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Out-break, Distribution and Management of fall armyworm, Spodoptera frugiperda J.E. Smith in Africa: The Status and Prospects

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ABSTRACT

A review was made to highlight various research works done so far regarding to the introduction, distribution and managements of fall army worm in Africa. It has been reported that the fall armyworm, Spodoptera frugiperda (J. E. Smith) is an economically important pest native to tropical and subtropical America has recently invaded Africa there by causing substantial damage to maize and other crops. Accordingly, signals increased negative impacts on agricultural production and food security on the continent. Reports also suggested that this pest has already moved to at least 30 African countries. It was first detected in Central and Western Africa in early 2016 (Sao Tome and Principe, Nigeria, Benin and Togo) and from there proceeded further. Currently, in Africa the pest is causing huge damage to maize crop and has been estimated to 25-67% for maize in many countries. African continent provides favorable climatic conditions for a constant reproduction of the pest, which is expected to result in severe damage to high priority crops. Various control methods, including cultural, chemical and mechanical have been adopted and practiced by farmers in many African countries. Large-scale eradication efforts are neither appropriate nor feasible. Thus, in near future gathering and analyzing experiences and best practices from other countries where the pest is native will help to design and test a sustainable

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fall armyworm management program for smallholders in Africa. Furthermore, in order to reduce negative impacts associated with inappropriate usage of insecticide, emphasize should be given to develop or adopt the management practices which is environmentally safe.

Keywords: Crop damages, *Spodoptera frugiperda*, management practices, prevalence in Africa, prospects

1. INTRODUCTION

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), was recognized as a destructive pest of many agricultural crops more than 200 years ago (Luginbill, 1928). It is a well-known sporadic and long-distance migratory pest with the adult moths being able to fly over 100 km in a single night (Johnson, 1987). Because the FAW has a wide distribution, it is subjected to much climatic diversity, namely, temperature, moisture, and soil type (Murúa *et al*., 2006). The environmental factors influencing development and survival, as well as genotype, agricultural practices, crop phenology, and plant maturity may contribute to the dynamics of the system in a given locale (Harrison 1984a; Pair *et al.,* 1986; Barfield & Ashley 1987; Simmons, 1992; Riggin *et al*., 1993). The pest has currently become a new invasive species in West and Central Africa where outbreaks were recorded for the first time in early 2016.

Fall armyworm, *Spodoptera frugiperda* (J E Smith), an economically important pest native to tropical and subtropical America has recently invaded Africa, causing substantial damage to maize and other crops (Andrews, 1980; Midega *et al*., 2018). The introduction of this highly polyphagous pest into the African continent is projected to constitute a lasting threat to several important crops (Goergen *et al*., 2016). Invasion of Africa by the fall armyworm adds to the diversity of lepidopteran pests of cereal crops, and signals increased negative impacts on agricultural production and food security on the continent (Midega A. *et al*., 2018). The presence of at least two distinct haplotypes within samples collected on maize in Nigeria and São Tome Â suggests multiple introductions into the African continent. It is expected to further spread in the continent, with devastating effects. Indeed, large numbers of fall armyworm larvae plaguing various crops of economic importance are now recurrently recorded in many African countries (Goergen *et al*., 2016). The continent provides a number of host plants, including grasses, and with favorable environmental conditions, it is postulated that the invading populations will persist and cause serious damage to key crops that provide livelihoods to many farmers (FAO, 2017). In America, where the pest is indigenous different management practices have been recommended so far to reduce the damage and losses caused by the FAW. However, due to recent introduction of this pest in to Africa there is a knowledge gap and management of FAW faced many challenges.

Currently, the fall armyworm has been distributed and causing huge damage to crops mainly of maize. However, there was limited information of this pest in all aspects. It is crucial to have detail information on the way or means of introduction, progress of distribution of this pest and associated crops losses, management practices taken so far, and encountered challenges and opportunities. Along with the biology of this pest, such information is very important to adopt or develop different technologies and bring sustainable management strategies of the fall armyworm. Thus, the objective of this review was to evaluate various works done by previous researchers or scholars concerning introduction, distribution, crop damage or losses, and managements as well as to develop a better understanding of the fall armyworm, *Spodoptera frugiperda* (Smith).

2. BIOLOGY OF FALL ARMYWORM, SPODOPTERA FRUGIPERDA (SMITH)

Understanding the biology of insect pest in general and fall army worm particularly is essential to take any action and also hasten scientific investigations to bring immediate solutions. Even though new agricultural pests are periodically introduced into the African agricultural environment and pose some degree of risk, a number of characteristic factors make FAW a more devastating pest than many others, including FAW consumes many different crops, spreads quickly across large geographic areas and it can persist throughout the year (B.M.Prasanna *et al*., 2018). Realizing importance of knowing the biology of this insect pest in its management, the overview of FAW life cycle, host range and ecology is described below.

