Zambia the figure is US$ 159.3m.

Table 3: Estimated national yield loss in Ghana based on farmer surveys

Agro-ecological zone	**Maize production (5 year FAOSTAT average)** (thousand tonnes)	**Maize value with no FAW (5 year FAOSTAT average)** (US$ million)	**Yield loss [Lower]** (thousand tonnes)	**Yield loss [upper]** (thousand tonnes)	**Yield loss [mean]** (thousand tonnes)	**Yield loss [Lower]** (US$ million)	**Yield loss [upper]** (US$ million)	**Yield loss [mean]** (US$ million)
Coastal savanna	119.6	45.1	0.0	47.8	31.8	0.0	18.0	12.0
Guinea savanna	223.8	84.4	0.0	89.5	59.4	0.0	33.8	22.4
Rainforest	69.5	26.2	0.0	27.8	18.5	0.0	10.5	7.0
Semi-deciduous forest	710.6	268.0	0.0	284.2	188.7	0.0	107.2	71.2
Sudan savanna	141.3	53.3	0.0	56.5	37.5	0.0	21.3	14.1
Transitional zone	505.7	190.7	0.0	202.3	134.3	0.0	76.3	50.6
National (all zones)	1770.4	667.6	0.0	708.2	470.2	0.0	267.0	177.3

Table 4: Estimated national yield loss in Zambia based on farmer surveys

Agro-ecological zone	**Maize production (5 year FAOSTAT average)** (thousand tonnes)	**Maize value with no FAW (5 year FAOSTAT average)** (US$ million)	**Yield loss [Lower]** (thousand tonnes)	**Yield loss [upper]** (thousand tonnes)	**Yield loss [mean]** (thousand tonnes)	**Yield loss [Lower]** (US$ million)	**Yield loss [upper]** (US$ million)	**Yield loss [mean]** (US$ million)
1	542.3	89.4	108.5	309.9	220.3	17.9	51.1	36.3
2a	1,630.4	268.8	326.1	931.6	662.2	53.8	153.6	109.2
2b	113.6	18.7	NA	NA	NA	NA	NA	NA
3	588.7	97.1	60.0	273.3	171.3	9.9	45.1	28.2
National (all zones)	2,761.4	455.3	441.8	1,380.7	965.9	72.8	227.6	159.3

Farmer surveys were not conducted in Zone 2b in Zambia in 2018 as this zone is a relatively minor producer of maize for the country.

3.9 Estimates of continental yield loss due to FAW

The losses of maize to FAW reported by farmers in Ghana and Zambia were extrapolated across agro-ecologically similar zones in other countries to obtain an estimate of potential losses and their associated economic value, assuming FAW is established across all maize production areas in these countries.

The total estimated national production and revenue loss for Zambia, Ghana and ten additional major maize producing countries in Africa (as in the 2017 Evidence Note) is summarised in Table 5. Major maize producers such as Kenya and South Africa were not included in the losses estimation as they share limited AEZ overlap with the two study countries, Ghana and Zambia. Losses were related to total expected maize production and value in each country based on average yields pre-FAW. The same lower and upper proportional loss limits (derived from the Ghana and Zambia methodology) were used for each of the other countries, extrapolated from loss figures for Ghana and Zambia, aggregated by AEZ. To provide perspective to these figures, the revenue losses have also been expressed as lower and upper percentage loss to agricultural GDP, averaged over the last five years (Table 6).

Table 5: Maize production and estimated yield and economic losses in the 12 maize-producing countries, based on farmer surveys in Ghana and Zambia

Country	Maize production (5 year FAOSTAT average) (thousand tonnes)	Maize value with no FAW (5 year FAOSTAT average) (US$ million)	Yield loss [Lower] (thousand tonnes)	Yield loss [upper] (thousand tonnes)	Yield loss [mean] (thousand tonnes)	Yield loss [Lower] (US$ million)	Yield loss [upper] (US$ million)	Yield loss [mean] (US$ million)
Ghana	1,770.4	667.6	196.7	843.0	541.3	74.2	317.9	204.1
Zambia	2,875.0	474.0	319.4	1,369.0	879.0	52.7	225.7	144.9
Benin	1,261.6	396.6	140.2	600.8	385.7	44.1	188.9	121.3
Cameroon	1,799.8	715.3	166.6	714.0	458.4	66.2	283.8	182.2
Democratic Republic of the Congo	1,172.0	320.1	122.8	526.2	337.8	33.5	143.7	92.3
Ethiopia	6,767.3	1,426.0	605.3	2,594.1	1,665.5	127.5	546.6	351.0
Malawi	3,542.4	829.2	393.6	1,686.9	1,083.0	92.1	394.9	253.5
Mozambique	1,665.3	279.1	184.6	791.2	508.0	30.9	132.6	85.1
Nigeria	9,323.4	2,884.7	1,030.8	4,417.9	2,836.4	318.9	1,366.9	877.6
Uganda	2,688.7	734.4	264.1	1,132.0	726.8	72.1	309.2	198.5
Tanzania	5,488.3	1,322.6	601.8	2,579.3	1,656.0	145.0	621.6	399.1
Zimbabwe	932.7	293.8	95.8	410.6	263.6	30.2	129.3	83.0

The estimates indicate that for these countries taken together, the potential impact of FAW on continent wide maize production lies between 4.1 and 17.7 million tonnes annually, out of the total expected production of 39.3 million tonnes, with losses lying between US$ 1,088 and US$ 4,661 million annually, of the total expected value of US$ 10,343 million. Losses in other major maize-producing countries not included in this assessment would be additional, as would FAW losses in crops other than maize. These loss estimates are considerably lower than those reported in the 2017 evidence note (US$ 2,481 - 6,187 million annually) and may reflect a change in farmer perception of the impacts of FAW, possibly influenced by improved awareness and deployment of management methods for this pest, compared to the time of its first arrival. The lower figures may also indicate improved crop performance and/or reduced FAW attack, both of which may be influenced by (and difficult to isolate from) a variety of biotic and abiotic factors including climatic conditions.

Despite the reduction in the continent-wide maize loss estimates to FAW compared to the 2017 values, the perceived losses are still very significant, particularly for a sector made up predominantly of smallholders growing maize and other crops for subsistence and sale. Although farmer perceptions of crop losses may not be highly accurate, these figures do indicate that an ongoing, coordinated and international response to FAW is required to reduce losses.

To provide context to the scale of the perceived maize losses to FAW and to demonstrate the importance of agriculture in SSA countries, the annual value of maize perceived to be lost to FAW was determined for each of the countries assessed, as a proportion of the total agricultural sector value. Total national gross domestic product (GDP) and agricultural sector economic values were also determined, along with the value of agriculture as a proportion of GDP (Table 6).

Table 6: Annual value of maize lost to fall armyworm as a proportion of the total agricultural sector

Country	**% Agricultural sector loss [Lower]**	**% Agricultural sector loss [Upper]**	**National GDP (5 year average 2011-15)** (US$ million)	**Agricultural sector (value added) (5 year average 2011-15)** (US$ million)	**Agriculture as % of GDP**
Benin	2.32%	9.93%	8,625	1,901	22.0
Cameroon	1.51%	6.45%	31,330	4,396	14.0
Democratic Republic of the Congo	0.54%	2.29%	32,331	6,268	19.4
Ethiopia	0.66%	2.83%	48,598	19,339	39.8
Ghana	0.84%	3.60%	41,147	8,830	21.5
Malawi	5.07%	21.74%	6,396	1,816	28.4
Mozambique	0.85%	3.64%	15,089	3,646	24.2
Nigeria	0.31%	1.34%	487,446	102,187	21.0
Uganda	1.18%	5.04%	24,457	6,139	25.1
United Republic of Tanzania	1.15%	4.93%	42,245	12,614	29.9
Zambia	2.68%	11.47%	25,063	1,968	7.9
Zimbabwe	2.06%	8.83%	14,798	1,464	9.9

The value of FAW losses as percentage of agricultural GDP is greatest in Benin, Malawi, Zambia and Zimbabwe. See section 3.19 below for further discussion on the vulnerability of countries to FAW losses.

