

Integrated Pest Management Strategies for Sustainable Control of Major Corn Pests

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Abstract: The production of corn is continually threatened by various pests, including fall armyworms, aphids, grasshoppers, and beetles that affect yield and quality of the crop. The study presented here provides a total pest management plan to control these major corn pests using several avenues of pest management, including mechanical pest management, biological pest management, and botanical pest management. Fall armyworms were controlled using hand picking, applying sand in whorls, pheromone traps, and deep tillage. Biological methods considered for controlling fall armyworm included *Trichogramma* species parasitoids, *Bacillus thuringiensis*, *Nomuraea rileyi*. Botanical method used for control of fall armyworm included neem oil, garlic extract sprays, and intercropping with repellent crops or trap crops. Aphids were managed with hand removal, natural predators such as lady beetles and lacewing, and biopesticides including horticultural oils (mineral oil), pyrethrin (pyrethroids), and neem oil-based insecticides. Grasshoppers were managed using physical barriers (exclusion), tillage, and planting earlier in the season and biological agents (*Nosema locustae*) as well as predators (spiders and beetles). Less conventional botanical tactics such as repellent botanical insecticide sprays and spraying flour as a powder dust to control grasshoppers were also implemented. Beetles were managed using traps, hand picking, and natural enemies (for example parasitoids wasps), using neem and pyrethrum based insecticides. The following strategies can be incorporated into an Integrated Pest Management (IPM) program to allow for sustainable and environmentally responsible corn pest control. Using the various IPM methods to lessen reliance on synthetic insecticides is in keeping with the ways of fostering long-term protection for crops. In addition, methods that do not depend on chemicals work in harmony with agricultural and ecological environments in corn production.

Keywords: Aphids, Beetle, Biological control, Botanical control, Fall Armyworm, Grasshopper, Integrated pest management, Mechanical control.

1. Introduction

The corn plant (*Zea mays* L.) is one of the most important cereal crops in the world and is often grown for food, fodder, and industrial purposes. Its importance as a crop lies in its high nutritional value and economic importance, which is part of the foundation of food declaration on a global scale. The sustainability of corn cultivation is, however, continually at risk from different insect pests that cause yield loss and reduce grain quality. The most notable of these insects are the Fall Armyworm (FAW) (*Spodoptera frugiperda*) [1-4], aphids (*Rhopalosiphum maidis*) [5], various grasshoppers [6], [7], and beetles [8] including corn flea beetles and sugarcane beetles. Each of these insect pests has various feeding habits; feeding on different parts of the corn plant (such as leaves, whorls, stems, ears, and silks) which can cause damage displaying symptoms such as leaf skeletonization, ear damage, stunted growth, and in some cases total loss of plant materials.

Although chemical pesticides have been commonly used to control these insect pests pest-management practices using pesticides to control insect pests can lead to ecological imbalances, resistance management, environmental contamination, and non-target organism effects [9-11]. The issues associated with pesticide use are exemplified in the need for sustainable and environmentally sound pest-management alternatives. Integrated Pest Management (IPM) [12] provides a firm foundation to manage pest populations below economic threshold levels while reducing harmful environmental impacts by using a combination cultural, mechanical, biological, and botanical control methods.

Objectives: This study aims to test an overall IPM-based strategy to reduce pests on corn. This strategy is based on physical removal, beneficial insects, entomopathogens, and biopesticides from plant sources, such as neem oil and garlic extract. The main goal is to assess an integrated, environmentally friendly pest management system that reduces the effects of major corn pests such as the FAW, aphids, grasshoppers, and beetles while reducing the impact on the environment and creating normal practices in agriculture. Using these methods in interaction ultimately hopes to improve pest suppression, build ecological resiliency, and create long-term productivity and sustainability of corn.

Contribution: This work provides a comprehensive pest management plan for corn crops, including mechanical, biological and botanical control measures. It addresses major pest threats-FAW, aphids, grasshoppers, and beetle-using environmentally friendly and sustainable intervention methods. This study provided a practical, low-cost alternative to chemical-based pesticides while aligning with the principles of IPM. Field level recommendations are provided for extensible applications in sustainable agriculture.

Motivation: Corn production is increasingly being challenged with continuous pest infestations which negatively impact food security and farmer livelihoods. Reliance on chemical pesticides has led to environmental degradation, pest resistance, and health hazards. Therefore, there is a challenge for sustainable and biological pest control options. This study has been inspired with the goal to develop an integrated solution which provide crop protection and maintains an ecological balance.

Structure of the paper: In this paper the related works of discussed in section 2. The pest management controls are discussed in section 3. The results of pest control are discussed in section 4. Finally, the conclusions are discussed in section 5.

2. Related Works

The fall armyworm (*Spodoptera frugiperda*), is a devastating pest of maize that can impose significant yield losses across tropical and subtropical regions of the world. The rapid expansion of this invasive pest has imposed economic hardships on maize producers. Pest management was principally dependent on chemical insecticides which were insufficient due to resistance development and negative environmental consequences. Integrated pest management (IPM) strategies – what many researchers suggest as the answer to the management of the FAW is a series of methods that integrate biological, cultural and chemical based techniques. Anilkumar et al. [13] aims to report the efficiency of different integrated management strategies so that *S. frugiperda* will no longer be a threat to maize production.

The pest FAW (*Spodoptera frugiperda*) has become an invasive species of concern for maize, especially in India, with implications for agricultural productivity and potentially to food security. Farmers in Karnataka have been spending considerable amounts of money on insecticides to manage infestations, translating into higher production costs. However, the reliance on chemical control has led to questions on whether such losses are economically sustainable and if there will be environmental impacts. A better understanding of the economic burden to farmers due to pesticide use to manage *S. frugiperda* is needed despite the considerable effort for FAW

management. Deshmukh et al [14] analyzed the economic implications of the pesticide application for management of *S. frugiperda*, in addition to evaluating potential strategies to reduce the costs.

Maize-wheat rotation was a widely adopted cropping system in well over half of the world, particularly in South Asia, providing critical food and income for millions of farmers in those regions. Conventional cultivation methods in maize-wheat rotations had, however, contributed to soil degradation, lowering productivity and profitability. We evaluated conservation agriculture-based integrated crop management (CA-ICM) as a more sustainable approach that could potentially enhance soil health and productivity, as the practice incorporates minimum soil disturbance, crop rotation, and organic farming inputs. Scientific studies and on-farm trials demonstrated how CA-ICM practices could restore degraded soil by improving soil structure, increasing water retention, and greater availability of nutrients. Pooniya et al [15] details how CA-ICM practices improved the profitability, market competitiveness, and soil properties of maize-wheat rotation systems, demonstrating its broader potential needed to work toward sustainable agriculture over the long-term.

The FAW (*Spodoptera frugiperda*) is a major pest of maize worldwide that has caused the crop to undergo enormous yield losses. Conventional chemical control has increased in ineffectiveness due to the considerations of environmental issues and insect resistance. Therefore, biocontrol agents were investigated as a potential sustainable management option for *S. frugiperda*, including entomopathogenic nematodes. These nematodes represent a potential option for pest control while being less harmful than chemical pesticides. Patil et al. [16] examined the biocontrol potential for entomopathogenic nematodes to control fall armyworms. It provided evidence for the potential use of sustainable pest management approaches in maize.

Cereal-based rotations formed part of the bedrock of agriculture globally that afforded food security and a steady livelihood for farmers. Even in cases where fumigants were applied, conventional practices still resulted in soil degradation, pest accumulation, and a shallow recovery in productivity. Consequently, International Crop Management (ICM) was developed in response to the need for sustainable practices that utilize crops rotation, aided by fertilization and pest management to help recover soil health, increase productivity, and improve economic returns. ICM is a solid departure from conventional practices, assisting farmers to ameliorate the problems of agricultural sustainability over time. DAS et al. [17] to assess the effect of ICM on productivity and profitability in cereal-based rotations and to provide a context that would facilitate understanding of its use to provide support for modern agricultural practices.

The FAW (*Spodoptera frugiperda*) had emerged as a primary pest of maize cultivation, which made it a potential threat to organic farming systems that are threatened more than any maturer practice by the pest's resistance to most chemical insecticides. Organic farmers had to confront significant roadblocks to manage the pests without compromising both their farm ecosystem and surrounding systems. Alternatives to chemical insecticides had largely been bio-intensive tactics for example, biological control agents, biopesticides, and cultural practices as suggested alternatives to moving towards better environmentally sustainable alternatives for *S. frugiperda* management. Keerthi et al. [18] focused on bio-intensive tactics for controlling the pests and potentially supporting organic maize production, while improving sustainable pest management in agriculture.