2.1 The Life cycle of fall armyworm

Recognizing FAW is the first step for management. The pest is new to Africa, and farmers need to be able to recognize FAW, and distinguish it from other pests. The Fall Armyworm life cycle includes egg, 6 growth stages of caterpillar development (instars), pupa and moth (FAO, 2018). The FAW life cycle is completed in about 30 days (at a daily temperature of ~28°C) during the warm summer months but may extend to 60-90 days in cooler temperatures. FAW does not have the ability to diapause (a biological resting period); accordingly, FAW infestations occur continuously throughout the year where the pest is endemic. In non-endemic areas, migratory FAW arrive when environmental conditions allow and may have as few as one generation before they become locally extinct. For example, FAW is endemic in south Florida (latitude ~28°N) and populates the entire eastern USA each summer by migration (B.M.Prasanna *et al*., 2018).

The egg is dome shaped: the base is flattened and the egg curves upward to a broadly rounded point at the apex. The egg measures about 0.4 mm in diameter and 0.3 mm in height. The number of eggs per mass varies considerably but is often 100 to 200, and total egg production per female averages about 1,500 with a maximum of over 2,000. Duration of the egg stage is only 2 to 3 days during the warm summer months (B.M.Prasanna *et al*., 2018). The FAW typically has six larval instars. Larvae tend to conceal themselves during the brightest time of the day. Duration of the larval stage tends to be about 14 days during the warm summer months and 30 days during cooler weather. Mean development time was determined to be 3.3, 1.7, 1.5, 1.5, 2.0, and 3.7 days for instars 1 to 6, respectively, when larvae were reared at 25°C (Pitre and Hogg, 1983; B.M.Prasanna *et al*., 2018). It pupates in the soil at a depth 2 to 8 cm. The larva constructs a loose cocoon by tying together particles of soil with silk. The cocoon is oval in shape and 20 to 30 mm in length. Duration of the pupal stage is about 8 to 9 days during the summer, but reaches 20 to 30 days during cooler weather. The pupal stage of FAW cannot withstand protracted periods of cold weather (B.M.Prasanna *et al*., 2018). For example, Pitre and Hogg (1983) studied winter survival of the pupal stage in Florida, and found 51% survival in southern Florida, but only 27.5% survival in central Florida and 11.6% survival in northern Florida. Adult FAW moths have a wingspan of 32 to 40 mm. In the male moth, the forewing generally is shaded gray and brown, with triangular white spots at the tip and near the center of the wing. The forewings of females are less distinctly marked, ranging from a uniform grayish brown to a fine mottling of gray and brown. Adults are nocturnal, and are most active during warm, humid evenings. After a preoviposition period of 3 to 4 days, the female moth normally deposits most of her eggs during the first 4 to 5 days of life, but some oviposition occurs for up to 3 weeks. Duration of adult life is estimated to average about 10 days, with a range of about 7-21 days (Luginbill, 1928; Sekul and Sparks, 1976; Sparks, 1979; B.M.Prasanna *et al*., 2018).

2.2 Host-range of fall armyworm

FAW is a moth that is indigenous throughout the Americas, where it is widely agreed to be one of the most damaging crop pests. It has a wide host range with almost 100 recorded plant species in 27 families (Sparks, 1979; Andrews, 1980; Capinera, 1999; Pogue M., 2002). FAW is capable of feeding on over 80 different crop species, making it one of the most damaging crop pests. The fall armyworm is a voracious pest and, given its polyphagous nature, it is expected that its accidental introduction in the African continent will constitute a lasting threat to several important crops (CABI, 2016). While FAW has a preference for maize, the main staple of SSA, it can also affect many other major cultivated crops, including sorghum, rice, sugarcane, cabbage, beet, groundnut, soybean, onion, cotton, pasture grasses, millets, tomato, potato, alfalfa and cotton (R.Day *et al*., 2017; FAO, 2018; B.M.Prasanna *et al*., 2018). It causes significant damage to economically important cultivated grasses including maize, rice, sorghum, sugar cane, but also vegetables and cotton. During the maize vegetative phase, constant feeding results in skeletonized leaves and heavily windowed whorls loaded with larval frass. Infestations during the mid-to-late corn stage may result in yield losses of 15-73% when 55-100% of the plants are infested (Hruska and Gould, 1997). Several factors suggest that *S*. *frugiperda* is likely to become more damaging to maize than other species of the same genus occurring in Africa which includes adult females of *S*. *frugiperda* directly oviposit on maize, the mandibles of caterpillars of the fall armyworm have comparatively stronger, serrated cutting edges, which ease the feeding on plants with high silica content (Pogue M., 2002; Brown ES and Dewhurst CF, 1975). Older larvae become cannibalistic and have the ability to dominate interspecific competitors and reduce intraspecific rivals (Chapman JW *et al*., 2002). Similarly, if climatic conditions allow a constant reproduction of the pest, the damage inflicted to maize is particularly severe. Thus, Caterpillars of *S. frugiperda* seem to be much more damaging to maize than most other African *Spodoptera* species having developed comparatively strong serrated cutting edges of mandibles as a way of overcoming high silica contents in wild grasses (Goergen *et al*., 2016).

2.3 Ecology of fall armyworm

It has not previously been established outside the Americas but its two strains have now appeared in Africa and are rapidly spreading throughout the tropical and subtropical regions of the continent. FAW is capable of migrating long distances on prevailing winds, but it can also breed continuously in areas that are climatically suitable (Dennis R. and Jannes V, 2017; R. Day *et al*., 2017). African continent provides favorable climatic conditions for a constant reproduction of the pest, which is expected to result in severe damage to crops (Goergen *et al*., 2016); and being a new pest in the continent, it might have found an enemy free space. Additionally, 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 favorable (P. Abrahams *et al*., 2018).