3.10 Methods used by farmers to manage fall armyworm

Use of pesticides was the commonest control method deployed by farmers to control FAW in both countries, although the use was higher in Ghana than Zambia (Table 7). 53% of farmers in Ghana and 43% of farmers in Zambia used pesticides. However, when compared with 2017 data, farmers were generally using fewer synthetic chemicals (72% in 2017 for Ghana, and 62% in 2017 in Zambia).

Table 7: FAW control methods used by farmers in Ghana and Zambia

Control practice	Ghana % (n=488)	Zambia % (n=437)
Synthetic pesticides	53.1	42.8
Biopesticides	37.1	1.4
Handpicking eggs and caterpillars	20.5	27.0
Frequent weeding	20.3	0.5
Early planting	19.3	5.5
Manure or fertilizer application	11.7	3.2
Destroying infected plants	4.7	3.2
Application of ash, sand or urea	2.5	14.9
No control practices	14.7	36.5

Noteworthy from our data was the increase in the use of biopesticides in Ghana compared to the 2017, where 37.1% of farmers tried biopesticides in 2018, while in Zambia it was less than 2%. This increase is assumed to be due to the enabling environment for biopesticide use, and the resulting greater awareness of the availability and efficacy of these products. Not only did the government decide to recommend “biorational” rather than synthetic pesticides; they also subsidised the products they were recommending.

The marked reduction in pesticide use in Zambia for the control of FAW compared to the previous year may be due to reduced purchase and distribution of pesticides by the government. When FAW was first detected ravaging maize fields, the government response was the free distribution of pesticides. In 2017, nearly 102,000 litres of pesticides valued at 18 million Zambian Kwacha (US$ 1.97 m) was distributed, and a further 3 million Kwacha (US$ 330,000) was spent on sprayers and personal protective equipment such as gumboots and respirators.

The current survey also established that in Zambia twice as many farmers were using traditional methods such as applying ash, urea or sand on larvae, while only 27% of farmers handpicked egg masses compared to 36% in 2017. The increase in farmers deploying a wider range of control methods may also be attributed in part to the lack of pesticide distribution as well as Zambian smallholder farmers’ traditional non-chemical approaches to maize cultivation. A third of farmers interviewed did not apply any control measure, compared to 23% in the 2017 survey.

In Ghana, the survey showed that 20.5% of farmers handpicked egg masses on the leaves, 20% weeded the field constantly, and 19% planted early (compared to 13% in 2017). The widespread use of these methods is not surprising as weeding, hand-picking, timely planting and the application of ash and sand in the funnel are among the recommended practices in the Pest Management Decision Guide (PMDG) developed with the relevant line ministries. The data also showed that 14% of farmers did not use any control practices in 2018, compared to 33% the previous year, indicating farmers still see a need to control the pest.

3.11 Gender differences in control practices

We disaggregated the most common control methods by the gender of the household head. The most commonly used FAW control method by both male and female headed households in both countries was application of pesticides. Nearly 64% of male headed households used pesticides in Ghana, compared to 47% in Zambia. Similarly, 47% of female headed households used pesticides in Ghana compared to 43% in Zambia (Table 8). However, a higher proportion of female headed households used biopesticides compared to male headed households in Ghana (35% compared to 33%). In Zambia, the six respondents that used biopesticides were male headed households.

In general female headed households in Ghana used more agronomic methods than male headed households, such as weeding, uprooting infected plants, early planting and handpicking of egg masses and caterpillars. In contrast, more male headed households handpicked larvae and egg masses than female headed households in Zambia. However, the female led households planted early, applied fertiliser/manure, and ash, sand or urea more often than the male headed households. Almost a third of female headed households applied no control measures again FAW compared to only a quarter of male headed households in Zambia.

Table 8: Most common FAW control methods used in Ghana and Zambia, disaggregated by gender of household head

Control practice	Ghana		Zambia	
	Male % n=427	Female % n=61	Male % n=339	Female % n=98
Pesticide	64.7*	47	47.1	43.9
Biopesticide	37.5	32.8**	1.7	0
Frequent weeding	19.7	24.6**	0.6	0.0
Manure or fertilizer application	11.9	9.8	2.1	7.1
Application of ash, urea or sand on larvae	2.6	1.6**	14.4	17.3
Uprooting and burning of infected plants	3.8*	11.5**	3.8	1.0
Early planting	19.0	21.3	3.5*	12.2
Handpicking egg masses and caterpillars	19.2	29.5	28.6	21.4
No control	15.0	13.1**	25.1	31.6

**significant differences between countries for female headed households
* significant differences between male and female headed households in Zambia and Ghana

3.12 Effectiveness of different control methods

The majority of farmers in Ghana (91.2%) and Zambia (97.0%) who used pesticides indicated the method worked (Table 9). Other widely used methods that farmers reported to have worked include early planting; 56.4% and 70.8% in Ghana and Zambia respectively. In Ghana, 88% of farmers who used biopesticides said the method worked.

A sizeable number of farmers used weeding and uprooting and burning infested plants as a control method, but a majority in both countries reported it had not been effective. The popular cultural method of hand-picking egg masses and caterpillars was also reported to be ineffective by a majority of farmers (76% in Ghana and 61.9% in Zambia). However, other studies in Namibia (FAO, 2018b) suggest that handpicking is somewhat successful. Therefore, further studies may be required to establish the actual costs and benefits of handpicking in terms of FAW damage, yield and the cost-benefit related to this method. Efficiency of handpicking is likely to be an important determinant of its success.

It is not entirely clear what happens when a method is found to “not work”, and how farmers judge this. These data should also be interpreted within the context that quite a significant number of farmers used 2 or 3 methods (Figure 14).

Table 9: Percentage of farmers using different control methods who felt the method worked or not

	Ghana		Zambia	
	N*	Yes%	N*	Yes%
Early planting	94	56.4	24	70.8
Frequent weeding	99	22.2	2	0
Manure or chemical fertilizer	57	43.9	14	35.7
Application of ash on larvae	12	58.3	28	53.6
Destroying infested plants	23	16.7	7	17.9
Synthetic pesticides	173	91.2	198	97
Handpicking of egg masses &caterpillars	100	24	118	38.1
Biopesticides	179	88.8	6	100
Others	50	19.2	31	15.4

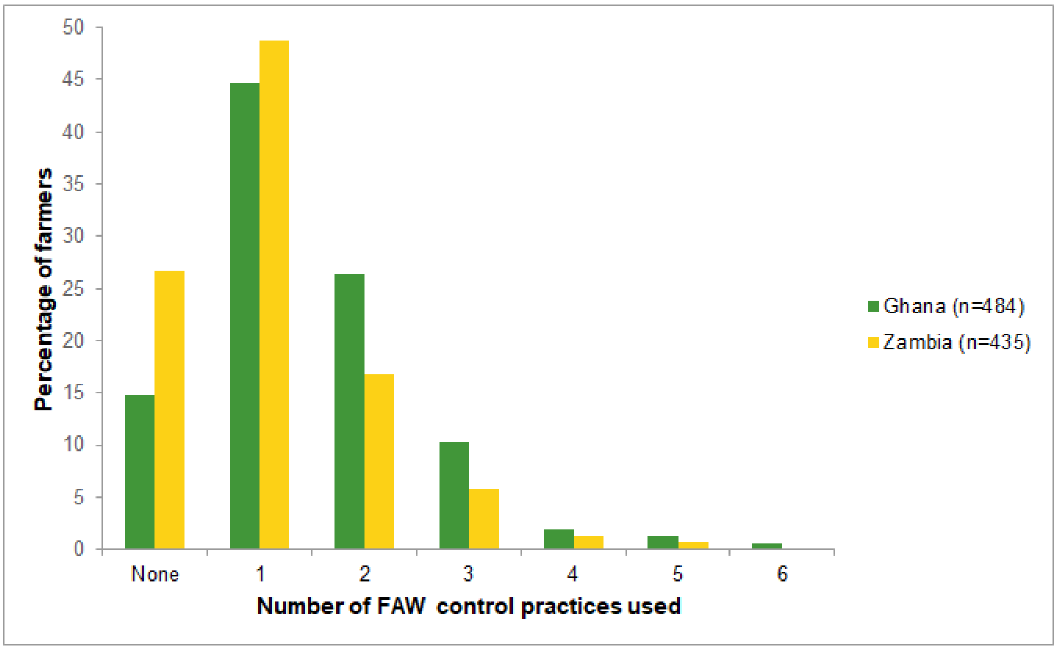
*N refers to the number of farmers who used the various control methods
Others (n<10) = biorationals, resistant varieties, crop rotation, intercropping, trap cropping, push pull, removal of crop residues, biological control

