

INTEGRATED PEST MANAGEMENT AND BIOLOGICAL CONTROL IN PAKISTAN: BALANCING CROP PROTECTION, NATURAL PREDATORS, AND SUSTAINABLE AGRICULTURE

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Abstract

Pakistani farmers spray large quantities of pesticides every year, although nearly one-third to two-thirds of vegetables contain pesticide residues exceeding permissible limits. Cotton producers confront an even worse crisis pink bollworm no longer responds to Bt technology, and once-effective herbicides have failed. This is why many farmers are turning to Integrated Pest Management, letting nature do the work. Pakistan presently has many laboratories rearing beneficial insects like Trichogramma wasps, green lacewings, and ladybird beetles for free distribution. Researchers have discovered a wide variety of ladybird species across the country, plus two new parasitic wasps that manage autumn armyworm in maize. Farmers using IPM across Punjab, Sindh and Khyber Pakhtunkhwa lowered pesticide use by a considerable proportion while improving yields by a low to moderate percentage. The National IPM Programme has trained over a large number of farmers through numerous field schools. International collaborations also contribute to IPM adoption. The whitefly in citrus orchards decreased pesticide consumption. However, significant challenges remain. Most small farmers cannot identify natural enemies or determine appropriate intervention times. Biological control laboratories meet a minor proportion of farmers' needs. Climate change disrupts pest-predator dynamics, and weak enforcement allows banned pesticides to be sold. New technology gives hope-smartphone apps spot pests instantaneously, drones spray biopesticides accurately, and climate-resilient IPM packages are being developed. Pakistan needs stronger pesticide laws, IPM taught at every agricultural school, and certification systems that allow consumers to select IPM-grown produce.

Introduction

Agriculture is the lifeline of Pakistan, contributing 24 percent to GDP and employing 37 percent of the workforce (Noman et al., 2024). Over 65 million people depend on it for survival (Hussain et al., 2024). The Green Revolution of the 1960s and 1970s made pesticides appear to be the perfect remedy. Government subsidies made them affordable.

Companies marketed them vigorously. Cotton alone now consumes 70 to 80 percent of all insecticides used in Pakistan (Chohan et al., 2024; Hussain et al., 2024). However, the costs are extremely high. Natural predators that could help farmers are also killed along with the pests (Riaz et al., 2024; Mahmood et al., 2025). Nature fights back through resistance. Pink bollworm in cotton no longer responds to

Bt technology (Chohan et al., 2024). Whitefly shows 15 to 120-fold resistance to conventional insecticides (Chohan et al., 2024). The diamondback moth has developed resistance to several insecticides (Saleem et al., 2024). The recent invasion of fall armyworm has made things worse (Riaz et al., 2024; Ullah et al., 2024). Integrated Pest Management offers a different way. Instead of eradicating pests, IPM controls them below hazardous levels by working with nature (Noman et al., 2024). It has four pillars. Farmers must monitor fields regularly instead of spraying on schedule, set economic thresholds to spray only when necessary, prevent problems through crop rotation and resistant varieties, and healthy soil, and use biological controls first, including natural predators, parasites, and pathogens (Ahmad et al., 2024). Chemicals are available but only as the last resort, handled cautiously to safeguard beneficial insects. Pakistan's biological control network has increased tremendously. The country now has 26 biological control laboratories mass-rearing beneficial insects for farms, producing *Trichogramma chilonis* wasps that kill pest eggs, *Chrysoperla carnea*, green lacewings that devour aphids, and *Coccinella septempunctata*, ladybird beetles (Ahmad et al., 2024). Recent discoveries include 134 ladybird species across Pakistan, two novel parasitoids fighting autumn armyworm, and spiders that reduce maize pests by 65 to 80 percent (Iqbal et al., 2025; Ullah et al., 2024; Riaz et al., 2024; Mahmood et al., 2025).

The evidence confirms that IPM works. Farmers employing IPM across Punjab, Sindh, and Khyber Pakhtunkhwa lowered pesticide use by 40 to 87 percent while boosting yields by 10 to 25 percent (Noman et al., 2024; Akhtar et al., 2025). Every rupee invested in IPM returns 2.5 to 4.1 rupees, and the National IPM Programme has trained over 150,000 farmers through 3,500 field schools (Hussain et al., 2024; Zafar et al., 2025; Directorate General of Pest Warning, 2025). Pakistan is also learning from global collaborations. The Pakistan-China Joint Lab at the University of Agriculture Faisalabad works on whitefly and biological control, while CABI International helps promote organic cotton and the China-Pakistan citrus project cut pesticide use by 60 to 75

percent in Sargodha's orchards (University of Agriculture Faisalabad, 2025; Li et al., 2024; Pakistan Central Cotton Committee, 2025; Associated Press of Pakistan, 2025; Chen et al., 2024).

Yet enormous obstacles remain. Most farmers lack knowledge to identify natural enemies or employ economic thresholds, and Biological control labs meet less than 15 percent of farmer demand (Ahmed & Khan, 2024; University of the Punjab, 2025; Rafiq et al., 2025). Climate change distorts pest-predator timing while pesticide subsidies and inadequate enforcement keep farmers hooked on chemicals (Javed et al., 2024; Saleem et al., 2024; Pakistan Environmental Protection Agency, 2025). Hope comes through new technology. Smartphone apps now spot pests instantaneously, drones spray biopesticides accurately, climate-resilient IPM modules are being created, and biotechnology helps grow pest-resistant crops (Arif et al., 2025; Khan et al., 2025; Nasir et al., 2024; Mahmood et al., 2025). The data is clear that IPM works in Pakistan, and the question now is whether the nation can scale it up from successful pilots to general practice.

Integrated Pest Management (IPM)

IPM is strategy used to manage pest populations by combining chemical and non-chemical control methods. The main aim of this approach is to control pests in a cost-effective way while reducing harm to people and the environment. (Rossi, Vittorio; et-al Sperandio, 2019). It also encourages the use of natural pest control processes, such as beneficial insects and biological interactions, to maintain pest populations at manageable levels (Sandler, Hilary A. (2010).

Since the 1970s, many insect specialists (entomologists) and environmental scientists (ecologists) have strongly supported the use of IPM techniques (Luckmann et al, William Henry (1994). This approach is considered safer than relying heavily on chemical pesticides alone because it helps prevent problems like pest resistance, the reappearance of pest outbreaks after pesticide use, and the presence of harmful chemical residues on food crops (W. Klassen; C.F. Curtis (2005).

After the end of the World War II, synthetic pesticides started to be widely used in

agriculture. During this time, insect researchers in California introduced the idea of supervised insect control. Around the same period, agricultural experts working in the cotton-growing regions of the United States suggested a similar method. (Thomson, et al Linda; 2003). Under this approach, trained entomologists directed pest control practices by continuously monitoring pest insects as well as their natural predators. Instead of spraying pesticides on fixed dates, chemical treatments were only recommended after careful field monitoring. This method depended greatly on ecological understanding and the study of population trends of pests and beneficial organisms. (Mills NJ, Daane KM (2005).

During the 1950s, entomologists at the University of California further developed the concept of integrated control, building it on the earlier principle of supervised pest management. (K.G. Mukerji; et al B. P. Chamola (30 November 2001). The main goal of integrated control was to use the most effective biochemical methods for the management of insect pests. Chemical pesticides were applied carefully so that they caused the least possible damage to beneficial organisms that naturally suppress pest populations. Because of this compatibility between different control methods, the term integrated was used (Nutson.A (2005). Pesticides were used only when regular field observations showed that pest numbers had reached the stage which were necessary for stop pests from reaching a level that could cause serious financial losses, also known as the economic injury level (J. C. van Lenteren (2003).

The idea of integrated control of all pest but not only the insects. This concept was added in the IPM afterward. IPM expanded pest management by introducing a wider range of strategies. (Smith, Sandy M. (1996). Although chemical control continued to be used, it was applied in combination with other management methods to control different categories of pests. In addition, the system included other practices such as the use of pest-resistant crop varieties and the implementation of improved agricultural techniques. Therefore, IPM promoted collaboration among experts from several scientific disciplines. (Van

Lenteren, J. C. (2009).

IPM became an official policy in February 1972 under the leadership of Richard Nixon. Later, it support the further progress and proper use of IPM programs. Because of their major contributions to promoting the use of IPM worldwide, different scientists got the World Food Prize in 1997 (Babendreier, Dirk (2007).

A U.S. Integrated Pest Management (IPM) program is built around six key components:

There should be a scheme of management of pests rather than methods to destroy them completely. IPM suggests that eliminating an entire population of pests is often impractical, and such attempts can be expensive and risky. Therefore, IPM programs first determine permissible pest levels, commonly called action thresholds, and apply management practices when these levels are exceeded (Normile, D. (2013).