3. OUT-BREAK AND DISTRIBUTION FALL ARMYWORM (SPODOPTERA FRUGIPERDA) IN AFRICA

As fall army worm is well known invasive insect pest new to African agricultural world, the earlier authors (scholars) have suggest various information concerning to its occurrence. Therefore, this section deals with outbreak, pathways of introduction and the present status of the pest in Africa.

3.1 The Out-break and pathways of Introduction

Native to the Americas, the fall armyworm; *Spodoptera frugiperda* (JE Smith); Lepidoptera, Noctuidae) was first reported as present on the African continent in January 2016 in Nigeria, Sao Tome, Benin and Togo (CIPV, 2016; Goergen, G. *et al*., 2016; CABI, 2017) and causes significant damage on maize crops. According to Georgen *et al.* (2016), the FAW is originated from the tropical regions of the Americas going from the United States to Argentina and the Caribbean region. It is a prime noctuid pest of maize and has remained confined there despite occasional interceptions by European quarantine services in recent years. It has been recently introduced into the African continent and has already moved to many countries where the pest has been reported for the past two years (Abraham *et al*., 2017; Stokstad, 2017; B.M. Prasanna *et al*., 2018). The genus *Spodoptera* comprises 31 species with seven species previously recorded from the Afrotropical region while six species are known to occur in West and Central Africa (Pogue, 2002). *Sopodoptera exempta* or African armyworm is the most common and well known amongst them in Africa.

Pathways of the introduction of fall armyworm into West and Central Africa are subject to speculations; but the presence of at least two distinct haplotypes within the collected material suggests that the present incursion originated from at least two introductions. *Spodoptera frugiperda* has a remarkable dispersal capacity, a feature that is understood to have evolved as part of its life history strategy (Johnson SJ, 1987). Thus, in annual migrations, the pest is able to expand from its endemic area in the warmer parts of the New

World over more than 2000 km across the entire US up to Canada in the North and reaching the northern parts of Argentina and Chile in the South (Pair SD *et al*., 1986). Similarly, the pathways of the recent accidental introduction of the fall armyworm into West Africa might be due to increase in international trade volume and easy air travel of people from one continent to another has amplified the phytosanitary risks of even multiple introductions.

Research to date suggests that both strains of FAW entered Africa, perhaps as stowaways on commercial aircraft, either in cargo containers or airplane holds, before subsequent widespread dispersal by the wind. The probability is high (>90%) that the introduction to Africa was from the characterised Florida strain of FAW, which is restricted to the eastern seaboard of the USA, and the Caribbean islands (CABI, 2017). How far the fall armyworm has already expanded into Africa is presently not known but with regard to its high spreading performance, large reproductive capacity and wide host plant range it is likely that the pest will soon be able to colonize most of tropical Africa (Goergen *et al*., 2016; B.M.Prasanna *et al*., 2018).

3.2 Current distribution of fall armyworm

The crop pest has since been found in over 30 African countries, posing a significant threat to food security, income and livelihoods (B.M. Prasanna *et al*., 2018). Like other moths in the genus *Spodoptera*, FAW moths have both a migratory habit and a more localized dispersal habit. In the migratory habit, moths can migrate over 500 km (300 miles) before oviposition. When the wind pattern is right, moths can move much larger distances (Rose *et al.* 1975; B.M.Prasanna *et al*., 2018). In most areas of North America, FAW arrives seasonally and then dies out in cold winter months, but in much of Africa, FAW generations will be continuous throughout the year wherever host plants are available, including off-season and irrigated crops, and climatic conditions are favorable. Although the patterns of population persistence, dispersal, and migration in Africa are yet to be determined, conditions in Africa, especially where there is a bimodal rainfall pattern, suggest that the pest can persist throughout much of the year (B.M.Prasanna *et al*., 2018). Adequate management strategy could not be developed without assessing its current distribution and elucidating its bio-ecology in this new environment (M. Tindo *et al*., 2017).

To-date, FAW has been detected and reported in almost all of Sub-Saharan Africa, except in Djibouti, Eritrea, and Lesotho. Since the pest was detected in Sudan, Egypt and Libya must be on alert (Goergen *et al*., 2016; FAO, 2018). It was first detected in Central and Western Africa in early 2016 (Sao Tome and Principe, Nigeria, Benin and Togo) and in late 2016 and 2017 in many other countries, and it is expected to move further. FAW's presence in Africa is irreversible (FAO, 2017). Information was collated from all 54 countries in Africa through literature searches, personal communications and internet mining 30 countries have confirmed the presence of FAW, while other countries suspect its presence, or are awaiting official confirmation of the pest in the country (table 1) **(**CABI, 2017). According to B.M. Prasanna (*et al*., 2018), the generally hospitable agro ecological conditions for FAW in SSA suggest that FAW will establish as an endemic, multigenerational pest in Africa.

Table1. The current distribution of fall armyworm in Africa, January 2018.

