Fall Armyworm Status

Impacts and control options in Africa: Preliminary Evidence Note (April 2017)

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Executive summary (Please follow links to relevant parts of the report)

Biology

The Fall Armyworm (FAW) is an insect that feeds on more than 80 plant species, including maize, rice, sorghum and sugarcane but also vegetable crops and cotton. It has a voracious appetite, and can reproduce and spread quickly given the right environmental conditions.

Continental distribution (current and forecast)

Whilst much of its biological and ecological adaptation to the African continent is still unknown, indications are that it has spread since 2016 across much of sub-Saharan Africa. It has been officially identified in 11 countries and is suspected to be present in at least 14 other countries. Environmental and climatic analyses of Africa show that the FAW is likely to build permanent and significant populations in West, Central and Southern Africa, and spreading to other regions when weather or temperatures are favourable. Prediction models so far present much uncertainty as scientific institutions are still learning of the pest's habits on the continent.

Economic impacts

FAW causes major damage to economically important crops: overall costs of losses for maize, sorghum, rice and sugarcane in Africa are estimated to be approximately $13,383m (~£10,400m). This does not take into account up to 80 other crops the insect has been known to feed on, as well as subsequent seed lost for the following growing seasons.

FAW affected crops in all countries	Total production (tonnes, m) assuming no FAW	Yield loss (tonnes, m)	Estimated/predicted loss (US$, m)
Maize	67.0	13.5	3,058
Sorghum	25.5	1.90	827
			Area of crop at economic risk (US$, m)
Rice, paddy	17.1	9.6	6,699
Sugarcane	90.1	46.0	2,799
		Total	**13,383**

Control options

In the Americas pesticides and genetically modified (GM) crops are the main methods of control, although FAW has developed some resistance to both. Most countries in Africa do not yet plant GM crops. (Bio)Pesticides including *Bacillus thuringiensis* are an option in Africa, though these are not always affordable to many small-scale farmers; subsidy or government-funded implementation is therefore being used in some countries. Lower-cost mechanical and cultural control methods have yet to be proven, but could be adopted in the meantime. Mass rearing and release of parasitoids and predators is used as an alternative in the Americas but currently costs may be prohibitive without subsidy in Africa. Classical (introduction) biological control should be pursued immediately. Virus-based biopesticides available in the Americas may offer a low-risk option, but are not yet registered in Africa, and again may be expensive for many farmers. In all cases a widespread communications programme is necessary to inform farmers how to monitor and identify the pest, and what management methods are available which can be selected according to local context.

Information resources

There are several information resources which can help inform and keep interested parties up to date on the latest news regarding spread, management research, and diagnostic protocols for monitoring and early detection techniques. These include CABI's Invasive Species Compendium, Plantwise's Knowledge Bank and Lancaster University's Armyworm Network.

This preliminary evidence report was commissioned by the UK's Department for International Development (DFID). *The information and opinions reported here do not represent the view of DFID.The Authors gratefully acknowledge the financial support of DFID, as well as contributions to the findings made by ACDI/VOCA (USA), AgBiTech (Australia), CIMMYT, FAO, IITA, Russell IPM (UK), University of Exeter (UK), University of Lancaster (UK), plus multiple national programme partners of Plantwise in Ghana, Kenya, Rwanda and Zambia.*

**If you have additional information/evidence on FAW which complements or challenges the information presented in this document, please contact the corresponding author Roger Day at r.day@cabi.org.*

Section 1: Introduction to the fall armyworm

Photo 1: FAW larva on maize

The fall armyworm (FAW) (scientific name *Spodoptera frugiperda*) is a moth, native to tropical and subtropical regions of the Americas, but it is the caterpillar or larva (photo 1) that causes damage. After mating, female moths lay egg masses of 100-200 eggs, usually on the underside of leaves and, within a few days, young larvae emerge and start feeding. Almost 100 different crops and other plants are susceptible to attack, but there is a preference for maize, rice, sorghum and sugarcane. The developing larvae eat different parts of the host plant, depending on the stage of crop development and the age of the larvae. Young larvae usually feed on leaves, creating a characteristic "windowing" effect and moist sawdust-like frass near the funnel and upper leaves. Early in the season, this feeding can kill the growing point, a symptom called 'dead heart' in maize, which prevents any cobs forming. Young larvae hide in the funnel during the day but emerge at night to feed on the leaves. In young plants, the stem may be cut. Older larvae stay inside the funnel and so are protected from spray applications and predators. In older plants the larger larvae can bore into the developing reproductive structures, such as maize cobs, reducing yield quantity and quality.

Fully developed larvae usually burrow into the soil to pupate inside a loose cocoon, but sometimes do so between leaves on the plant. Adult moths emerge at night and can travel great distances by flying up into the low-level jet stream. In North America this has been recorded as enabling them to fly from Mississippi to Canada in 30 hours.

The rate at which larvae develop is affected by diet and temperature (optimum range between 11°C and 30°C). In Southern Florida, for example, where it breeds continuously, the life cycle takes about one month in summer, two months in spring and autumn, and three months in the winter. In cooler climates development slows down to one or a few generations per year. Frost kills the insect, so in the USA damage in the cooler more northerly states is caused by moths migrating from populations in southern Texas and Florida.

Whilst larvae of *S. frugiperda* are distinct in their aggressive feeding behaviour and dark coloration, they are hard to identify in the field: they are easily confused with similar species such as the African armyworm (*S. exempta*) and the cotton leafworm (*S. littoralis*), but also different genera, like the spotted stem borer (*Chilo partellus*).

