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AGROECOLOGICAL INTERVENTIONS FOR THE SUSTAINABLE MANAGEMENT OF FALL ARMYWORM, *Spodopera Frugiperda* (J.E SMITH) FOR SMALLHOLDER FARMERS

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ABSTRACT

The fall armyworm, *Spodoptera frugiperda* J.E Smith, is a worldwide invasive pest of maize, but also damages sweet corn, rice, and sorghum. This pest originates from the Americas and spread to Africa, Asia, and Australia, with more than 80 countries. Pesticidal management practices always get a priority for the immediate intervention of this pest. These practices are against the environment, biodiversity, and human health. Hence efforts are interestingly growing to develop agroecological strategies for fall armyworm management. This review is focused on diagnosing the various agroecological practices that apply to the sustainable management of fall armyworms. The most common pest management practices that are popular among smallholder farmers are intercropping, push-pull systems, crop rotations, mulching, cultural practices, use local pesticidal plants, habitat diversification, soil nutrient management, and many more.

Intercropping including push-pull farming systems with leguminous crops reduces the number of fall armyworm eggs by increasing the biological control (BC) activities and inhibits the movement of pest larvae. Mulching on the soil ameliorates soil microclimate and improves plant health. Habitat diversification improves the quality of farms and improve BC activities by providing shelter, nectar, alternative food, and pollen to the pest's natural enemies. Similarly, local pesticide plants could be a sustainable alternative to synthetic pesticides. Hence, agroecological practices for pest management improve a balanced environment, regulate natural pests, reduce inputs, diversify the agroecosystem, improve biologically mediated soil fertility, increase yields, and finally improve ecosystem services. These practices must be promoted to replace agricultural intensification with sustainable intensification in maize fields.

Keywords: Fall armyworm, invasive, agroecological practices, sustainable intensification

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INTRODUCTION

Fall armyworm (FAW) (*Spodoptera frugiperda* JE Smith, Lepidoptera: Noctuidae) is a generalist and voracious insect pest of many cultivated crops, and is native to America. This pest was first recorded with its invasive status in the mainland of West Africa in 2016 and has rapidly spread across Sub-Saharan Africa from 2017 to late 2018 (FAO, 2018). By 2019 November, this species had been confirmed in Middle East, followed by other Asian countries. By May 2020, it was confirmed in Australia, Mauritania, with more than 80 countries (Kalleshwaraswamy et al., 2018; Sisay et al., 2018). Its rapid spread along with its potential yield losses in corn causes a threat to the food and nutritional security of millions of smallholding farmers (Day et al., 2017).

Montezano et al. (2018) reported more than 353 host plant species of FAW belonging to 76 plant families with major plant families of Poaceae, Asteraceae, and Fabaceae. *Zea mays* L. is the major host of fall armyworm and is considered as a major pest of maize worldwide. Other host crops are paddy, *Oryza sativa* L., sorghum, *Sorghum bicolor* (L.) Moench, wheat, *Triticum aestivum* L., millet, *Eleusine coracana* Gaertn, barley, *Hordeum vulgare* L., etc. (Montenzano et al. 2018).

Spodoptera frugiperda is a sporadic pest with a long-distance migratory habit that can fly more than 100 km per night (Johnson, 1987). This is a noctuid moth with complete metamorphosis. It has six larval stages; the first three instars (i.e. I. II and III) are relatively less voracious and late instars (IV, Vand VI) are more voracious (Sharma et al., 2022). Fall armyworm larvae in maize plants feed young leaves, whorl, ear and tassel, and maize cob.

Pesticide recommendation always got a priority in most of the invasion countries, which was not effective, environmentally friendly, and economical (Kumar and Kumar, 2019; Yang et al., 2021; Kumar et al., 2022). Large farmers can effectively manage this pest with machine spray of synthetic insecticides and adopting precautionary measurements during pesticide spray, but small farmers don’t have access to such chemicals as well as protective equipment during pesticide spray and are considered a vulnerable group. Hence, in such countries, environmentally friendly and cost-effective agroecological strategies are demanded by smallholder farmers.

Agroecological approaches support sustainable pest management in three different ways: First, it acts on soil health improvement, and thereby improve crop health and pest resistance; second, diversified habitat in agroecological strategies support to improve biological control by increasing the abundance and diversity of pest natural enemies; and third, specific management activity that acts directly on reducing pest outbreak and pest infestations (Harrison et al., 2019).

This review paper tries to address the potential and popular FAW management practices for smallholder poor farmers with emphasis on the locally available, cost-effective, environmentally friendly, and relevant to small farmers. Agroecological approaches always offer culturally appropriate low-cost pest control strategies and can be integrated into the core component of integrated pest management (IPM).

REVIEW OF LITERATURE

The definition of each agroecological method and its significance with supporting examples are presented and discussed. There are more than fifteen such potential agroecological practices in this review paper that are directly or indirectly linked to FAW management.

