

Review on management methods of fall armyworm (*Spodoptera frugiperda* JE Smith) in Sub-Saharan Africa

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Abstract

The Fall armyworm (FAW), *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), FAW is one of the most devastating pests in terms of crop loss and economic impact, let alone developing countries, even in high income countries. It spread quickly across the African continent, causing extensive damage to crops and having covered about 38 countries in the continent, since it was first reported in 2016. Smallholder farmers in the Sub-Saharan Africa demand environmentally friendly and cost-effective management method for FAW. Therefore, sustainable management of FAW requires efficient and cost-effective management strategies that suits for smallholder farmers. Several findings show that there are multiple cost-effective control options involving cultural, biological, botanical, push-pull and other methods as well as integrated FAW management approaches relevant to smallholder farmers in the region. This paper reviews FAW management options (prevention, monitoring, cultural, push-pull, botanical, biological and chemical methods as well as integrated FAW management) that are relevant to smallholder farmers who lack the financial resource to purchase chemical pesticides and other expensive control mechanisms.

Keywords: fall armyworm (FAW), smallholder farmers, integrated FAW management, push-pull technology

1. Introduction

Background

The Fall armyworm (FAW), *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), believed to be originated in the tropics and subtropics of the America, is a devastative insect pest that causes damage to almost 100 plant species including maize, rice, sorghum, wheat and sugarcane but also vegetable crops and cotton^[1, 2].

FAW is one of the most devastating pest in terms of crop loss and economic impact, let alone developing countries, even in high income countries such as United States, yearly losses to *S. frugiperda* ranges between USD 39 million and 297 million^[3, 4]. It has been calculated that FAW could cause up to \$US13 billion per annum in crop losses across sub-Saharan Africa (SSA)^[3]. Moreover, due to the high consumption of these cereal crops, particularly maize, in smallholder farmers, FAW could have a substantial negative impact on food security.

More recently, several African countries have faced outbreaks of the FAW causing devastating effect on production of maize and other cereal crops. The FAW was first detected on the African continent in 2016^[5, 6, 7], in Western and Central African countries. It spread quickly across the continent, causing extensive damage to crops^[3] and having covered about 38 countries in the continent, since it was first reported in 2016^[5, 7, 8, 9]. The rapid spread of FAW might be because of its sporadic and long-distance migratory behavior, with the adult moths capable of flying over 100 km in a single night.

Given its voracious feeding behavior, vast geographical coverage in short period of time and diverse host ranges, FAW could be a devastative pest threatening the smallholder farmers in Sub-Saharan Africa and could potentially undermine progress on sustainable development goals (SDGs) for millions of poor farmers in the region.

Although efforts have been made by farmers to apply available insecticides, it was not effective and economical^[4, 10]. Smallholder farmers in the Sub-Saharan Africa demands environmentally friendly and cost-effective strategy for the management of this pest so that their productivity can be increased and contribute for the success of SDGs. Therefore, sustainable management of FAW requires efficient and cost-effective management strategies that suits for smallholder farmers. Based on reports from several research findings, there are multiple potential cost-effective control options relevant to smallholder farmers in the region. This paper reviews potentially cost effective FAW management options that are relevant to smallholder farmers who lack the financial resource to purchase chemical pesticides and other expensive control mechanisms.