From further analysis of the 2017 farmer survey data, Tambo *et al.* (in press) showed that farmers who used a control method significantly reduced their self-reported yield loss. Combined used of pesticide application and handpicking of eggs and caterpillars produced the highest yield gain. Households that controlled FAW also had higher consumption of their maize, suggesting that FAW may be having some effect on food security at household level.

3.13 Frequency of using different control methods

Figure 14 shows the number of control practices used by households. More households in Zambia did not implement any control practices compared to Ghana. There was no difference between male and female headed households on the number of control methods used. Farmers who used two or more methods were likely to be combining pesticides as the first method and handpicking, or other cultural control options, a scenario evidenced in other countries (Kumela *et al*., 2018).

Figure 14: Number of FAW control practices used by farmers



3.14 Analysis of pesticides used for FAW control

During the survey, farmers provided trade names for the products (30 in Ghana, 39 in Zambia) they were using, from which the active ingredient was determined.

3.14.1 Pesticide use in Ghana

Farmers in Ghana used a combination of synthetic chemicals and biopesticides for management of FAW on their farms (Table 10). Compared to 2017, there was a marked increase in the use of biopesticides. In 2017, no farmers from Ghana had reported using any biopesticide. However, it should be noted that many farmers did not know that they were using a biopesticide, but followed the advice of a Dept. of Agriculture officer on which products to use.

Table 10: Most common active ingredients used by farmers in Ghana who (N=440)*

Name of active ingredient	No. of farmers	% of farmers
Bacillus thuringiensis (Bt)	110	25.0
Emamectin Benzoate	55	12.5
Ethyl palmitate	54	12.3
Lambda-cyhalothrin	43	9.8
Lambda- cyhalothrin+Acetamiprid	38	8.6
Chlorpyrifos ethyl	29	6.6
Emamectin Benzoate+Acetamiprid	26	5.9
Maltodextrin	16	3.6

*Multiple responses recorded. Only includes farmers who reported using pesticides

3.14.2 Pesticide use in Zambia

In Zambia farmers continue to predominantly use products such as lambda-cyhalothrin, cypermethrin and emamectin benzoate for FAW control, which is similar to last year (Table 11). About 9% of farmers used Monocrotophos, a highly hazardous pesticide on the Plantwise Pesticide Red List (Plantwise, 2017), Class 1b in the WHO classification, and listed in the Rotterdam Convention. This is a major concern. The regulatory authority has not provided a list of all registered pesticides in Zambia to determine the registration status of the products farmers reported they had used, but monocrotophos should not be registered for FAW, even if it is registered for other specific uses.

Table 11: Most common active ingredients used by farmers in Zambia (N=175)

Name of active ingredient	No. of farmers	% of farmers
Lambda-cyhalothrin	55	31.43
Cypermethrin	41	23.43
Monocrotophos	16	9.14
Emamectin benzoate	10	5.71
Malathion	9	5.14
GS-omega/kappa-Hxtx-Hv1a (biopesticide)	6	3.43

*Multiple responses recorded. Only includes farmers who reported using pesticides

3.15 Cost of applying pesticides

3.15.1 Ghana

The average amount spent on pesticides per household, including those who received subsidised products, was US$13.3 (median = US$2.7). However, when subsidies were removed and we considered only farmers who spent on pesticides, the average amount spent was US$25.3. The average cost per hectare for all farmers who did not use subsidised products was US$9.3/ha. This was lower than the 2017 estimates, when on average a farmer spent US$ 13.1/ha on pesticides.

The most used chemical pesticide, emamectin benzoate, cost the farmer on average US$22.0 (median= US$12.6) per purchase, while the second most popular, lambda-cyhalothrin, cost on average US$6.51 (median=US$3.4) per purchase. Removing subsidies, the average cost for emamectin benzoate was US$28.0 (median=US$16.8), and for lambda-cyhalothrin, US$12.3 (median=US$5.0). In Kenya, the IITA rapid response service for FAW estimates that a farmer requires an investment of US$ 13.2/ha for pesticide treatment (Woomer, pers comm), similar to the values from our survey.

There were 181 farmers who reported using biopesticides in Ghana, of which 121, or two thirds received the product free. The average cost per purchase of biopesticide in Ghana was US$38.1 (median=US$11.1). Fifty nine percent of Bt users obtained the products free, whilst 41% were purchased. The average price per purchase of Bt was US$37 (median US$21). Based on the average land size of farmers' who paid for their own inputs, this amounts to an average of US$15.2/ha. Of the 54 that used ethyl palmitate, only 13 (or 24%) paid for the product. The average price per purchase was US$45.0 (median=US$25.2). Based on the average land size of farmers who paid for their inputs, this amounts to an average of US$18.6/ha. This data supports the contention that biopesticides tend to be more expensive than synthetic pesticides, which is one of the reasons they are reported to be less frequently used.

3.15.2 Zambia

The average amount spent on pesticides per household in Zambia was US$7.3, when subsidies were included. When the subsidies were removed, and we considered only farmers who spent on pesticides, the average expenditure was US$14.2. The average cost per hectare for all farmers who did not use subsidies was US$8.1/ha. This cost is 19.8% higher than 2017 estimates, where on average a farmer spent US$ 6.5/ha on pesticide treatments alone.

Of the 56 respondents who reported the use of lambda-cyhalothrin, 20 received the pesticide free. The remaining 36 farmers paid on average US$9.3 (median=US$4.5) per purchase, or US$7.4/ha. The second most used chemical pesticide was cypermethrin (41 farmers), of which 27 or 66% received the pesticide free. The remaining 14 farmers spent on average US$25.8 (median=US$4.6) per purchase, or US$20.6ha.

3.16 Pesticide safety

A key issue around pesticide use in Africa has been the risk to human health. Pesticides are frequently applied without appropriate safety precautions being taken, and in the current study, 53.5% of farmers in Ghana and 42.7% in Zambia did not use proper PPE. We explored this aspect further in the current study, and found that around half of farmers in both countries reported health effects from using pesticides (Table 12), including headache, stomach ache, dizziness and skin itching. When we considered only farmers who used PPE in Ghana (n=231) and Zambia (n=168), 62.3% and 13.0 % reported no side effect or only one side effect respectively in Ghana, while in Zambia 47.0 % and 26.8% report no or a single side effect respectively.

Table 12: Pesticide-related health symptoms associated with FAW control

Health symptoms	Ghana (n=352)	Zambia (n=198)
None	58.2	47.5
Headache	25.6	16.2
Stomach ache	5.7	2.0
Dizziness	17.1	13.1
Skin itching	18.2	22.7
Others	2.7	11.6

Sixteen farmers in Zambia reported using monocrotophos, a highly toxic pesticide. In countries where it is still used, application is usually recommended only on non-food products such as cotton. It was not clear if farmers were buying the product for a registered use, and were diverting it for maize, but we assume that using for FAW control is illegal in Zambia. The side effects reported by farmers using this pesticide were largely in line with the effects indicated on the pesticide label. Of the 16 farmers using this product, 3 farmers reported no effects, but 13 reported symptoms including itching, likely caused by direct contact with the pesticide.

