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# INTEGRATED PEST MANAGEMENT STRATEGIES FOR INVASIVE FALL ARMYWORM

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## ABSTRACT

The fall armyworm (*Spodoptera frugiperda*) is a major pest that can cause significant yield losses in various crops worldwide. Traditional chemical control measures have proven to be ineffective and unsustainable, leading to an urgent need for alternative management strategies. Agronomic practices, such as crop rotation, intercropping, and tillage, can reduce the pest's impact on crops. Biological control measures, such as the use of natural enemies, microbial agents, and pheromone traps, have also shown promise in managing fall armyworm infestations. Biotechnological approaches, including the use of RNA interference and transgenic plants expressing insecticidal proteins, have demonstrated potential in controlling fall armyworm populations. Despite their promising results, these management strategies require further research and development to optimize their efficacy, cost-effectiveness, and environmental safety. Integration of multiple management strategies is likely to provide the most sustainable and effective approach to manage fall armyworm infestations in agricultural systems.

***Keywords***: Fall Armyworm, IPM, Resistance Management

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## 1. INTRODUCTION

Fall armyworm (FAW) is a highly destructive pest of many economically important crops worldwide (Chao et al. 2019; Padhee and Prasanna 2019; Chen and Palli 2022). The scientific name of fall armyworm is *Spodoptera frugiperda*. It is a moth of the Noctuidae family, and the larvae (caterpillars) are the destructive stage of this insect. The adult moth is brown with a wingspan of about 3-4cm, and it can fly long distances, making it a potential threat to new areas. FAW is native to the tropical and subtropical regions of the Americas (Ren et al. 2019). However, it has recently invaded and caused significant damage to crop in Africa, Asia, and Oceania. The insect was first detected in Africa in 2016, and since then, it has spread to more than 70 countries, causing significant losses to maize, sorghum, rice, and other crops. The larvae of FAW are known to feed on more than 350 plant species, including important crops such as maize, rice, sorghum, cotton, and vegetables. The damage caused by FAW is due to the feeding activity of the larvae, which can result in significant yield losses. In severe cases, the entire crop can be destroyed, leading to food insecurity and economic losses (Tippannavar et al. 2019). FAW is a particularly challenging pest to manage because of its high reproductive potential, wide host range, and ability to rapidly develop resistance to insecticides. Furthermore, FAW has a short life cycle, allowing for multiple generations to occur within a single cropping season, further exacerbating the damage. To address the challenge posed by FAW, there is a need for integrated pest management strategies that incorporate a range of control measures, including cultural practices, biological control, and the use of insecticides. Additionally, there is a need for ongoing research to better understand the biology and behavior of this pest, as well as to develop new control measures that are effective, affordable, and environmentally sustainable (Guo et al. 2020).

## 2. Distribution

Fall armyworm (*Spodoptera frugiperda*) is native to the tropical and subtropical regions of the Americas, but it has spread rapidly and become a global invasive pest in recent years. The insect was first detected in Africa in 2016 and has since spread to over 70 countries in Africa, Asia, and Oceania. It has also been reported in parts of Europe and the Mediterranean (Nagoshi et al. 2018). The rapid spread of fall armyworm has been attributed to its ability to fly long distances and adapt to new environments quickly. Under favorable wind patterns, moths have been

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recorded to travel distances of up to 1600 km. While in some regions, they arrive seasonally, under conducive weather conditions and with the availability of alternate hosts, they can establish endemic populations and spread to adjacent areas throughout the year. Fall armyworm is known to appear in large numbers, particularly following a dry period, and its larvae stage is the most destructive to crops (Firke et al. 2019; Hafeez et al. 2021; Zhu et al. 2022).

### 2.1. Spread

The spread of fall armyworm has been facilitated by international trade, human migration, and natural factors such as wind and weather patterns. The insect is known to travel long distances during its adult stage, and the presence of suitable host plants and favorable environmental conditions can enable its rapid colonization of new areas. The spread of fall armyworm has caused significant economic losses to many crops worldwide (Day et al. 2017; Hasanuzzaman et al. 2018; Shwethakumari et al. 2021; Wang et al. 2022).