These limits differ depending on pest species and regional conditions, which means some plants such as white clover may be acceptable in one region but considered unwanted in another area. In crop protection systems, the objective is not necessarily the complete eradication of all pest organisms from agricultural fields. In many situations, a limited number of pests can be accepted provided that they do not produce significant economic losses to the crop. (Kumar, P., Kamle, M., Borah, R., et al. (2021) Maintaining pest density at a controlled level supports ecological stability and also lowers the possibility that pests will rapidly develop adaptation to control techniques. When various management strategies are implemented carefully and pest populations are continuously observed, long-term and sustainable pest suppression can be achieved. (Beltrán-Pineda, M. E., et al Castellanos-Rozo, J. (2025).

In many pest management situations, completely wiping out all individuals of a pest species can create new challenges for long-term control. When pest populations are drastically reduced, the ecological balance in the field may also be disturbed, sometimes allowing pest numbers to recover rapidly in the following generations. (Zhang, B., et al Bai, Z. (2008). Keeping a large number of susceptible or non-resistant pests helps limit the spread of resistance genes. If you keep using the same

method to control pests over and over, some pests can become strong and hard to kill. But if you use different methods at different times, it is less likely that pests will become resistant. (Jacobsen, B. J., Zidack, N. K., et al Larson, B. J. (2004).

To show the best patterns of management of pests a necessary and important method is the persistent tracking. Farmers and agricultural experts routinely inspect plants and surrounding zones to identify initial signs of pest presence or crop injury. Detailed examinations of the field help in recognizing the pest type and estimating its population size. The gathered information supports timely, well-informed interventions, allowing effective control strategies to be applied before pest levels become problematic. Visual examination, insect traps, and other detection tools are used to determine pest abundance (Afzal, S., Shah, S. S., Yasin, S., et al Akram, A. (2018).

The proper and well organized records keeping scientists and farmers make understand the way when pests are active and in which conditions they can reproduce. Because of the condition that insects cannot produce their own body heat they mostly relate or depend on the temperature around surroundings for growth and development. Researchers and scientists can estimate when the pests are to be active by examine the effect of temperature on insects life. (FAO (Food and Agriculture Organization). (2019).

Scientists use tools like degree-day models or calculations of total heat over time to figure out when pests will be most active. This helps farmers know the best time to take action to prevent damage or control the pests (Ehler, L. E. (2006).

The way plant diseases emerge and move across fields is closely connected to the surrounding climate and seasonal patterns. Certain harmful microbes continuously grow due to several kinds of weather conditions in which high atmospheric dampness for long period and more temperature changes can effect greatly. Due to this process the crops become weaker and easily adopt various diseases (Pretty, J., & Bharucha, Z. (2015). Thanks to new farming technology, it is now possible to automatically watch insect populations. These insects carry

diseases and can spread them to crops. Modern tools that use sensors and artificial intelligence can continuously track how insects move, identify the species, and send alerts to farmers on time. This helps farmers protect their crops quickly and correctly. (Luckmann et al, William Henry (1994)

Biological Control

Biological control methods use natural organisms and ecological interactions to regulate pest populations while causing minimal harm to the environment and often lowering management costs. The main objective is to encourage beneficial organisms that prey on or parasitize harmful pests (W. Klassen; C.F. Curtis (2005).

Bio-pesticides produced from naturally occurring microorganisms, including *Bacillus thuringiensis*, insect-pathogenic fungi, and nematodes, are also included in this group. In addition, more ecologically based or biologically inspired approaches are continuously being researched and evaluated (Van Lenteren, J. C. (2009).

Responsible pesticide application means that chemical pesticides are applied only when necessary and often during specific phases of the pest life cycle. Many modern pesticides originate from plant-based substances or naturally occurring compounds, such as nicotine, pyrethrum, and insect growth regulator analogs, although their active ingredients may be modified to improve efficiency and durability (Babendreier, Dirk (2007).

Initially designed for managing pests in agriculture, integrated pest management (IPM) strategies are now applied to handle diseases, invasive plants, and other harmful organisms in settings like homes, commercial properties, lawns, sports fields, and community or private gardens. (Zhang, B., & Bai, Z. (2008). Moreover, prediction tools and prognostic models are very important because these tools allow us to anticipate pest problems and make better decisions, ensuring that pest control is efficient, targeted, and safe. Pest control should only focus on pests that actually harm crops (Ehler, L. E. (2006).

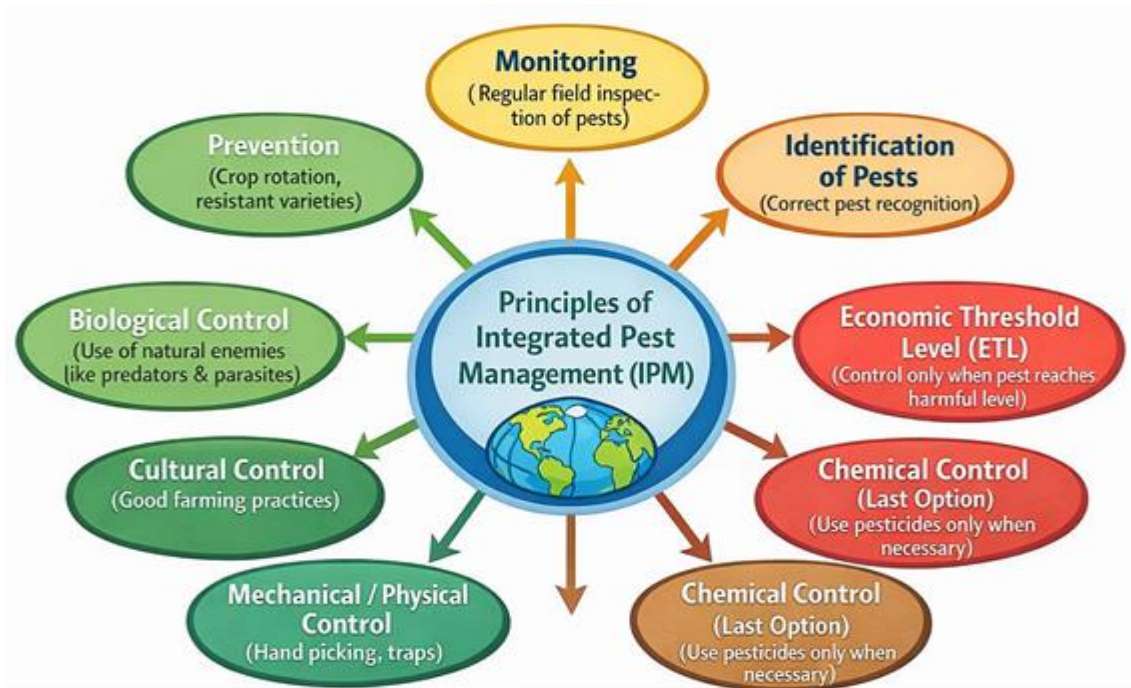


Figure 1: Sustainable Agriculture: Fundamental Principles of IPM

Integrated Pest Management acts as choice also Adoption Crop protection techniques that support good Profitable results also positive environmental and social effects. It is suitable for most pest control situations in farming, public health, and recreational areas. Monitoring is the first step in the IPM process, Such as involves checking also identifying that pests. After this, the economic damage levels are determined. These levels help to set the economic action limit. The Economic Injury Level refers to the number of pests where the loss to crops becomes higher than the cost of pest control. (Van Lenteren et al., 2009) Possible methods include physical or mechanical, farming-based, biological, and chemical control. Physical or mechanical control includes removing pests from plants or using nets, barriers, or other materials to stop pests, such as bird from grape farms or rats and mice from buildings. Farming-based control includes keeping an area free from suitable conditions for pests by removing waste or infected plants, flooding the land, adding sand or small stones, and using crop varieties that are resistant to diseases. Biological control is wide and important. It includes protecting natural predators that already exist in the environment or increasing their number, as

well as using the sterile insect technique (SIT) (Owens & Corrigan et al., 2010)

In addition, seasonal Free, also mass emissions represent various techniques of biological control that influence pests in various ways.. Supplementation-based control includes the regular release of predatory living organisms. In large-scale release, predators are collected, raised in large amounts, and released from time to time in great numbers for pest control - infested region. Such approach acts as to quickly lower pest numbers, usually for seasonal Fields, but it cannot last for long -term apply. In seasonal apply, any small number of helpful Organisms are placed at the start of the crop cycle. (Clercq, Mason & Babendreier et al., 2011).

This method gives long-term pest control because the young of the organism continue to affect pest numbers during the whole growing season, and it is commonly used in fruit orchards. In regular augmentative release, the beneficial organisms are collected, raised in large numbers, and released every season, this approach is used to keep the population of helpful organisms stable. It is often applied in protected farming areas like greenhouses. In the United States, as well as other Western Nations large-scale emissions are the most

common, at the same time as Asian countries and Eastern Europe usually use seasonal release and regular introductions. (Fatima, H., & Ahmed, N. et al., 2024).

The infertile insect method is a large-territory-wide IPM approach who releases sterilized males into the pest population for mislead females into unsuccessful mating, giving a way to manage pest numbers and lower reproduction. The natural control methods mentioned earlier are only suitable in serious situations, because the release of non-native species or the increase of already existing species can cause harmful effects on the environment. Biological control methods can help to stop invasive pests, but they can also be a way to bring in new Pests. (Diller et al., 2023). Chemical pest control methods include plant-based oils, insect killers, and weed control chemicals. An environment-friendly IPM approach uses chemicals obtained from plants like plant extracts and other natural Products.