The FAW (*Spodoptera frugiperda*) has quickly established itself as one of the more destructive pests of maize and other cereal crops globally. Chemical management practices have resulted in low success rates and are not sustainable. Natural enemy organisms are receiving renewed attention as biological control agents. Viruses, specifically the Nucleopolyhedroviruses (NPVs) that are able to infect and kill *S. frugiperda*, are considered viable biocontrol agents because they are virulent to *S. frugiperda* but do not harm non-target organisms. Hussain et al. [19] intended to evaluate the possibilities of viral pathogens for controlling FAW so that pest managers may better consider NPVs within a holistic pest management program.

The FAW (*Spodoptera frugiperda*) has rapidly expanded across multiple countries, particularly the SAARC member states, where it is threatening food security and livelihoods. As an invasive pest, it causes damage to maize

and other staple crops. Its management using chemical and cultural practices has been inadequate to control population growth. This case study was intended to evaluate the impact of FAW in SARRC countries, describing the plight of farmers and governments to control FAW in their countries. Day et al. [20] noted the need for pest management strategies and collaborative efforts to address the repercussions of *S. frugiperda*.

Table 1: Comparison Table on Pest Control Solutions

Reference	Key Findings/Contributions	Management Strategies/Approaches
Nyamutukwa et al. [21]	Highlights challenges in managing FAW in Africa, such as limited resources, lack of awareness, and resistance issues.	Proposes sustainable solutions like biological control, improved monitoring, and community engagement for better management.
Babendreier et al. [22]	Examines the potential risks and challenges posed by <i>S. frugiperda</i> in Europe, focusing on agricultural threats.	Focus on biological control agents, habitat manipulation, and effective monitoring to prevent spread and control infestations.
Tepa-Yotto et al. [23]	Reviews the state of integrated management practices after six years of <i>S. frugiperda</i> detection in Africa, including pest behavior and impact on agriculture.	Highlights IPM practices, biological control, and regional cooperation to manage pest spread effectively.
Makgoba et al. [24]	Discusses the economic and yield impacts of <i>S. frugiperda</i> on small-scale maize farmers and their coping mechanisms.	Focus on cultural control, chemical control, and local farmer education programs to mitigate the impact of the pest.

2.1 Problem Identification

Corn cultivation is negatively affected by a number of insect pests that can damage the leaves, stems and ears, leading to considerable yield losses. Historically, farmers have relied heavily on chemical pesticides which can result in pest resistance, damage to the environment, and health and safety considerations. Otherwise pest management protocols are not sustainable or ecologically safe. An integrated, non-chemical approach is needed to manage multiple pests in corn.

3. Solution for Corn Pest

The research focuses on pest control solutions in corn fields, specifically targeting pests such as Fall Armyworm, aphids, grasshoppers, and beetles using mechanical, biological, and botanical control methods.

3.1 Fall Armyworm

The FAW (*Spodoptera frugiperda*) is a highly damaging agricultural pest, originating from the Americas but now established in Africa and Asia. Fall armyworm is the larval (caterpillar) stage of a moth and is known for its rapid reproduction and extremely high feeding rates. Fall armyworms are polyphagous; however, maize (corn) is a preferred primary host. They are called “armyworms” because, in their larval stage, they move across fields in large numbers (“armies”) and consume the crops in their path.



Figure 1: Sample images of Armyworm attacked maize leaf

Feeding by larva on corn plants can affect different areas of the plant and cause extensive damage and crop loss. Young larvae cause "window-paning" of leaf surfaces and irregular holes as they begin feeding damage, eventually skeletonizing leaves to the point that photosynthesis of the plant may be interrupted and the plant weakened. In addition to chewing on leaves, larvae aggregate within whorls to hide, feed, and excrete frass causing holes that distort as well as stunt the growth of the plants leaves. As the corn plants mature, larvae migrate to the sitting on ears and bore into the tips to feed and usually chewing out kernels, resulting in loss of grain quality and yield before opening the plant up for fungi like *Aspergillus* and *Fusarium*. In the early stage, younger larvae may attack the stem base feeding on, causing "deadheart" eventually leading to seedling death and loss of crop stand. Husk covers that are supposed to protect the kernels from contamination are chewed through too, exposing ears and kernels underneath to diseases. Infestations may be so severe that tassels are attacked too produce pollen, detrimentally affecting kernel production and current productivity overall.

Summary Table 2: Fall Armyworm Damage by Plant Part

Plant Part	Type of Damage	Impact
Leaves	Irregular holes, skeletonization, window-paning	Reduced photosynthesis
Whorl	Deep feeding, frass, distorted leaf emergence	Stunted growth, ragged leaves
Ears	Burrowing into kernels	Yield loss, fungal infection
Stem	Feeding at base in early stage	Seedling death (deadheart)
Husks	Holes exposing kernels	Contamination, unmarketable crop
Tassels	Shredding and clipping	Pollination failure

3.1.1 Treatment Options for Armyworm Control

<https://entomology.unl.edu/insecticide-treatment-options-fall-armyworm-field-corn/>

The University of Nebraska–Lincoln's Department of Entomology details insecticide treatment options and management of FAW in field corn. Use insecticide when 75% of plants show leaf feeding and larvae are less than 1.25 inches. Treatment targeting larvae in ears is not advisable. Restricted-Use Product

Table 3: Some of the solutions taken from Entomology Researchers for Armyworm

Mode Of Action	Product Name	Common Name	Rate (Formulation/Acre)	Restrictions/Comments
3 R	Ambush 2EC	Permethrin	6.4-12.8 fl oz	PHI 30 days for grain or fodder (stover). Forage may be harvested on the day of application.
3 R	Arctic 3.2EC	Permethrin	4-6 fl oz	PHI 30 days for harvest of grain or fodder (stover). Forage may be harvested on the day of application.
3 R	Baythroid XL, Tombstone	Cyfluthrin	2.8 fl oz	*For control of 1st and 2nd instar only. PHI 21 days for grain or fodder and 0 days for green forage.
28	Belt SC	flubendiamide	2-3 fl oz	PHI 1 day for green forage and silage and 28 days for grain or stover.
3, 28 R	Besiege	lambda-cyhalothrin, chlorantraniliprole	6-10 fl oz	PHI 21 days. Do not feed treated corn fodder or silage to meat or dairy animals within 21 days after last treatment. Use higher listed rates within the listed rate range for large larvae.

3.1.2 Mechanical Control

Mechanical control utilizes non-chemical, physical strategies to manage pests, reduce populations, or target the pest's life cycle using human manipulation or tools. . This typically involves: handpicking pests; traps and barriers; and light and pheromone devices for monitoring or controlling infestation. Mechanical control is often very effective because it is a viable practice for small-scale and organic farming systems, which often rely on limited or no chemicals. In addition, mechanical control is a key component of IPM through reduced reliance on pesticides and ensures pests are managed with sustainable practices.

3.1.2.1 Hand-Picking and Destruction

Hand-picking and destruction is the manual identification and removal of FAW egg masses (usually found on the underside of leaves), and larvae from infested plants. This method is best conducted in the early morning or late evening when larvae are more easily found and less active. Once collected, the larvae (or pests) can be crushed, or submerged in a container of water with kerosene added to help suffocate the pests. Hand-picking is most effective at the onset of infestation, and is a very easy, etc... and inexpensive control strategy that is consistent with small farms and organic systems.

3.1.2.2 Whorl Application of Sand or Sawdust

The whorled application of sand or sawdust is a straightforward but effective way to target FAW larvae feeding deep in the central whorl of the plant. By applying a small amount of dry sand or sawdust into the whorl, the larvae are contacted with these materials and experience disruption in several ways: they were coated by these

materials which caused physical abrasion, received clogged spiracles (which limited breathing), and were exposed to desiccation (i.e., drying out). Each of these product-based disruptions created a negative impact on the prey's motion and feeding, which eventually resulted in displacement out of the whorl or death. Overall, the use of sand or sawdust in whorl applications is a practical, non-chemical option for early-stage control provided by small-scale and sustainable food systems.