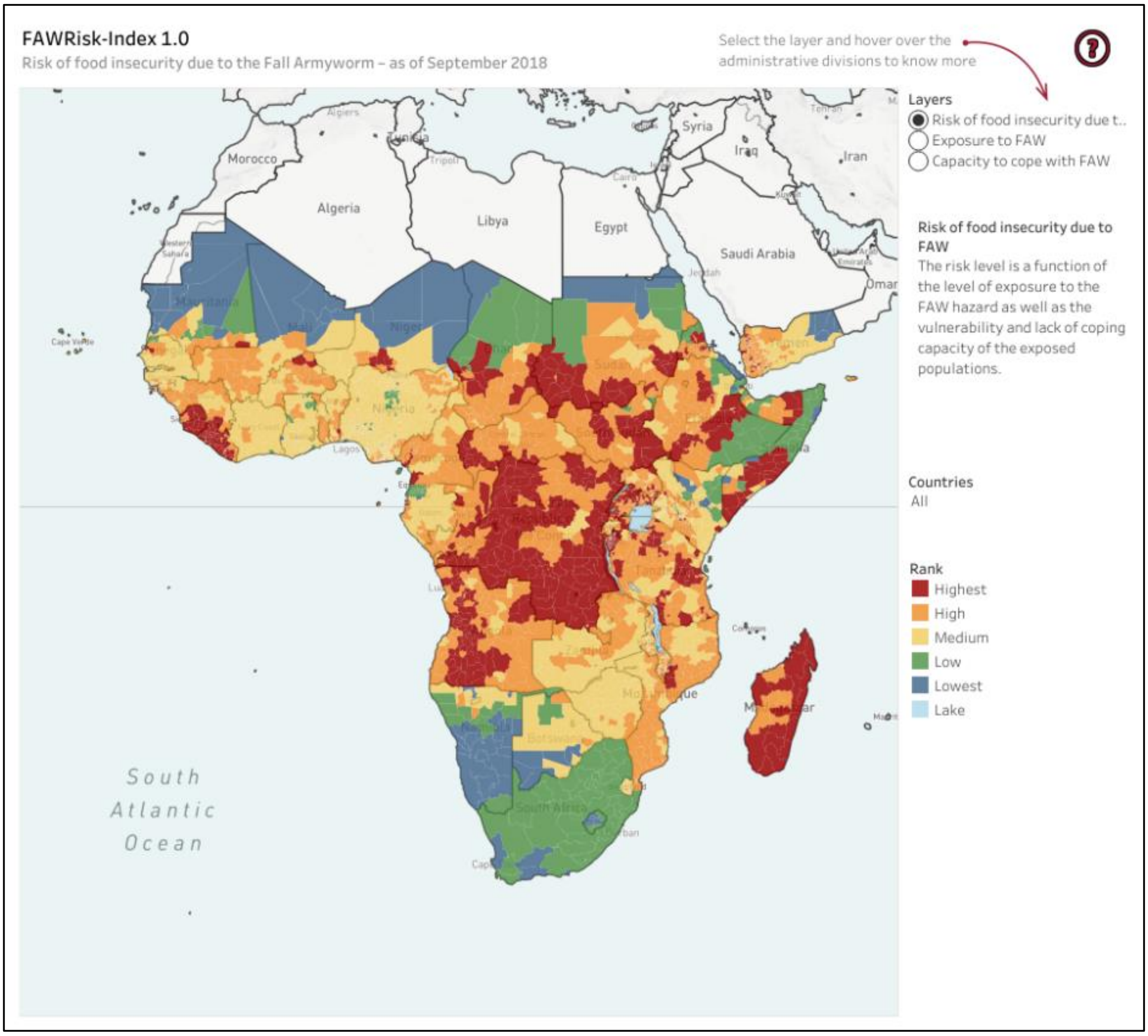
3.17 Fall armyworm risk mapping

FAO has developed a model to calculate the relative risk of food insecurity caused by FAW, based on approaches used for comparing other major risks. The FAWRisk-Index is comprised of data from twenty-two indicators, in two broad categories. Exposure to FAW indicates the risk of the pest occurring and its effects on crop production, and the second covers the capacity to cope with FAW. The overall food insecurity risk is thus a combination of the exposure and ability to cope or vulnerability.

The FAWRisk-Index is available through FAO's online and interactive FAWRisk-Map application (Fig 15), displayed at the district (or Admin 2) level. The relative level of risk of household food insecurity due to FAW is ranked according to five categories. By highlighting potential "hotspots", the tool is intended to assist decision-makers in prioritizing and preparing for early action in targeted areas. A manual is under development that will explain the maps and how they can inform decision-making in more detail.

Future updates of the FAWRisk-Map will include prevalence data from the Fall Armyworm Monitoring and Early Warning System (FAMEWS) mobile app and global platform, collected through field scouting and pheromone traps. The FAWRisk map can be accessed on (http://www.fao.org/emergencies/resources/maps/detail/en/c/1110178/)

Figure 15: Risk of food insecurity due to FAW.



3.18 Potential impacts of FAW on trade

In 2017 we noted that the presence of FAW in Africa could potentially constrain exports, particularly to Europe where FAW had already been identified as a risk. Directive 2000/29/EC listed FAW as a harmful organism whose introduction into and spread within all member states was banned, it not being present in any member state. Jeger *et al.* (2017) conducted a pest categorisation of fall armyworm, and concluded that it could be regarded as a "Union quarantine pest".

In response to the increased risk to Europe from the establishment of FAW in Africa, the EU instigated emergency measures with effect from 1 June 2018 for a period of two years. The measures cover *Capsicum*, *Momordica*, *Solanum* and maize, and require strict controls to be in place in countries to reduce the risk of the pest reaching Europe. In 2017 two consignments from Africa containing FAW were intercepted in Europe, and 17 interceptions have been made in the first eight months of 2018, nine of which were on the specified crops (Table 13). These levels of interceptions suggest African exporters are currently managing the situation satisfactorily. It is not clear how much additional cost this is incurring, but it may be that by including FAW in already established phytosanitary procedures for other quarantine pests, the marginal cost is low.

Table 13: Number of interceptions of FAW in Europe on commodities originating from Africa, to September 2018 (from Europhyt database)

Year	Country	Commodity								Total
		Capsicum	Coriandrum	Eryngium	Eustoma	Pisum	Rosa	Solanum	Zea mays	
2017	Kenya						1			1
	Zambia						1			1
2018	Kenya		1	1			2			4
	Mali							1		1
	Senegal							1	4	5
	Tanzania				1					1
	Togo							1		1
	Uganda	1								1
	Zimbabwe					1	1			2
Total		**1**	**1**	**1**	**1**	**1**	**5**	**3**	**5**	**17**

4. FAW Control

There are two broad categories of methods for controlling FAW: those that reduce the likelihood of damage occurring (such as resistant crop varieties, habitat management); and interventions that are made when attack is already occurring (such as spraying pesticides, releasing natural enemies, or picking the insects off plants by hand). This section summarises the main options in both categories, including those being used in Africa. It also highlights ongoing research and recent results and findings since the 2017 Evidence Note. Additional information on control methods is available in Prasanna *et al*. (2018), FAO (2018a), Bateman *et al.* (2018), and the 2017 evidence note.

4.1 Pesticides

Numerous synthetic pesticides are able to kill FAW, and manufacturers and distributors have been pursuing registration for many different active ingredients. This may require only efficacy trials for products already registered for other uses, to support a "label extension". Governments are also recommending a range of active ingredients and products. For example, by April 2018, Kenya had a list of 8 pesticides being recommended for FAW; in 2018 Ghana has recommended (and subsidised) only "biorational" pesticides, including several biopesticides (see below). Pesticides being used by farmers have different modes of action, and span the various WHO hazard categories, including some classified as highly hazardous (WHO Class 1b) such as monocrotophos. However, it is not clear whether the Class 1 pesticides being used are registered for FAW, even though they may be registered for other uses.