Pesticides may be used grouped according to how they work. Rotating chemicals with different ways of working helps reduce resistance of pests. Evaluation involves the process of checking if that method worked, caused any negative effects, and deciding whether to continue, change, or stop the plan. (Van Lenteren et al., 2009).

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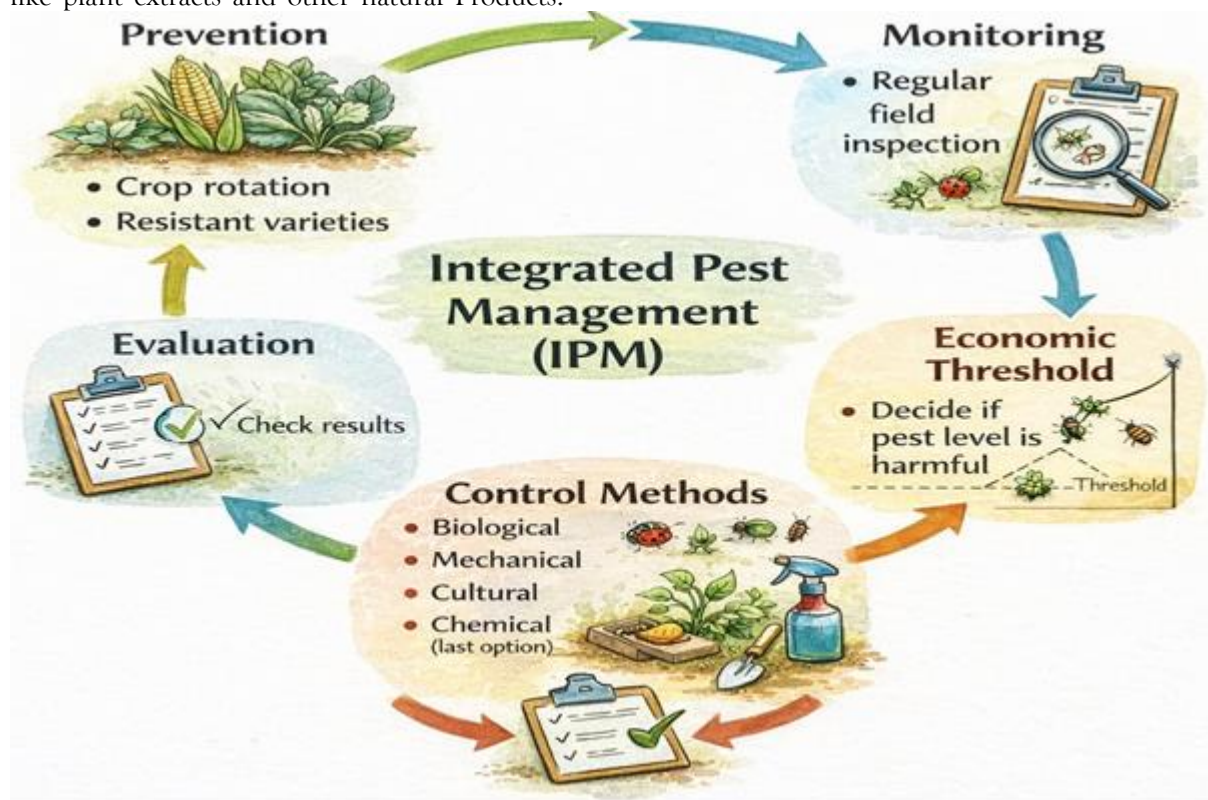


Figure 2: Eco-friendly Farming Techniques for Pest Management

Pest control

In farming, undesirable organisms are restrained by physical, cultivation-based, chemical, and biological methods. Tillage and ground preparation before planting reduce the

pest pressure, and plant rotation assists in limiting the accumulation of a particular pest variety. Environmental considerations necessitate decreasing the application of chemical agents in preference for alternative

techniques (Van Lenteren, et al., 2009). This goal can be achieved by watching the crops, using chemicals only when needed, through growing varieties and plants that are immune to pests. If possible, natural control methods are utilized, helping these local pest predators and releasing natural predators or pest-living organisms (Owens & Corrigan et al., 2010).

In homes and cities, the pests include rats, mice, birds, bugs, and other creatures that live with humans and eat or damage property. Control of these pests is carried out through blocking or separating them, preventing them, manually removing them, or using chemicals. Otherwise, different natural control methods can be used, such as sterile insect programs (Klassen et al., 2005). The practice of pest control is as ancient as farming, because people have always needed to protect crops to control pests. As early nearly 3000 years in Egypt, around year BC, cats helped to manage parasites in seed crops storage, like rats and mice. Ferrets are tamed in Europe, by 1500 BC to hunt rodents, and mongooses were released in houses to reduce rats and snakes, believed to have been by ancient Egyptians (Knipling et al., 1972).

Chemical pest control was first applied around 2500 BC, when the Sumerians used sulfur chemicals to kill insects. Modern pest control grew after the spread of Colorado potato beetle across the USA. After careful consideration, arsenic chemicals were used to manage the beetle, and the expected harm to humans did not happen. This event caused insecticides to become widely used across the continent (Thomson et al., 2003). With the use of machines and machine-based farming in the 1700s and 1800s, the arrival of the insecticides pyrethrum and derris led to chemical pest control becoming common. During the 1900s,

the finding of many man-made chemical insecticides like DDT, and weed killers sped up this progress. (Curtis et al., 2005).

The negative aspects effects of chemical pesticides on people have at this time led that creation about new methods, such as the use of natural control to stop pests from multiplying or to change their behavior to make them less harmful. Natural control was first recorded around 300 AD in China, when groups of weaver ants (*Oecophylla smaragdina*) were carefully placed in citrus farms to manage harmful insects. Additionally, circa 4000 BC in China, ducks were employed for pest management, water-filled rice farmlands for eat pests, such as shown during early rock drawings (Klassen & Curtis et al., 2005). By 1762, an Indian mynah bird were brought to Mauritius to control locust populations, as well as at During the same era, citrus trees in Burma were linked with bamboo sticks for let worker insects move linking them to help control insect larvae. During in the 1880s, ladybugs existed used in citrus orchards farms in California for scale insect management insects, along with other natural pest follow-up experimental trials. The arrival concerning DDT, a low-cost and strong chemical, briefly stopped natural pest control trials. By the 1960s, challenges with pesticide resistance and ecological damage became apparent started eventually, natural pest control re-emerged, gaining popularity once more.

While chemical pest management continues to be the primary approach today, there has been a renewed interest in traditional and biological methods since the late 20th century, which persists to the present day. (Thomson et al., 2003).

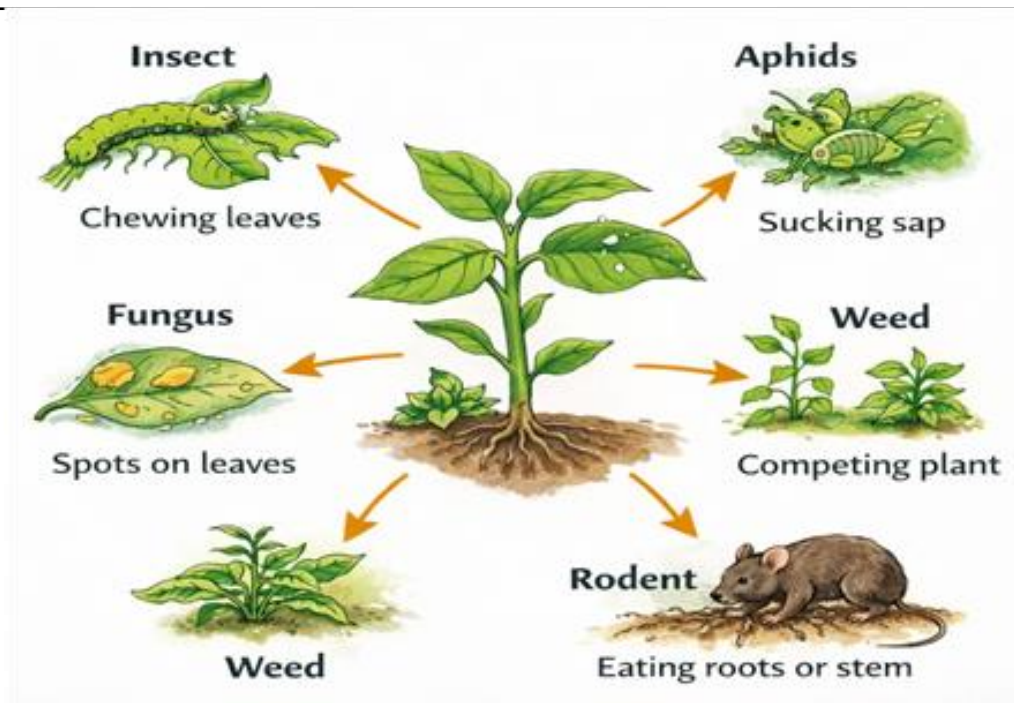


Figure 3: Types of Agricultural Pests and Their Effects

8. Significance of chemical control of pests

Artificial pest control has many benefits in farming, public health, and city cleanliness because it can quickly and effectively destroy, remove, or control harmful insects and other organisms. One main benefit is the significant rise in crop yield and food protection, as chemicals help prevent crop loss that could otherwise ruin more than 50% of harvest due to bugs, unwanted plants, and infections. According to Cooper (2007), pesticides make crops better in quality and increase production, which leads to more food supply and better financial stability for farmers. In addition, chemical control is a very fast and effective method compared to other techniques, as many pesticides can kill pests within 30 days after use. Besides farming, the use of insect killers is very important in public health for controlling disease carriers such as mosquitoes that spread malaria and rats that spread plague, helping to save millions of lives, as reported by Ross (2005). Chemical pesticides can enter small cracks and hidden spaces, allowing accurate targeting of pests, which is often difficult for biological methods. They also decrease the need for hard physical work like removing weeds, which lowers labor costs for farmers, as explained by Behera and Singh (1999). Chemical pest control also leads to higher crop