Country	**Year detected**	**Country**	**Year detected**
Cameroon	August 17	Nigeria	June 2016
Chad	July 2017	Republic of Congo	August 2017
Tanzania	May 2017)	Rwanda	June 2017
Ethiopia	April 2017	Sao Tome et Principe	June 2016
Ghana	June 2017	South Africa	July 2017
Guinea	June 2017	South Sudan	July 2017
Kenya	May 2017	Swaziland	March 2017
Malawi	June 2017	Tanzania	May 2017
Mozambique	2017	Togo	June 2016

Namibia	March 2017	Uganda	July 2017
Niger	March 2017	Zambia	March 2017
Benin	late 2016	Zimbabwe	May 2017
Botswana	late 2017	Togo	late 2016
South Africa	July 2017		
Sierra Leone	July 2017	Angola	late 2017
		Burundi	late 2017

Sources: Goergen *et al*. (2016); FAO (2018); Phil Abrahams *et al*. (2017)

4. EMERGING IMPACTS ACROSS AFRICA

Investigations have revealed the fall armyworm (*Spodoptera frugiperda)* in nearly all of sub-Saharan Africa (SSA), where it is causing extensive damage, especially to maize which is a staple food consumed by over 300 million African smallholder farm families and to a lesser degree sorghum and other crops. According to B.M.Prasanna (*et al*., 2018) due to its rapid spread and distinctive ability to inflict widespread damage across multiple crops, FAW poses a serious threat to the food and nutrition security and livelihoods of hundreds of millions of farming households in SSA particularly when layered upon other drivers of food insecurity. In Southern Africa, for example, the 2016-17 FAW outbreak arrived just as households in the region were still reeling from the 2015-16 El Niño-induced droughts, which affected an estimated 40 million people. FAW will have an impact on many different aspects of household livelihoods. As seen through the prism of the DFID livelihood framework, the pest will affect natural capital, through yield losses and the ability of agricultural lands to respond to shocks; and financial capital, through increasing the cost of production, and its effect on income (R. Day *et al*., 2017). It will also indirectly affect households' social and physical capital (the household's assets).

4.1 Crops damage and prospective losses

To date, the main crop affected in all invaded African countries is maize. However, the FAW is polyphagous and other important food crops are at risk, particularly rice, sorghum and sugarcane. 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 (R.Day *et al*., 2017).

4.1.1 Maize damage and yield losses

Corn plants are susceptible to fall armyworm (*Spodoptera frugiperda)* attack during practically all stages of its development cycle, and severe losses occurs when the whorl is destroyed, reducing photosynthetic area and compromising the grain yield. It may also attack the basal portion of the ear, destroying the grain or favoring infection by microorganisms (Cruz *et al*., 1999; Goergen *et al*., 2016). In Africa the pest is causing huge damage to maize crop where the larger larvae can act as cutworms by entirely sectioning the stem base of maize seedlings (Goergen *et al*., 2016). Damage on maize may be observed on all plant parts depending on development stage. The extent of damage, however, depends on factors such as planting season, geographical region, cultivar planted and cultural practices inherent in and around the field (De Almeida Sarmento *et al*., 2002). Due to favorable environmental conditions, *S. frugiperda* can able to reproduce at a fast rate and caterpillars appear to be much more damaging to maize in West and Central Africa than most other African *Spodoptera* species (Goergen *et al*., 2016; IITA, 2016).

In the absence of proper control methods, FAW has the potential to cause maize yield losses of 8.3 to 20.6 M metric tons per year, in just 12 of Africa's maize producing countries. This represents a range of 21-53% of the annual production of maize averaged over a three-year period in these countries. The value of these losses was estimated at between US$2.48 billion and US$6.19 billion (R. Day *et al*., 2017; CABI, 2017; B.M.Prasanna *et al*., 2018). Authors are also mentioned that several seed companies in SSA have reported significant damage to their maize seed production fields over the past year, potentially impacting both the availability of seed to farmers over the coming growing seasons and the economic viability of Africa's emerging private seed sector. CABI conducted a household socio-economic survey in Ghana and Zambia in July 2017. Survey questions examined farmers' perception of losses specifically due to FAW over the last full growing season. Accordingly, the estimated national mean loss of maize in Ghana was 45% (range 22-67%), and in Zambia 40% (range 25-50%). Using the data from Ghana and Zambia, CABI estimated the potential impacts on national yield and revenue in 10 other major maize-producing countries that are likely to occur in the maize-producing seasons, assuming that the FAW will spread throughout all areas where it is predicted to survive (table 2) (CABI, 2017).