### 2.2. Host Plants

Fall armyworm is known to feed on more than 80 plant species belonging to different families. The insect has a strong preference for grasses, and its primary hosts include maize, sorghum, rice, and sugarcane. However, it has also been reported to feed on other crops such as cotton, soybean, peanut, tobacco, and vegetables such as tomato, cabbage, and onion. The wide host range of fall armyworm makes it a significant threat to food security and agricultural production globally (Kumela et al. 2019; Bista et al. 2020; Tambo et al. 2021). In addition to cultivated plants, fall armyworm can also feed on wild grasses and other plant species, which can serve as alternative hosts, allowing the insect to survive and reproduce even in the absence of cultivated crops. The ability of fall armyworm to exploit a diverse range of host plants and adapt to different environments contributes to its invasive potential and makes it a challenging pest to manage (Ren et al. 2019; Hillman 2022; Degaga and Degaga 2023).

## 3. Life Cycle

A thorough comprehension of the life cycle of insect pests is critical in developing effective management approaches. The life cycle of fall armyworm is dependent on its surrounding environment. In the USA, the insect can complete its life cycle within 30 days during summer conditions with a daily temperature of about 28°C, while it may take up to 60-90 days during spring and winter (Pogue, 2002). The development of fall armyworm has a minimum threshold of 13.01°C and a maximum threshold of 30°C (Day et al. 2017). The number of generations varies depending on the arrival of dispersing adults and meteorological factors in a particular area. Female adult fall armyworm lays eggs in clusters on both sides of leaves, with each female laying approximately 1500-2000 eggs. The eggs are dome-shaped, 0.3-0.4 mm in diameter, and hatch within 2-3 days (Baudron et al. 2019). During summer, fall armyworm undergoes six instars, with immature larvae appearing greenish with black heads. Interestingly, Wu et al. (2021) reported that invasive populations of *S. frugiperda* employ a bet-hedging strategy, leading to earlier reproduction and a prolonged reproductive lifespan, thus enhancing their invasion success. Mature larvae have a brownish coloration and a reddish-brown head, with a white inverted "Y"-shaped suture indicating full maturity. Pupation occurs in a cocoon measuring 20-30mm in diameter and oval in shape, at a depth of 2-8cm in the soil. The pupa is reddish-brown, 14-18mm long and 4.5mm wide, and undergoes an 8-9 days pupal phase (Wu et al. 2021). The adult fall armyworm has a gray and brown color scheme, with silvery-white hind wings featuring a small dark mark around the margins. The adult is nocturnal, emerging only during hot and humid evenings, and has an average lifespan of 7-10 days (Cock et al. 2017).

## 4. Nature and Symptoms of Damage

The larvae of the fall armyworm are the stage where this pest causes damage. Initially, the immature larvae consume the top portion of the leaf blade, while leaving the opposite epidermal layer unharmed. During the second or third instar, they make holes in young leaves, and as they mature, they feed on the leaf from its edge towards the center. The impact of young larvae is mostly limited to the whorl stage, but as the leaf expands, the affected plants display shot hole symptoms (Brévault et al. 2018; Sisodiya et al. 2018; Sokame et al. 2020). As the larvae mature, their population typically decreases due to cannibalistic behavior, and generally only one or two larvae can be observed per plant. Nonetheless, mature larvae can cause significant defoliation (Pogue 2002; Branco et al. 2016; Horikoshi et al. 2021). In uncontrolled situations, larvae can strip all green leaves within a brief period, leaving only leaf ribs and stalks that seem torn. The plant's sensitivity to the larvae varies depending on the stage of growth, with the late whorl stage being the most vulnerable. Infestation with mean densities of 0.2 to 0.8 larvae per plant during this stage can result in production losses of 5 to 20%. In severe cases, larvae move up to the ear and feed on kernels, leading to complete yield loss (Terefe and Gudero 2019; Bastarache et al. 2020; Deshmukh et al. 2020; Njeru and Kusolwa 2021).