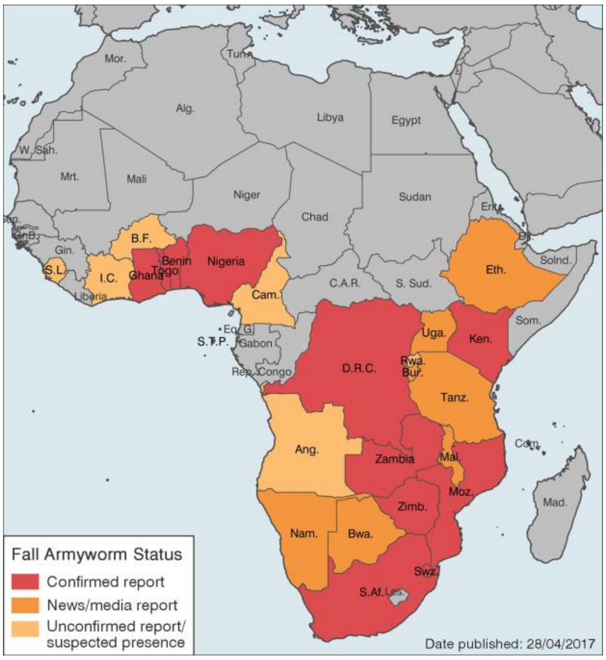
Further research is needed across the continent, through national and regional institutes, to understand the insect's lifecycle stages and feeding habits in Africa. These may be different to what has been found so far in the Americas given that the material introduced into Africa probably reflects the introduction of a small number of individuals from one location. It therefore cannot be assumed that all biology recorded in the Americas will be found in Africa.

Furthermore, since the 1980s, FAW in the Americas has been thought to occur as two strains: a rice strain and a maize strain (although both feed on maize). Recent genetic studies indicate that these represent two genetically distinguishable but morphologically identical populations. They occur together from Argentina to Southern USA and both disperse into temperate regions. Both strains have now been documented in Africa (Ghana and Zambia) and the indications are that they are spreading together through Africa. Research will be needed to understand this situation better and assess the implications for management strategies and phytosanitary measures.

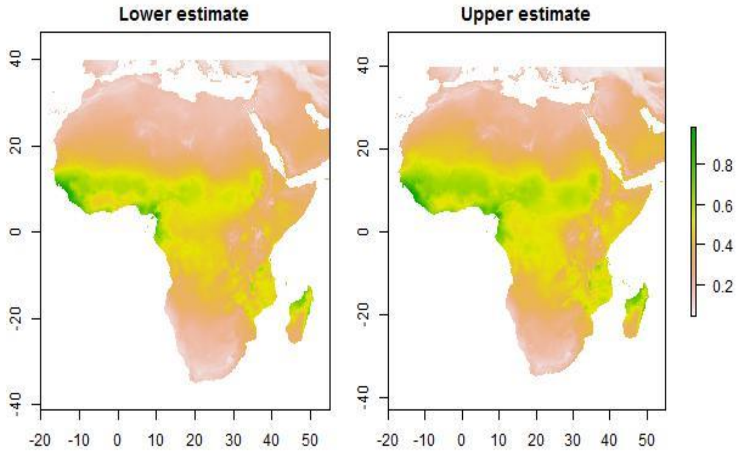
Section 2: Known, reported and forecast distributions of fall armyworm in Africa

Current distribution

Map 1 (next page) shows the current distribution of FAW at a country level. The red confirmed status relates to official reports from the FAO, IPPC or government agricultural departments. Dark orange represents media-reported presence. Light orange denotes countries with initial or unconfirmed reports. A detailed breakdown of references can be found in Annex 1.



Map 1: Current known and suspected distribution of FAW in Africa (April 2017)



Map 2: Forecast FAW distribution based on growing degree day temperature and precipitation

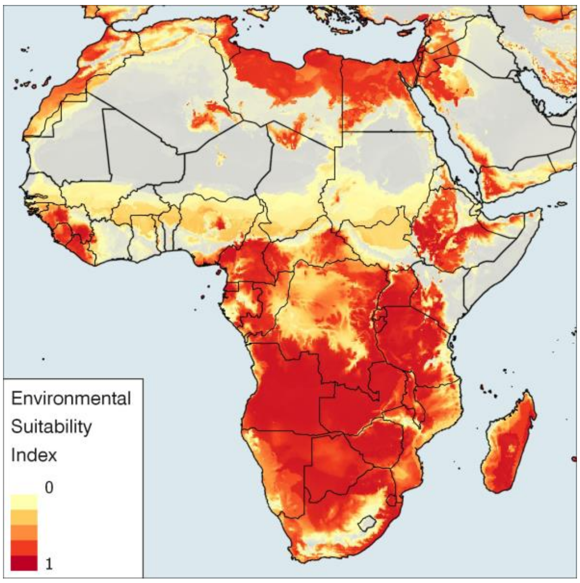
Forecast distribution

Forecasts usually differ according to the modelled variables used for the forecast. For FAW, the lack of knowledge on the pest's biological and ecological adaptations to African circumstances makes forecasting all the harder. Therefore, in this section, two FAW distribution models (by Regan Early from Exeter University) are presented. Map 2 uses variables such as growing degree day temperature and precipitation at both the driest and wettest times of year. Map 3 uses key species-related climatic variables (such as the length of the warm season, the temperature of the cold season, the length of the wet season, and the wetness of the wet season).

Both maps differ in some regions and match in others. However, it is important to note that future forecasting models will improve, as they continually add actual distribution data, clearer understanding of FAW biology, and boost modelling power through linkages with other predictive model templates (e.g. CLIMEX).

In both maps, West Africa, Madagascar and central southern Africa are forecast to be severely affected. However, Map 2 shows countries on the 15th Parallel (Cote D'Ivoire to Sudan) will also be affected, which contradicts Map 3 findings. South Africa is projected to be attacked by FAW in Map 3, which conversely doesn't show up on Map 2.

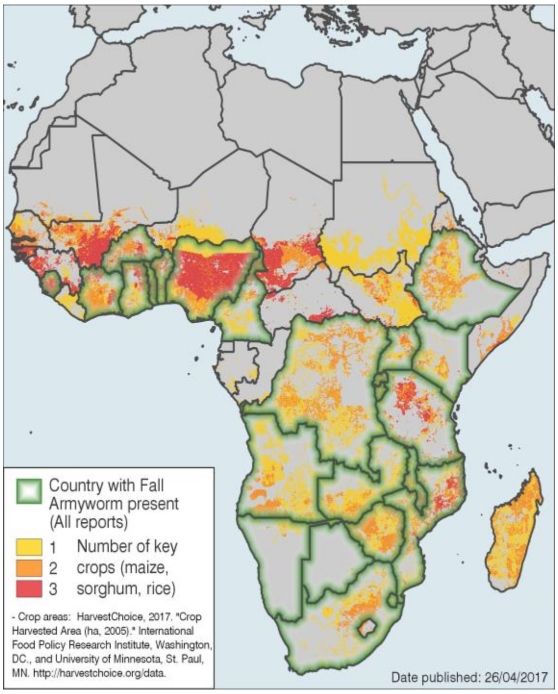
It is important to remember that these models are not only to show where FAW might build stable populations over time, but also its likely spread given favourable climatic conditions, and the severity of those effects when it does enter a new region.