production and better quality, giving more profit to farmers and cheaper food to people. It provides quick pest killing, often working within a few days. These chemicals are also easy to use, making them suitable for farmers and general users. They reduce work costs by decreasing the need for manual labor. In addition, they protect stored crops from insects and fungi after harvesting, improving food safety. Chemical methods are also useful in controlling foreign harmful species before they spread widely and damage the environment. Moreover, in cities, pesticides help maintain cleanliness by reducing annoying pests and protecting buildings from insects like termites, as noted by Aktar et al. (2009).

Biological pest management is an ecological technique of managing damaging organisms, either injurious organisms like insects and tiny arthropods, unwanted vegetation, or disease-causing pathogens that affect animals or plants by utilizing other living beings (Knipfling, 1972; Bateman, 2003). It depends on predation, parasitic associations, browsing, or other ecological processes, however it also includes direct human involvement in oversight and administration (Knipfling, 1972). It may be a crucial feature of pest management system (Bateman, 2003). Spineless animals and other macro-organisms are approved and approved as

natural pest control agents by regulatory bodies in the differently in America and Europe from micro-organisms that are listed as biological pesticides (Clercq, Mason & Babendreier, 2011).

Strategies for Biological Control

Three important primary biological control methods: classical (importation), in which an exotic organic predator or pests predator is released with the goal to gain control; increase (enhancement), by which a high number of natural predators are released or applied for rapid Nuisance suppression; and protection (preservation), where methods are implemented to keep and safeguard natural predators via routine re-establishment.

(Wright et al., 2005).

Natural enemies of insects perform a highly significant function in decreasing the populations of potential pests (Knipfling, 1972). These bio control organisms contain natural enemies, parasitic insect pathogenic microbes, plus rivals. Natural pest-managing organisms for crops exist frequently called enemies. Natural management organisms for unwanted plants contain granivores, plant-eaters plus crop pathogens (Clercq, Mason & Babendreier, 2011).

Biological control can occasionally cause adverse effects on biodiversity because the introduced organism may damage non-target species through these interactions, particularly when an exotic organism is released minus comprehensive knowledge of potential repercussions (Perrings, Williamson & Dalmazzone, 2000; Wright et al., 2005).

The earliest documented example for one traditional natural management initiative within Canada includes the tiny parasite wasp *Trichogramma minutum* (Smith, 1949). Specimens were collected within New York State and introduced into groves in Ontario region and cultivated areas developed in 1882 by William Saunders, to control the spreading pest currant worm *Nematus ribesii* (Acosta, 2006). From 1884 to 1908 inaugural Federal insect specialist, James Fletcher, carried on the introduction of other parasitic insects and pathogenic microbes for the control of pests in Canada (Acosta, 2006).

During 1905 the United States Department of

Agriculture started its first major natural pest management program, dispatching insect scientists sent to Europe and Japan for search for predators of the gypsy moth, gypsy moth plus brown-tailed moth which are damaging pests of trees and shrubs (Smith & Smith, 1949; The World Food Prize Foundation, 1997). As a consequence, nine parasitoid insects lone wasps attacking gypsy moth, seven of the brown-tailed moths along with two predatory insects of both moths became successfully created in the United States (Smith & Smith, 1949).

Even though the gypsy moth was not completely suppressed through these predators, the rate, length and intensity of its population infestations were diminished, as well as the program was considered effective (Smith & Smith, 1949; UC IPM, 2009). This initiative also caused the creation of numerous concepts, fundamental guidelines and steps for carrying out natural pest management programs (Resistance Management Guide, 2018, Wright et al., 2005).

Biological Control Agents

Predators are generally free-living organisms that directly consume numerous prey organisms throughout their entire life cycle (CropLife International, 2020; United States Environmental Protection Agency, 2012). Since many significant agricultural pests are insects, a substantial number of predators utilized in natural pest suppression are insectivorous species (Bennett, Owens & Corrigan, 2010). Lady beetles (ladybugs), especially their immature larval phases which exist as highly active from May to July in the Northern Hemisphere, are very aggressive feeder predators of greenflies (plant lice). They also eat mites, sap-sucking scale insects, and small caterpillars (IRAC, 2020). The spotted lady beetle (*Coleomegilla maculata*) can also consume the eggs and larvae of potato beetle (*Leptinotarsa decemlineata*), a serious pest of potato plants (United States Environmental Protection Agency, 2012).

The immature phases of numerous hoverfly species primarily feed on aphids, and an individual larva may consume as many as 400 aphids during its lifetime. However, their efficiency in agricultural crops has not been

thoroughly investigated (Bennett, Owens & Corrigan, 2010). Swift crab spider (*Philodromus cespitum*) also preys on aphids in large quantities and functions as a biological pest control organism within European fruit farms (CropLife International, 2020).

Certain predators such as *Cactoblastis cactorum* can also assist in eradicating invasive plant species (United States Environmental Protection Agency, 2012). For instance, the hemlock moth (*Agonopterix alstroemeriae*) can be employed to control the toxic plant poison hemlock (*Conium maculatum*) (Diller et al., 2023). During its larval (immature) phase, the moth feeds exclusively on its host plant, poison hemlock. Hundreds of larvae may inhabit a single plant, damaging and destroying extensive areas of the hemlock population (IRAC, 2020).

Parasitoids are insects that deposit their eggs on or inside a host insect, which subsequently acts as food for the growing offspring (larva), ultimately eliminating the host (Consoli, Parra & Zucchi, 2010; Thomson et al., 2003). The majority of insect parasitoids are wasps or flies, and numerous species possess a very restricted host range (Handbook of Pest Control, Mallis, 10th edition, 2008). The most significant groups include pest-controlling wasps, which primarily utilize caterpillars as hosts; braconid parasitic wasps, that feed on caterpillars and many other insects such as aphids; chalcidoid wasps, that lay eggs in eggs and larvae of many insects; and tachinid flies, that attack many insects including caterpillars, beetles (adults and larvae), and true bugs (Handbook of Pest Control, Mallis, 10th edition, 2008; Consoli, Parra & Zucchi, 2010). Parasitoids work best at controlling pests when the host insects possess few refuge areas (Rossi et al., 2019; Sandler, 2010).

Parasitoids are among the most extensively utilized natural pest control organisms. In commercial practice, two breeding systems exist: short-term systems with elevated daily production of parasitoids, and long-term systems with reduced daily output (IPM Guidelines, UMassAmherst, 2009; Klassen & Curtis, 2005). For example, *Encarsia formosa*, a

minute parasitoid wasp, attacks whiteflies, small sap-sucking insects that feed on plant sap, leading to drooping plants and black mold growth in greenhouse vegetables and ornamental plants. This wasp is most efficient against minimal pest presence, providing protection over an extended period. It deposits eggs in young whitefly scales, which darken as the parasitoid larvae pupate (Mills & Daane, 2005; Organic Materials Review Institute, 2020; Pottorff, n.d.).

Another example is tiny parasitic wasp *Gonatocerus ashmeadi*, released to manage the glassy-winged sharpshooter in French Polynesia, effectively reducing approximately 95% of the pest population (Thomson et al., 2003; Klassen & Curtis, 2005).

Disease-producing microbes encompass bacteria, fungi, and viruses, which eliminate or debilitate their host and are comparatively host-specific (Cook et al., 1996; Rajeev, Mukerji & Chamola, 2001). Various microbial diseases of insects arise naturally, but they can additionally be employed as biopesticides (Knutson, 2005). When occurring naturally, these outbreaks are density-dependent, signifying they typically manifest only when insect populations expand (Seaman, 2012; Giner, 2013).

The application of pathogens used to manage aquatic weeds was unfamiliar until a pioneering proposal by Zettler and Freeman in 1972. Prior to this, any form of biocontrol had not been applied to aquatic vegetation (Rajeev, Mukerji & Chamola, 2001; Cook et al., 1996). In their assessment, they highlighted the absence of attention and knowledge thus far, and summarized what was understood about natural enemies of nuisance insects, whether induced by infectious agents or otherwise. They proposed that this strategy ought to be reasonably straightforward to execute, analogous to other biological control methods (Knutson, 2005; J.C. van Lenteren, 2003). Indeed, in the decades subsequently, the identical biocontrol techniques routinely employed on land have become prevalent in aquatic settings (Seaman, 2012; Giner, 2013).