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## 5. Agronomic Practices for The Management of Fall Armyworm

### 5.1. Sowing Window Management

Sowing window management is one of the strategies that can be used to manage fall armyworm infestations. This approach involves planting maize at specific times to reduce the risk of infestation and limit the severity of damage caused by the pest. Early planting is one of the methods used to reduce the impact of fall armyworm on maize crops. Early planting helps the maize crop to reach the critical growth stages before the pest becomes active, thus reducing the chances of infestation. Early-planted maize crops also have a higher yield potential than those planted later in the season (Rahmathulla et al. 2012). Another approach is to delay planting until the risk of infestation has passed. This method involves monitoring the pest's presence and waiting until the eggs hatch and the larvae emerge before planting the maize crop. This reduces the risk of infestation and ensures that the maize crop is not exposed to the pest during its most vulnerable stages of growth (Kumar et al. 2022). Crop rotation is another management approach that can be used to reduce the impact of fall armyworm. Crop rotation involves alternating maize with other crops such as legumes, which are not hosts of the pest. This reduces the build-up of the pest population, as the larvae will have limited food sources in the maize fields (Kumar et al. 2022). Overall, sowing window management is an effective approach to managing fall armyworm infestations. By planting maize at specific times and monitoring the pest's presence, farmers can reduce the risk of infestation and limit the severity of damage caused by the pest.

### 5.2. Tillage and Land Preparation

A study evaluated the effect of tillage systems on the population dynamics of fall armyworm in maize. The study compared the conventional tillage system with the no-tillage system. Results showed that the no-tillage system had significantly lower fall armyworm populations than the conventional tillage system. This was attributed to the fact that the no-tillage system resulted in reduced soil disturbance, which may have minimized the exposure of fall armyworm eggs to natural enemies (Harrison et al. 2019; Regan et al. 2020; Mutyambai et al. 2022). Another study conducted by Wang et al. (2022) in China, investigated the effect of different tillage practices on the population dynamics of fall armyworm in maize. The study compared the conventional tillage system with the deep tillage system and the shallow tillage system. Results showed that the deep tillage system had significantly lower fall armyworm populations than the conventional and shallow tillage systems. This was attributed to the fact that the deep tillage system resulted in greater soil disturbance, which may have exposed fall armyworm eggs and larvae to predators and parasitoids. The ridge-tillage system had significantly lower fall armyworm populations than the conventional tillage system. This was attributed to the fact that the ridge-tillage system resulted in greater soil disturbance, which may have exposed fall armyworm eggs and larvae to natural enemies (Kalele 2021; Kumar et al. 2022).

The minimum tillage system had significantly lower fall armyworm populations than the plowing and harrowing system. This was attributed to the fact that the minimum tillage system resulted in reduced soil disturbance, which may have minimized the exposure of fall armyworm eggs to natural enemies (Kumar et al. 2022). Studies have shown that reduced soil disturbance, such as in the no-tillage and minimum tillage systems, can result in lower fall armyworm populations. However, greater soil disturbance, such as in the deep tillage and ridge-tillage systems, may also expose fall armyworm eggs and larvae to predators and parasitoids, leading to lower populations. Therefore, the choice of tillage and land preparation system should take into account the local conditions and the specific objectives of pest management (Altieri and Nicholls 2003; Day et al. 2017; Bateman et al. 2018; Assefa 2018).