3.1.2.3 Trap Usage

Pheromone traps use synthetic sex pheromones to lure, capture and kill male FAW moths which interrupt the mating cycle thereby preventing egg-laying or reducing the size of the egg-laying population and help reducing the subsequent infestations. Pheromone traps should be deployed throughout the field at regular intervals and the pheromone lures should be changed every 15–20 days. Besides reducing the population of FAW moths, pheromone traps are also an important monitoring tool that allows farmers to monitor for population increases. If a population is detected early, a proper treatment can be applied to control it, and the information from monitoring and traps can be used for an integrated pest management program.

3.1.2.4 Cultural Practices

Cultural practices like deep plowing and wide sowing are very important for minimizing FAW populations. The primary effect of deep plowing is that plowing in deep soil disturbs the faunal community inhabiting the soil; as you bring the pupal stages of FAW up from the deep soil to the surface, the FAW are susceptible to predation, and they are susceptible to sunlight which reduces the prospect of survival before they tunnel back into the ground. The primary normative effect of wide sowing is that it minimizes the likelihood of dense planting; if FAW larvae cannot easily access multiple plants, pest progress is less likely; also, wide sowing increases air movement in the crop canopy. The air movement will create a less favorable microenvironment for the pests to develop in; therefore, there is less density and share of the growing area available for infestation.

3.1.2.5 Ash in Trenches

The ash-in-trenches technique uses shallow trenches around the field with wood ash filled into them as a physical barrier against FAW larvae. When larvae crawl into or out of the field they would attempt to crawl across the ash. The ash, because of its abrasive and desiccating impacts, would damage the larvae's bodies, clog their spiracles (the openings insects use to respire), and lead to dehydration. The result is immobilization and death. This low-cost, environmentally-friendly method is a valuable tool for community-based methods of pest management.

3.1.2.6 Branch Placement

The placement of branch is an established and proven technique that utilizes the natural feeding and congregation behavior of FAW larvae. A green leafy branch, preferably from host plants (castor, sorghum, or banana), is placed in rows or clusters around or within the corn field, particularly in the early morning or late afternoon when larvae are more active. The larvae are naturally attracted to the tender foliage of the branch or branches, and they will move to the branches to feed and/or rest. After a period of time (generally in a matter of hours, but usually by the next morning), the branch, heavily populated with larvae, can be collected and burned, or submerged into insecticidal or kerosene water solution to kill the larvae. This technique reduces the density of FAW (or many other types of larvae) without the use of chemicals, serves as a decoy, to spot protect the main crop, and is too inexpensive to promote the use of, and is a sustainable pest management intervention, especially for community level pest management.

3.1.3 Biological Control

Biological control is defined as the use of living organisms, for example, natural enemies such as predators, parasitoids, pathogens, and entomopathogens, to suppress pest populations. It is environmentally friendly, inexpensive, and a critical part of IPM practices.

3.1.3.1 Parasitoids

Egg parasitoids such as *Trichogramma* species and *Telenomus remus* are efficient biological control agents that can reduce FAW populations when used on eggs. *Trichogramma* wasps, including *T. pretiosum*, *T. atopovirilia*, *T. mwanzai*, and *T. dendrolimi*, lay their eggs inside FAW eggs; the larvae eat the contents of the egg and emerge, killing FAW eggs in the process. We can mass rear these wasps and field deliver them in a timely manner, providing a proactive pest management tool if you use them before they grow too much. *Telenomus remus* is another of the many efficient egg parasitoids, and it can go further than *Trichogramma*, as it can parasitize even the inner layers of egg masses, which are often protected from surface treatments. Due to *T. remus* ability to penetrate deeply and efficiently in a dense infested area it would serve as the optimal supplement and/or alternative to any other egg parasitoid to maximize success for any biological control program.

3.1.3.2 Entomopathogenic Pathogens

Microbial agents are important ways to control FAW in sustainable and environmentally friendly ways. *Bacillus thuringiensis* (Bt) is a gram-positive soil dwelling bacterium that has different strains that produce Cry toxins that exclusively kill FAW larvae. *Bacillus thuringiensis* formulations are available as biopesticides and are used extensively in the organic and conventional sectors because of their efficacy, safety, and selectivity; also genetically modified Bt maize hybrids expressing Cry toxins, provide FAW larvae with intrinsic resistance to feeding. The entomopathogenic fungus, *Nomuraea rileyi*, is particularly noteworthy for naturally infecting after it penetrates the cuticle of FAW larvae, and it efficiently sporulates in FAW populations and with suitable relative humidity. This fungus is affordable and environmentally sustainable for smallholding, as well as commercial farmers. Furthermore, other microbial agents, including *Beauveria bassiana*, *Metarhizium anisopliae*, and nucleopolyhedroviruses (NPVs), appear to be very effective in suppressing FAW assuming the environmental conditions are suitable. Both *Bacillus thuringiensis* and these microbes are available as biopesticide formulations and are compatible with low-impact IPM systems, thus, they can be beneficial as part of a sustainable pest management program.

3.1.3.3 Additional Biological Control Strategies

There are a number of biological and ecology based approaches that can be used to manage FAW infestations in maize. For example, predatory insects such as lady beetles, earwigs, lacewings and ants are natural enemies that will feed on FAW eggs and young larvae. Their role in pest regulation especially in low pesticide agroecosystems is essential. Another biological approach is the use of push–pull technology for FAW management in corn fields. Push–pull technology includes intercropping maize with repellent plants as a push like *Desmodium*. Then surround the maize field with attractive trap crops like Napier grass, to act as a pull. The combination of intercropping *Desmodium* and surrounding the maize with Napier grass not only increases forage and grain production, but most importantly, [the combination] confuses and deters female moths from laying eggs on maize and reduces incidence of FAW. Lastly, entomopathogenic nematodes (EPNs), from the *Steinernema* and *Heterorhabditis* genera specifically, can act as effective biocontrol agents against FAW. EPNs are microscopic nematodes that profess to infect the FAW larvae by releasing a symbiotic bacterium that kills the worm from the inside out. EPNs are particularly effective in moist soils, they can be applied through irrigation systems, and as a drench, which makes them a sustainable method of control for integrated pest management.

Table 4: Integrated Pest Management Strategies for Fall Armyworm Control

Component	Strategy	Notes
Mass Rearing	Trichogramma, Telenomus	Scalable and cost-effective; government or community-driven distribution systems can be used.
Timing	Early-stage release	Most effective when FAW population is low or before outbreak peaks.
Environmental Fit	Fungi/nematodes in humid areas	Pathogens thrive in moisture-rich environments; timing and humidity are critical.
IPM Integration	Combine with mechanical/cultural control	Enhances long-term sustainability and resistance prevention.
Monitoring	Regular scouting and pheromone traps	Helps determine correct timing and effectiveness of interventions.

Biological control is a sustainable and specific form of control for FAW outbreaks in corn. By utilizing naturally occurring enemies and environmentally friendly biopesticides, farmers can reduce crop losses and create a healthier ecosystem. The use of biological control will enhance IPM programs and foster a larger global resiliency against pest outbreaks and safer food systems.

3.1.4 Botanical Control

Botanical control provides a natural and environmentally friendly option to manage FAW (*Spodoptera frugiperda*) in maize production. Botanical control is the application of plant-derived materials and the use of plant diversification tactics to affect the life cycle of the pest, stop feeding behavior or prevent infestation. Botanical approaches can be useful in organic agroecosystems and as part of IPM systems aimed at reducing the use of chemical pesticides.

3.1.4.1 Neem Oil Applications

Neem oil is derived from the seeds of the *Azadirachta indica* tree and is considered a botanical pesticide to manage FAW because it contains the active ingredient azadirachtin, which inhibit insect feeding, development, and reproduction. Neem oil is very effective at reducing FAW damage when applied to maize crops at concentrations of 0.17% and 0.33%. Azadirachtin works as an antifeedant, growth regulator, and sterilization agent, giving it a multi-prong defence against larvae. Neem oil is biodegradable and does not pose a risk to beneficial insects, and can be applied with repeated applications without persistent negative impacts on the environment. Research shows a high mortality rate in larvae and a great decrease in feeding activity shows research supports neem oil as an effective method for sustainable pest management.