Map 3: Forecast FAW distribution based on temperature, length and precipitation of warm/wet season

Section 3: Estimation of crop sector level economic impacts and prospective yield loss

References and methodology for CABI's impact estimations are available in annex 2



Map 4: Importance of maize, rice and sorghum in FAW affected countries

To date, the main crop affected in all invaded countries is maize. However, the FAW is polyphagous and other important food crops are at risk, particularly rice, sorghum and sugarcane. In this section, estimations of the yield and economic losses to these four crops are presented for countries in Sub-Saharan Africa.

Combining the estimated current and projected economic losses to yield for maize and sorghum only, for the countries where FAW has been confirmed, suggests that the insect is already threatening nearly 9% of the total combined agricultural GDP of these countries. This is based on an assumed average of 52% area of crops infested over the next year and 30% average yield loss to maize; 16% to sorghum. This assumption does not take into account possible additional losses through impacts on associated industries (e.g. seed farms) or other crops.

In all confirmed and suspected FAW presence countries, these form a total value at risk of over $13.3 billion or approximately £10.4 billion.

Maize

The total production values of maize (2014 data) and estimated yield and economic losses for countries falling into the four reports and risk categories are given in Table 1. Across Sub-Saharan Africa, the estimates indicate 13.5m tonnes of maize (valued at US$3,058.8m; ~£2,386m [@ 20/4/2017]) are either attacked or at risk from FAW in the next year; **this forms over 20% of total production for the region**.

Table 1. Estimated likely current and predicted yield loss (combined) and economic impact to maize from FAW over 2017-2018 season, Sub-Saharan Africa

FAW report and risk category	Total production (tonnes, m) assuming no FAW	Yield loss (tonnes, m)	Estimated loss/predicted loss (US$, m)
Confirmed reports (risk=1)	37.6	4.6	710.0
Confirmed reports(risk=0.75)		5.1	1,241.8
News/media reports(risk=0.5)	21.1	3.2	871.7
Unconfirmed/suspected presence (risk=0.25)	7.2	0.5	177.1
No report (risk=0.1)	1.1	0.1	58.2
Total	**67**	**13.5**	**3,058.8**

Sorghum

The total production values of sorghum (2014 data) and estimated yield and economic losses for countries falling into the four report and risk categories are given in Table 2. Across Sub-Saharan Africa, the estimates indicate nearly 2m tonnes of sorghum (valued at US$827.1m; ~£645m [@20/4/2017]) are either attacked or at risk from FAW in the next year; **this forms nearly 8% of total production for the region**.

Table 2. Estimated likely current and predicted yield loss (combined) and economic impact to sorghum over 2017-2018 season, Sub-Saharan Africa

FAW report and risk category	Total production (tonnes, m) assuming no FAW	Yield loss (tonnes, m)	Estimated loss/predicted loss (US$, m)
Confirmed reports (risk=1)	10.8	0.8	348.9
Confirmed reports(risk=0.75)		0.4	183.7
News/media reports(risk=0.5)	4.4	0.5	168.8
Unconfirmed/suspected presence (risk=0.25)	1.4	0.1	58.2
No report (risk=0.1)	8.9	0.1	67.5
Total	**25.5**	**1.9**	**827.1**

Rice and sugarcane

No information is available for the damage and yield loss caused to rice and sugarcane from FAW. However, the production of these crops and the value of this *at risk*, assuming the same risk categories used for maize and sorghum for all countries, is given in Table 3. The potential 'economic risk' to rice and sugarcane are 56% and 51% of total production. In all confirmed and suspected FAW presence countries**, these form a total value at risk of over $9.5 billion or approximately £7.4 billion.**

Table 3. Production and value of rice paddy and sugar cane at risk from FAW (figures for Sub-Saharan Africa as a whole)

FAW report category	Rice, paddy		Sugar cane	
	Production (tonnes, m) assuming no FAW	Value at risk (US$, m)	Production (tonnes, m) assuming no FAW	Value at risk (US$, m)
Confirmed reports(risk=1/0.75)	7.8	4,125	28.6	1,297
News/media reports(risk=0.5)	5.7	1,999	42.1	1,274
Unconfirmed/suspected presence (risk=0.25)	3.1	542	12.3	186
No report (risk=0.1)	0.5	33	7.1	42
Total	**17.1**	**6,699**	**90.1**	**2,799**

Country focus

Examples of the estimated yield and economic losses for maize and sorghum to some specific countries – Ghana and Kenya – are given in Table 4.

Table 4. Estimated likely current and predicted yield loss and economic losses, over one year (from April 2017) for Ghana and Kenya

Country	Crop	Crop area likely infested/not infested (but at acute risk)	Total production, combined assuming no FAW (tonnes, m)	Yield loss (tonnes, m)	Estimated loss/predicted loss (US$, m)
Ghana	Maize	Confirmed reports (risk=1)	1.8	0.3	97.4
		Confirmed reports(risk=0.75)		0.2	48.7
	Sorghum	Confirmed reports (risk=1)	0.3	0.03	11.8
		Confirmed reports(risk=0.75)		0.01	5.9
		Total	**2.1**	**0.54**	**163.8**
Kenya	Maize	Confirmed reports (risk=1)	3.5	0.3	119.3
		Confirmed reports(risk=0.75)		0.6	208.8
	Sorghum	Confirmed reports (risk=1)	0.2	0.01	5.2
		Confirmed reports(risk=0.75)		0.02	9.2
		Total	**3.7**	**0.93**	**342.5**

Other impacts
So far FAW has not caused measurable problems with trade but this is another potential loss, as FAW is a quarantine pest in Europe. However, this analysis, which focuses on aggregated economic cost of crop losses, will have numerous macro-level indirect effects, such as on food security. At household level socio-economic impacts of FAW can be expected, including the gender-related effects that occur with loss of food or income. As of yet, it is extremely difficult to estimate any gender related socio-economic impacts. However, in the case of maize, household tasks in these crops are likely to be affected by the insect's comprehensive impact on all stages of the crop's development. A more detailed analysis of the pest's socio-economic impacts will be required in the future.