A key issue around pesticide use in Africa is the risk to human health, as pesticides are frequently applied without sufficient safety precautions being taken. Resource-poor farmers are often unwilling or unable to buy the appropriate safety equipment. Class 1 pesticides should never be registered or used for FAW control, and Class 2 pesticides should be avoided as far as possible.

Togola *et al.* (2018) have shown that five insecticide compounds commonly used against FAW (cypermethrin, deltamethrin, lambda-cyhalothrin, permethrin, and chorpyrifos) remained in soil samples where FAW had been treated, with possible adverse effects on soil borne organisms and other non-targeted species. However, no residues were found on the plants.

Although farmer surveys suggest pesticides are the commonest control method used by farmers, users are not always satisfied. In Ethiopia and Kenya 46% and 60% of farmers, respectively, believed insecticides were ineffective (Kumela *et al*., 2018). Pesticides may fail to work due to wrong use, such as incorrect application rate, wrong dosage, applying after the damage has been caused; or the pesticide itself may be ineffective due to fake labelling or adulteration, both of which are thought to be frequent. Some of the most widely used pesticides in Africa fall into the mode-of-action classes to which resistance has developed in the Americas. We have no data to suggest that FAW in any African countries has already developed resistance, or that the FAW populations were already resistant on arrival. Therefore the reports from some places of pesticides being ineffective are likely to be due to inappropriate use or fake/adulterated products rather than pesticide resistance. Nevertheless, it is recommended that strategies for reducing repeated exposure of successive generations of FAW to chemicals with the same mode of action be devised and implemented to reduce the likelihood of pesticide resistance developing.

The 2017 Evidence Note identified seed treatment as a possible use of pesticides for FAW control, and a product (Fortenza Duo) based on cyantraniliprole and thiamethoxam is being promoted by Syngenta and the African Development Bank. Results from trials of seed treatment in Zambia suggest that the product offers protection of seedlings for up to 4 weeks and potentially saves the farmer 1- 3 foliar insecticide sprays in commercial farms. Seed treatments may be more useful when they complement insect resistant seed traits, as the treatment will not protect the crop from the larvae that migrate from the whorl and feed on the ears during later crop stages. The efficacy of the seed treatment may also be affected by soil type, as seed sown in sandy soils emerges faster and benefits from longer protection than seed sown in loamy or clay soils. Whether seed treatment will be cost-effective for smallholders remains to be seen.

4.2 Biopesticides

Biopesticides are products based on pathogens of the pest, but may also be taken to include other biologically based products such as plant extracts (botanicals), biochemicals with various modes of action, and even predators and parasites (macrobials).

A recent study assessing biopesticides (broad sense) potentially useful for FAW management (Bateman *et al.*, 2018) reviewed products registered in 30 countries, 11 in FAW's native range and 19 in Africa. 50 biopesticide active ingredients were identified. Twelve of these are already reported as being effective against FAW outside Africa, most of these being already registered in at least some African countries for other pests. However, there are safety concerns regarding four of these, which need to be assessed in a local context. The remaining eight active ingredients were recommended for immediate field testing in Africa, and some such tests are in progress (see below).

One of the microbial biopesticides identified as a priority by Bateman *et al.* (2018) was baculoviruses, which are highly host specific, non-pathogenic to beneficial insects and other non-target organisms, and are attractive candidates for integrated pest management. Littovir (RAVAGEX), a *Spodoptera sp.* baculovirus based product, initially developed for control of the African cotton leafworm, has been tested and registered against FAW in Cameroon by Andermatt Biocontrol (pers communication). Trials are in progress in 6 countries in Africa to test the efficacy of a product (Fawligen, manufactured by AgBiTech) based on a multiple nucleopolyhedrovirus isolate, but so far no naturally occurring viruses of FAW have been detected in Africa (Prof K. Wilson, pers comm). African Armyworm is attacked by a virus, but attempts to commercialise production of the virus in Tanzania failed.

Bacillus thuringiensis (Bt)-based products are relatively widely available in Africa, and as reported above, were widely used in Ghana in the most recent season. However, different subspecies/strains of Bt are more or less effective against different pests, so not all Bt products in the market may be suitable for FAW. Trials are required to confirm which strains/products are most effective in Africa, and such work is ongoing at icipe.

Beauveria bassiana is reported as effective against FAW in the laboratory in the Americas, and *Metarhizium anisopliae* is effective against related pests, so products based on these fungi are also worth testing, although preliminary trials at icipe were not immediately promising. Work on entomopathogenic nematodes of FAW is in progress at University of Neuchatel, where novel methods of formulation have been developed that can enhance efficacy.

Spinetoram and spinosad, bacterial fermentation products, are reported effective against FAW, but present some risks that need mitigation. Methoxyfenozide and silicon dioxide are also reported effective against FAW in its native range and should be trialled in Africa.

4.3 Botanicals

A large diversity of plants have insecticidal properties. The active ingredients of some of these, or their synthesised equivalents, are the basis for formulated products, while various local concoctions use such plants (see below). Azadirachtin (neem) is effective against FAW in the Americas, and in Ghana, for example, three products based on azadirachtin are already registered for use against FAW. Oxymatrine and matrine (found in *Sophora* spp) are reported effective against FAW in the field and laboratory bioassays respectively in the Americas so are worth trialling in Africa where they are already registered in some countries for other pests. Garlic oil, orange oil and maltodextrin are reported effective against related pests so could also be tested against FAW. Pyrethrins (from *Chrysanthemum cinerariaefolium*, formerly *Pyrethrum*) are effective against FAW and registered in Africa, but have non-target risks that require mitigation.

In Mexico, recent studies have shown that extracts of *Couroupita guianensis* and *Myrtillocactus geometrizans* could be good candidates for the control of *Spodoptera* due to their larvicidal activity. Also, extracts from *Synedrella nodiflora* and *Lupinus stipulatus* have shown to have biological effects on mature insects of the genus (Ayil-Gutiérrez *et al*., 2018). And researchers from Brazil have also demonstrated that the application of a 5% extract concentration of pequi fruit decreased the amount of damage caused by the FAW caterpillars (Souza *et al*., 2018), although a higher concentration was phytotoxic.

While botanicals are generally thought to be “natural” and therefore “safe”, this is not always the case, some having negative impacts. For instance, although azadirachtin does not meet any of the criteria for highly hazardous pesticides, and is generally considered safe to beneficial insect species, some adverse effects on hymenopteran parasitoids (wasps) have been reported. It can also cause an allergic skin reaction in humans in some cases.

4.4 Biological control

Biological control covers several approaches including encouraging local natural enemies of FAW through various agronomic and cultural practices (see below), classical biological control, and inundative releases.

Classical biocontrol, the introduction of a natural enemy not already present, is particularly suitable for a pest that has invaded a new area, where the natural enemies that attack it in its native range are absent. In the 2017 evidence note the egg parasitoid *Telenomus remus* was suggested as a candidate agent for introduction, but it has recently been reported from South Africa and Cote d’Ivoire, so could be considered for redistribution or inundation. CABI is undertaking exploration for more effective natural enemies in Latin America to identify other efficient parasitoids that might be introduced in Africa. There are also efforts underway within Africa (IITA) to test the efficacy of the egg-larval parasitoid *Chelonus insularis* and the larval parasitoid *Cotesia marginiventris.*

Inundative releases of various insect predators and parasitoids of FAW have been attempted in the Americas. *Trichogramma* spp. (egg parasitoids) have been successfully used, and commercial products of *Trichogramma pretiosum* are registered for use against FAW in Brazil. *Trichogramma* spp. are commercially available in Africa, so they, along with indigenous species, should be tested against FAW.