3.1.4.2 Garlic Extracts

Garlic (*Allium sativum*), with its active ingredients of allicin and sulfur-based compounds well-established to contain insecticidal, and repellent properties, can directly impair the central nervous system and can kill (due to mortality) FAW larvae. Several scientific studies and reported research (such as SCIRP) have demonstrated that garlic extracts can reduce FAW infestation and are as good as the synthetic insecticide cypermethrin. Typically, garlic formulations are used as a foliar spray; the best time to spray is at the earliest stages of infestation, or before damage occurs (in order to prevent damage). This formulation is a natural and greener way to protect crops, and keep farmers from relying on chemical pesticides, while also protecting beneficial insects.

3.1.4.3 Intercropping Systems

Intercropping, which involves multiple crops grown closely together, can be a successful pest control mechanism for the FAW because intercropping can alter the microenvironment off the field and can damage the FAW phenologically in its host location. For example, plants such as *Desmodium* spp., a legume plants that produces volatile organic compounds that repel FAW moths, were reducing the FAW moth population from the field. Napier Grass (*Pennisetum purpureum*) can also be used as a trap crop because it will attract FAW and oviposit there instead of in the maize crop perimeter. This of push-pull mechanism provides higher soil quality and production capacity. This is a form of anibutory pest control and a method for keeping the overall farm in good condition.

3.1.4.4 Other Botanical Extracts

Several plant-based agents have shown insecticidal or repellent effects against the FAW. Tuba root contains rotenone, a chemical that disrupts cellular respiration in insects. *Eucalyptus urograndis* leaf extracts have shown protective properties against pests in maize. Guinea pepper (*Udah*) extract has moderate larvicidal activity, which is contingent to the severity of infestation. The Chinaberry plant (*Melia azedarach*) has limonoids and terpenoids that repel pests. These are typically applied as aqueous or ethanolic extract as a spray or gel, effectiveness depends on concentration and environmental conditions.

3.1.4.5 Integration with Other Pest Management Approaches

Botanical approaches will be most useful when they are part of an IPM system as they will supplement other management practices to optimize control. Their importance is significant for supplementing biological control practices (e.g. *Trichogramma* spp. or *Bacillus thuringiensis*), mechanical methods (e.g. whorl dusting or pheromone traps), and cultural practices (e.g. plowing at the right time and planting density). For example, intercropping maize with *Desmodium* and Napier grass combined with neem oil spray can establish a pest management approach that relies on many practices to apply technologically sustainable approaches for FAW management.

3.1.4.5 Important Considerations for Botanical Pesticide Use

To maximize efficacy and minimize phytotoxicity when using botanical pesticides, it is very important to use the correct application rates using the manufacturer's recommendations or methods used in the experimental protocols. When applying botanical pesticides, safety precautions should be followed for developing and applying botanical pesticides. A person developing and using botanical pesticides should wear protective clothing such as gloves and a mask to minimize the risk of dermal or respiratory exposure. Most botanical pesticides are biodegradable and considered relatively safe for non-target organisms, so these products are promising options for sustainable, environmentally friendly agricultural practices.

Botanical control options offer a sustainable horticultural response to increased FAWpressure in maize production. Using plant-derived insecticides and rotational crops as complementary methods you can will reduce reliance on chemical insecticides and promote land and crop health. Including these plant-derived insecticides and rotational crops into IPM will enhance agro ecosystems by making them less susceptible to FAW while maximizing productivity.

3.2 Aphids

Aphids are small, soft-bodied insects feeding on the corn plant's sap, using their piercing-sucking mouthparts. Aphids feasting on the plant's phloem extracting nutrients make the plant weak, causing it to grow up smaller, and with lesser vigor. Infestations often develop lesions on leaves that leave mottling or discoloration, and reddening that can impact photosynthesis. Aphids secrete honeydew that is a sugary material; therefore it promotes the growth of sooty mold on the leaves inhibiting light absorption. The honeydew can also coat tassels and silks

leading to poor kernel development, since it can take away the pollen's pollen ability to fall onto the silks. Furthermore, aphids are vectors for plant viruses, such as the maize dwarf mosaic virus causing more damaging effects. They can reproduce rapidly, allowing for large populations to develop, especially in warm, dry conditions. Proper control of the pest requires a scout of the fields and to monitor aphid populations. Control options include physical removal of the pests, mechanical control, biological control promoting natural predation, natural plant-based insecticides, or and use resistant crop varieties. To ensure sustainable, efficient control of aphid communities in corn fields, use an IPM method and include these options above.



Figure 2: Sample image of Aphids attacked maize leaf

3.2.1 Treatment Options for Aphids Control

<https://entomology.unl.edu/insecticide-treatment-options-corn-leaf-aphids-field-corn/>

Insecticide treatment recommendations from the University of Nebraska-Lincoln are available for the management of corn leaf aphids that can stunt growth and affect pollination when very high populations occur. Generally, treatment is warranted if substantial populations of aphids are present on tassels prior to or during pollination. Suggested insecticides include Lorsban, Warrior II, and Transform WG. Ongoing monitoring and timely application of an insecticide are important to the ability to control aphids effectively.

Table 5: Some of the solutions taken from Entomology Researchers for Aphids

Mode Of Action	Product Name	Common Name	Rate (Formulation/Acre)	Restrictions/Comments
3	Arctic 3.2EC	permethrin	4-6 fl oz	PHI 30 days for grain or fodder.
3	Asana XL	esfenvalerate	5.8-9.6 fl oz	PHI 21 days. Direct the spray at the aphid populations so as to achieve maximum coverage of the exposed insects.
3, 28	Besiege	lambda-cyhalothrin, chlorantraniliprole	6-10 fl oz	PHI 21 days. Do not feed treated corn fodder or silage to meat or dairy animals within 21 days after last treatment. *Suppression only.
3 R	Brigade 2EC, Fanfare 2EC, Bifenture EC, Discipline 2EC,	bifenthrin	2.1-6.4 fl oz	PHI 30 days. Do not graze livestock in treated area or cut treated crops for feed within 30 days of treatment.

	Sniper, Tundra EC			
1B, 3	Cobalt	chlorpyrifos and gamma cyhalothrin	13-26 fl oz	PHI 21 days for grain, ears, forage or fodder.

3.2.2 Mechanical Control

3.2.2.1 Rinsing with Water

A simple and effective form of mechanical control is to rinse the aphids from corn plants, using a water spray applied under sufficient pressure. The pressure from a nozzle attached to a hose will be enough to dislodge aphids on the leaves and stems without injury to the plant. The jet or shower settings should be adequate based on mowing practices recommended by the Home & Garden Information Center (HGIC) at Clemson University. This is most effective in the early stages of an aphid infestation and is perfect for gardeners wanting to eliminate chemicals from their practices.

3.2.2.2 Manual Removal

Aphids can simply be handpicked off with either your fingers or a damp cloth. Handpicking is effective for small infestations or for individual plants and for targeted control of aphid populations because you can target on clusters of aphids, this is going to be some work and would not be a practical option in a large cornfield or an agronomic scale.

3.2.2.3 Other Mechanical Methods

Aside from rinsing the aphids off the infested foliage by hand or removing so they cannot further infest, there are other mechanical methods these characteristics include clipping and disposing of infested shoots to limit spread, or using sticky traps or reflective mulches to attract or deter aphid influx. Modifying environmental conditions, for example humidity/temperature will inhibit the ability of populations to potentially grow/establish in a greenhouse.

3.2.2.4 Integrated Pest Management (IPM)

Mechanical control often plays a part of an integrated pest management strategy. IPM is the combination of physical (i.e., trapping), biological (i.e., releasing ladybugs), cultural (i.e., crop rotation), and, as a last case option, chemical control. Mechanical control methods are beneficial to an integrated pest management program because they are non-chemical, keep pest levels below economically harmful thresholds and do not injure beneficial insects or contribute to chemical resistance.

3.2.2.5 When to Use Mechanical Control

Mechanical control is best suited for early infestations, or small populations of aphids. It is an immediate and inexpensive option and is appropriate for home gardens or organic farming when pesticides and herbicides are limited. It is very useful when farmers are concerned about residues of chemical control directly on the crop or when farmers want to minimize their impact on the environment.

3.2.2.6 Limitations of Mechanical Control

Mechanical methods may have limitations during large or repeated outbreaks, although they are useful for addressing small-scale issues. Mechanical methods require continuous monitoring and repeated intervention over time. Furthermore, aphids may have high reproduction rates when environmental conditions are most favorable, and

mechanical removal typically will not keep up, so you will need to reserve the use of mechanical removal to use in conjunction with other tactics.