Section 4: Review of current and prospective control options and their constraints in Africa and the Americas

Options and constraints
Table 5 briefly summarises control options, their effectiveness and use in the Americas, the status of their use in Africa, evidence gaps in relation to their use in Africa, and possible constraints. Many direct control methods target the larvae, but two aspects of the biology pose constraints:

- Larvae are relatively inactive during the day, so treatment (e.g. spraying) is best done in the early or late part of the day
- Older larvae tend to bore into the whorl or cob (of maize), so contact pesticides are *not effective* unless applied when the larvae are young. Monitoring is required to detect the young larvae, and to determine whether treatment is justified.

In the Americas, pesticides and genetically modified crops are the most widely used options; there are instances of resistance to both.

Monitoring for treatment decision making
Two approaches to monitoring are used, both of which need further investigation in Africa:
Trapping adults: Pheromone traps attract the male moths with a synthetic sex pheromone, and give an indication of the adult population in an area.
Scouting: Plants are inspected in detail, and different aspects of the damage and/or the presence or number of eggs and different sizes of larvae recorded. Different scouting protocols may be used for different crops, and times of the season.

Based on the results of monitoring, a decision whether to treat (usually with a pesticide) can be made, depending on whether a pre-defined threshold has been reached. Thresholds vary with crop, crop stage, monitoring method. Some example thresholds include:

- Pheromone trap catches of 10 to 20 per night (70 to 100 per week)
- Egg masses present on ≥ 5% of the plants or ≥25% of the plants show damage symptoms and live larvae are still present
- ≥5% of seedlings are cut or ≥20% of whorls of small plants (first 30 days) are infested.

Pesticide registrations and recommendations
To be legally used for FAW control, a pesticide must be registered, requiring efficacy and toxicity data. Large numbers of pesticides are registered in the Americas; Brazil has around 40 products registered for FAW. In the USA each state makes its own recommendations, usually by crop, and recommendations show much variation. Annex 3 shows a list of active ingredients registered and/or recommended in selected USA states.

Pesticides kill insects in different ways, and can be grouped according to their mode of action. FAW is susceptible to multiple modes of action. However, in the Americas resistance has developed to some modes; the risk of this can be reduced by rotating pesticides with different modes of action.

In Africa registration processes exist, but can be lengthy. No pesticides are fully registered for FAW yet; in some cases emergency registration is possible. Much un-registered (and therefore technically illegal) pesticide use is occurring.

Immediate control options
Farmers need advice on what actions they can take immediately. The following are suggested, though not all are supported by evidence, and they should be adjusted when more evidence is available on alternatives to pesticides and how agronomic practices can reduce risk/damage.

- Monitor susceptible crops at least weekly, with the aim of detecting egg masses and/or young larvae. Large scale farms could consider using pheromone traps for monitoring but visual inspection is also advised
- On detecting FAW or early damage (windowing of leaves) consider treatment:
    - Small farms, depending on resource availability: Handpicking; placing sand/soil mixed with ash/lime into the whorl; pesticide application. Give priority to damaged plants but treat whole field if possible
    - Large farms: Pesticide application to affected fields
    - Pesticides: Use WHO Class 3 or U if possible (though lower risk products tend to be more expensive), from a nationally recommended list. Use personal protective equipment and follow manufacturer's instructions
- After treatment, continue monitoring, and consider further treatment if more young larvae appear. Continue until plants become too large to monitor/treat.

Immediate government actions
It is suggested that national authorities undertake the following steps as far as possible:

- Promote awareness of FAW, its identification, damage and control
- In consultation with agro input suppliers, prepare and communicate a list of recommended pesticides. The pesticides should be available, and preferably already registered for the crop in which they are to be used, and/or for use on other larvae. Pesticides registered/recommended for FAW control in the Americas could be selected, but extremely or highly hazardous WHO class 1a or 1b pesticides should never be recommended (recommendations in USA are for very specific uses)
- Provide emergency/temporary registration for the recommended pesticides. Registrants should provide supporting data from the Americas within a specified period
- Arrange for laboratory efficacy tests of recommended pesticides to be conducted by authorised national laboratories
- Regularly review recommendations and publicise changes promptly and widely
- Consider short term subsidies for small scale farmers, for example to reduce prices for lower risk products.

With regard to the evidence gaps, at this stage of our review the priorities would be to:

a) Commence **Classical biological control.** The known specialist parasitoid reported to have impact (*Telenomus remus*) would be a first candidate for introduction, through organisations such as IITA and ICIPE. Risk analysis is required, and rapid regulatory approval sought whilst exercising responsible scientific due diligence.

b) Establish and implement **pesticide testing protocols**, so that evidence-based recommendations can be made. In the short term, representative countries in west, east and southern Africa could be agreed, focussing first on laboratory trials, extending to field trials as soon as feasible. Testing should include lower risk pesticides such as *Bacillus thuringiensis* (which is already available in some countries), and virus-based product(s) already registered in the Americas. These protocols should provide the basis for pesticide resistance monitoring, as part of a resistance management strategy.

c) Test the effectiveness of applying sand (mixed with lime or ash), sawdust or soil in the whorl for providing protection or control. Although anecdotally effective, no scientific evidence has been found thus far.

d) Establish **studies on FAW biology, ecology and population dynamics** that provide the basis for improved recommendations to minimise pesticide use. This should include, *inter alia*, establishing the role indigenous natural enemies play, and the patterns of FAW attack and dispersal in relation to seasons and various agronomic practices. Monitoring and surveillance methods and systems are required at different levels.