Several organisations are also conducting surveys for native natural enemies attacking FAW, and various species have been identified. In surveys in Kenya, Tanzania and Ethiopia, Sisay *et al*. (2018) found parasitoids including *Cotesia icipe*, *Palexorista zonata*, *Charops ater* and *Coccygidium luteum,* with up to 45, 12.5, 12 and 8.3% field parasitism, respectively. Studies in West Africa (CABI) have recorded up to 70% parasitism in some samples. Research is needed to examine what factors increase or reduce the mortality caused by the main natural enemies.

4.5 Agronomic and cultural practices

Agronomic practices including habitat management can suppress or avoid pest damage through a variety of mechanisms, including conserving and encouraging the proliferation of natural enemies.

Planting promptly can in some cases allow the maize crop to escape FAW attack, and FAO (2018a) recommends avoiding late planting, and avoiding staggered planting (i.e. planting of fields at different dates in the same area), as this would continue to provide the favoured food of FAW locally (i.e. young maize plants). Farmer Field School (FFS) farmers in Kenya reported significant yield losses to FAW on late-planted maize plots, compared to adjacent earlier planted crops (FAO 2018a).

As noted in 2017, there is mixed evidence on the benefit of weeding maize fields. The species of weed involved may be important, which could affect whether they serve as host plants for the pest, as well as reservoirs for natural enemies. Research on this is needed.

New evidence from trials in Africa suggests that intercropping maize with food legume crops can reduce FAW damage levels by 30% with bean, 21% with soybean and 31% with groundnut (Hailu *et al*, 2018). However, because some of the legumes used as intercrops are also reported as hosts of FAW in the Americas, and usually emerge earlier, their role in sustaining the pest population that may infest the maize crop requires some attention.

A combination of intercropped companion plants that repel the pest and attractant trap crops round the edge of the field, dubbed "push-pull", was pioneered in Australia for *Heliothis* in cotton (Pyke *et al.*, 1987). Since then it has been extensively researched in Africa and shown to reduce damage due to various pests in maize systems, most recently including FAW (Midega *et al.,* 2018). They report reductions of 82.7% in the average number of larvae per plant and 86.7% in plant damage per plot in climate-adapted push-pull compared to maize monocrop plots. Similarly, maize grain yields in the climate-adapted push-pull plots are 2.7 times those in monocrops. Kebede *et al.* (2018) have shown that landscape level complexity can mediate the relative impact of push-pull.

Although apparently very effective, adoption of push-pull is still relatively low. Various reasons have been cited including its complexity or knowledge intensiveness, the increase in labour requirement for the three components in the system, the period of time taken to establish companion plants, access to seed, and adaptation of the technology to existing farming systems (Kassie *et al*, 2018). Concerns have also been raised that the companion crops are potentially weedy and/or invasive (Witt and Luke, 2017). A weed risk analysis is being conducted (in the Zambian context), to clarify what, if any, the risks might be.

Handpicking egg masses and caterpillars has proven a popular method for FAW control in Africa and is widely used by farmers as a first line of defence against FAW.

4.7 Farmers' control methods

Farmers experiment and innovate, particularly if they are confronted with the problem such as FAW. Ingredients in the concoctions farmers are trying out for FAW control include soil, charcoal, ash, detergents, paraffin, engine oil. Various plant extracts are often included, such as chilli, neem, *Tephrosia*, *Tithonia*, *Lantana*, garlic. As noted above, there is good evidence that at least some of these plant extracts can be effective insecticides.

Other farmers' control methods aim to encourage and attract natural enemies. FAO (2018a) suggests options such as spraying sugar water to attract and maintain populations of ants and other natural enemies. While there is some published evidence that this practice does attract natural enemies, it is not clear whether it is sufficient to reduce yield loss. Other substances such as cooking fat have also been tried by farmers. FAO (2018a) also recommends "recycling pathogens" by collecting caterpillars killed by disease, and using them to prepare a solution for spraying on plants.

4.8 FAW Pheromones

As well as using synthetic sex pheromones for monitoring FAW, research is in progress to see if they can be used for control. There are two approaches; trapping and mating disruption. In trapping, the aim is to reduce the male population to such an extent that females are unable to mate. Gilson *et al*. (2018) report tests using traps made from plastic drinks bottles with a pheromone lure, but there is no evidence yet that sufficient males can be caught in an area to reduce FAW damage.

Mating disruption involves releasing so much pheromone into the environment that males become confused and cannot find the females whose own pheromone emissions are lost in the cloud of synthetic pheromone. Often this approach is impractical as pheromones are expensive to produce. However, a company in US (Provivi) has developed a new method of synthesising such molecules which should reduce the cost by up to 90%. Trials are therefore being conducted in East Africa to test the mating disruption approach, although as with trapping, it is likely to be most effective when implemented over a large area.

4.9 Host Plant Resistance

This can be a useful technology for sustainable FAW management, particularly in the African context, where a majority of the farmers are smallholders with limited access to safe and affordable FAW control options. Recent advances have been made in identifying FAW-resistant maize populations, developed using diverse sources of resistance. CIMMYT is working on rapid conversion of the preferred but FAW-susceptible lines into resistant versions. Ten promising CIMMYT maize inbreds have been identified and validated in Kenya with leaf damage ratings between 2.0 and 6.0, and ear damage ratings below 3.0, while the susceptible check ratings were 7.0 or above. Key will be how fast first-generation FAW-tolerant maize varieties can be scaled-up and deployed as an immediate relief to the farming communities. So far, 5 materials look promising and may be available within 2-3 years. This will need to be coupled with accelerated breeding for improved Africa-adapted varieties with FAW resistance and other farmer-preferred traits, leading to the release and deployment of second-generation FAW-tolerant maize hybrids/OPVs in the coming years. Critical to this technology will be the systematic analysis of compatibility and possible synergies between host plant resistance with other IPM approaches (e.g. biological control).

Additionally, AATF has been working on drought-tolerant (DT; *DroughtGard®* or *CspB* from *Bacillus subtilis*) and insect-resistant (*Bt* from *Bacillus thuringiensis*) transgenes or traits donated royalty-free, to develop white maize varieties under the trademark TELA®. Preliminary results from confined field trials carried out in Kenya, Mozambique and Uganda with TELA® varieties stacked with both DT and *Bt* traits showed partial but significant control of the FAW. Six TELA® varieties with only *Bt* insect-resistant trait have already been commercialized in South Africa, the only country in the continent where planting genetically modified maize is currently permitted. Trials of GM crops are in progress in another seven African countries (Cameroon, Egypt, Ghana, Kenya, Malawi, Nigeria, and Uganda).

There is much debate around the suitability of genetically modified crops for smallholder farmers in Africa. Much of this is not about safety, but around socio-economic issues and the capacity of regulators, even where appropriate legislation is in place. If introduced, effective regulation is required to reduce the risk of resistance developing. Fatoretto *et al*. (2017) report that most Bt maize hybrids lost their ability to control fall armyworm within 3 years of introduction in Brazil.

4.10 Genetically engineered fall armyworm

Recent research advances have proposed the use of genetically engineered fall armyworm as another strategy for FAW management. Males containing the ‘self-limiting’ gene are released in large numbers, and when this gene is passed on to the offspring, the females do not survive to adulthood. Intrexon (US) and Oxitec (UK) have been researching this approach for several years and claim to be making good progress. However this kind of technology requires regulatory approval and a proper risk assessment before it can be used widely, that could take several years.

5. Advice, information and communication

5.1 Who is providing advice?

The role of advisory services in supporting farmers' decision-making is particularly important when farmers have a new situation to cope with, such as the arrival of a new pest. The 2017 evidence note highlighted that many players in the private and public sectors are involved in providing advice to farmers (Swanson and Davis 2014), and that for a new pest, this presents a challenge in ensuring farmers receive sound and consistent advice.