Intercropping

Intercrops are grown between the main crops. There are four major mechanisms for the reduction of the FAW population and infestation in intercropping maize fields. First, intercropping practices improve soil health and promote plant health, thereby increasing the resistance to FAW damage. Second, intercrops interrupt the movement of FAW larvae in maize fields. Third, disrupts the egg-laying capacity of female moths by visual and chemical cues and finally, provides suitable environmental conditions for the fall armyworm biocontrol agents (Khan et al., 2010). Kumar et al. (2022) reported that intercropping maize with leguminous crops resulted a considerable reduction of the fall armyworm population, notably during the early growth stages of the maize to tasseling compared to monocrop maize (Kumar et al., 2022). Another study conducted by Keerthi et al. (2023) reported that the maize crop intercropped with lady’s finger, *Abelmoschus esculentus* (L.) Moench significantly reduced the pest infestation and increased the yield (6.17 q/ha) compared to other intercropping systems such as french bean, *Phaseolus vulgaris* L., lablab, *Lablab purpureus* (L.) Sweet, cowpea, *Vigna unguiculata* (L.) Walp., coriander, *Coriandrum sativum* L. and spinach, *Spinacia olearacea* L.

The study conducted by Wu, Jiang, Zhou, and Yang, (2022) in southwest China reported that compared to sole maize cropping, intercropping maize fields significantly reduced the infestation by 80% compared to maize monocrop. These results were also supported by the study conducted by Altieri, (1980) and Khan et al. (2010) who reported that bean intercropping maize fields reduced FAW infestation by 20-23 %. The study conducted by Udayakumar, Shivalingaswamy, and Bakthavastasalam, (2021) in Banglore, India reported that maize and Desmodium intercropping maize fields had the lowest plant damage with a reduced number of FAW larvae compared to monocrop of maize. The authors also added that such intercropping maize fields increased the parasitism rate of *Trichogramma* spp compared to monocrop. Similarly, the abundance of Coccinellid predators and Geocorid bugs was significantly higher in maize intercropped with groundnut compared to the sole maize.

Push-pull farming system

A push-pull farming system is a kind of intercropping system in which trap plants, act as ‘pull’ that attracts the pests and ‘push’ crops drive away the pests from the main crops (Cook et al., 2007). In this farming system Napier (*Pennisetum purpureum* (Schumach.) Morrone was used as a ‘pull’ crop and Desmodium was used as a ‘push’ crop to manage the maize stem borer (*Chilo partellus* Swinhoe) in Africa (Khan et al., 2018). Midega et al. (2018) in their study in East Africa reported that FAW population and plant damage were significantly lower in the push-pull farming system in the desmodium intercropping maize field and planting *Brachiaria* as a border crop compared to maize monocrop plots. In such fields, maize yield was 2.7 times greater compared to monocrop plots.

Cover cropping

Cover crops are used to cover the soil in the main field which is grown either before or after the main crop is harvested. Leguminous cover crops are normally grown inside the main crop to increase the soil nutrients, suppress the weed populations, increase moisture conservation as well as provide shelter for pests' natural enemies (Adetunji et al., 2020). For FAW management, an experiment conducted in Florida, USA suggested that sunn hemp, *Crotalaria juncea* (L.), and cowpea cover crops in corn fields reduced the FAW larvae populations by 70-96% compared to sorghum-sudan grass cover crops (Meagher et al., 2022). Similarly, a greenhouse study conducted in the USA suggested that *Triticale* cover crops could strengthen maize resistance to FAW compared to *Pisum sativum* L., *Raphanus sativus* L., and no-cover crops (Davidson-Lowe, 2021).

Crop rotation

Crop rotation is a traditional method of managing pest damage in agriculture by rotating host and non-host crops in alternate years. Crop rotation directly does not affect the FAW population. However, crop rotation improves soil fertility, provides adequate plant nutrition, supports healthy plant growth, and increases pest resistance (Bullock, 1992). These practices also increase the diversity of farm and increase natural enemy abundance and diversity (Meagher et al., 2016). Similarly, according to Dotasara and Choudhary, (2023), crop rotation is a kind of agroecological pest management strategy that disrupts FAW breeding cycles in maize farms.

Mulching practices

Mulching is the practice of spreading dead or living materials on the soil surface. Living mulches increase the plant biomass in the soil, increase the nutrient and moisture content, reduce weed growth that helps to grow healthy plants, and reduce pest damage (Barche, Nair, and Jain, 2015). There are very little evidences of the direct impact of mulching on lowering the fall armyworm population including improving yield but reduced fall armyworm damage on maize leaves by mulching practices was reported by Medega et al. (2018). Similarly, neem leaf residue on soil increases the grain yield by 410-600% which was likely a combined effect of the control of fall armyworm and improved soil fertility (Ewansiha et al., 2023).