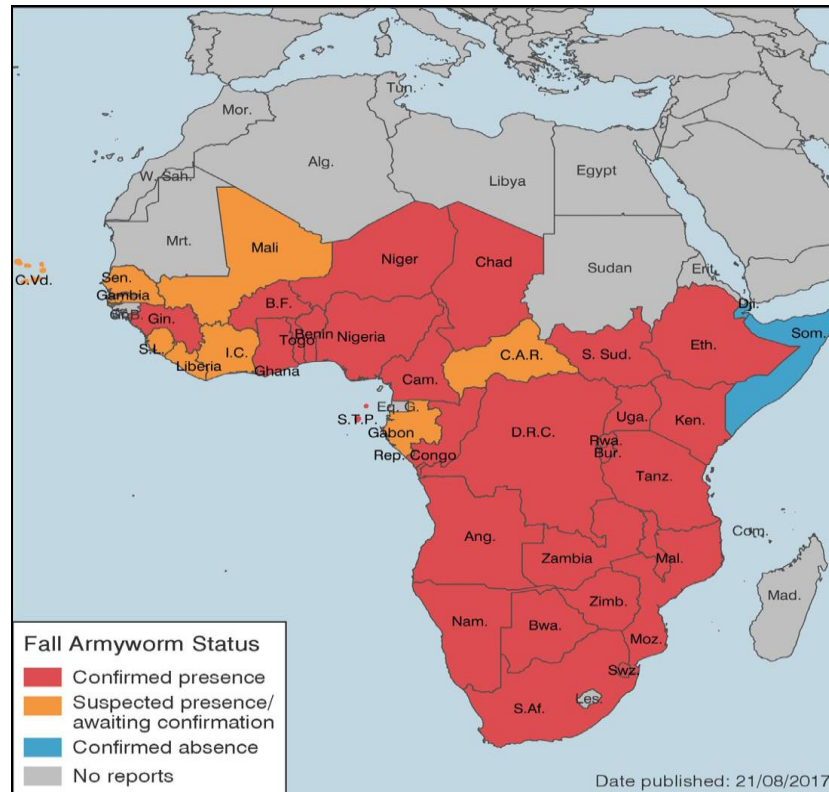
2. Status of FAW in Sub-Saharan Africa

The FAW was first detected on the African continent in 2016^[5, 6, 7, 8], with outbreak of the pest has been reported West and Central Africa involving Botswana, Democratic Republic of Congo, and Ghana. It spread quickly from West and Central Africa across the continent, causing extensive damage to crops^[3, 8] such as Kenya, Malawi, Namibia, South Africa, Swaziland, and Zambia since in the same year when the FAW was detected in the continent^[2, 3]. Further spread of Fall Armyworm was observed in Ethiopia, Tanzania, and Zimbabwe in February 2017^[2].

The spread of the pest within a country and among the African Countries was rapid. For instance, within Ethiopia, the FAW infestations was reported in the Southern Nations, Nationalities and Peoples` State on March 2017 and spread fast to all states to become an epidemic pest in June 2017^[11]. That is, the pest spread to all states of the country within three to four months. Among the African countries, as of December 2017, out of 54 African countries surveyed, FAW

is found to be spreading very fast, having covered about 38 countries in Africa, since it was first reported in 2016 [5, 7, 9]. These shows the spread of FAW within a country and among countries in the continent has been dramatically fast. Not alone in Africa, it has also subsequently spread across

Asia in 2018 such as India and Yemen (by July 2018), Bangladesh, Sri Lanka and Thailand (by December 2018), Myanmar, China, Indonesia, Laos, Malaysia and Vietnam, and the Republic of Korea (by June 2019) and to Japan (by July 2019) [12].



Map 1: Distribution of FAW till August 2017 [8]

In terms of economic loss, preliminary assessments estimate about US\$2.5 to 6.2 billion losses to maize in 12 major maize growing countries in Africa due to FAW [4, 13]. Maize infestation has been reported higher in plots of maize crop without any management, percent of plant damage ranging from 80 to 95%, 80 to 94% and 67% in Kenya, Uganda and Tanzania respectively [14].

What makes this pest devastating is that future forecasts show for high possibility of FAW spread to all other African countries and might sustain and become regular pest in the continent [7, 8]. Thus, FAW might substantially affect the many millions of smallholder farmers in the continent unless cost effective integrated pest management approaches are in place to keep the pest below economic threshold.

3. FAW management methods

Continental research centers and developmental organizations have indicated that FAW have become the most destructive pest in reducing maize production in Africa [3, 15]. Considering its impact on crop production of the continent, efficient and affordable management methods of FAW for smallholder farmers is vital.

In many countries, management of FAW is mainly monitoring-based Integrated Pest Management. Monitoring methods for FAW in various countries such as USA, mainly involve use of specific pheromone traps (involving [(Z)-7-dodecenyl acetate (Z7-12: Ac), (Z)-9-dodecenyl acetate (Z9-12: Ac), (Z)-9-tetradecenyl acetate (Z9-14: Ac), and (Z)-11-hexadecenyl acetate (Z11-) and push-pull method [1, 11, 16].

Pheromone-based monitoring has been proven effective in controlling adult stage of many lepidopteran species [1, 11, 16] including FAW [11, 17, 18]. Based on monitoring results, different management approaches are applied depending on the status of the pest.