Table 5: Control options for *Spodoptera frugiperda* (reported from the Americas)

Option	Effectiveness	Status in Africa	Evidence gaps	Possible constraints
Synthetic Pesticides Numerous pesticides can kill FAW including WHO Class lll (slightly hazardous) and U (unlikely to present acute hazard).	Effective when used correctly. Rotation of mode-of-action classes is recommended to reduce risk of resistance developing. Feeding stimulants/attractants mixed with pesticide reported to increase effectiveness at lower concentrations	Widespread use of pesticides; choice of pesticide often determined by what is available. Many reports of pesticides “not working”, though reasons often unclear.	Little formal pesticide testing has so far been conducted in Africa. Not known if any resistance in current populations.	In the Americas resistance to pesticides has been reported for several mode-of-action categories including 1A (Carbamates) 1B (Organophosphates), 3A (Pyrethroids-Pyrethrins). Spray application requires equipment (smallholders often lack this), and water (200-400 L ha^{-1}) for the common aqueous formulations Resource poor farmers often lack protective equipment Potential environmental damage
Bacillus thuringiensis (Bt) Spray based on a naturally occurring bacterium and/or its product. Main subspecies used are *kurstaki* and *aizawai.*	Effective when used correctly. Genetic modification of Bt has been used to try to enhance effectiveness	Bt is being promoted in some countries	Not known if any formal Bt testing has been conducted in Africa. Not known if any resistance to Bt products	In the Americas resistance has been reported to mode-of-action category 11A (Bt and the insecticidal proteins they produce)
Virus-based biopesticide A commercial product is available in Brazil. A similar product has just been registered in US.	Effective when used correctly, but slow acting. Host specific; very low non-target risks.	Lab tests on FAW population from Africa being conducted in UK. IITA has imported strains from USDA.	Not known if virus is already present in Africa.	Only kills FAW, so if other pests present, might not be attractive. Registration of an exotic insect pathogen might be difficult in some countries
Botanicals Neem (*Azadirachta indica)* seed cake and leaf extracts; other plants with insecticidal and/or anti-feedant effect on FAW include *Senecio salignus, Salvia microphylla, Crescentia alata, Tagetes erecta, Chrysanthemum leucanthemum*	Not clear if used commercially. Seed cake extract more effective than leaf extract.	Farmers are trying locally available botanical preparations.	Many plants in Africa have some insecticidal properties (such as *Tephrosia)* but their effect on FAW is unknown	Can be time consuming to prepare, and for long term use requires sustained production of the plant. Preparations vary in concentration of the active ingredient(s)
Host plant resistance Various mechanisms are observed to reduce feeding/fitness of FAW larvae.	Not widely used; genetically modified rather than bred varieties are promoted by seed companies	CIMMYT has lines that may provide some resistance, but breeding needed Anecdotal evidence of indigenous varieties being less attacked	Susceptibility of preferred varieties in Africa not known.	Resistance is being sought for other pests (such as. Maize Lethal Necrosis), so securing all desired traits in one variety might be difficult.
GM crops Several varieties of several crops (maize, cotton, soya bean) with Bt genes have been developed	Effective. Use of susceptible “refuge” crops can reduce the risk of resistance developing and is required in some states.	GM crops only used in a few countries but include Bt maize and cotton.	Susceptibility of GM maize and cotton in Africa not known.	Resistance has been reported to the Cry1F protein (group) in Bt Maize, with some cross resistance to CryAb. Also resistance to Bt Cotton. Pyramiding genes is still effective, but resistance is likely to develop.

Option	Effectiveness	Status in Africa	Evidence gaps	Possible constraints
Rearing and release of parasitoids Rearing and repeated release of large numbers (tens/hundreds of thousands) of parasitic wasps. Species used: *Trichogramma pretiosum, T. atopovirilia, Telenomus remus (*egg parasitoids*)*.	In S America egg parasitoids are produced commercially, including for FAW control.	No trials have been conducted	Little knowledge of what parasitoids are attacking FAW in Africa	In Africa this approach is mainly used in high value crops (e.g. export horticulture). Cost might be prohibitive for lower value crops depending on economics of rearing and distributing the wasps.
Rearing and release of predators *Doru luteipes* (earwig) *Orius insidiosus* (pirate bug)	Brazil's national research agency recommends *Doru*. *Orius* is commercially produced; not clear if used for FAW.	No trials have been conducted	Little knowledge of what predators are attacking FAW in Africa	In Africa this approach is mainly used in high value crops (e.g. export horticulture). Cost might be prohibitive for lower value crops depending on economics of rearing and distributing the predators.
Classical biological control The egg parasitoid, *Telenomus remus*, was introduced to Caribbean countries where it had not already been found.	The introductions were credited with reducing the numbers of FAW and other *Spodoptera* spp	Not attempted. IITA has plans to introduce *Telenomus* and other species.	Not known if other *Telenomus* species in Africa attack FAW. Other candidates for potential introduction to Africa (many natural enemies have been recorded in the Americas)	Usual constraints with classical biological control (import permits, establishment, and possible climate differences).
Cultural methods Plant early Use early maturing varieties Intercrop maize with beans Remove weeds Remove and destroy all crop residues Rotate maize with a non-host Ploughing/cultivating to expose larvae and pupae Handpicking egg masses and larvae. Applying sand (mixed with lime or ash), sawdust or soil in the whorl	Unlikely to provide adequate control alone, but contribute to reducing populations and damage. Planting early may be most effective where infestation occurs through the arrival of migrant moths.	Being recommended in several countries. Observations (Bunderson, pers comm): less FAW damage on farms that plant early, grow a variety of crops/trees, intercrop maize with *Desmodium uncinatum*, grow *Brachiaria* on cropland edges	No trials/research has been conducted in Africa	Some methods may be incompatible with other farm practices (e.g. low tillage).
Pheromones Synthetic mimics of the female moth's sex pheromone used to mass-trap males or disrupt their mate-finding	Reduced losses reported in trials, but little evidence of successful commercial use.	Pheromone blend has been optimised in Zambia (Russell IPM, UK). Other products being imported from America.	Control potential unknown.	Control with pheromones works best at large scale, so would probably only be effective on large farms.