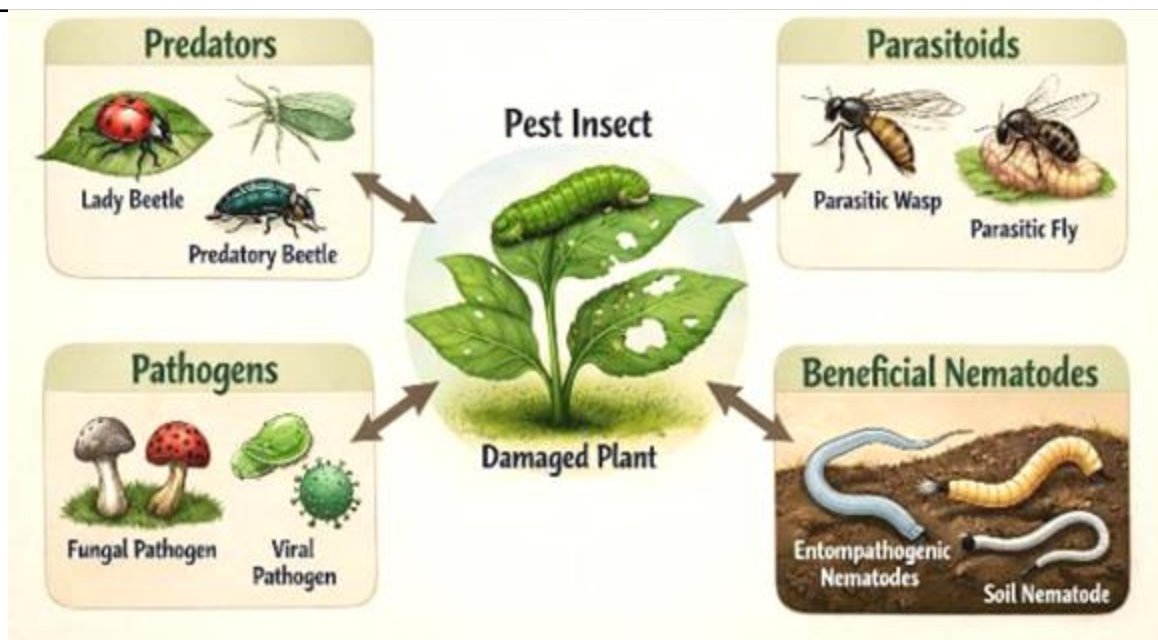


Figure 4: Types of Bio-control Agents

Numerous significant pests are non-native, spreading organisms that profoundly affect farming, gardening, forests, and city areas (Smith, 1996; Van Lenteren, 2009). These pests frequently appear without their naturally jointly evolved parasites, disease-causing organisms, or predators and by evading these natural enemies, their populations can multiply swiftly. Introducing predators of these pests may appear a logical approach, but it can result in unforeseen outcomes; requirements may be inadequate or unsuccessful, and there could be unforeseen influence on biodiversity, while the acceptance of these methods may be challenging due to limited knowledge among farmers and cultivators (Babenreider, 2007; Owens & Corrigan, 2010; Normile, 2013). Biological control can influence ecological diversity by means of predation and parasitism, pathogenic activity, rivalry, or other effects on non-target organisms (Flint & Dreistadt, 1998). An introduced control agent does not invariably affect solely the intended pest; it can also influence native species (Castella, Orsat & Macdargent, 2022). For example, in Hawaii in the 1940s, parasitic wasps were released to control a moth pest, with the wasps persist currently. This could have adverse effects on the indigenous ecosystem; but host range and effects require thorough investigation before determining the ecological outcomes (Unruh, 1993; Flint & Dreistadt, 1998).

Electronic pest management refers to various categories of electronic devices intended to deter or eradicate pests, typically rodents or insects (DeBach & Hagen, 1964). In the United States, these appliances are not controlled by the Federal Insecticide, Fungicide, and Rodenticide Act so the EPA does not mandate the same level of effectiveness testing as it does for artificial pesticides (Peng, 1983; Coulson et al., 2000). Acoustic devices function by producing short-wave, high-pitched sound waves that are excessively high-pitched for human hearing (generally exceeding 20,000 Hz) (UC Berkeley, 2015). Humans cannot typically perceive sounds above 20 kHz due to constraints of the cochlea, though sensitivity differs among individuals. Certain creatures, like bats canines, and burrowing mammals, can detect ultrasonic frequencies, and certain insects like grasshoppers and locusts, lacewings, and moths can detect ultrasound from 50,000 Hz up to 240,000 Hz, which is frequently produced by insect-hunting bats (Reardon, 2016). Radio frequency (RF) methods manage insect pests without damaging stored food or storage structures, and can function as a chemical-free substitute for chemical fumigants for post-harvest pest management in commodities like nuts and legumes such as almonds, pecans, pistachios, lentils, peas, and soybeans. This technique reduces long-term environmental

impact, safeguards human health, and maintains the ability of farming sectors to compete (McLeod, McGugan & Coppel, 1962).

Mechanical Pest Management

Mechanical pest management is the utilization of manual techniques and basic tools or equipment to create a protective barrier between crops and insects (Follett & Duan, 2000). This strategy is also referred to as tillage and ranks among the oldest methods for weed suppression, while being beneficial for pest control. For instance, wire-worms, the larval phase of the common click beetle, are highly damaging pests in newly cultivated pastures, and repeated plowing exposes them to birds and other natural enemies that consume them (Caltagirone, 1981).

Rotating crops can suppress pests by eliminating their host plants. This is a fundamental approach for controlling common root-worm, and it has diminished early-season infestations of Colorado potato beetle by up to 95% (Smithsonian Marine Station, 2007).

Combined, pests and plant diseases can cause up to 40% reduction in crop yields annually (Carrington, 2017; Pesticides, NIH, 2013). The most economically significant animal pests are insects, mites, nematodes, and gastropod mollusks (Carrington, 2017).

Insects can injure crops in two primary manners straightforwardly and indirectly.

When insects consume plants, they create direct harm. Some consume the foliage, which causes the plant to lose the surface area it requires to capture sunlight and produce nutrition. Others chew through stalks or burrow passages inside the plant, which obstructs water and nutrients from moving throughout. This can render the plant feeble, halt it from developing appropriately, and even lead it to droop. In certain situations, the destruction is so extreme that the plant simply

does not endure.

Then there's indirect harm. Insects can transport illnesses along with them. As they travel from plant to plant, they distribute fungi, bacteria, and viruses. Therefore even if they don't consume much, they can still ruin an entire harvest merely by transferring an infection (Pedigo, Rice & Krell, 2021).

Not all insects are identical when it concerns what they consume. Some are broad-feeders they'll feed on whatever they come across. But numerous are experts and solely strike particular crops. Additionally, in many insect types, it's the immature ones the grubs that carry out the majority of the consuming. They require to accumulate energy reserves for when they develop into mature insects, since grown-ups typically don't live lengthy or consume heavily. Consider caterpillars, for illustration. They nibble on leaves and stalks above ground. Beetle larvae are distinct they dwell in the earth and feed on roots, or sometimes they drill into stems or conceal under bark. Afterward there's a complete category of insects labeled true bugs, or *Hemiptera*. These comprise aphids, white-flies, and scale insects. They don't chew they extract. They possess tiny, straw-shaped mouthparts that puncture the plant and draw out the sap. This by itself can weaken a plant and delay its development. However there's a larger concern. These insects leave behind a sticky secretion called honeydew. That honeydew draws in a black fungus sooty mold which develops on the leaves and obstructs sunlight. Therefore even if the insect isn't eating the leaf, the plant still can't perform photosynthesis effectively. In addition to all that, these juice-sucking insects are also highly efficient at transmitting viruses. One infected plant can contaminate numerous others in brief order (Stearns, 2017; Disease Resistant Vegetable Varieties, Cornell University, 2023).