Table2. Estimated lower and upper yield and economic losses in the 12 maize-producing countries in Africa

Country	Maize production (three-year mean) (thousand tonnes)	Value of maize (three year average FAO stats)US $ million	Yield loss (lower) (thousand tonnes)	*Yield loss (upper)(thousand tonnes)*	*Mean yield loss (thousand tonnes)*	*Economic loss (lower) (US$ mil lion)*	*Economic loss (upper)(US$ million)*
Benin	1,285.30	376.5	295.6	735.8	530.4	86.6	215.6
Cameroon	1,665.70	697.8	319.2	794.4	687.4	133.7	332.8
D. Republic of Congo	1,173.40	343.7	254.5	633.4	484.2	74.5	185.5
Ethiopia	6,628.30	1,580.20	1,227.20	3,054.70	2,735.20	292.6	728.3
Ghana	1,825.50	629.8	401.6	1,213.90	824.3	138.5	418.8
M Malawi	3,344.90	979.7	769.3	1,915.00	1,380,3	225.3	561
Mozambique	1,247.20	365.3	99.7	239.2	514.7	35	84.1
Nigeria	9,302.70	3,271.80	2,129.10	5,299.70	3,838.90	748.7	1,863.60
Uganda	2,748.30	805	558.9	1,391.10	1,134.10	163.7	407.5
Tanzania	5,732.60	1,679.10	1,301.30	3,239.00	2,365.60	381.2	948.8
Zambia	2,913.00	500.9	728.1	1,456.10	1,154.00	125.2	250.4
Zimbabwe	1,104.10	360.7	234.8	584.4	455.6	76.7	190.9
Total	**38,971**	**11,590.5**	**8,319.30**	**20,556.70**	**16,104.70**	**2,481.70**	**6,187.30**

Source: Roger Day *et al*. (2017); Phil Abrahams *et al*. (2017)

4.2 Other Economic and Health impacts

Fall armyworm (*Spodoptera frugiperda)* (FAW) could have serious impacts on regional and international trade. Exports of crops that are host plants for FAW from African countries with confirmed presence of FAW will come under new scrutiny from importing countries that haven't reported FAW (B.M. Prasanna *et al*., 2018). Establishment of FAW populations in Africa has broader implications for global agriculture, as it also increases the risk that the pest will further migrate to Europe (possibly via North Africa and Egypt) and Asia (possibly via Ethiopia) (R.Day *et al*., 2017; B.M. Prasanna *et al*., 2018). In addition to FAW's emerging economic and food security impacts, initial responses to the pest highlight the potential for negative human and environmental health impacts. In particular, extensive, indiscriminate, and unguided use of synthetic pesticides is already being reported anecdotally from several countries in SSA for controlling FAW in farmers' fields. Damage to populations of natural enemies and predators of FAW and high risk of pesticide exposure for women and children at the farm level, as women primarily manage agricultural operations in Africa are the critical problems associated with un-safe usage insecticides.

5. MANAGEMENT PRACTICES

Fall armyworm (*Spodoptera frugiperda)* is likely to remain a significant agricultural pest across much of SSA for the foreseeable future. It is therefore essential to develop an effective, coordinated, and flexible approach to manage FAW across the continent. Such an approach should be informed by sound scientific evidence, build on past experience combating FAW in other parts of the world, and be adaptable across a wide range of African contexts, particularly for low-resource smallholders. An integrated pest management (IPM) approach provides a useful framework to achieve these goals (FAO, 2017; B.M. Prasanna *et al*., 2018). Large-scale eradication efforts are neither appropriate nor feasible. Below are presented with an overview of the managements that have been practiced so far in some African countries and needs to be adopted in other areas of the continent.

5.1 Cultural Methods

Different cultural methods have been adopted and practiced by farmers in many African countries, including: Plant early, use early maturing varieties, intercrop maize & beans, remove weeds, remove/destroy crop residues, rotate with non-hosts, ploughing/cultivating to expose larvae & pupae, handpicking egg masses and larvae, applying sand sawdust or soil in the whorl (with ash/lime). Many of the measures recommended so far, therefore represent general agro ecological best practices for pest control though where indicated, emerging evidence suggests efficacy against FAW in Africa, particularly for the "Push-Pull" intercropping approaches. The benefits of cultural and landscape management approaches often arise from the interplay of ecological factors across a range of spatial scales from plot to field to farm to landscape that disrupt and control the pest at multiple stages throughout its life cycle (table 3) (Veres *et al.* 2013; Martin *et al.* 2016). For example, cultural practices such as intercropping, companion cropping, conservation agriculture, and agroforestry may simultaneously improve the health of the crop, provide shelter and alternative food sources for natural enemies, and reduce the ability of FAW larvae to move between host plants. Cultural and ecological management options are highly compatible with host plant resistance and biological control approaches (Martin *et al*., 2016; Pumariño *et al.,* 2015; Stevenson *et al*., 2012).

Table3. Recommended cultural and landscape management options for control of FAW in Africa

Method	Effectiveness	Financial cost	Source
Increased ground-cover	As trap crops, repellent crops that interrupt egg laying and larval development, and as shelter for natural enemies.	Medium: availability of seed and suitability of the cover crops.	Altieri *et al*. (2012); Bugg *et al*. (1991); Hoballah *et al*. (2004); Ratnadass *et al*. (2011); Meagher *et al*. (2004); Wyckhuys and O'Neil (2007)
Plant nutrition	Good fertilization reduces plant damage by increasing plant health and defenses against pests, but damage may increase with excessive nitrogen application.	Medium: if additional input purchase is required	Altieri and Nicholls (2003); Morales *et al*. (2001); Rossi *et al*. (1987)
Inter cropping	Likely to be more effective either when non-host plants are used, when crop diversity may interrupt egg laying, and can increase the diversity of beneficial organisms including natural enemies of the pest.	Low: often a traditional practice.	Pichersky and Gershenzon (2002); Landis *et al*. (2000); Coolman and Hoyt (1993)
Conservation agriculture (CA)	Effective, if all principles of CA are applied and continued for some time. Unlike other pests, FAW cannot be controlled by burning of crop residues.	Medium: some specific tools and inputs may be required for establishing effective CA systems.	All (1988); Tillman *et al*. (2004); Rivers *et al*. (2016)
Hedgerows and live fences	Fields close to hedgerows are usually less infested with pest due to biological control agents (birds) activities.	Medium to high: extra land may be required for establishing	Veres *et al*. (2013); Landis *et al*. (2000); Martin *et al.* (2016); Marino and Landis (1996); Wyckhuys and O'Neil (2007)