Section 5: Summary of knowledge resources and institutional linkages

Table 6: Key sources of information listed and categorised to provide a summary of readily available knowledge on FAW *(all sources are open access unless stated; for complete list, see Annex 4)*

Source	Provider	Notes
Invasive Species Compendium	CABI	Expert-written and peer-reviewed datasheet. The ISC also includes 156 bibliographic records relating to FAW
Plantwise Knowledge Bank	CABI	Technology factsheets and identification photosheets
FAW as a pest of field corn	Penn State College of Agri Sciences	PennState College of Agricultural Sciences Extension Factsheet
Armyworm identification keys	Center for Systematic Entomology, Gainesville, Florida at	A key to *Spodoptera frugiperda, S. exigua, S. latifascia, S. ornithogalli, S. dolichos, S. sunia and S. eridania* with colour illustrations of rare and typical forms is presented. Potential problems in identifying Spodoptera species are discussed. DigitalCommons@Universityof Nebraska - Lincoln
Armyworm network	Lancaster University	Resource provides up to date information on both the endemic African armyworm (*Spodoptera exempta*) and the new invasive FAW (*Spodoptera frugiperda*) - both of which are important pests of staple crops and pasture grasses in sub-Saharan Africa. Resources available on this website include the latest armyworm forecasts, press reports of armyworm outbreaks, photos, videos, publications, and lots of useful information on the biology, ecology and control of these important African crop pests
FAW curated twitter list	CABI	Current awareness of news, shared content and activities concerning FAW as shared on Twitter
Koppert Side effects database	Koppert B.V.	Presents data on indirect effects of pesticides (based on a once-only application of the pesticide at the authorised dose) such as killing natural enemies or pollinators. Can be used as a guideline for the use of chemical pesticides in combination with biological crop protection and/or natural pollination.
Spodoptera frugiperda v2; In: ensembl.lepbase	Lepbase	Lepbase: the Lepidopteran genome database
HarvestChoice	HarvestChoice	Host distribution data for use in modelling spread of FAW HarvestChoice is cultivating a novel hub of geographically tagged datasets organized into a matrix of 10km x 10km grid cells spanning sub-Saharan African. This data-rich platform allows more fine-grained visualization of the enormous mix of farming, cultural, and socio -economic conditions that exist across Africa. Specific User License needed and aimed at promoting non-commercial use of the data

Annex 1 Table of confirmation of presence of FAW

Confirmed reports

Country	Date Published	Source	Link	Notes
Benin	27/10/2016	Peer-reviewed journal	Goergen G, Kumar PL, Sankung SB, Togola A, Tamò M (2016) First Report of Outbreaks of the Fall Armyworm Spodoptera frugiperda (J E Smith) (Lepidoptera, Noctuidae), a New Alien Invasive Pest in West and Central Africa. PLoS ONE 11(10): e0165632. Doi:10.137	First report (18/06/2016 – IITA) First report of outbreaks of the “Fall Armyworm” on the African continent
Nigeria	27/10/2016	Peer-reviewed journal	Goergen G, Kumar PL, Sankung SB, Togola A, Tamò M (2016) First Report of Outbreaks of the Fall Armyworm Spodoptera frugiperda (J E Smith) (Lepidoptera, Noctuidae), a New Alien Invasive Pest in West and Central Africa. PloS ONE 11(10): e0165632. Doi:10.137	First report (18/06/2016 – IITA) First report of outbreaks of the “Fall Armyworm” on the African continent
Togo	27/10/2016	Peer-reviewed journal	Goergen G, Kumar PL, Sankung SB, Togola A, Tamò M (2016) First Report of Outbreaks of the Fall Armyworm Spodoptera frugiperda (J E Smith) (Lepidoptera, Noctuidae), a New Alien Invasive Pest in West and Central Africa. PloS ONE 11(10): e0165632. Doi:10.137	First report (18/06/2016 – IITA) First report of outbreaks of the “Fall Armyworm” on the African continent
Sao Tome and Principe	27/10/2016	Peer-reviewed journal	Goergen G, Kumar PL, Sankung SB, Togola A, Tamò M (2016) First Report of Outbreaks of the Fall Armyworm Spodoptera frugiperda (J E Smith) (Lepidoptera, Noctuidae), a New Alien Invasive Pest in West and Central Africa. PloS ONE 11(10): e0165632. Doi:10.137	First report (08/09/2016 – IPPC) Les dégâts causés par Spodoptera frugiperda
Ghana	03/02/2017	IPPC	Report on Fall armyworm (Spodoptera frugiperda)	CABI barcoded specimens
Zimbabwe	03/02/2017	FAO	Fall army worm outbreak, a blow to prospects of recovery for southern Africa	
South Africa	10/02/2017	IPPC	First detection of Fall Army Worm (Spodoptera frugiperda)	
Zambia	16/02/2017	IPPC	Preliminary Report on Fall Armyworm in Zambia	CABI barcoded specimens
DR Congo	20/02/2017	FAO	La RDC nouvelle victime de la chenille légionnaire	IPAPEL-FAO, 2017. Rapport de mission

				d'évaluation de l'incidence de l'attaque de la chenille Spodoptera sp et prélèvement des échantillons de la chenille dans les territoires de Kambove et de Pweto à kilwa dans la Province du Haut Katanga du 07 au 10 février 2017. FAO and L'Inspection Provinciale de l'agriculture, pêche et élevage (IPAPEL). DR Congo, Université de Lubumbashi.
Swaziland	28/02/2017	IPPC	Detection of Fall Army Worm Spodoptera frugiperda in Swaziland	
Kenya	06/03/2017	Kenya Ministry of Agriculture (KALRO)	Status of Fall Army Worm in Western Kenya March 2017	