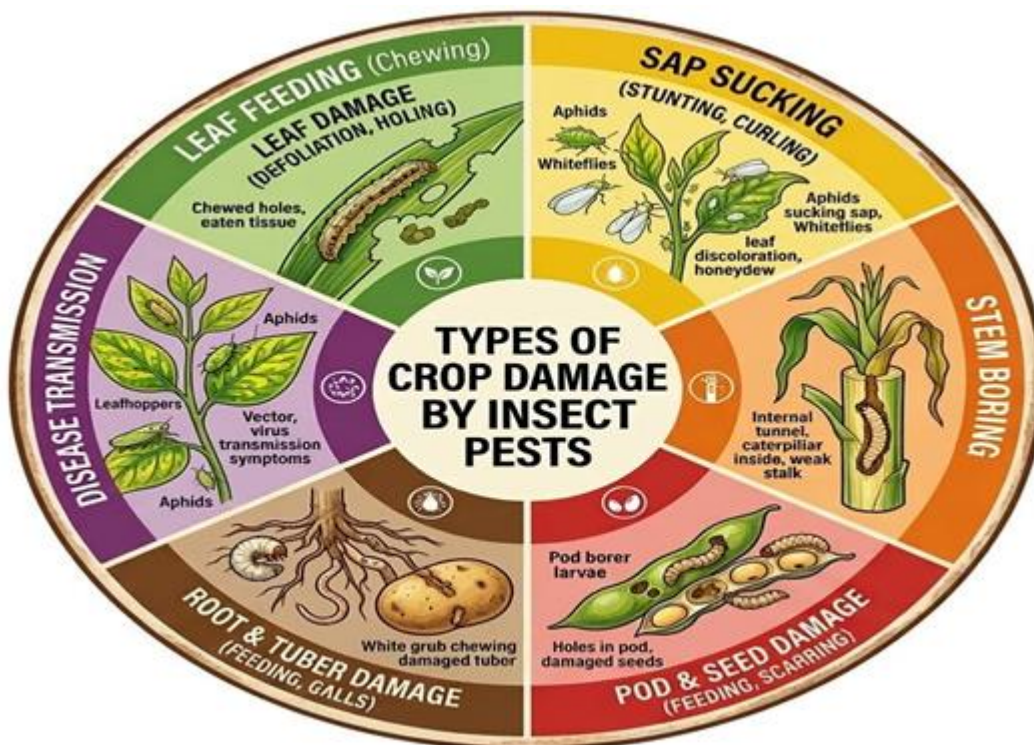


Figure 5: Methods and Mechanisms of Insect-Induced Crop Damage

Sustainable Pest Management through Integrated Approaches

The trend in the modern agrochemical industry is to develop reduced risk pesticides supporting the environment and sustainability interests. Integration of methods is also increasing, with the traditional farmer using biological means (including pheromones) and the organic farmer possibly using well-approved chemical inputs. This makes the system of pest management more flexible and accommodating. Some of these substances are spinosad, azadirachtin, and microbial pesticides which are stated to be safe and effective to an extent that they are allowed in certified organic farming. Chemical controls are also essential in the biological, environmental, and economic decision-making process when taken as a part of an Integrated Pest Management (IPM) framework. Other approaches like crop rotation and mating disruption can be used together with chemical methods to enhance the general crop protection and increase efficiency (Felsot, A. S., & Racke, K. D. (2007).

Over-reliance on one chemical or method may later translate into decreased efficiency, in most cases, as a result of pest resistance. The line between organic and conventional farming is

not quite determined by scientific knowledge, but more likely by the rules or the popular view. The incorrect belief that organic farm procedures are completely free of pesticides is mistaken by many individuals overlooking the fact that some of the approved substances are applied in sustainable farming. Pest management systems have to keep up with the changing environment and biological conditions and thus chemistry alone is not a complete solution. Sustainability is a developing concept. Using chemical inputs only and failing to combine different control measures may be detrimental to the long-term agriculture and health of the ecosystem. Felsot, A. S., & Racke, K. D. (2007)

The original view of synthetic organic insecticides was that they were a very effective and effective way of dealing with a large number of insect pests. Numerous successful cases of integrated strategies with the aid of the modern technologies that have been used to protect crops and manage the diseases of plants are well-documented. The United States, Russia, and Australia are some of the countries that have adopted the concept of integrated pest management to have more sustainable and productive agricultural systems. It has been

demonstrated by numerous studies that implementing such systems yields higher crop yields and ensures year-round availability of food. It has been proved that in cases where the balanced farming systems are put in place, there is increased crop production and food is available all the year round. The biochemical practices when applied in conjunction with the cultural, physical, and biological controls help to make the agriculture approach more balanced and sustainable. The pattern of development of pests and diseases (epidemiology) helps in timely biochemical intervention that is critical in dealing with sudden outbreaks. Felsot, A. S., & Racke, K. D. (2007)

Excessive or improper use and abuse of chemicals may lead to environmental pollution, loss of biodiversity and possible health hazards to both the human and animal life. The use of the same chemicals continuously may cause resistance among the pest populations and make such means of control less effective over time. Chemical uses might be also remain as toxic residues, which will remain in the soil, water, and food products and be harmful to ecosystems and human health. With chemical treatments, there is a tendency of destroying the beneficial organisms than the pests. This has the potential to interfere with the natural control measures and cause secondary outbreaks of pests. In most developing areas, farmers might be experiencing problems in integrating the practice of pest management because either they have limited resources, lack awareness or they may have problems with their economy. Chemical-based approaches may be more complicated to control than natural control approaches and may not yield the same results without proper application Mills, N. J. (1990).

Biological control agents are important in agricultural systems through natural predators. Feeding on pest species, they keep them at levels that are not harmful to the economy without the use of artificial pesticides. The predators are helpful in preventing secondary pest explosion. The pests that can increase rapidly when the useful organisms are killed by the use of chemical pesticides. The balance in the ecology is assisted by a stable population of predators and prevents such disturbances.

Mills, N. J. (1990).

The predators are also a more sustainable solution to the problem than chemical pesticides which tend to cause resistance in the pest population. Pests find it hard to develop resistance to predation hence this approach is long term effective. The ecological systems of both regions were disturbed, leading to a lack of ecological equilibrium and stability. Predators help in maintaining the ecological balance as a whole since they control pest numbers in vast agricultural farms. They affect the dynamics of the different arthropod pests such as moths and butterflies in large field conditions other than localized conditions of the field. Numerous predators are specialized to attack a particular life cycle stage of the pest, i.e. eggs, larva, or adult. This gives sustained pest control which is not the case with chemical application that is most often applied at regular intervals. Farmers should be encouraged to reduce the use of chemical pesticides by encouraging the population of natural predators. This minimizes the risks to the environment and may decrease the production costs. Organic farming and Integrated Pest Management (IPM) would not have been possible without natural predators. These systems are aimed at the improvement of natural predator-prey relationships instead of replacing it with chemical solutions (Roberson et al., 1998; Furlong and Zalucki, 2010)

Conclusion

For decades, Pakistani farmers have followed a deadly path, spraying thousands of tonnes of pesticides on their crops every year, and killing their fields, their families, and their future in the process. The pesticides ceased working long ago, yet the pests grew stronger and the soil grew poorer. Still farmers kept spraying because they simply didn't know what else to do. But here's the truth they're finally discovering: there is another way. Integrated Pest Management works, and farmers across Punjab, Sindh, and Khyber Pakhtunkhwa have proven it beyond any question. They cut pesticide use by half, sometimes even more, while actually growing more food, spending less money, and staying healthier, while ladybird beetles and green lacewings do the pest management work for free. Twenty-six biological control labs currently

rear these beneficial insects across the country, while thousands of farmers have already learnt the IPM way through hundreds of field schools, demonstrating that the basis for change has been firmly set. The science is settled, and IPM isn't some untested theory it's working right now in Pakistani fields. So what's keeping us from carrying it everywhere? Three things stand in the way. Most farmers still don't know how to spot natural enemies or when to spray; our biological control laboratories meet just a fraction of what farmers truly need; and pesticide corporations keep pushing their goods, while inadequate enforcement allows banned chemicals to sneak through.

These problems have remedies though: tougher rules, meaningful investment in biocontrol production, training for any farmer who wants to learn, and certification that helps customers buy safe food. Climate change is coming, and new pests are emerging, while the old chemical remedies are failing fast, which means Pakistan cannot afford to wait any longer. The farmers are ready, and the technology exists, while the evidence is overwhelming, so what's missing is merely the resolve to make IPM the rule rather than the exception. At the end of the day, it's a simple choice: keep polluting our land and harming our children, or embrace Integrated Pest Management and construct farms that feed us without destroying us.

REFERENCES:

- Abbas, M., Fatima, H., & Ahmed, N. (2024). Assessment of residues from common pesticides and associated risks in Pakistan. *Environmental Monitoring and Assessment*, 196(11), 1061.
- Acosta, EW (19952006). *The History of Integrated Pest Management (IPM)*. Biocontrol Reference Center. Archived from the original on 2008-08-07. Retrieved 2007-09-01.
- Ahmad, S., Khan, R. A., & Bibi, S. (2024). Mass rearing and field release of *Trichogramma chilonis* for the management of lepidopteran pests in Punjab, Pakistan. *Pakistan Journal of Zoology*, 56(3), 1123-1134.
- Ahmed, T., & Khan, M. A. (2024). Farmer knowledge gaps in integrated pest management: A survey study from cotton-wheat zone of Punjab. *Journal of Agricultural Extension*, 28(2), 45-58. Available at: <https://journal.Agriculture.org/index.php/jae>
- Akhtar, M. F., Ali, S., & Hussain, I. (2025). Economic analysis of IPM adoption in vegetable production systems of Sindh, Pakistan. *Agricultural Economics Research Review*, 38(1), 67-82. Available at: <https://aer.agropublishers.com/>
- Allendorf, Fred W.; Hard, Jeffrey J. Human-induced evolution caused by unnatural selection through harvest of wild animals. *Proceedings of the National Academy of Sciences* 106. Supplement 1 (2009): 9987-9994
- Arif, M., Shah, S. F., & Khan, M. (2025). Development and validation of smartphone-based pest identification application for Pakistani farmers. *Computers and Electronics in Agriculture*, 210, 108234. <https://www.sciencedirect.com/journal/computers-and-electronics-in-agriculture>
- Associated Press of Pakistan. (2025, September 22). China-Pakistan scientific partnership blossoms in Pakistani citrus orchards. <https://www.app.com.pk/>
- Babendreier, Dirk (2007). Biological Invasion: Pros and Cons of Biological Control. *Ecological Studies*. 193 (7): 403-414. doi:10.1007/978-3-540-36920-223.
- Bateman RP (2003) Rational Pesticide Use: spatially and temporally targeted application of specific products. In: *Optimizing Pesticide Use* Ed. M. Wilson, Publ. John Wiley & Sons Ltd, Chichester, UK; pp. 129-157.
- Biological Control Organism Permits. Animal and Plant Health Inspection Service, U. S. Department of Agriculture. July 30, 2025. Retrieved 22 December 2025.