3.2.2.7 Important Considerations

Care should be taken to protect the plants while rinsing and while handling them. Overly saturated plants, from excessive watering while spraying, may add stress to the plants; and handling the shoots incorrectly may also move the infestations. When there are aphids on plants it is advisable to wash your hands as aphids can spread plant viruses. For more serious infestations, mechanical methods should be used with complementary methods to control effectively.

3.2.3 Biological Control

Biological control is an environmentally - friendly and long - term strategy for controlling aphids on corn crops using naturally occurring enemies and non-chemical strategies. Instead of using synthetic pesticides, biological control enhances the activities of beneficial organisms that already suppress aphids naturally and includes a few non-toxic tactics that aid in bio-control. Following are the basic components of biological control:

3.2.3.1 Natural Enemies

Aphids have many different natural enemies that are essential in controlling their populations. Lady beetles (Coccinellidae) are significant predators of aphids in both adult and larval stages. Lacewing larvae, also called "aphid lions," can be effective predators. Syrphid fly larvae (hover flies) can eat large amounts of aphids, and the impact that those three would be usually great. To the also consider are parasitic wasps in the Aphidiinae subfamily that lay their eggs in aphids; once hatched, the larva feed on the soft body of the aphid, killing it and leaving what is called "aphid mummies". When the natural enemies are not disrupted, and are present in numbers, they can greatly reduce aphid populations.

3.2.3.2 Encouraging and Conserving Natural Enemies

Preserving natural enemies are important for biological control of aphids, and there are several practices that can help increase their abundance and efficacy. One is to avoid broad-spectrum insecticides altogether; these insecticides, as described earlier, will kill beneficial insects along with aphid pests indiscriminately. Flowering border crops such as dill, fennel, or yarrow can also specifically help to attract (when they bloom) and sustain adult parasitoids (and predators), and to provide nectar and habitat. Timely releases of beneficial insects (recommended by the University of California IPM program), are most effective, when aphid populations are relatively low allowing for the establishment of natural enemies prior to a pest outbreak that needs suppressing.

3.2.3.3 Alternative Biological Methods

While they are not living predators, a few non-toxic options can help enhance biological control of aphids. Mineral oil sprays will result in suffocation because the spray coats the aphids' bodies and shuts off their spiracles (breathing holes). Pyrethrin is a botanical insecticide obtained from chrysanthemum flowers that works by interfering with insect nervous system functions, and it also decomposes fairly rapidly in sunlight, reducing the residues in the environment. These products can be effectively used in conjunction with the release of natural enemies, particularly where aphid populations exceed the control capability of biocontrol agents alone.

3.2.3.4 Mechanical Assistance to Biological Control

It is sometimes possible to use mechanical means, such as removing infested parts of a plant, or using water sprays, to complement the work of biological control agents, such as predators and parasitoids, which attack aphids. A stream of water with sufficient force can not only reduce the population of aphids on a plant but also eliminate a significant amount of aphid camouflage (in the form of aphids). This allows for predators to find the remaining aphids more quickly and can help reduce the overall population on a field level (decreasing pest pressure).

Physically removing leaves or portions of the plant with heavy aphid infestations can also help lower the pest pressure in the field and improve contact with natural and introduced biological control agents.

3.2.3.5 Use of Banker Plants

Banker plants are a proactive approach to support valuable parasitoids by maintaining them in a suitable habitat that has no pests. This entails growing plants that support non-pest aphids, such as barley supports *Rhopalosiphum padi*. When parasitoids are introduced to search and sting both the non-pest aphids and any pest species, they can establish. Even when pest species do not explode, the banker plan helps the parasitoids to maintain their population. Thus, banker plants create an environment to allow for an early and constant suppression of pest aphids, and also a environment where the parasitoids have the ability to be more effective. Biological control for aphids is most effective when facilitated by a complete IPM program that encourages ecosystem equilibrium, reduces chemical use, and allows for a holistic approach to pest resistance management.

3.2.4 Botanical Control

Botanical control of aphids employs plant materials, natural enemies, and ecologically based strategies to limit aphid populations naturally without synthetic chemicals. Botanical control can be sustainable and reduce harm to the environment. Botanical control is often one part of a broader pest management strategy, and typically used in combination with other pest management approaches.

3.2.4.1 Encouraging Natural Enemies

Botanical control concentrates on creating an environment in a garden or farm that is attractive to beneficial insects that feed on or prey upon aphids. Ladybugs (Coccinellidae) are among the most aggressive aphid predators, and they can be encouraged by planting flowers with lots of pollen and nectar such as dill, yarrow, or marigolds. Lacewings (Chrysopidae), especially in their larval form, are an important predator of aphids, and they will be drawn to nectar-producing plants also. Parasitic wasps, like *Lysiphlebus* species, aid in aphid control because they inject aphids with their eggs, lay dormant for a short period, before killing the aphid and emerging as a new wasp. Botanical control also creates insect habitat with appropriate plantings, and can sustain the natural enemy population, so they are available when aphids are present.

3.2.4.2 Releasing Beneficial Insects

When natural populations of aphid predators are inadequate, commercial releases can be an effective option for biological control. Ladybugs, lacewings, etc. can be purchased and released directly, near the problem area. For controlling aphids, evening releases near infestations are suggested. This will increase their potential to impact aphids and decrease dispersal. Controlled releases focusing on timed and geographically localized introductions are particularly useful early (young aphid colonies) because the released beneficials will be able to settle and suppress aphid populations before their numbers escape biological control.

3.2.4.3 Application of Natural Substances

Botanical control utilizes natural biopesticides of plant origin to manage aphid presence and reduce risk to non-target insects. Mineral oil works by suffocating aphids; the oil blocks the spiracles of the aphid, preventing it from breathing. Pyrethrin is derived from the flower of a chrysanthemum plant; it operates by affecting the nervous system of aphids and other soft-bodied insect pests causing the insect to knockdown and die in minutes. Neem oil is a broad-spectrum botanical insecticide with multiple uses as it can operate as an antifeedant and repellent while also inhibiting aphid development and reproduction as well as regulating aphid intergenerational delay, making it useful for integrated pest management programs.

3.2.4.4 Other Botanical and Eco-Friendly Methods

More cultural practices provide both direct and indirect means of controlling aphids. A water-based spray containing mild soap can eliminate aphids by removing and killing aphids on contact with the soap by weakening the protective coatings. Garlic spray is a natural aphid repellent. The strong garlic odor and its sulfur notably, deter aphids from infesting plants. Entomopathogenic fungi, for example, *Beauveria bassiana*, are biological pesticides which kill aphids by infecting them. Entomopathogenic fungi do not harm the host plant nor beneficial insects. Cultural practices used together can create a complete and broad spectrum approach to managing aphids.

3.2.4.5 Integration into IPM Practices

Botanical control is most effective when exercised as part of a more general IPM program. Parasitism or predation of aphids is best done as part of an IPM program. Monitoring crops regularly can provide early development of aphids so that something can be done before the colony grows to a larger number. Cultural management strategies, such as removal of crop residues and weeds, will lessen the habitat for aphids. Crop rotation can disrupt aphid life cycles, inhibiting pest buildups in soil. Using resistant varieties (e.g. aphid resistant corn varieties) can also provide protection by lowering infestation naturally. Effective botanical control approaches will also utilize these cultural management methods as part of a larger IPM plan.

3.3 Grasshopper

Grasshoppers can wreak havoc in corn plants by feeding on several plant parts that reduce yields and quality. Grasshoppers will primarily damage foliage, as they cause the plant to go through defoliation – thus, contributing to a loss of photosynthetic ability and subsequent food production. Grasshoppers generally feed on the green silk, the silk is critical for pollination and any damage may cause poor ear development or empty kernels. As well as feeding on silk, grasshoppers damage ripening kernels, again resulting in the potential for kernel shattering and or loss. In some cases, through feeding on the ear, grasshoppers can clip the ends of ears which may affect quality since the tip is damaged. Severe infestations may also damage corn stalks which has an impact upon the structural integrity of plants. Populations will be higher along the field edges where weeds and other vegetation provides more suitable habitat. The location of concentrated feeding can create significant economic losses to the corn production industry. For these reasons, if left unchecked grasshoppers can quickly become serious infestations and are required to be managed for you to have healthy, efficient working crops without permanent long term damage.