News/media reports

Country	Date Published	Source	Link	Notes
Burundi	24/12/2016	Georg Goergen	E-mail to Pestnet	Reports that first samples were collected from northern Burundi
Uganda	24/12/2016	Georg Goergen	E-mail to Pestnet	Reports of recent FAW complaints, farmers are awaiting confirmation of its presence in Uganda.
Uganda	28/02/2017	New Vision (newspaper)	Deadly maize worm attacks 20 districts'	Western districts
Uganda	26/03/2017	News Ghana	Scientists warn armyworm invasion to endanger East Africa's food security	Prasanna Boddupalli, director of CIMMYT 'disclosed that the armyworm infestation was discovered … Namulonge, Kasese and Gulu regions of Uganda.'
Namibia	06/02/2017	BBC	Fall armyworm 'threatens African farmers' livelihoods'	
Malawi	06/02/2017	BBC	Fall armyworm 'threatens African farmers' livelihoods'	
Mozambique	06/02/2017	BBC	Fall armyworm 'threatens African farmers' livelihoods'	
Ethiopia	27/03/2017	Ministry of Agriculture and Natural Resources	FallArmyworm Invades Southern Ethiopia	
Tanzania	17/02/2017	E-mail from Roger Day, CABI Africa		Reports of positive identification in Tanzania

Botswana	27/02/2017	Ken Wilson, Lancaster University	Fall armyworm threatens livelihoods in Africa	IRLCO-CSA, USAID and media reports. Countries affected include Nigeria, Benin, Togo, São Tomé and Princípe, Zambia, Malawi, Zimbabwe, Mozambique, Botswana and South Africa.'

Unconfirmed reports/suspected presence

Country	Date Published	Source	Notes
Cameroon	21/02/2017	E-mail from Appolinaire Tagne	Reports from entomologists of serious larvae damages in maize fields during our 2016 surveys.
Burkina Faso	12/03/2017	CABI E-CH	'La chenille legionnaire invasive Spodoptera frugiperda est observée dans notre pays depuis 2015. Plusieurs regions du Burkina Faso sont affectées par le ravageur qui est essentiellement sur le maïs.' Quote from plant protection official
Rwanda	13/03/2017	Pers. Comm. Via Ken Wilson, Lancaster University	Unconfirmed reports of FAW in Rwanda (visual ID by entomologist)
Canary Isl		email correspondence	Unconfirmed reports
Sierra Leone	23/04/2017	email correspondence	Unconfirmed reports
Angola		Matthew Cock e-mail to DFID	Suspected presence based on distribution in Zambia.
Cote d'Ivoire		Matthew Cock e-mail to DFID	Suspected presence based on distribution in Ghana.

Annex 2 Impact estimate references and methodology

References

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Methodology

CABI made estimates for likely current and potential yield losses over the 2017-18 crop growing seasons based on what was known about the FAW distribution in April 2017. To estimate these losses, risk values were assigned to the three categories of country report (see Annex 1) plus a category of countries neighbouring these with no report as follows:

- Confirmed reports (10 countries). This category was divided into two: Risk = Acute (1)- the area of crop estimated as infested; and, Risk = Very high (0.75) - the remaining area of crop at immediate risk
- News/media reports (8 countries). Risk = High (0.5)
- Unconfirmed/suspected presence (6 countries). Risk = Medium (0.25)
- Neighbouring countries with no report (10 countries). Risk = Low (0.1)

The area of crop currently infested in countries where FAW is present (risk=1) was estimated based on the reports (Annex 1) and literature; these are very approximate as the reports from Africa contain little detail. On average, across 10 countries in this category, the area assumed infested within the next year was 52%; that not infested as 48%.

An approximate one year period was chosen for the estimations as the risk levels also factored in the high dispersal capacity of FAW; for example, from studies in N. America Johnson (1987) reports that FAW can travel nearly 3000km in 24 hours. Many factors will influence the actual dispersal rate in any one place (e.g. prevailing wind) but the insect is migratory in habit.

Total areas, total production and values/tonne (US$) of the four crops for each country in Sub-Saharan Africa were taken from FAO (2017); figures for the 2014 period were used as this is the latest data available. Data on agricultural GDP was taken from World Bank (2015).

Figures on yield loss caused by FAW were taken from the literature although data only exists from a few studies in the Americas and this is only for maize and sorghum. Maize is more susceptible to FAW attack at the mid-late whorl stage compared with earlier stages of growth. An average figure of 30% over one season was used. Data was taken from: Huis (1981), Cruz and Turpin (1983), Hruska and Gould (1997), and Lima et al. (2010). As with maize, the severity of damage caused by FAW to sorghum depends on the stage of growth of the crop attacked and the level of larval population. An average figure of 16% yield loss over one season was used. Data was taken from Henderson et al. (1966) and Starks and Burton (1979).

The yield loss figures for these crops are extrapolated to the situation in Africa and estimation made by summing across countries in each of the risk categories; the analysis for rice and sugarcane is made at the regional level only. The method will require robust testing in any advanced and potentially-commissioned full evidence report.

Annex 3 Pesticides for FAW control

The table below shows pesticides registered for FAW control in Brazil, and/or recommended for FAW control in selected US States. Additional data are to be added, including recommendations from Africa. Extremely / highly hazardous WHO Class 1 pesticides have been excluded from the table.

Active Ingredient	**[1]Mode of Action Category**	**[2]WHO Class**	**Active Ingredient**	**[1]Mode of Action Category**	**[2]WHO Class**	**Active Ingredient**	**[1]Mode of Action Category**	**[2]WHO Class**
Abamectin	6	n	Chromafenozide	18	n	Lambda-cyhalothrin	3A	2
Acephate	1B	2	Cyantraniliprole	28	n	Lufenuron	15	n
Acetamiprid	4A	n	Cypermethrin	3A	2	Malathion	1B	3
Alpha-cypermethrin	3A	2	Deltamethrin	3A	2	Methoxyfenozide	18	U
Azadiractin	UN	n	Diflubenzuron	15	3	Novaluron	15	U
Bacillus thuringiensis	11A	3	Emamectin benzoate	6	n	Permethrin	3A	2
Beta-cypermethrin	3A	n	Esfenvalerate	3A	2	Profenofos	1B	2
Bifenthrin	3A	2	Etofenprox	3A	U	Spinetoram	5	U
Carbaryl	1A	2	Fenitrothion	1B	2	Spinosad	5	3
Carbosulfan	1A	2	Fenpropathrin	3A	2	Sulfur	UN	3
Chlorantraniliprole	28	U	Flubendiamide	28	n	Tebufenozide	18	U
Chlorfenapyr	13	2	Gamma- cyhalothrin	3A	n	Teflubenzuron	15	U
Chlorfluazuron	15	U	Imidacloprid	4A	2	Thiodicarb	1A	2
Chlorpyrifos	1B	2	Indoxacarb	22A	2	Triflumuron	15	U