### 5.3. Nutrient Management

Among the cultural practices, nutrient management is a promising strategy that involves balancing soil nutrient levels to improve crop growth and increase plant resistance to pests and diseases. Several studies have investigated the effect of nutrient management on fall armyworm management. According to Morales et al. (2001), the use of organic fertilizers and biofertilizers can improve maize growth and reduce the damage caused by fall armyworm. The researchers found that the use of organic fertilizers such as cattle manure, poultry manure, and green manure, as well as biofertilizers such as rhizobia and mycorrhizal fungi, increased maize plant height, stem diameter, and leaf area index, while reducing the number of fall armyworm larvae per plant and the percentage of damaged leaves. The use of high nitrogen rates (150kg/ha) increased the severity of fall armyworm infestation, resulting in lower maize yields. In contrast, moderate nitrogen rates (75kg/ha) resulted in a lower number of fall armyworm larvae per plant, reduced the percentage of damaged leaves, and increased maize yield. The study suggests that proper nitrogen management is crucial in reducing fall armyworm infestation and improving maize yields (Kumar and Girijesh 2015). High nitrogen rates (100kg/ha) resulted in a higher number of fall armyworm larvae per plant and a lower maize yield, while moderate nitrogen rates (50kg/ha) and high phosphorus rates (60kg/ha) reduced fall armyworm infestation and increased maize yield. The study highlights the importance of balanced nutrient management in reducing fall armyworm damage and improving maize yields (Singh 2020).

### 5.4. Cropping System Measures

***5.4.1. Crop Rotation:*** Crop rotation involves the planting of different crops in a field in a sequence to reduce pest populations and increase soil fertility. Crop rotation helps in the management of fall armyworm by reducing the availability of food and shelter to the pest. Crop rotation also helps in breaking the pest's life cycle, reducing the build-up of pest populations. Several studies have reported that crop rotation with non-host crops reduced the incidence and severity of fall armyworm infestation in maize (Lamsal et al. 2020; Van den Berg et al. 2021; Kumar et al. 2022).

***5.4.2. Intercropping*****:** Intercropping involves the planting of two or more crops in the same field. Intercropping helps in the management of fall armyworm by reducing the availability of food and shelter to the pest. Intercropping also helps in breaking the pest's life cycle, reducing the build-up of pest populations. Several studies have reported that intercropping maize with leguminous crops reduced the incidence and severity of fall armyworm infestation in maize (Kebede et al. 2018; Tanyi et al. 2020; Kumar et al. 2022).

***5.4.3. Trap Cropping*****:** Trap cropping is a method of pest management that involves planting a crop that is attractive to the pest and serves as a trap to lure them away from the main crop. In the case of the fall armyworm, trap cropping has shown promise as an effective management strategy. Several studies have explored the use of trap cropping for managing fall armyworm infestations (Khatri et al. 2020; Kumar et al. 2022). A study conducted in Brazil found that planting maize as a trap crop reduced fall armyworm damage in the main crop by 54%. The researchers also found that planting sorghum as a trap crop reduced damage by 40%. In addition to intercropping, other trap cropping strategies have also been explored for managing fall armyworm. A study conducted in Zambia evaluated the use of a "push-pull" system, where maize is intercropped with Desmodium, a plant that repels fall armyworm, while a second plant, Napier grass, is planted around the field perimeter to attract and trap the pests. The researchers found that the push-pull system reduced fall armyworm damage to crops significantly (Midega et al. 2018; Bhusal and Bhattarai 2019; Guera et al. 2020).

***5.4.4. Pheromone Traps*****:** Pheromone traps are an effective and environmentally friendly approach to managing fall armyworm populations. Pheromones are chemicals released by female insects to attract males for mating. By mimicking these chemicals, pheromone traps can lure male fall armyworm moths into a sticky trap, preventing them from mating with females and reducing the number of offspring produced. Several studies have investigated the effectiveness of pheromone traps in managing fall armyworm populations. The use of pheromone traps reduced fall armyworm infestations by up to 96% in maize fields (Ganiger et al. 2018; Assefa and Ayalew 2019; Giner Jiang et al. 2022). However, the effectiveness of pheromone traps can be influenced by factors such as trap design, placement, and density. The trap placement and density significantly affected the capture rate of fall armyworm moths, with higher trap density leading to greater moth capture rates. Furthermore, while pheromone traps can be effective at reducing fall armyworm populations, they may not be sufficient as a stand-alone management strategy. The use of pheromone traps alone did not significantly reduce fall armyworm infestations in maize fields, but the combination of pheromone traps and chemical insecticides was effective at reducing infestations (Cruz et al. 2012).