In America and Brazil, different strategies have been used to manage FAW including cultural practices, biological control using [parasitoids (*Cotesia marginiventris* (Cresson), *Chelonus texanus* (Cresson) and *Archytas marmoratus* (Townsend))], predators (birds, rodents, beetles, earwigs and pathogens [nuclear polyhedrosis virus (NPV), *Bacillus thuringiensis* (BT), *Entomophaga aulicae*, *Nomuraea rileyi*, and *Erynia radicans* and botanicals [2, 15, 19]. The management methods that can be useful in combatting FAW in Africa are presented below.

3.1 Preventative methods

Sustainable management of FAW starts with prevention. Different preventative methods of FAW can be employed by smallholder farmers. The methods can be used before or when planting the crop. Before planting farmers are recommended to use high quality seeds with high germination viability, and should be free of insect pest and disease. Best pest management starts with planting healthy plant [5]. As late planted crops are expected to attract female moths of FAW, it is necessary to avoid late planting in preventing FAW moths from laying eggs on plant. Increasing plant diversity or polyculture is another mechanism to prevent FAW. In polyculture, planting the target crop with other crops that repel FAW moths is

recommended. In addition, polyculture can increase the population of natural enemies like predators (ants, lacewings, predatory beetles) and parasitoids (egg parasitoids and larvae parasitoids) that can attack FAW eggs and larvae.

3.2 Monitoring of FAW

FAW is better managed if appropriate monitoring methods, indicators of the presence and absence of a given pest, are in place. Good FAW management approach is mainly monitoring-based Integrated Pest Management. The FAW can be monitored using different techniques such as regular field inspection, pheromone traps and light traps [5, 20].

3.2.1 Regular scouting

Detecting fall armyworm infestation before it causes economic damage is the key to their management [15]. During the first 40 days after planting, it is necessary to regularly scout crop fields every 3-4 days. If FAW is detected from scouting, it is necessary to apply control measures. For instance, on maize, if 5% of seedlings are cut or 20% of whorls of small plants (during the first 30 days) are infested with FAW, it is recommended to apply an effective control measure to prevent further damage [15, 21].

3.2.2 Light traps

The moths of FAW are attracted to light sources [20]. Therefore, use of night-time light traps can be one of the monitoring mechanisms for FAW. If moths are caught in light traps, it is an indication of presence of the pest and possibly can damage the crops. Thus, management methods that are mentioned from 3.4 to 3.8 can be applied separately or in integrated approach.

3.2.3 Pheromone traps

Pheromone-based monitoring has been proven effective in controlling adult stage of many lepidopteran species [16, 17, 22] including *S. frugiperda* [16, 18, 22]. Monitoring methods for FAW in various countries such as USA, mainly involve use of specific pheromone traps (involving [(Z)-7-dodecenyl acetate (Z)-7-12: Ac), (Z)-9-dodecenyl acetate (Z)-9-12: Ac), (Z)-9-tetradecenyl acetate (Z)-9-14: Ac), and (Z)-11-hexadecenyl acetate [16, 22]. Therefore, in addition to regular scouting and light traps, pheromone lures can be considered as options for monitoring in the Sub-Saharan Africa.

3.3 Cultural methods

Cultural method, an important component of a pest management strategy for FAW, mainly involves the application of appropriate agronomic practices. It is given first priority before any other control methods. Use of clean planting material (seeds) [23], avoid late planting (late planted crops would be heavily attacked by a higher FAW infestation than those of the early plantings [15], appropriate planting depth, optimum fertilization, proper irrigation, removal of damaged plants or wastes are some of the cultural methods that can reduce the occurrence of and infestation by FAW. Besides, handpicking, destroying egg masses and larvae, and putting sand mixed with lime or ash in the whorl of attacked maize to kill the larvae [3, 13]. A survey conducted in Ethiopia and Kenya showed that 14% and 39% of the farmers practiced cultural methods (such as handpicking), respectively, for FAW management [10].

3.4 Push-pull technology (PPT)

The push-pull technology (PPT), also called Push-Pull Technology (PPT), involves intercropping crops with a repellent plant, such as desmodium, *Desmodium uncinatum* J. (Leguminaceae) (a push plant) that repels or deters insect pests, and planting an attractive trap plant which is highly apparent and attractive to a pest, such as Napier grass, *Pennisetum purpureum* Schumach (Poaceae) (a pull plant), as a border crop around intercropped field, thus, facilitating pests control [2, 7, 14, 24]. In the PPT, the push plant release volatile chemicals such as (*E*)- β -ocimene and (*E*)-4, 8-dimethyl-1, 3, 7-nonatriene, that have repellent characteristics to the female moths of FAW, whereas, chemicals released by the pull plant are more attractive than maize to adult moths of FAW and stem borer, facilitating its concentration in the pull plant.