Soil residue and nutrient management

Healthy soil provides adequate nutrients to the plant to produce healthy plants. Soil health can be improved by adding organic manure, FYM, green manuring, legume intercropping, cover cropping, mix cropping as well as exogenous application of balanced nutrients. Healthy plants are likely less damaged by insect pests and diseases.

The study conducted in southwest Ethiopia in 2018/2019 reported that maize plots with retained crop residue had a significant reduction in FAW infestation compared with plots without maize residue (control). Furthermore, cattle manure-fertilized maize plots had a lower percentage of FAW infestation when compared with maize plots. Researchers in their study focused on conventional tillage with 100% maize residue with cattle manure showed a significant reduction of FAW compared to the control maize field (Bayissa et al., 2023). Another study conducted by Baudron et al. (2019) reported that applying the optimum dose of cattle manure in maize fields reduces FAW infestation in maize crops.

The study conducted by Singh, Waltz, and Joseph, (2021) at the University of Georgia in 2018/2019 suggested that the growth and development of FAW larvae were favored by the Nitrogen (N) but discouraged by the Potassium (K) on bermudagrass. Similarly, K plays a significant role in various physiological processes such as photosynthesis, respiration, carbohydrate metabolism, translocation, and protein synthesis (Pettigrew, 2008), and directly influences the insect pests and disease resistance on crops (Altieri and Nicholls, 2003).

Another study by Reddy, Sugeetha, Asha, and Mahadevu, (2024) highlighted that nutrient components like nitrogen, phosphorous, magnesium, and sulfur may influence the attack of FAW with greater damage, whereas, potassium, calcium, zinc, and manganese reduce the infestation by FAW.

Another important element, silicon (SiO2) significantly influences the growth and development of *S. frugiperda* larvae, particularly on colonization and damage in maize by reducing the fecundity and increasing the mortality of newly emerging FAW larvae (Haq et al. 2022). To support these findings, Zimba et al. (2022) suggested that silicon element (Si) accumulation in plants acts as a mechanical barrier to insect herbivory but creates a suitable chemical environment to increase the attraction of nymphs of *Euthyrhynchus floridanus* L., a generalist predator of FAW. Hence, using silicon sources of organic manure or compounds on maize crops reduces the fall armyworm damage which can be integrated into integrated pest management (IPM) or organic pest management (OPM) (Pavani, Kalleshwaraswamy, and Onkarapp, 2023).

Whorl application of soils and sand

Smallholders and poor farmers around the world have been using various local and traditional practices for vegetable pest management including FAW management in corn fields. Soil materials when touching the skin of FAW can damage the protective wax layer of the larval skin may increase abrasiveness, absorption, and desiccation on the larval bodies, and finally increase larval mortality (Hruska, 2019). Similarly, soil contains entomopathogenic communities such as *Bacillus thuringiensis* Berliner, *Beauveria bassiana* (Bals.-Criv.) Vuill. and virus (sfMNPV) also induce fall armyworm larval mortality (Williams, 2023).

The use of diatomaceous earth which is found in sediments of rivers, streams, and lakes are rich in silica, which increases FAW larval mortality by 47%. Similarly, Bentonite, a natural soft, fine, and highly absorbent clay may cause FAW larval mortality by 93% in laboratory conditions (Silva et al., 2016).

Chawanda et al. (2023) reported that soil types as well as methods of application influence their effectiveness on the FAW larval population and damage level. According to them, dry soil applied after watering was the most effective to reduce larval population. However, the application of wet soil before watering can also significantly reduce the number of FAW larvae and reduce leaf damage percentage (Chawanda et al., 2023).

Whorl application of wood ash

Wood ashes from various types of wood fires are a common practice of fall armyworm management by smallholder farmers in Africa and Asia. When wood ashes touch the larva they induce suffocation, abrasion, and desiccation on the larval body. A study conducted from 2020 to 2021 in Malawi by Chawanda et al. (2023) suggested that wood ash (3 g/plat) on maize whorl significantly reduced the FAW larval population and maize leaf damage by 50% and increased the grain yield by 24-36% as compared to the untreated control. A similar study conducted by Jalali et al. (2024) in Pakistan reported that ash-treated plots reduce the FAW larval population and reduce the damage on maize leaves.

Whorl application of animal urine

Urine spray or whorl application is also a general practice of pest management in some parts of the world (Hruska, 2019). Cow urine, buffalo urine, or rabbit urine are the common animal urine used to manage this invasive pest. Farmers of South Asia use animal urine alone or mixed with other ingredients such as plant extracts as an alternative to insecticides. Research in Gujarat, India in 2019-2020 reported that cow urine or buffalo urine sprayed on maize farms reduced the incidence of FAW (Patel et al., 2020).