***5.4.5. Biotechnological Approaches*****:** Biotechnological approaches have emerged as a promising tool for the management of fall armyworm (FAW) infestations. In recent years, several studies have been conducted to evaluate the effectiveness of various biotechnological approaches for controlling FAW populations. One approach is the use of genetically modified crops that produce insecticidal proteins such as Bacillus thuringiensis (Bt). Studies have shown that Bt maize can effectively control FAW infestations, reducing larval populations and damage to the crop. However, the use of Bt crops can also lead to the development of resistance in FAW populations, highlighting the need for careful management strategies (Bernardi et al. 2015; Zafar et al. 2020; Santos-Amaya et al. 2022). Another biotechnological approach is the use of RNA interference (RNAi) technology to target FAW (Munawar et al. 2023). RNAi works by silencing specific genes in the FAW genome, preventing the production of essential proteins required for survival. Several studies have shown that RNAi can effectively reduce FAW populations and damage to crops. However, the technology is still in its early stages and requires further research to determine its long-term effectiveness and potential risks (Yao et al. 2022). In addition to genetic approaches, biopesticides derived from natural sources such as bacteria, fungi, and plant extracts have also been explored for FAW management. Studies have shown that certain biopesticides can effectively control FAW populations and reduce damage to crops, with

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minimal harm to non-target organisms and the environment. Another promising biotechnological approach for FAW management is the use of pheromones to disrupt mating behavior (Books 2019).

Overall, biotechnological approaches show great promise for the management of fall armyworm infestations. However, careful management strategies are required to prevent the development of resistance and minimize potential risks to non-target organisms and the environment. Further research is needed to optimize the effectiveness and sustainability of these approaches.

***5.4.6. Biological Control*:** Biological control is one of the most promising management options for the fall armyworm, as it is environmentally friendly and sustainable. This approach involves the use of natural enemies such as predators, parasitoids, and pathogens to control pest populations. There are several examples of successful biological control strategies against fall armyworm in different parts of the world. One of the most successful biological control strategies against fall armyworm is the use of egg parasitoids. Egg parasitoids are natural enemies that lay their eggs in the eggs of the pest, which then develop and kill the pest eggs. There are several species of egg parasitoids that have been found to be effective against fall armyworm, including *Telenomus remus, Trichogramma* spp., and *Habrobracon hebetor*. Studies have shown that releasing these parasitoids can reduce fall armyworm populations by up to 90% (Wu 2020). In addition, several entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* have been found to be effective against fall armyworm larvae (Gowda et al. 2021). Predatory insects such as ants and earwigs can also be effective in controlling fall armyworm populations. These predators feed on fall armyworm eggs and larvae, reducing the number of pests in the field. In addition, several parasitic wasps such as *Cotesia marginiventris* and *Chelonus insularis* have been found to be effective in reducing fall armyworm populations (Kumar et al. 2022).

## 6. Conclusion

In conclusion, managing the fall armyworm infestation requires a multidisciplinary approach. Agronomic practices such as crop rotation, intercropping, and trap cropping have been effective in reducing the fall armyworm population. Biological control methods such as the use of natural enemies, biopesticides, and pheromone traps have shown promising results in reducing the damage caused by the pest. Biotechnological approaches, such as the development of transgenic plants, RNA interference, and gene editing, also hold great potential for managing the fall armyworm. However, it is crucial to conduct further research to ensure the safety and efficacy of these biotechnological interventions. Overall, the integration of these management strategies can lead to a sustainable and effective approach in managing the fall armyworm and ensuring food security.

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