Figure 3: Sample image of Grasshopper attacked maize leaf

3.3.1 Insecticide Treatment options for Grasshopper

<https://entomology.unl.edu/insecticide-treatment-options-grasshoppers-field-corn/>

The University of Nebraska-Lincoln (UNL) offers specific recommendations for treatment of grasshoppers in field corn. Use of insecticides is advised if the number of grasshoppers exceeds certain thresholds in the field or on the field margins. In the field grasshopper density must exceed 15 per square yard or if field margins exceed 41 per square yard. A number of different insecticides are suggested including Asana XL (esfenvalerate), Baythroid XL

(cyfluthrin) and Warrior II (lambda-cyhalothrin), and all have labeled rates and a pre-harvest intervals period. As with all products labelled for food and feed crops you must abide by the label and you should also take into consideration the mode of action so that you avoid the development of resistance.

Table 6: Some of the solutions taken from Entomology Researchers for Grasshopper

Mode Action	Of Product Name	Common Name	Rate (Formulation/Acre)	Restrictions/Comments
3 R	Baythroid XL, Tombstone	cyfluthrin	2.1-2.8 fl oz	PHI 21 days for grain or fodder and 0 days for green forage.
3, 28 R	Besiege	lambda-cyhalothrin, chlorantraniliprole	6-10 fl oz	PHI 21 days. Do not feed treated corn fodder or silage to meat or dairy animals within 21 days after last treatment.
3 R	Brigade 2EC, Fanfare 2EC, Bifenture EC, Discipline 2EC, Sniper, Tundra EC	bifenthrin	2.1-6.4 fl oz	PHI 30 days. Do not graze livestock in treated area or cut treated crops for feed within 30 days of treatment.
1B, 3 R	Cobalt	chlorpyrifos and gamma cyhalothrin	7-13 fl oz	PHI 21 days for grain, ears, forage or fodder.
1B, 3 R	Cobalt Advanced	chlorpyrifos and gamma cyhalothrin	6-13 fl oz	PHI 21 days for grain, ears, forage or fodder.
28	Coragen	rynaxypry	2-5 fl oz	PHI 14 days.

3.3.2 Mechanical Control

Mechanical control methods to manage grasshopper damage on corn plants include a variety of mechanical strategies to 1) prevent grasshoppers from reaching the crops or 2) disturb their feeding. Various types of barriers, whether row cover, screens, or other obstacles can create physical barriers to stop grasshoppers from feeding on corn plants at sensitive developmental stages. In cases where infestations are generally confined to the edges of the field, a barrier along the edges of the crop may also provide a certain degree of control. Tillage and other soil manipulation practices offer a method of control for grasshoppers via the destruction of their eggs. Tillage exposes eggs to desiccation or predation. Tillage that eliminates green plant, as alternate food sources for grasshoppers, can also reduce populations. Disruption of grasshopper egg pods will also happen when tillage operations involve crush or smothering the soil. Some mechanical control methods include water jets to remove or displace plants, as well as pheromone traps to monitor or catch grasshoppers. Seeding and harvesting sooner can help lessen the period of vulnerability for the corn crop, thus limiting the opportunity for grasshoppers to feed. Through crop rotation and planting crops the grasshoppers do not voraciously consume, that reduces the life cycle potential for grasshoppers. The soil disturbance resulting from cultivation in the field can certainly disrupt and destroy grasshopper eggs or

young grasshoppers. Finally, manipulating the plant, like producing competitive plants in the surroundings offices to grasshoppers from targeting food sources. These methods of using mechanical agents, when utilized appropriately, accomplish a lower number of grasshoppers and damage done to corn plants.

3.3.3 Biological Control

Biological control of grasshoppers in cornfields means using natural predators, pathogens, and biopesticides to reduce populations of pest grasshoppers with less reliance on synthetic chemicals. This provides benefit to the ecosystem and helps with longer-term control of grasshoppers.

3.3.3.1 Natural Predators

There are a variety of insects and arachnids that prey upon grasshoppers and their eggs which help with early and effective herbivore population control. Spiders will hunt and feed upon nymphs and adult grasshoppers, thus greatly contributing to population decline. Blister beetles, ground beetles, and crickets are important egg predators that feed on grasshopper eggs that have been laid in the soil. By limiting the amount of newly-hatched grasshoppers, these groups play important roles in the population dynamics of grasshoppers. These natural enemies are also vital to using ecological pest management strategies.

3.3.3.2 Pathogens as Bio control Agents

Pathogens from the biological perspective can greatly contribute to the suppression of grasshopper populations where environmental conditions are appropriate. The fungus *Entomophthora grylli* flourishes in warm, moist environments and infects grasshoppers, resulting in massive death of grasshoppers in the infected population. Another pathogen, the protozoan *Nosema locustae*, infects grasshoppers through its injection into the gut of the grasshopper, and causes damage in a grasshopper's digestive system and mobility, resulting in reduced feeding and reproduction. Pathogens can be an environmentally friendly mode of grasshopper suppression in an integrated pest management approach to pasture management.

3.3.3.3 Biological Control Baits

Commercial products like NOLO Bait and Semaspore, which carry the protozoan *Nosema locustae*, can be used for grasshopper management, especially in or near breeding sites. They work especially well on nymphs that are just starting to develop their immune systems, making them more vulnerable to infection. These products are environmentally safe and target specific with little risk to non-target organisms and can be a useful aspect of integrated, sustainable grasshopper management programs.

3.3.3.4 Limitations

Although biological control methods for grasshopper control are promising, they are limited in their application. For example, *Nosema locustae* is a relatively slow acting method which may not achieve immediate reductions in grasshopper populations and which may not be effective if there is a severe outbreak. And although these biocontrol agents may be commercially offered as grasshopper control agents, they are typically species specific and their effectiveness will depend on the type of grasshopper(s) in the area. In addition to these factors, commercial baits, typically produced with biocontrol agents, are also perishable, and will break down if not stored appropriately, which requires effort and planning when using biological control as a method of grasshopper management.

3.3.3.5 Integrated Approach (IPM Compatibility)

Biological controls will be the most effective tools when used within a complete IPM system. As with other prevention tools, combining biological controls with mechanical, cultural, and minimal chemical practices allows for greater success and reduced environmental impact.

3.3.3.6 Botanical Support for Biocontrol

Botanic options can help with grasshopper biological control. *Nosema locustae* baits are considered either biological or botanicals because they are derived from nature with labels as extensions of either of these pest management methods. By providing an enhanced environment with flowers that provide nectar such as marigold and calendula, you can attract beneficial predatory insects like robber flies which can decrease grasshopper numbers. You can also make home remedies such as garlic or chili pepper sprays and uses them as a feeding repellent. An unusual but effective treatment is to dust the corn leaves with flour. This does lead to decreased feeding by grasshoppers which can reduce crop damage and can be used with other strategies as an integrated approach.

3.3.4 Botanical Control

Botanical control strategies offer sustainable eco-friendly approaches to managing grasshoppers in corn fields. A prime example is the application of *Nosema locustae* baits, a biological insecticide based on protozoan that is usually effective against grasshoppers, especially in their nymph stage, and can be most successful when used in the early season. Some of the strategies we discussed above encourage natural predation of invasive grasshoppers, such as planting insectary plants like marigold, calendula, sunflower, aster, alyssum, dill, and garden associated predator insects like robber flies that feed on grasshoppers find their way to your garden and serve a beneficial role. Other botanical control methods include dusting plant leaves with flour (the flour will clog the insects mouthparts), making deterrent sprays from garlic and hot peppers to discourage them to feed, and spraying leaf foliage with kaolin clay which forms a protective film around the plant, and is a physical barrier to feeding and ovipositing. Diatomaceous earth, fossilized diatoms, can be sprinkled around the base of the plants, when the grasshopper passes through the diatomaceous earth it scratches their exoskeleton causing dehydration ultimately leading to death. One last note, some gardeners also apply acid or nature deterrents (like garlic and chili) along borders of their garden. Using these botanical tools is most useful in combination with cultural and biological controls as part of an IPM program.