Spray of fish soup

Use of fish soup alone and fish soup with sugar spray are common FAW management practices in Sub-Saharan Africa. It is reported that fish soup and sugar solutions attracted a wide range of insects, including potential natural enemies (predators and parasitoids) of FAW (Njuguna et al., 2021), and potentially improved BC activity in sprayed plots. Chemical analysis demonstrated that fish soups are rich in N, P, and Ca with 76 volatile organic compounds, out of which 16 compounds are insect attractants (Niassy et al., 2024).

Insecticidal plant materials

In many parts of the world, insecticidal plants are recommended as safe biopesticides which are considered as a substitute for synthetic insecticides. Various studies are conducted to evaluate the efficiency of such insecticidal plant materials in reducing FAW populations and their damage to maize crops. Commonly used such repellent plant materials are *Azadirachta indica* Juss, *Melia azedarach* L., *Nicotiana tabacum* L., *Ageratum conyzoides* L., and many more. Plant families under Asteraceae, Euphorbiaceae, Meliaceae, Sapindaceae, Verbanaceae are insecticidal plant families and are mostly tested to the FAW larvae (Rioba and Stevenson, 2020). The larval mortality of such plant extract ranges from 20-80% and largely such mortality depends on the type of plant species, plant parts used, bioassay environment, bioassay type, concentration of extracts as well as FAW larval stages (Phambala et al., 2020; Ribo and Stevenson, 2020).

Habitat diversification at farm and landscape scales

Diversification of crop or non-crop habitats in or off- the field increases the abundance of natural enemies (Tiwari, Sharma, and Wratten, 2020) and improves the BC activity according to the natural enemy's hypothesis reported by Russell, (1989). Such diversified habitats provide shelter, nectar, alternative food, and pollen to the pest's natural enemies and increase the fitness of biological control agents (Gurr et al., 2017). Crop diversity and landscape complexity provide the resources for alternative prey of generalist predators and regulate the natural population of fall armyworms in the maize cropping system (Dassou et al., 2023). On the other side, diversification increases the partitioning of resources and reduces pest infestations (Root, 1973). Suitable examples of habitat diversification in maize farms are intercropping, mix cropping, cover cropping, trap cropping, planting insectary plants, bund management, creating beetle banks, weed management, agroforestry, etc. (González-Chang et al., 2019; Collins et al., 2002).

The study conducted in Ghana in 2019 reported that FAW damage on corn increased significantly with distance from the semi-natural habitat (field edges) this is because of the increasing richness and diversity of Hymenoptera with a decrease in the distance from the semi-natural habitat (Jordon et al., 2022). Legume-based field diversification in corn fields increases the number of *Trichogramma*, Coccinellid predators, and Geocorid bugs and reduces the infestation of fall armyworms (Udayakumar, Shivalingaswamy, and Bakthavatsalam, 2021). Maize field diversification with some cover crops such as sun hemp and cowpea increase the larval parasitoids of FAW, *Chelonus insularis* Cresspon (Hymenoptera: Braconidae) and potentially reduces the FAW larval population by increasing parasitism (Meagher et al., 2022).

Weed management practices at the farm level

Plants in general become unwanted if they grow in an unwanted place, overlay abundance and time. They are considered as a weed and pest of the main crop because they compete to the main crop for nutrients, irrigation, space, and sunlight (Ekwealor et al., 2019). But leaving a small patch or strips in fallow land is useful for pests' natural enemies. In some circumstances, if such weeds are flowering plants and grow in field bunds, margins, or between the main crops, are considered ‘beetle bank’ that increases the abundance of natural enemies and often reduces the fall armyworm infestation by improving biological control of pest (Harrison et al., 2019). But sometimes, weeds provide shelter to the FAW increase the abundance of the fall armyworm population and may create an ecosystem disservice (González-Chang et al., 2019)

Crushing egg masses and hand-picking fall armyworm larvae

Regular visits to the maize field, observation of various life stages of the pest, and manual destruction can significantly reduce the FAW populations (Makale et al., 2022). These methods do not require any extra investment and time.

CONCLUSION

Agroecological pest management practices include biodiversity conservation, sustainable farming, promoting multiple ecosystem services, and creating a healthy ecosystem. Such practices focus on utilizing local resources that are economical, socially acceptable, and environment friendly. None of the countries in the world are successful in getting rid from invasive species such as fall armyworm, tomato leaf miners, and many other transboundary pests. In early years, farmers were forced to use synthetic insecticides to manage such invasive threats. Now, such practices are considered non-economical, and highly hazardous. Hence, agroecological pest management has gained prominence. For fall armyworm management, agroecological practices became more popular where multiple ecosystem services such as improving predation, parasitism, and mineralization, soil water conservation, reducing the input cost, increasing soil microbial activity and improving soil health and finally increasing grain yield by promoting sustainable agriculture.

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