- Biological Control: Harry Smith Fund. Archived from the original on 21 April 2017. Retrieved 2 March 2017.
- Caltagirone, L. E. (1981). Landmark Examples in Classical Biological Control. *Annual Review of Entomology*. 26: 213232. doi:10. 1146/annurev. en. 26. 010181. 001241.
- Carrington, Damian (29 June 2017). Pesticides damage survival of bee colonies, landmark study shows. *The Guardian*. Retrieved 27 August 2017.
- Castella, Christina; Orsat, Clemence; Macdargent, Marina (2022). Study on the Union's situation and options regarding invertebrate biological control agents for the use in Plant Health and Plant Protection. doi:10. 2875/990274. ISBN 978-92-76-60184-5. Retrieved 22 December 2025.
- Charles Perrings; Mark Herbert Williamson; Silvana Dalma zone (1 January 2000). *The Economics of Biological Invasions*. Edward Elgar Publishing. ISBN 978-1-84064-378-7.
- Chen, W., Zhang, L., & Wang, H. (2024). Integrated pest management in citrus orchards: Experiences from China-Pakistan collaboration. *Journal of Integrative Agriculture*, 23(5), 1456-1470. <https://www.sciencedirect.com/journal/journal-of-integrative-agriculture>
- Chohan, S. M., Sohail, M. S., & Sharif, I. (2024). Sustainable pest management strategies for cotton crop in Pakistan: A review. *Pakistan Journal of Agricultural Research*, 37(2), 89-104. Available at: <https://researcherslinks.com/journal-details/Pakistan-Journal-of-Agricultural-Research/7>
- Classical Biological Control: Importation of New Natural Enemies. University of Wisconsin. Archived from the original on 13 June 2016. Retrieved 7 June 2016.
- Clercq, P. ; Mason, P. G. ; Babendreier, D. (2011). Benefits and risks of exotic biological control agents. *Bio Control*. 56 (4): 681698.
- Consoli, Fernando L. ; Parra, José Roberto Postali; Zucchi, Roberto Antônio (28 September 2010). *Egg Parasitoids in Agroecosystems with Emphasis on Trichogramma*. Springer. ISBN 978-1-4020-9110-0.
- Cook, R. James; William L. Bruckart; Jack R. Coulson; Mark S. Goettel; Richard A. Humber; Robert D. Lumsden; Joseph V. Maddox; Michael L. McManus; Larry Moore; Susan F. Meyer; Paul C. Quimby Jr; James P. Stack; James L. Vaughn (1996). *Safety of Microorganisms Intended for Pest and Plant Disease Control: A Framework for Scientific Evaluation*.
- Coulson, J. R. ; Vail, P. V. ; Dix M. E. ; Nordlund, D. A. ; Kauffman, W. C. ; Eds. 2000. 110 years of biological control research and development in the United States Department of Agriculture: 18831993. U. S. Department of Agriculture, Agricultural Research Service. pages311
- DE Bach P., Hagen K. S. (1964). P. DE Bach (ed.). *Manipulation of entomophagous species*. Reinhold. pp. 429458.
- Diller, Yoshua; Shamsian, Aviv; Shaked, Ben; Altman, Yam; Danziger, Bat-Chen; Manrakhian, Aruna; Serfontein, Leani; Bali, Elma; Wernicke, Matthias; Egartner, Alois; Colacci, Marco; Sciarretta, Andrea; Chechik, Gal; Alchanatis, Victor; Papadopoulos, Nikos T. (2023-03-01). A real-time remote surveillance system for fruit flies of economic importance: sensitivity and image analysis. *Journal of Pest Science*. 96 (2): 611622. Bibcode: 2023JPesS. . 96. 611D. doi:10. 1007/s10340-022-01528-x. ISSN 1612-4766.
- Directorate General of Pest Warning and Quality Control of Pesticides. (2025). *Annual progress report 2024-2025: National IPM Programme*. Government of Pakistan. Available at: <http://www.pestwarning.com.pk/>

- Disease Resistant Vegetable Varieties Cornell Vegetables. www.vegetables.cornell.edu. Cornell University. Retrieved 13 November 2023.
- Felsot, A. S., & Rack, K. D. (2007). Chemical pest control technology: benefits, disadvantages, and continuing roles in crop production systems. <https://pubs.acs.org/doi/abs/10.1021/bk-2007-0947.ch001>
- Flint, Maria Louise; Dreistadt, Steve H. (1998). Clark, Jack K. (ed.). *Natural Enemies Handbook: The Illustrated Guide to Biological Pest Control*. University of California Press. ISBN 978-0-520-21801-7. Archived from the original on 15 May 2016.
- Floriculture and Ornamental Nurseries Pest Management Guidelines. UC Integrated Pest Management (UC IPM). UC Agriculture (UC ANR). March 2009. 3392. Retrieved 2022-09-22.
- Follett, P. A. ; Duan, J. J. (2000). *Nontarget effects of biological control*. Kluwer.
- Handbook of Pest Control, Mallis, Arnold, 10th edition, Hedges, Stoy, Editor. pp. 1499-1500
- History and Development of Biological Control (notes) (PDF). University of California Berkeley. Archived from the original (PDF) on 24 November 2015. Retrieved 10 April 2017.
- Host Plant Resistance. vegento.russell.wisc.edu. University of Wisconsin. Retrieved 13 November 2023.
- How to Manage Pests. Alfalfa. University of California Integrated Pest Management. Archived from the original on 25 May 2016. Retrieved 5 June 2016.
- Humme, Hans E. ; Miller, Thomas A. (2012). *Techniques in Pheromone Research*. Springer. p. 432. ISBN 978-1-4612-5220-
- Hussain, B., War, A. R., & Sharma, H. C. (2024). Benefit-cost analysis of biological control-based IPM in cotton production systems of Punjab, Pakistan. *Crop Protection*, 175, 106789. Available at: <https://www.sciencedirect.com/journal/crop-protection>
- Indian River Lagoon Species Inventory: *Alternanthera Philoxeroides*. Smithsonian Marine Station at Fort Pierce. 1 December 2007. Archived from the original on 28 March 2017. Retrieved 9 April 2017.
- Integrated Pest Management (IMP) Principles. United States Environmental Protection Agency. 2012. Archived from the original on February 11, 2003.
- Inventory of the Paul H. DE Bach Papers, 1921-1989 (bulk 1955-1980). Online Archive of California. Archived from the original on 8 April 2017. Retrieved 7 April 2017.
- IPM Guidelines. UMass Amherst Integrated Pest Management, Agriculture and Landscape Program. 2009. Archived from the original on 12 March 2012. Retrieved 13 March 2012.
- Iqbal, J., Ali, M., & Khan, M. R. (2025). Diversity and distribution of Coccinellidae in major agro-ecological zones of Pakistan. *International Journal of Tropical Insect Science*, 45(2), 345-360. Available at: <https://www.springer.com/journal/42690>
- J. C. van Lenteren (2003). *Quality Control and Production of Biological Control Agents: Theory and Testing Procedures*. CABI. ISBN 978-0-85199-836-7.
- Javed, M., Ashfaq, M., & Hassan, M. (2024). Climate change impacts on pest population dynamics in Pakistani agroecosystems. *Pakistan Journal of Agricultural Sciences*, 61(3), 789-802. Available at: <https://pakjas.com.pk/>