		hedgerows.	
Enhance agroforestry systems	Long-term intervention to create biodiversity and biological pest control can be very effective once trees are established.	Medium: land needs to be shared with main crops.	Wyckhuys and O'Neil (2006); Wyckhuys and O'Neil (2007); Hay-Roe *et al*. (2016); Ratnadass *et. al*. (2011)

Adapted from: CABI Evidence Note (2017)

Midega *et al*., (2018) demonstrated that climate-adapted push-pull technology developed for control of cereal stemborers and effectively controls fall armyworm in smallholder farming systems in East Africa. The technology thus has potential for expansion in the African continent to manage key pests affecting cereal production in the continent (table-4). The ability of the technology to manage such a devastating pest, together with the positive perceptions of the smallholder farmers, where it was already implemented for stemborer and striga control, indicate its stability and resilience, and confirms that it is an ecologically sustainable and socially acceptable approach to pest management (Midega *et al*., 2018). Reductions of 82.7% in average number of larvae per plant and 86.7% in plant damage per plot were observed in climate-adapted push-pull compared to maize mono crop plots. Similarly, maize grain yields were significantly higher, 2.7 times, in the climate-adapted push-pull plots. Farmers rated the technology significantly superior in reducing fall armyworm infestation and plant damage rates (table-5). The authors also reported that the technology is effective in controlling fall armyworm with concomitant maize grain yield increases, and represent the first documentation of a technology that can be immediately deployed for management of the pest in East Africa and beyond (Midega *et al*., 2018)

Table4. Comparisons of sole stands (monocrop) and climate-adapted push–pull treatments for fall armyworm management in maize in Kenya, Uganda and Tanzania.

Country	Sub-county	Cropping System	% plants damaged	t-value	% reduction	Number of larvae/plant	t-value	% reduction
Kenya	Bungoa	Push-pull	5.2(1.0)	32.7	94.6(1.0)	0.003(0.002)	11.4	82.7(6.3)
		Mono crop	95.4(1.0)			0.49(0.04)		
	Busia	Push-pull	18.6(1.5)	30.3	80.2(1.6)	0.18(0.02)	30.7	90.7(1.1)
		Monocrop	94.3(0.8)			2.07(0.08)		
	Siaya	Push-pull	4.1(0.9)	34.4	95.0(1.1)	0.008(0.004)	3.01	96.5(1.6)
		Monocrop	80.0(1.5)			0.23(0.08)		
	Vihiga	Push-pull	4.7(0.6)	32.1	94.4(0.7)	0.003(0.002)	10.7	99.3(0.4)
		Monocrop	85.2(1.3)			0.36(0.04)		
	Migori	Push-pull	3.2(0.7)	27.6	95.5(0.7)	0.002(0.001)	30.4	99.6(0.2)
		Monocrop	91.3(1.4)			0.69(0.03)		
	Homabay	Push-pull	9.5(2.2)	16.2	88.2(2.6)	0.06(0.03)	12.9	94.6(2.5)
		Monocrop	84.4(2.7)			0.95(0.08)		
Uganda	Iganga	Push-pull	27.3(2.1)	13.2	70.9(2.2)	0.15(0.23)	12.2	75.2(4.7)
		Monocrop	94.0(2.3)			0.60(0.02)		
	Bugiri	Push-pull	23.8(3.2)	10	72.6(3.9)	0.13(0.04)	6.01	72.4(8.7)
		Monocrop	88.0(3.3)			0.52(0.05)		
	Tororo	Push-pull	22.0(4.0)	7.9	71.1(6.8)	0.14(0.04)	5.93	68.1(11.5)
		Monocrop	80.0(5.0)			0.56(0.06)		
	Bukedea	Push-pull	26.0(2.8)	7.3	68.4(4.3)	0.17(0.03)	6.01	76.2(6.1)
		Monocrop	86.0(4.7)			0.83(0.12)		
Tanzania	Tarime	Push-pull	5.4(1.6)	12.7	92.3(2.1)	0.02(0.01)	15.8	96.5(1.6)
		Monocrop	67.1(3.5)			0.38(003)		
Average reduction					**86.7(0.8)**			**82.7(1.9)**

Note: *In each sub-county and district, means represent data averages of 30 farmers in Kenya, 10 in Uganda and 30 in Tanzania. Figures in parentheses are standard errors. All t-values were associated with p < 0.0001 except in Siaya where the t-value under mean number of larvae per plant was associated with p = 0.004.*

The regions are known as sub-counties in Kenya and districts in Tanzania and Uganda. **Source:** C.A.O. Midega *et al.,* 2018

Table5. Famers' perceptions on fall armyworm and effectiveness of climate-adapted push-pull on its management in Kenya, Uganda and Tanzania.