The PPT is proven to be climate-smart, farmers friendly and affordable control method FAW [10, 20, 24]. Several research reports have shown the effectiveness of PPT for the control of FAW. For instance, PPT applied maize (intercropped maize) in Uganda has shown 36% infestation symptom as compared to 95% infestation by FAW in mono-cropped maize [4]. In a field experiment in Ethiopia, PPT treated maize plots significantly reduced infestation of maize by FAW compared to monocropped maize plots [20]. In another study in western Kenya, eastern Uganda and northern Tanzania, there were highly significant reductions in infestation levels of FAW (average of 82.7%) in climate-adapted push-pull relative to the maize monocrop across study sites¹. As a result, overall mean yields have been found 2.5, 2.1 and 3.5 times higher in Kenya, Tanzania and Uganda in the climate-adapted push-pull plots than in the maize monocrop plots. These provide field-based evidence for benefits of PPT-based farming for mitigating FAW in Sub-Saharan Africa. Therefore, PPT is an appropriate technology for smallholder farmers to control FAW and is friendly and be integrated with other control methods for more efficiency in controlling the pest.

3.5 Biological control methods

Biological control can be considered as a powerful tool and one of the most important alternative control measures providing environmentally safe and sustainable plant protection [15]. Microbial pathogens and arthropod biocontrol agents have been successfully used in agricultural systems [15, 25]. Thus, Biological control methods could be a good option for the management of FAW. A number of parasitoids, predators and pathogens readily attack larval and adult stages of FAW.

Surveys conducted in three East African countries involving Ethiopia, Kenya and Tanzania revealed the presence of four hymenopteran (*Cotesia icipe* Fernandez-Triana & Fiobe (Braconidae), *Chelonus curvimaculatus* Cameron (Braconidae), *Coccygidium luteum* (Brulle) (Braconidae), *Charops ater* Szepliget (Ichneumonidae)) and one dipteran (*Palexorista zonata* Curran) (Tachinidae) parasitoid [26]. With the exception of *C. curvimaculatus*, an egg-larval parasitoid, the rest are larval parasitoids. All these species are new associations with FAW and were never reported before from Africa, or North and South America. Among these parasitoids, *C. icipe* was the dominant larval parasitoid in Ethiopia with parasitism ranging from 33.8 to 45.3%, while in Kenya, *P. zonata*, was the primary parasitoid with 12.5% parasitism, and *C. luteum*

was the most common parasitoid in Tanzania with parasitism ranging from 4 to 8.3% [26].

A study in Ethiopia showed that significant percent parasitism of larvae has been found. Findings show that parasitoids at three locations involving Hawassa (*Cotesia icipe* and *Palexorista zonata* with larval parasitism of 33.8 and 6.4% respectively), Jimma (*Charops ater* and *Cotesia icipe* with parasitism of 4.6 and 45.3% respectively) and Awash-Melka (*Cotesia icipe* and *Palexorista zonata* with larval of 33.8 and 5.7 respectively) [27].

Similarly, in Kenya, a tachinid fly, *Archytas marmoratus* was the main parasitoid with 12.5% parasitism. *Charops ater* and *Coccygidium luteum* were commonly encountered parasitoids in Kenya and Tanzania where parasitism ranged from 6-12% and 4-8.3%, respectively [27].

There are also predators that attack FAW eggs and larvae which could possibly be biological control options. The predators of FAW are generalists that attack larvae of other lepidopterans. For instance, in the Americas, the most important predators of FAW that have been reported include various ground beetles (Coleoptera: Carabidae); the striped earwig, *Labidura riparia* (Pallas) (Dermaptera: Forficulidae, Labiduridae), *Doru luteipes*, *D. lineare*, and other earwigs [15, 28]; the spined soldier bug, *Podisus maculiventris* (Hemiptera: Pentatomidae); and the insidious flower bug, *Orius insidiosus* (Hemiptera: Anthracoridae) [15]. These predators can be considered for the control of FAW.

The FAW is reported to be susceptible to at least 16 species of entomopathogens including viruses, fungi, protozoa, bacteria, and nematodes [15]. Among these, *Bacillus thuringiensis*, *Metarhizium anisopliae* and *Beauveria bassiana* can cause significant mortality in FAW populations and help to reduce leaf defoliation in crops [15, 29].