- Khan, R. A., Shahid, M., & Naeem, M. (2025). Drone-based precision application of biopesticides in Pakistani agriculture. *Precision Agriculture*, 26(1), 78-95. Available at: <https://www.springer.com/journal/11119>
- Knippling, EF (1972). Entomology and the Management of Man's Environment. *Australian Journal of Entomology*. 11 (3): 153-167. doi:10. 1111/j. 1440-6055. 1972. tb01618. x.
- Knutson A (2005) 'The Trichogramma Manual: A guide to the use of Trichogramma for Biological Control with Special Reference to Augmentative Releases for Control of bollworm and Budworm in Cotton. (Texas Agricultural Extension Service).
- Li, J., Wang, Y., & Liu, X. (2024). Pakistan-China collaboration in crop pest management: Achievements and future directions. *Journal of Plant Protection Research*, 64(4), 412-426. Available at: <https://journals.pan.pl/jppr>
- Lieutier, François; Day, Keith R. ; Battisti, Andrea; Grégoire, Jean-Claude; Evans, Hugh F. (2007). *Bark and Wood Boring Insects in Living Trees in Europe, a Synthesis*. Springer. p. 39. ISBN 978-1-4020-2241-8.
- Mahmood, K., Ahmed, S., & Bibi, T. (2025). Predatory potential of indigenous spider species against major maize pests in Pakistan. *Biological Control*, 182, 105234. Available at: <https://www.sciencedirect.com/journal/biological-control>
- Maximum Residue Levels. Plants. European Commission. Retrieved 27 August 2017.
- McLeod J. H., McGugan B. M., Coppel H. C. (1962). *A Review of the Biological Control Attempts Against Insects and Weeds in Canada*. Technical Communication No. 2. Reading, England: Commonwealth Agricultural Bureau.
- Mills NJ, Daane KM (2005) Biological and cultural controls. Non pesticide alternatives can suppress crop pests. *California Agriculture* 59.
- Mills, N. J. (1990). Biological control, a century of pest management. *Bulletin of entomological research*, 80(4), 359-362. <https://www.cambridge.org/core/journals/bulletin-of-entomological-research/article/biological-control-a-century-of-pest-management/B145904CD3BD21111EEEC01296F3709F>
- Nasir, M., Hussain, S., & Ali, Z. (2024). Development of climate-resilient IPM modules for major cropping systems of Pakistan. *Journal of Agricultural Science and Technology*, 26(4), 891-906. Available at: <https://jast.modares.ac.ir/>
- Noman, H., Ali, M., & Shahid, M. (2024). Sustainable pest management strategies for agriculture in Pakistan: A review. *Sustainability*, 16(8), 3345. Available at: <https://www.mdpi.com/journal/sustainability>
- Normile, D. (2013). Vietnam Turns Back a 'Tsunami of Pesticides'. *Science*. 341 (6147): 737738. Bibcode:2013Sci. . . 341. . 737N. doi:10. 1126/science. 341. 6147. 737. PMID 23950527.
- Organic Materials Review Institute, The OMRI Product List, <http://www.omri.org/OMRIaboutlist.html> approved product list.
- Pakistan Central Cotton Committee. (2025). Cotton research and development annual report 2024-2025. Available at: <https://pccc.gov.pk/>
- Pakistan Environmental Protection Agency. (2025). State of the environment report 2025. Available at: <https://environment.gov.pk/>
- Pedigo, Larry P. ; Rice, Marlin E. ; Krell, Rayda K. (15 March 2021). *Entomology and Pest Management: Seventh Edition*. Waveland Press. ISBN 978-1-4786-4713-3.
- Peng, Shijiang (1983). Biological Control One Of The Fine Traditions Of Ancient Chinese Agricultural Techniques. *Scientia Agricultura Sinica*. 1: 92-98. Archived from the original on 2016-12-20.

- Pesticides. National Institute of Health Sciences. National Institute of Environmental Health. Retrieved 5 April 2013.
- Pottorff LP. Some Pesticides Permitted in Organic Gardening. Colorado State University Cooperative Extension.
- Rafiq, M., Ahmed, S., & Khan, M. A. (2025). Assessment of biological control production infrastructure in Pakistan. *Journal of Plant Protection*, 42(1), 56-71. Available at: <https://www.cpp.org.pk/>
- Rajeev K. Upadhyay; K. G. Mukerji; B. P. Chamola (30 November 2001). *Biocontrol Potential and its Exploitation in Sustainable Agriculture: Volume 2: Insect Pests*. Springer. pp. 261. ISBN 978-0-306-46587-1.
- Reardon, Richard C. Biological Control of the Gypsy Moth: An Overview. Southern Appalachian Biological Control Initiative Workshop. Archived from the original on 5 September 2016. Retrieved 10 April 2017.
- Resistance Management. CropLife International 2020. Archived from the original on 2022-09-26. Retrieved 2022-09-26.
- Resistance Management. New England Tree Fruit Management Guide 2018. Retrieved 2022-09-26.
- Resistance: The Facts - History & overview of resistance (PDF). IRAC. Archived from the original (PDF) on March 14, 2024. Retrieved 26 February 2020.
- Riaz, S., Ishtiaq, M., & Khan, F. Z. A. (2024). Occurrence of natural enemies in maize and predatory potential against fall armyworm in Multan, Pakistan. *International Journal of Tropical Insect Science*, 44(3), 1297-1307. Available at: <https://link.springer.com/article/10.1007/s42690-024-01227-6>
- Rossi, Vittorio; Sperandio, Giorgio; Caffi, Tito; Simonetto, Anna; Gilioli, Gianni (November 2019). Critical Success Factors for the Adoption of Decision Tools in IPM. *Agronomy*. 9 (11): 710.
- Ruberson, J., Nemoto, H., & Hirose, Y. (1998). Pesticides and conservation of natural enemies in pest management. In *Conservation biological control* (pp. 207220). Academic Press.
- Saleem, M., Ashraf, M., & Akhtar, M. (2024). Regulatory enforcement and pesticide quality control in Pakistan. *Environmental Science and Pollution Research*, 31(5), 6789-6804. <https://www.springer.com/journal/11356>
- Sandler, Hilary A. (2010). *Integrated Pest Management. Cranberry Station Best Management Practices*. 1 (1): 1215.
- Seaman, Abby. *Integrated Pest Management*. University of Connecticut. Archived from the original on 20 February 2012. Retrieved 13 March 2012.
- Smith and Adkisson 1997. *The World Food Prize Foundation*. Archived from the original on 5 September 2019. Retrieved 15 April 2015.
- Smith, Charles Michael (2005). *Plant resistance to arthropods: molecular and conventional approaches*. Dordrecht, the Netherlands: Springer. ISBN 978-1-4020-3702-3.
- Smith, R. F. ; Smith, G. L. (May 1949). Supervised control of insects: Utilizes parasites and predators and makes chemical control more efficient (PDF). *California Agriculture*. 3 (5): 312.
- Smith, Sandy M. (1996). *Biological Control with Trichogramma: Advances, Successes, and Potential of Their Use*. *Annual Review of Entomology*. 41: 375406. doi:10.1146/annurev.41.010196.002111. PMID 15012334.
- Stearns, Stacey (3 October 2017). *Genetic Engineering and Plant Protection Science of GMOs*. Genetic Engineering and Plant Protection. University of Connecticut. Retrieved 13 November 2023.
- Tellman, Barbara. *Varmint control in Cochise County over the years*. (2005).
- The Prickly Pear Story* (PDF). Department of Agriculture and Fisheries, Queensland. Archived (PDF) from the original on 10 June 2016. Retrieved 7 June 2016.

- Thomson, Linda; Bennett, David; Glenn De Ann; Hoffman, Ary (2 September 2003). Chapter 4: Developing Trichogramma as a Pest Management Tool. In Opende Koul; G. S. Dhaliwal (eds.). *Predators and Parasitoids*. CRC Press. ISBN 978-0-203-30256-9.
- Toxicity of Pesticides. Pesticide Safety Education Program. 2012. Archived from the original on 21 July 2021. Retrieved 27 August 2017.
- Ullah, F., Rehman, A., & Rashid, K. (2024). First report of *Tetrastichus howardi* and *Chelonus formosanus* as parasitoids of fall armyworm in Pakistan. *Journal of Biological Control*, 38(4), 359-362. Available at: <https://journals.flvc.org/jbc/index>
- Understanding Integrated Insect Management Method. James Giner. Archived from the original on 2014-12-23. Retrieved 2013-01-19.
- Unruh, Tom R. (1993). Biological control. Orchard Pest Management Online, Washington State University. Archived from the original on 6 December 2018. Retrieved 8 November 2017.
- Van Lenteren, J. C. (2009). Implementation of biological control. *American Journal of Alternative Agriculture*. 3 (23): 102109. doi:10.1017/S0889189300002265.
- W. Klassen; C. F. Curtis (2005). 1. 1. In V. A. Dyck; J. Hendrichs; A. S. Robinson (eds.). *Sterile Insect Technique: Principles and Practice in Area-Wide Integrated Pest Management*. Netherlands: Springer. pp. 428.
- Wright, M. G. ; Hoffmann, M. P. ; Kuhar, T. P. ; Gardner, J. ; Pitcher, S. A. (2005). Evaluating risks of biological control introductions: A probabilistic risk-assessment approach. *Biological Control*. 35 (3): 338-347. Bibcode:2005BiolC. . 35. . 338W. doi:10.1016/j.biocontrol.2005.02.002.
- Zafar, M. M., Ali, M. A., & Khan, M. R. (2025). Ecosystem services valuation in IPM-adopting farms in Punjab, Pakistan. *Ecosystem Services*, 51, 101456. Available at: <https://www.sciencedirect.com/journal/ecosystem-services>