Parameter	Re-sponse/rating	Country								Statistics	
		Kenya		Tanzania		Uganda		Total		Chi	Sig
		N	%	N	%	N	%	N	%		
Pest presence on own farm	No	50	33.3	19	63.3	0	0.0	69	32.5	36.46	0.000
	Yes	11	100	66.7	36.7	32	100.0	143	67.5		
Seriousness of infestation in CAPP vs mono	Lower	97	97.0	11	100.0	28	87.5	136	95.1	21.21	0.000
	Same	3	3.0	0	0.0	4	12.5	7	4.9		
	Higher	0	0.0	0	0 0	0	0.0	0	0.0		
CAPP decreases infestation	Yes	150	100.0	30	100.0	31	96.9	211	99.5		
[a]Maize damage under CAPP	None	94	62.7	17	56.7	0	0.0	111	52.4	26.967	0.000
	Low (< 25%)	47	31.3	12	40.0	27	84.4	86	40.5		
	Average (25-50%)	9	6.0	1	3.3	5	15.6	15	7.1		
[b]Pest damage in maize mono	Average	4	2.7	1	3.3	2	6.3	7	3.3	9.681	0.139
	High (50-75%)	65	43.3	14	46.7	20	62.5	99	46.7		
	Severe (> 75%)	81	54.0	15	50.0	10	31.2	106	50.0		

Note: [a] *No respondents rated maize damage by fall armyworm as high and severe under climate-adapted push-pull.*
[b] *No respondents rated maize damage by fall armyworm as none and low under maize monocrop system. CAPP, Climate-adapted push-pull; mono, maize monocrop. Rating of plant damage: None, 0% plants damaged by fall armyworm larvae; Low,<25% plants damaged; Average, 25-50% plants damaged; High, 50-75% plants damaged; Very high,>75% plants damaged.* **Source:** C.A.O. Midega *et al. (*2018)

5.2 Mass Trapping (Pheromonal Control)

Synthetic mimics of the female moth's sex pheromone used to mass-trap males or disrupt their mate-finding. Set up 4-6 FAW Pheromone traps per hectare to suppress the moth population build up. The infestation is reduced by using different management options and continuous monitoring, and by using integrated fall army worm management method (cultural i.e. early planting, input used, hand picking) pheromonal control, insecticide spraying together reduced this pest infestation (Tamiru, 2017).

5.3 Host-plant Resistance

Historically, considerable effort was undertaken in the Americas to breed for FAW resistance, especially in maize. Similar efforts have only been recently initiated in Africa, following the identification of FAW on the continent in 2016 (Georgen *et al.* 2016). However, there are presently no Africa-adapted maize cultivars with scientifically validated resistance to FAW. Transgenic Bt-maize (expressing Cry1F toxin) has been developed and is currently used in the US, but its deployment in tropical Africa might not be as straightforward owing to economic, logistic and socio-cultural considerations. Moreover resistance to Cry1F has already been widely reported.

5.4 Biological Control

In its native range numerous parasitic wasps and flies have been recorded as natural enemies of the fall armyworm and some species, in particular egg and larval parasitoids, are frequently introduced, resulting in noticeable levels of control. The egg parasitoid *Telenomus remus* is frequently introduced to effectively control fall armyworm and other *Spodoptera* species. Natural levels of larval parasitism are often very high (20-70%), mostly by braconid wasps, larval parasitism by a *tachinid* and a *Cotesia sp.* has already been noted. A large number of isolates of nucleopolyhedroviruses (NPV) have been obtained from the field and screening efforts only recently resulted in the detection of promising isolates. Similarly, the development of bio pesticides including the use of endophytic entomopathogenic fungi is still in its infancy and needs increased attention for providing viable alternatives to conventional insecticides. Indeed, laboratory experiments have demonstrated that evolution of insect resistance to pest-control measures can be delayed or prevented in the presence of natural enemies (Liu *et al.* 2014). However, indiscriminate spraying of toxic pesticides often adversely affects these natural enemies, reducing benefits from biocontrol (Meagher *et al*. 2016) and potentially increasing the population of secondary pests (Tscharntke *et al*. 2016).

5.5 Chemical (Insecticides)

Chemical treatment has been the most frequently used control method against *S. frugiperda.* Management of the fall armyworm has been mainly effected through use of synthetic insecticides (Cook *et al*., 2004). Twenty-nine active ingredients have been recommended for *S. frugiperda* (Gallo *et al*., 2002). The pyrethroid deltamethrin was often used in the past and remains as one of the most important available insecticides for insect pests' control of corn crops (Badji *et al*., 2004). In addition, there have been reported cases of *S. frugiperda* resistance evolution in this insect to this group of insecticides used (Figueiredo *et al*., 2005). Although some of these are both effective against the pests and less harmful to the environment, experience indicates that choice of insecticides is largely based on a farmer's knowledge and purchasing power, with a tendency to select cheaper products (Dal Pogeto *et al*., 2012). Interventions based on pest incidence thresholds are primarily meant to better protect young plants and reproductive stages of maize. Therefore, monitoring activities together with alternated application of insecticides such as pyrethroids, carbamates and organophosphates are recommended as immediate measure. Early detection is primordial, as the application of chemical insecticides is only efficient on young larval stages (Goergen *et al*., 2016).