[1] Mode of Action Category. From Insecticide Resistance Action Committee www.irac-online.org/modes-of-action/
[2] WHO Class. From www.who.int/ipcs/publications/pesticides_hazard/en/ (1a-Extremely hazardous; 1b-Highly hazardous; 2-Moderately hazardous; 3-Slightly Hazardous; U-Unlikely to present acute hazard; n-not listed, as list published in 2009)

Annex 4 Information resources on FAW

Information	Source	Provider	Notes
General pest biology / ecology / utilising current pest management knowledge	Invasive Species Compendium	CABI	Expert-written and peer-reviewed datasheet. The ISC also includes 156 bibliographic records relating to FAW
	Plantwise Knowledge Bank	CABI	Technology factsheets and identification photosheets
	CIMMYT, MaizeDoctor	CIMMYT	Factsheet introducing simple, stepwise method for identifying maize production problems and providing possible solutions
	EPPO Global Database	EPPO	Factsheet maintained by the Secretariat of the European and Mediterranean Plant Protection Organization (EPPO)
	Fall Armyworm as a pest of field corn	Penn State College of Agri Sciences	PennState College of Agricultural Sciences Extension Factsheet
Current awareness and up-to-date information on spread of pest	CABI Invasives Spodoptera frugiperda curated twitter list	CABI	Current awareness of news, shared content and activities concerning fall armyworm as shared on Twitter
	PestLens	USDA-APHIS	PestLens collects and distributes new information on exotic plant pests and provides a web-based platform for documenting safeguarding decisions and resulting actions. It is used as an early-warning system supported by USDA's Animal and Plant Health Inspection Service (APHIS) to protect U.S. agriculture and natural resources against exotic plant pests.
	PestNet Listserve	PestNet	PestNet is an email network that helps people worldwide that obtains rapid advice and information on crop protection, including the identification and management of plant pests.
	Emergency Transboundary Outbreak Pest (ETOP) Situation Updates, monthly	USAID	Monthly updates on Emergency Transboundary Outbreak Pests (ETOP), including latest distribution records and news on surveillance and mitigation activities.
	FAO News	FAO	News Service of FAO
	FEWSnet	USAID	Famine Early Warning Systems Network is a leading provider of early warning and analysis on food insecurity. Created by USAID in 1985 to help decision-makers plan for humanitarian crises, FEWS NET provides evidence-based analysis on some 34 countries. Implementing team members include NASA, NOAA, USDA, and USGS, along with Chemonics International Inc. and Kimetrica
	IITA News	IITA	News Service of the CGIAR centre, International Institute of Tropical Agriculture (IITA).
	CIMMYT	CIMMYT	News service of the CGIAR centre, International Maize and Wheat Improvement Center (Centro Internacional de Mejoramiento de Maíz y Trigo, CIMMYT)
	IAPPS News	IAPPS	News Service of the International Association of Plant Protection Sciences (IAAPS News)
	National news websites	News Ghana; Ethiopian News Agency; The Southern Times; BBCnews	National and regional news websites are vital to keep updated on spread of disease. These may not always be accurate, but they are important to consider

Official reporting services	IPPC	IPPC	IPPC Official Pest Reports
	EPPO Reporting Service	EPPO	The EPPO Reporting Service is a monthly information report on events of phytosanitary concern. It focuses on new geographical records, new host plants, new pests (including invasive alien plants), pests to be added to the EPPO Alert List, detection and identification methods etc.
	EPPO Pest Alerts via Scoop.it	EPPO	A news aggregator site for EPPO pest alerts curated by Anne-Sophie Roy of EPPO.
Research and identification	CAB Direct	CABI	Search engine containing 4,795 records on FAW dated between 1915 and 2017
	PubMed	US National Library of Medicine National Institutes of Health	Search engine containing 2,372 records on FAW dated between 1968 and 2017
	Bugwood	Center for Invasive Species and Ecosystem Health, University of Georgia	Bugwood Image Database System (images.bugwood.org), Center for Invasive Species and Ecosystem Health, University of Georgia, with 463 images
	Diagnostic protocol for Spodoptera sp.	EPPO, John Wiley & Sons, Inc	This protocol provides guidance for the identification of Spodoptera species
	Armyworm identification keys	Center for Systematic Entomology, Gainesville,	A key to *Spodoptera frugiperda, S. exigua, S. latifascia, S. ornithogalli, S. dolichos, S. sunia and S. eridania* with color illustrations of rare and typical forms is presented. Potential problems in identifying Spodoptera species are discussed.
Management and control	Homologa	Homologa	Homologa™ is a database containing registration information of agrochemical products for more than 60 countries, including information about active ingredients, companies, approved crops, maximum dose rates, Pre-Harvest Interval (PHI), risk and safety phrases and approval status of agrochemicals in the EU.
	Koppert Side effects database	Koppert B.V.	Presents data on indirect effects of pesticides (based on a once-only application of the pesticide at the authorised dose) such as killing natural enemies or pollinators. Can be used as a guideline for the use of chemical pesticides in combination with biological crop protection and/or natural pollination.
	Spodoptera frugiperda v2; In: ensembl.lepbase	Lepbase	Lepbase: the Lepidopteran genome database
	SPODOBASE	INRA	An integrated database for the genomics of the Lepidoptera Spodoptera frugiperda
	HarvestChoice	HarvestChoice	Host distribution data for use in modelling spread of FAW HarvestChoice is cultivating a novel hub of geographically tagged datasets organized into a matrix of 10km x 10km grid cells spanning sub-Saharan African. This data-rich platform allows more fine-grained visualization of the enormous mix of farming, cultural, and socio -economic conditions that exist across Africa. Specific User License needed and aimed at promoting non-commercial use of the data