Subsequent events have shown that this is indeed the case. Many different organisations have been involved in seeking to provide advice to farmers, using a variety of communication methods. However, while most stakeholders would claim to be promoting an integrated pest management approach, different stakeholders emphasise different elements of IPM, arising from their differing objectives, experience and knowledge. Objectives and interests of those providing advice on how FAW is managed include:

- supporting a particular group or community of farmers already linked through some other initiative which FAW could jeopardise
- promoting the sale of one or more particular products
- promoting a research area or the introduction of a particular technology
- promoting the use of a particular communication channel or approach
- promoting a particular approach to agriculture (eg organic, conservation agriculture)

The result is that farmers and decision-makers at various levels sometimes receive conflicting, biased or even erroneous advice. This chapter therefore discusses some of the key issues that need to be considered by those seeking to ensure farmers receive timely and useful advice, and those who need to evaluate the information and advice they are receiving.

5.2 Areas of advice

Methods for controlling FAW is the main area in which advice is given, but there are also a number of other related areas.

- *Monitoring:* Advice is provided on methods for different types of monitoring techniques and protocols (trap catches, damage levels, yield loss). Advice on methods and protocols for field scouting of FAW is generally consistent.
- *Action thresholds:* An action threshold is the value for a parameter that when reached should trigger a response. In FAW management the parameter is usually the percentage of maize plants showing fresh damage, but there is no consensus on what this value should be for smallholder maize farmers in Africa. Action thresholds vary with context, including the value of expected yield, the relationship between damage and yield loss (which is not yet well documented in Africa), and the stage of the crop. Because maize has the capacity to recover from some damage, appropriate action thresholds may be higher than might be expected.
- *Methods for avoiding FAW damage*: Several of the methods recommended for managing FAW work through avoiding damage occurring, such as various agronomic practices (see Chapter 4). Use of such methods requires forward planning and decision-making, and therefore some understanding of the risk of FAW damage.
- *Methods for controlling a FAW infestation*: Other methods recommended for managing FAW are interventions for reducing populations that are adjudged to have reached levels at which some treatment is required. It is in this context that pesticides are most frequently used.
- *Pest forecasts*: So far there are no operational FAW forecasting services, although research to support such forecasts is in progress, and FAO produces a broad quarterly forecast. The latest

bulletin (FAO, 2018e) for the period October-December 2018 lists 17 countries for which there is a high threat to food and nutrition security from fall armyworm (Angola, Burundi, Congo, Eritrea, Ethiopia, Madagascar, Malawi, Mozambique, Namibia, Rwanda, Somalia, South Africa, Sudan, Swaziland, Uganda, Zambia, Zimbabwe). Experience with forecasting African armyworm (*Spodoptera exempta*) in East Africa showed that forecasts are only of value if the recipient's decision context is taken into account.

- *Safety advice*: Various control methods entail some risk, so advice on safety precautions is important. For various reasons, such advice is not always followed.

5.3 Criteria for control advice

Ideally advice or recommendation on a method for managing FAW should not be made without consideration of the following criteria.

Efficacy. This is often assumed to be the most important criterion, even if not stated explicitly. If a practice is to be recommended there should be some evidence that it will be effective in at least some situations. Where a product has to be registered, this generally includes demonstration of efficacy, but many IPM practices do not involve a registered product. Results from controlled trials in an appropriate context are desirable, though not always available.

Safety. Even registered products can be hazardous to human health without precautions. Safety should thus be considered from a consideration of how the product is likely to be used rather than whether recommended safety precautions are adequate. Some practices not requiring registration can also be hazardous, such as some plant extracts.

Sustainability. Possible effects on non-target organisms such as pollinators, natural enemies and other organisms should be considered. A control method may also have potential to create new problems such as resurgence of other pests or pesticide resistance.

Practicality. Some methods may be impractical for some farmers, particularly those requiring elaborate safety precautions. Others may be only practical at a small-scale.

Availability. Availability of regulated products is initially determined by their registration status, but even registered products may not be widely stocked if distribution is expensive and/or the perceived market is small. Unregulated inputs for some control methods may not be easily available, such as seeds of companion plants.

Cost-effectiveness. At the simplest level the cost of control must be less than the value of crop loss avoided for it to be worthwhile. Opportunity and other costs may need to be considered.

In practice many of these criteria are context specific, so recommendations and advice are unlikely to suit all farmers in all situations. This highlights different underlying approaches to the role advisory services. The linear "transfer of technology" approach emphasises prescriptive advice on the use of new technologies. Participatory approaches emphasise educating and empowering farmers to use information and experience to make their own choices. Both approaches have advantages and disadvantages.

5.4 Communication channels

Many different methods are being used to communicate with farmers and other stakeholders. Different channels have different advantages and disadvantages, the following being some of the factors to consider when using a particular approach.

- *Outreach speed.* Some channels enable information to reach users very rapidly, while others are slower. Rapid outreach might be required to ensure information is timely.
- *Numbers reached.* Some communication channels, particularly the mass media, can reach much larger numbers than some other methods.

- *Cost.* One measure of cost is the marginal cost per person reached with a particular message. Some channels have much higher start-up costs than others.
- *Complexity of messages*. Complex messages are best communicated when there is an opportunity for dialogue, such as face-to-face channels. Some mass media approaches can incorporate dialogue, such as radio phone-ins. IPM can be “knowledge intensive”, which is why farmer field schools are particularly appropriate for promoting IPM.
- *Audience*. Different channels may be more or less suitable for different audiences, such as men, women or youth. Language is also important to consider.

Often a trade-off is required between these different factors, so in practice an effective communication campaign is likely to require a combination of approaches.

Much experimentation and innovation is taking place in the use of ICTs for communicating agricultural advice, and the management of FAW is no exception. USAID has sponsored a competition (the “Tech Prize”) on the use of ICTs, and the finalists are briefly summarised in Table 14.

Table 14: Fall Armyworm Tech Prize finalists

Africa Rising (South Africa) is an SMS based service which assists farmers to prevent and mitigate FAW, by taking appropriate measures to respond based on the severity, likely impact on the current crop, and cost benefit.
AfriFARM (Africa Fall Armyworm Response Mechanism) (United States) is a mobile phone application that provides current, quality information about FAW tailored to meet user needs by overcoming technology gaps of connectivity and data/SMS costs, as well as literacy gaps.
Agri-Poll (Uganda) is a smart survey platform that allows gathering, analysis, and dissemination of specific information (images, video, text, audio) in locations which FAW has been detected, via smart phones and web platforms, for broad-scale surveillance, and actionable advice.
AI-based Digital Monitoring System (Israel) is a digital monitoring system that deploys artificial intelligence to provide diagnoses and generate warning alerts for FAW outbreaks based on geographical spread and forecasting models.
Boa Me ("Help me" in Tiwi) (Ghana) consists of a web application, a USSD & bulk SMS alerts system, a mobile app, a special PA system and an IVR to detect, alert, and educate farmers on how to prevent and control FAW.
CdPAS (Crop Disease & Pest Advisory Service) (Ghana) combines IVR and a smart app, which allows farmers to report, predict, identify, monitor, and mitigate the outbreak of FAW and to subscribe and access educational content on FAW in text, audio, pictures and video formats.
CornBot (Nigeria) is an audio-visual mobile application that interacts with farmers in their local dialect, talking them through a process that helps them to identify, prevent and control FAW and linking them with agrovets.
Digicult (Taiwan) is a digital platform using mobile communication devices, multimedia processing, and crowdsourcing to analyze and share FAW data, and provide advice help farmers prevent and fight FAW.
EzyAgric (Uganda) is a pest and disease diagnostic app, utilizing the EzyArmyWorm (EAW) module that allows farmers to detect FAW life stages, and predict the estimated yield loss.
Fall Armyworm Virtual Advisor (United Kingdom) is a combination of a chatbot and a progressive web app, that guides farmers through a training on how to identify and manage FAW.
FarmSmart FAW CONTROL (Nigeria) is an integrated image recognition app for FAW that links solution providers (researchers, manufacturers, and financial institutions) with farmers and allows paying a fraction of the control cost, and rating the effectiveness of the solution provided.
FAWLEA: Pests? Problem solved! (Uganda) is an android smart phone app that uses image recognition to detect and accurately identify FAW and the extent of crop damage, then provide the farmer with control options and approved pesticides and agrovets.
Igeza (Ghana) is a cloud-based mobile application enabling early detection of FAW via video, image or voice, with geolocation which then sends all notifications to a pool of experts (entomologists, pathologists, agronomists etc) to analyse the data and recommend appropriate control options.
Light Watch: Autonomous Pest Monitoring Solution (USA) is a monitoring solution using solar-powered LED lure, intelligent cameras, and a convolutional neural network to detect and alert central pest management authorities and local farmers via SMS of FAW outbreaks.
Lindafarm (Kenya) employs mobile technology, and databases/maps, to help farmers send alerts on FAW on their farms via USSD/SMS and get instant help from nearby community extension service providers.
myAgro (United States) is mobile application that allows myAgro field agents, equipped with smartphones, to easily report and act on FAW prevalence based on heat maps, as they monitor farmers' fields.