5.6 Integrated Insect Management

The most common management strategy for the fall armyworm in the Americas has been the use of insecticides and genetically modified crop (*Bt* maize). However, the worm has evolved resistance both to several pesticides and to some kinds of transgenic maize (Adamczyk *et al*. 1999; Abraham *et al*. 2017). It is also complicated by chronic poisoning of farmers in some localities due to incorrect use (Tinoco and Halperin, 1998); use of insecticides as a pest management tool for small scale farmers in Africa is minimal, largely due to shortage of information, inaccessibility of appropriate and effective products, and high costs (Midega *et al*., 2012). Hence, there is an urgent need for developing ecologically sustainable, economically profitable and socially acceptable IPM programs to fight the fall armyworm in Africa (Goergen *et al*., 2016**).** Furthermore, challenges observed with the conventional control methods highlighted above, notably development of resistance by the pest to some insecticides and Bt-maize events, indicate that an integrated management approach for fall armyworm that fits within the mixed cropping nature of the African farming systems is necessary for resource constrained farmers (Midega *et al*., 2018).

Currently, integrated management strategies are thought to be the best options. These include monitoring (weekly plant inspection) for treatment decision making, good practices (early planting, use early maturing varieties, intercrop maize with legume, weeding, 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 etc.(M. Tindo *et al*., 2017). In addition, according to Abraham *et al* (2017), government of countries with FAW presence should immediately promote awareness of FAW, its identification, damage and control, provide emergency/temporary registration for the recommended pesticides.

6. CHALLENGES AND PROSPECTS

6.1 Challenges

To date, development and implementation of a coordinated, evidence-based effort to control fall armyworm (*Spodoptera frugiperda)* in

Africa has faced a number of challenges. In particular, FAW is a recently introduced pest in Africa. Therefore, FAW scouting by farming communities and effective monitoring at the country, regional, and continental levels are limited. In addition to delaying recognition of the pest's movement through Africa, this lack of surveillance, monitoring, and scouting capacity has delayed efforts to determine several key unknowns about FAW populations on the continent and the dynamics of the pest's establishment and spread. Beyond the challenges of recognizing and characterizing the presence of FAW in Africa, the lack of validated strategies to effectively manage FAW in an African context also poses challenges. Proven approaches to prevent and avoid FAW are presently limited, and efforts to suppress the pest have largely focused on the application of synthetic pesticides at times in an indiscriminate manner with high potential to damage human, animal, and environmental health. Thus, putting all these problems under consideration, future management of this pest should focus on the development of ecologically and environmentally friend options.

6.2 Prospects (Future line works)

There are many literatures on fall armyworm (*Spodoptera frugiperda)* control in the Americas. Therefore, gathering and analyzing experiences and best practices from the Americas will help to design, test and develop a sustainable FAW management program for smallholders in Africa. Even though there is a range of experience applying cultural and landscape management practices to control other pests in Africa there is still considerable uncertainty about how effective such approaches will be against FAW, and these knowledge gaps require additional research. Furthermore, education, research, and regulatory processes are yet to be scaled up and effectively coordinated across the continent, so as to rapidly disseminate and support emerging best practices for fall armyworm (*Spodoptera frugiperda)* control as they are identified. Control of FAW requires an integrated pest management (IPM) approach. Immediate recommendations include, awareness raising campaigns on FAW symptoms, early detection and control, including beneficial agronomic practices; national preparation and communication of a list of recommended, regulated pesticides and bio pesticides and their appropriate application methods. Work should also focus to assess preferred crop varieties for resistance or tolerance to FAW; introduce classical biological control agents from the Americas. Conducive policy environment should promote lower risk control options through short term subsidies and rapid assessment and registration of bio pesticides and biological control products. The use of plants that possess insecticidal activity is not a recent technique in insect control. In the past decades, as problems of organic synthetic insecticides on insect resistance, effects on natural enemies, environments, and humans increased, interest in natural insecticides expanded worldwide. Hence, research should focus on this as eco-friendly control methods as well.

7. CONCLUSIONS

The fall armyworm (*Spodoptera frugiperda)* has been recently introduced into the African continent and has already moved to many countries. In, Africa the pest is causing huge damage to maize crop. African continent provides favorable climatic conditions for a constant reproduction of the pest, which is expected to result in severe damage to crops. Therefore, effective control should focus since it is impossible to avoid this pest unless developing sustainable management. Furthermore, there is an urgent need to generate awareness among the farming communities about the life stages of the pest, scouting for the pest (as well as its natural enemies), understanding the right stages of pest control, and implementing low-cost agronomic practices and other landscape management practices for sustainable management of the pest. At the same time, it is important to introduce, validate, and deploy low-cost, environmentally safer, and effective technological interventions over the short, medium and long-term for sustainable management of FAW in Africa, especially keeping in view that a huge majority of African farmers are low-resource smallholders.

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