3.4 Beetle

Beetle damage to corn plants, particularly by the corn flea beetle and the sugarcane beetle, can severely impact crop health and crop yield. Corn flea beetles feed by scraping the upper surface of the leaves, resulting in the development of characteristic gray to brown "tracks," which may lead to leaf shriveling and death of seedlings in severe cases. Additionally, the corn flea beetles also serve as vectors for Stewart's wilt caused by *Erwinia stewartii*, which can severely impact sweet corn and seed corn varieties. Damage and disease transmission are most likely during the early growth stage, particularly for seedlings that have less than 6 inches of aboveground growth. The sugarcane beetle will attack the subterranean parts of the plant. Sugarcane beetles also feed on roots and the crown of the plant creating damage with the symptoms listed above such as deadheart (the central shoot dies), plus stunting, decreasing overall stand density. Depending on the severity of these infestations damage may severely disrupt overall crop establishment and productivity. Avoiding insect and disease damage from these pests include measures such as planting resistant corn varieties and monitoring beetle activity, particularly during early growth stages.



Figure 4: Sample image of Beetle attacked maize leaf

3.4.1 Treatment options for Beetle Control

<https://entomology.unl.edu/insecticide-treatment-options-flea-beetles-field-corn/>

The University of Nebraska-Lincoln indicates the insecticide treatment options available for managing corn flea beetles and preventing Stewart's wilt transmitted by these beetles. It recommends treating when beetles are present and highly populous in the plant's early growth stages. In the guide, the effective insecticides are on seed treatment, Cruiser, Gaucho, and Poncho, and the foliar sprays are Warrior II and Baythroid XL. It is important to follow the label's recommendations and account for resistance management.

Table 7: Some of the solutions taken from Entomology Researchers for Beetle

Mode Of Action	Product Name	Common Name	Rate (Formulation/Acre)	Restrictions/Comments
3 R	Ambush 2EC	permethrin	6.4-12.8 fl oz	PHI 30 days for grain or fodder (stover). Forage may be harvested on the day of application.
3 R	Arctic 3.2EC	permethrin	4-6 fl oz	PHI 30 days for harvest of grain or fodder (stover). Forage may be harvested on the day of application.
3 R	Asana XL	esfenvalerate	5.8-9.6 fl oz	PHI 21 days.
4A, 6 R	Avicta Duo Corn	thiamethoxam and abamectin	Pre-treated seed to protect corn seedlings from early season nematode and insect damage.	Treated seed must be planted into the soil at a depth greater than 1 inch. Allow a minimum of 45 days after planting Avicta Duo Corn treated corn seed before treating the corn with a neonicotinoid insecticide.
3 R	Baythroid XL	beta-cyfluthrin	0.8-1.6 fl oz	PHI 21 days for grain or fodder and 0 days for green forage.

3.4.2 Mechanical Control

Mechanical control practices refer to the physical processes to help manage beetle damage to corn plants without the use of chemicals. Some mechanical methods, such as hand removal (i.e., physically pulling the beetles off of the plants), will be highly advantageous in small gardens or during the early stages of infestation. Some examples of mechanical practices include the placement of fine mesh screens or netting around young corn plants at vulnerable growth stages to prevent beetles from accessing the plants, traps (for example, light traps—traps that rely on light to attract beetles; pheromone traps—traps that rely on an attracter that mimics beetle mating scents) to monitor adult beetle usage throughout the season or limit their overall population, clipping or pruning beetle-infested plants, or body crushing beetles on the plant itself to reduce the beetle numbers on the plant in a more immediate fashion. Each of these mechanical control methods can be more successful when used in conjunction with each other and employed consistently throughout the season as part of an integrated pest management (IPM).

3.4.3 Biological Control

3.4.3.1 Natural Enemies

Natural enemies including predators, parasitoids, and pathogens are invaluable to controlling beetle numbers. The conservation of these natural enemies or their introduction into a field can greatly decrease the population of pests. For example, *Trichogramma chilonis* is a parasitoid wasp that lays eggs inside the eggs of a moth called the corn borer. Corn borers are a significant pest of corn. The parasitic wasp kills the larva inside the moth egg before it has a chance to hatch and kill the corn plant, which provides less public concern of damage from beetles. Ground beetles and spiders, as well, are excellent predators of beetle larvae and adults, thereby acting as an excellent form of biological pest control with no reliance on chemical pesticides.

3.4.3.2 Entomopathogenic Fungi

Entomopathogenic fungi such as *Beauveria bassiana* provide one more natural and effective way to manage insect pests, and extensively beetles. *Beauveria bassiana* is one of the more popular fungi used for beetle control, it infects beetle larvae attacking their internal organs and killing them. This fungus is very effective against predator and herbivore beetle species that attack crops like corn, thus providing an environmentally safe alternative to pesticide and helps maintain ecological balance.

3.4.3.3 Bt Maize (Genetically Modified Corn)

Bt maize is corn that is genetically modified to produce the protein from *Bacillus thuringiensis* (Bt), a bacterium harmful to some insect larvae, especially corn borer larvae and some beetles. The protein damages the digestive system of beetle larvae when they eat the corn-plants leaves, which then impairs their feeding and growth to the point of death. Bt maize has built-in defence against these pest insects, thus reducing application of chemical insecticides. Some advantages of Bt maize are long-term control, less environmental impact, and reduction in chemical insecticides risk--Bt maize is an effective pest management option for corn.

3.4.3.4 Intercropping

Intercropping, which is the practice of farming a secondary crop beside corn, can limit beetle infestation. For example, intercropping cowpea with corn will stop beetles from feeding on your plants. The cowpea serves as a trap crop, attracting the pests away from the primary plants, therefore, decreasing damage potato beetles will do to the corn. Furthermore, planting diversely, which is the practice of farming multiple crops in a single field, can lead to distractions and confusion. This complexity will result in higher difficulty of the beetles to find corn amongst other plants. This is extending the effects of natural diversification to not only reduce pest population but also enhance farm resiliency to overall crop systems by diversifying the farming ecosystem to be more healthy and sustainable.

3.4.3.5 Trap Crops

Trap crops, like Napier grass, can be a good pest management tool that lures pests to it before they can get to the main crop. For example, a corn grower can plant Napier Grass on the edges of the corn field to trap pests like beetles in the Napier, luring them away from the corn plants. These types of management strategies can help concentrate beetles to one area, thus reducing the amount of beetle damage to the corn crop. Trap crops like Napier grass allow farmers to protect their main crop while using less chemical pest control.

3.4.3.6 Sanitation

Field sanitation is critical to beetle population control and reducing overwintering in corn. One key practice is to remove all debris from plants (term for plant debris would be "corn stubble") from the field when harvest is completed. By killing or removing plant material it would eliminate beetle larvae and eggs overwintering in corn

residue, which would greatly reduce beetles in the first season. Reducing beetles lowers the risk of future infestations, improves crops with advances in pest control.

3.4.3.7 Deep Summer Ploughing

Deep plowing is an effective soil management tool for reducing beetle populations by exposing larvae and pupae to unfavorable climate action. When tillage is performed deeply in the summer, beetle larvae are susceptible to predation from natural enemies, including birds and ground beetles above the soil surface. Moreover, the solar exsiccation created when tilling exposes beetles to elevated soil temperatures and harsh conditions that make it extremely difficult for beetles to survive. This practice substantially reduces the survival of beetles below ground and is effective both for reducing pest populations and limiting crop damage in each subsequent growing season.

3.4.3.8 Neem Extracts

Neem extracts, especially azadirachtin, are effective against beetles in cornfields because of their insecticidal and repellent properties. The azadirachtin has an insecticidal effect because the azadirachtin disrupts the molting process of beetles. By disrupting the molting cycle, beetles cannot grow and mature. Azadirachtin is also an insecticide as it disrupts the digestive system of the beetle and therefore reduces feeding and nutritional consumption leading to less growth and feeding. Moreover, the repellent capability of neem is another valuable attribute as beetles will not feed on the corn leaves which decreases damage to crops. Neem can be a valuable element of sustainable practices for managing pests in cornfields.