Over all, biological control method which is environmentally friendly (nature with nature type of control) can be recommended for smallholder farmers as one means of FAW management. The application of biological control can be through classical, augmentative or conservational means. Especially, through conservational methods by which natural enemies are enhanced through crop diversification rather than monocropping, natural enemies can keep the FAW population below economic threshold and be a good addition to the FAW management efforts and be good natural friends for the smallholder farmers.

3.6 Botanicals

There are reports in which farmers try and report satisfaction with using a number of botanicals or extracts from local plants. The use of botanical pesticides is recommended as a substitute to synthetic insecticides, such as pyrethroids and organophosphorus which may result in disturbances in the environment, increasing user cost, pest resurgence and pest resistance to insecticides [30, 31]. Among many other botanicals, extracts of plants such as *Azadirachta indica*, *Milletia ferruginea*, *Croton macrostachyus*, *Phytolacea docendra*, *Jatropha curcas*, *Nicotina tabacum* and *Chrysanthemum cinerariifolium* have been used successfully to control insect pests [32].

Fifty biopesticide were identified, which have been registered in one or more of 30 countries for FAW management [31]. Accordingly, twenty three of these are recommended for follow-up, for example field trials or bioassays. These are good options for smallholder farmers.

Tests on efficacy of botanical insecticides found that the best insecticide to control the immature fall armyworm is Solaris 6 SC[®], followed by the insecticide made of garlic extract, neem, and detergent. Also, the natural parasitism of the FAW on the area not treated with pesticides reached values of 60% where the *Chelonus* sp. was the parasitoid that was present at all times. This shows, in addition to control of larva of FAW, botanicals are friendly to natural enemies of FAW [33].

Because of affordability and availability of botanical insecticides, farmers in developing countries have been using botanicals and are highly recommended for smallholder farmers to use them as they are safer and more environmentally friendly tools.

3.7 Chemical pesticides

Insecticides have to be the last resort as they may pose negative impact on the environment, human health and natural enemies. Control of FAW is usually achieved through the application of synthetic insecticides [15, 34], but it involves high cost, potential environmental contamination, and development of resistance to chemicals, and often pest resurgence.

Insecticides can be used at different stages. For instance, *chlorantraniliprole* and *cyantraniliprole* can be used as seed treatments as reports show reduction of FAW infestation [15]. In laboratory tests, *thiodicarb* and *clothianidin* reduced the number of plants cut or injured by FAW [15, 35]. Emamectin benzoate 5 SG[®] 0.4 g/l, Spinosad 45 SC[®] 0.3 ml/l, Chlorantraniliprole 18.5 SC[®] 0.4 ml/l can be applied at early larval stage (up to fourth instars). Though insecticides can be options of FAW management, it should be considered as last resort.

3.8 Integrated FAW management

It is difficult to control FAW with a single stand-alone control method. It is advisable to consider integrated approach, an integrated FAW management that keeps the pest below economic threshold with least disturbance on the environment. Integrated FAW management might involve integrating two or more than two of the previously described methods that discourage the development of FAW population with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms. To implement IPM in farmer's field, it should be supplemented with effective monitoring, growing healthy plants in a healthy system, conserve natural enemies and train farmers to make them experts of their field. The integrated FAW management involves preventative methods to prevent the occurrence of the pest, monitoring the presence and absence of the pest through regular scouting, light traps or pheromone lures, and based on the result of monitoring, make decision on what control methods has to be applied or integrated. Along with the prevention and monitoring, cultural methods, push-pull technology, biological control methods or integration of the can be applied.

4. Conclusion

FAW has become one of the sever pests in Sub-Saharan Africa and is affecting millions of smallholder farmers. It has become one of the most devastating pests in terms of crop loss and economic impact. It is difficult to control FAW with a stand-alone single management method. The

FAW in Sub-Saharan Africa can be sustainably managed through integrated approach with preventative- and monitoring-based integrated FAW management involving a combination of preventative and monitoring methods, integrated with two or more than two control methods such as cultural methods, botanicals, push-pull technology, or biological control methods. Future line of work remains mainly on awareness creation of smallholder farmers about the pest, conducting exploration for native natural enemies of FAW or introduce from the center of origin of the pest, registering safer insecticides, increase the spread and adoption of the push-pull technology to smallholder farmers and conduction research on assessing different integrated FAW management approaches

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