Shape Up Against Armyworm (Kenya) is a make-over reality TV and radio, print, mobile and internet accessible programme that provides up-to-date information weekly to farmers through the Shamba Shape Up TV/Radio series on FAW control, access to inputs, and links to further information, via the iShamba mobile call centre and SMS services.

UDefeatFAW (United States) incorporates interactive radio and SMS/interactive voice response (IVR) for two-way communication with smallholder farmers for delivery of vouchers for appropriate and affordable pesticides, and the correct stage of application and provides guidance on control of FAW.

WeFAW (United States) is a FAW early warning, response and control model for smallholder farmers utilizing data from millions of farmer interactions on “Wefarm” platform to provide real-time 'alerts' and access to the knowledge and resources from subscribed smallholder farmers by SMS.

Zaois-Tech (Kenya) allows farmers and service providers to use one or more of the system digital tools to identify, eliminate, and prevent FAW using either an SMS text-based query system, a smartphone app, a website portal and/or an image identification tool.

5.5 Information resources and tools

A large volume of materials and resources on FAW has been produced in the last 12 months. Two key resources, each compiled with contributions from multiple authors and containing a wealth of detailed information for researchers and advisers (rather than directly for farmers) are:

- Integrated management of the Fall Armyworm on maize: A guide for Farmer Field Schools in Africa (FAO, 2018a)
- Fall Armyworm in Africa: A Guide for Integrated Pest Management (Prasanna *et al.,* 2018).

CABI launched a Fall Armyworm Portal (www.cabi.org/fallarmyworm), as an integral part of the open access Invasive Species Compendium. The portal includes a wide variety of information for farmers, policymakers, researchers and other stakeholders, collated from multiple sources including many of the key organisations collaborating in the FAO Framework for Partnership and the International Research for Development Consortium.

5.6 Policy toolkit for strategic communication during pest outbreaks

Policy makers need to be empowered with the right evidence to make informed, science based decisions, in developing and implementing responses to pest outbreaks. The FAO Communications working group met in Lusaka, Zambia in August 2018, and identified the need for a policy toolkit to support strategic communication during pest outbreaks. It was agreed that such a toolkit was necessary at government level, for accessing the resources needed to communicate effectively and for planning and managing coordination of stakeholders during the response to a pest’s invasion.

The policy toolkit will be aimed at government officials representing agricultural, research and communication departments – those responsible for coordinating the response to pest outbreaks in their countries. FAW will be used as the specific example, but it is envisaged that this tool should assist with developing capacity to respond to future pest outbreaks. Topics to be covered will include:

- evidence on the importance of effective communication during pest outbreaks, focussing on recent examples
- communications within the scientific context of response to pest outbreaks looking at preparedness, regulation and more
- approaches to resourcing
- roles and responsibilities of stakeholders during the lifetime of a response
- effective planning and monitoring

6. Recommendations

Since the identification of FAW on the African continent, many stakeholders have collaborated in order to limit the pest's impacts. In early 2018 the United Nations Food and Agriculture Organisation's *Partnership framework for Sustainable Management of the Fall Armyworm in Africa* was endorsed at a meeting in Rome. This framework is intended as a guide for the development of projects and programmes by the various stakeholders in the areas of their comparative advantage. Within the ambit of this framework, FAO established open technical working groups, convened by various organisations. The groups are: Agroecology; Biological control; Bio-pesticides; Synthetic Chemical Pesticides; Host Plant Resistance; Transgenic Resistance; Yield Loss Determination; Risk & Impact Assessment; Monitoring & Early Warning; Communications, Awareness & Knowledge Management; Farmer Field Schools, Extension, Plant Clinics; Quarantine & Phytosanitary Measures. Some groups have operated well, holding regular virtual meetings, and in 2018 the communications group held a workshop in Zambia. Some other groups have met rarely if at all.

In September 2018 a new Fall Armyworm Research for Development Consortium was formed. Focusing on applied research, the consortium joins other global efforts and coordinates with international bodies working against FAW. Consortium members will pursue a wide range of options for fighting fall armyworm, with a strong emphasis on the technical components of integrated pest management. Currently 35 organisations have agreed to be part of this R4D consortium, co-led by CIMMYT and IITA. Its mode of operation will be discussed at the October 2018 international conference in Ethiopia.

Through these two mechanisms, coordination and collaboration on research as well as implementation is essential. Currently only a few national organisations in Africa are involved in either, yet they play a critical role in what happens in practice. Thus while international players have a major role to play in addressing a problem of this magnitude, most of our recommendations are directed at national or subnational organisations.

National FAW coordination task forces should:

- Ensure the voice of different stakeholders, especially smallholder farmers, is heard
- Monitor FAW crop loss and control practices, to provide evidence for national decisions
- Use any subsidies to encourage the use of low risk control methods
- Learn lessons from tackling FAW that can be applied to other invasives

Advisory Services should:

- Use a combination of both traditional and novel communication methods
- Tailor messaging to specific target audiences
- Consider efficacy, safety, sustainability, practicality, availability and cost effectiveness when recommending control practices
- Encourage farmers to:
  - Maintain plant diversity through intercropping and habitat management
  - Avoid practices which kill natural enemies of FAW
  - Observe and monitor fields regularly after germination
  - Experiment with different control practices
  - Refrain from intervening as soon as leaf damage is observed

Regulators should:

- Maintain regulatory credibility by providing emergency/temporary registration for government-recommended control products

- Work with industry associations to identify and stop companies selling unregistered and/or dangerous products
- Within the existing legal framework, expedite registration of lower risk products
- Continue efforts to regionally harmonise pest control product regulations

Researchers should:

- Test and validate control methods commonly used by farmers
- Develop simple and robust action thresholds based on FAW damage levels
- Determine why recommended control actions are sometimes not effective
- Monitor FAW natural enemies and identify practices that conserve and enhance the mortality they cause
- Identify opportunities for establishing local enterprises producing bio-inputs
- Continue research on the use of host plant resistance and classical biological control
- Continue research on FAW biology and ecology, with the aim of improving control decisions by farmers and other stakeholders
- When developing and introducing new control practices, consider efficacy, safety, sustainability, practicality, availability and cost effectiveness for smallholder farmers.

Glossary

Diapause: a period of suspended or arrested development during an insect's life cycle. Insect diapause is usually triggered by environmental cues, like changes in daylight, temperature, or food availability. Diapause may occur in any life cycle stage – embryonic, larval, pupal, or adult – depending on the insect species

Sympatrically: Two related species or populations existing in the same geographic area and thus frequently encounter one another

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