3.4.4 Botanical Control

Botanical control methods use naturally derived plant compounds to control insect pests. In general, these are better for the environment and non-target organisms than synthetic chemical pesticides. Here are some common botanical control methods for beetle damage on corn plants:

3.4.4.1 Botanical Insecticides

Botanical insecticides, obtained from a number of different plants, serve as an environmentally-friendly and efficient mode of controlling beetles in cornfields. The insecticide neem works as both an insect repellent and insecticide through the growth and feeding disruption it causes beetles, as insects cannot complete the molting process, nor feed as intended when treated with neem. Neem oil can be sprayed on leaves, or applied to the soil as it poses no harm to humans, animals, or beneficial insects. As a result, this botanical insecticide can contribute greatly to the overall scheme of sustainable pest control. Pyrethrum has been derived from chrysanthemum flowers, and is a natural insecticide that will attack the nervous system of beetles. Beetles that receive a dose of pyrethrum face rapid knockdown, and death occurs upon contact. Pyrethrum can be sprayed on beetles directly, as well on the plants. Rotenone is extracted from a number of plants, including Derris and Lonchocarpus. Rotenone reduces insect's ability to do cellular respiration, leading to death of the insect. Rotenone is also effective against beetles; however, may exhibit more toxicity towards humans and animals, remaining less than ideal for application in certain areas. There are other, lesser-known botanicals to consider such as pyrethrins from the chrysanthemum family (i.e. also natural nervous system targeting insecticides). Additionally, it is important to consider the same classification of derivatives which include Derris, of which there is abundance in the world, and act as insecticides due to their effects on the insect's nervous system and/or behaviour of feeding. Again, botanicals can be applied to plants or in the soil making it a form of environmentally safe, pest control with a reduced impact on non-target organisms.

3.4.4.2 Biological Control

Metarhizium anisopliae is a species of insect killing fungus for biological pest control, including corn flea beetles. This fungus infects this beetle by penetrating their exoskeleton and colonizing their whole body. As the fungus colonizes them, it ultimately kills beetles. When beetles interact with the fungus, it infects them causing eventual death, by a natural sustainable and environmentally sustainable means. *Metarhizium anisopliae* can be

applied as a biopesticide in a spray or it can be soil bound so it can be applied in many different forms in cornfields. *Metarhizium anisopliae* is very effective at reducing populations of beetles and provides a sustainable pest management plan that does not rely on traditional chemical pesticides. Biocontrol agents like *Metarhizium anisopliae* help maintain the ecosystem by managing pest populations while causing no harm to beneficial insects or plants that may be present in the area.

3.4.4.3 Cultural Practices

There are several other cultural methods of control that, in addition to botanical and biological control, can be effective in reducing populations of beetles in your cornfields. The use of Weed and Residue Removal, for example, will help deny beetles their necessary resources (i.e., shelter, food, and reproductive capabilities) as this method controls weed populations (and as a result, beetle populations) and also cleans up crop debris from the previous growing season before planting. Once a farmer begins to clean up the plant debris and weed population, then resources or necessary capabilities will be removed for beetles to use, therefore feeding beetle population decreases and reproductive capacity of beetle's decreases. Crop Rotation is another cultural method of control that can help reduce the beetle life cycle by rotating with crop types that beetles do not need or want (also called preferred crops). For example, after corn planting, if the next season provides legumes or grasses for planting, then the adult beetles will not need the corn as they've already lost their inclination to utilize it. Trap Crops will include legumes or grasses in a small area within your cornfield, with the aim of attracting beetles away from your corn plants to stack beetles in specific areas of the field, using "traditional" tactician of managing them there. Early Planting of corn benefits plant establishment before beetles are most active, and it reduces early damage to the plants from the beetles. And lastly, Seed Treatment can involve the use of neem-based products or other natural insecticides to provide protection against larvae of the beetle, offering protection early in the production cycle while also reducing infestations. The cultural practices may collectively complement your botanical and biological control methods to manage beetle populations in corn.

3.4.4.4 Integrated Pest Management

Integrated Pest Management (IPM) utilizes an integrated, sustainable approach utilizing pest management tactics known as botanical control, biological control and cultural controls allows farmer or pest manager to appropriately manage pests with different control strategies. IPM begins with monitoring the pests to know when controlling the pest is necessary and whatever possible, an emphasis is placed on letting natural pest controls, such as predators or parasitoids act naturally to control the pests of concern. If necessary, botanical or other control method can be implemented, therefore a crop with pre-existing pest damage would be managed as IPM utilization determined it should be treated. An IPM strategy minimizes the need to utilize pesticide, minimizes the impact on beneficial species, and minimizes the environmental impact of pest management. Since farmers will ultimately benefit from reduced costs, less reliance on chemical pesticide and long-term control of pests, there is no question why IPM is a more sustainable environmental approach to pest management.

A botanical method of controlling insects when utilized in conjunction with biological and cultural practices provides an ecosystem friendly, holistic approach of controlling beetle damage in cornfields. No matter if a farmer uses neem oil, pyrethrum, or intercropping, the objective of all of these botanical management strategy is based on one of several approaches... disrupting the behavior of the beetles, reducing beetle populations, or introducing a natural enemy or pathogen that targets the pest. Each action farm managers take with botanical controls deductively gets incorporated into the IPM strategy to minimize environmental impact while protecting their crops using minimal or no pesticide.

4. Results and Discussions

The pest management approaches were evaluated on several sample corn leaves affected by common pests including armyworms, aphids, grasshoppers and beetles. Diverse control approaches included mechanical, botanical, and biological approaches based on the severity of the infestation. The measure of how successful each approach was evaluated through the effectiveness of pest reduction and the crop recovery rate.

Pest Type	Infection Severity	Control Strategy Used	Dosage (ml/L)	Observed Effectiveness (%)	Remarks
 Armyworm	Mild to Severe	Lambda-Cyhalothrin	2–3	85–89%	Dose increased with severity. Consistent and effective control noted.
 Aphids	Mild to Moderate	Neem Oil / Imidacloprid	1.5–2	78–81%	Botanical option preferred for mild cases to minimize chemical use.
 Grasshopper	Moderate	Malathion	2.5	83–84%	Maintained consistent efficacy across trials.
 Beetle	Mild	Chlorantraniliprole	2	87–88%	Biological alternatives like Spinosad evaluated for sustainability.

4.1 Discussions

- **Armyworm Control:** Lambda-Cyhalothrin showed robust control across varying infection severities. Adjustments in dosage, especially during severe cases (up to 3 ml/L), significantly improved pest suppression. The chemical's fast action made it suitable for emergency treatment.
- **Aphid Management:** Neem oil was effective in mild cases, supporting the shift toward botanical pesticides to reduce chemical load. However, for moderate infections, imidacloprid was sometimes considered for faster knockdown effect.
- **Grasshopper Suppression:** Malathion consistently delivered positive results. No dosage changes were required as previous field data confirmed its effectiveness even at standard concentration.
- **Beetle Infestation:** Chlorantraniliprole provided high efficacy, but biological alternatives like Spinosad were explored for long-term sustainability and lower environmental impact. Botanical repellents (e.g., neem) were considered in parallel trials.
- **Integration of botanical and mechanical methods**, such as neem oil and flour dusting, proved effective in reducing mild to moderate infestations without harming pollinators.
- **Lifecycle-aware intervention** significantly increased treatment efficiency. Early detection and targeted application avoided unnecessary chemical exposure.
- **Success rates varied slightly** based on infection severity, crop growth stage, and dosage calibration from historical field data.

5. Conclusions

In the modern context, pest management for corn production is vital for food security, economic security, and environmental security. This article provides the foundation for a comprehensive, non-chemical method to manage the major pests of corn ('Zea Mays L.') including fall armyworm, aphids, grasshoppers, and beetles through mechanical, biological, and botanical control strategies. Mechanical methods such as handpicking, adding sand to plant whorls, barriers, and traps can be used economically and practically for immediate pest management. Biological methods using parasitoids such as *Trichogramma* spp., entomopathogens such as *Bacillus thuringiensis* and *Nomuraea rileyi*, and natural enemies like lady beetles and lacewings can be used for effective long-term pest management with no environmental impact. Botanical methods include various intensive pest management practices including; neem oil, garlic extract, and cropping-system management by intercropping with a repellent crop or trap crop. These emerging pest management practices are good choices when considering alternatives to synthetic pesticides (or are used concurrently or ahead of synthetic pesticides) and can contribute to limiting pest populations without harming non-target and beneficial populations and the environment. The incorporation of these alternative strategies in an IPM program ensures that more pest suppression is delivered, offers reduced reliance on pesticides, and an improved resilience of the crop. This multi-faceted process promotes adherence to sustainable agriculture and could be customized or adapted for varying corn-growing environments. In conclusion, this study provides a scalable and sustainable approach to pest management in corn that is part of worldwide efforts for greener food production. Future research can focus on automation, precision delivery of biocontrols, and pest-resistance surveillance to further improve the effectiveness of this IPM.

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