Review Article

Maximizing Yield and Sustainability: A Comprehensive Approach to Integrated Pest Management in Horticulture Crops

Abstract

"Maximizing Yield and Sustainability: A Comprehensive Approach to Integrated Pest Management in Horticulture Crops" offers a holistic perspective on addressing pest-related challenges in horticulture. This approach emphasizes the integration of various strategies, including cultural, biological, and chemical methods, to effectively manage pests while minimizing adverse impacts on the environment and human health. By combining pest monitoring, crop rotation, biological control agents, and judicious use of pesticides, growers can optimize yield while reducing reliance on conventional chemical interventions. This approach not only mitigates the development of pest resistance but also promotes ecosystem health and biodiversity. Moreover, by prioritizing sustainability, growers can safeguard long-term productivity and profitability while meeting the demands for safe and high-quality produce. Overall, adopting an Integrated Pest Management approach underscores the importance of balance and synergy in achieving both economic viability and environmental stewardship in horticulture crop production.

Keywords: Pest Management, challenges, prioritizing, profitability

Introduction

By combining a number of common sense techniques, Integrated Pest Management (IPM) manages pests in an efficient and ecologically conscious manner. The most up-to-date and thorough data on pest life cycles and environmental interactions are used by IPM programs. Using this data in conjunction with current pest control strategies allows for the most cost-effective management of pest damage while minimizing risks to humans, their homes, and the environment [1].

Both agricultural and non-agricultural environments, including gardens, homes, and offices, may benefit from the integrated pest management (IPM) strategy. In integrated pest management (IPM), the use of pesticides is only one of several acceptable methods for controlling pests. Organic farming, on the other hand, uses integrated pest management (IPM) principles but restricts itself to using pesticides derived from natural sources rather than synthetic poisons [2].

Instead of being just one technique of pest control, integrated pest management (IPM) is a process that involves several assessments, choices, and actions. When cultivators are cognizant of the possibility of pest invasion, they use a four-pronged strategy in integrated pest management (IPM) [84]. First, there are four steps:

fig .1 Integrated pest management

Threshold level

In integrated pest management (IPM), the first step in controlling pests is determining when the number of pests or other environmental factors reach a certain degree, known as the action threshold. It is not always necessary to take control measures just because you see one bug. If we want to make informed judgments about pest management in the future, we need to know how bad pests will become financially [3].

Keep an Eye Out for Possible Insects

Some insects, weeds, and other forms of life don't need management. A lot of creatures are harmless, and some are even helpful. In integrated pest management (IPM) systems, the goal is to keep an eye out for pests and correctly identify them so that, when combined with action thresholds, the right treatment choices may be taken. By keeping an eye out for potential problems and identifying them, we can make sure that pesticides are only used when absolutely necessary [4].

Prevention

The goal of integrated pest management (IPM) systems is to control pests before they cause damage to crops, lawns, or interior spaces. Cultural approaches may be used to agricultural crops in several ways, such as crop rotation, pest-resistant variety selection, and pest-free rootstock planting. There is minimal to no danger to humans or the environment from these management approaches, and they may be very successful and economical [5].

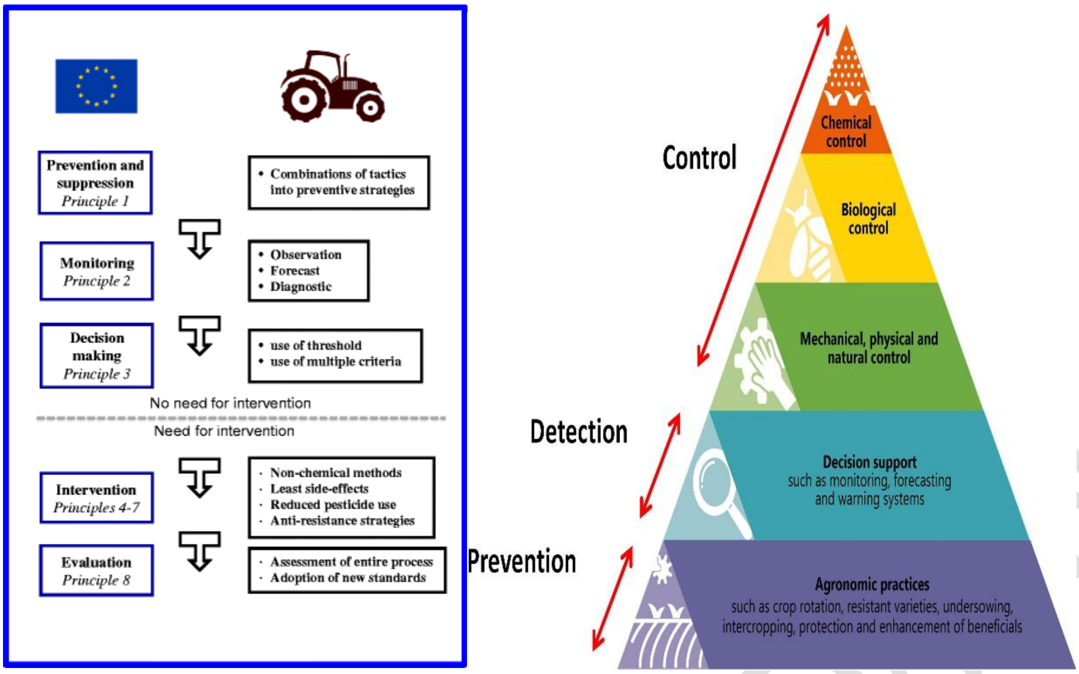


fig . 2goal of integrated pest management (IPM) systems

Control

In integrated pest management (IPM) programs, the right control strategy is assessed for efficacy and risk once monitoring, identification, and action thresholds show that pest treatment is necessary and preventative strategies are ineffective or unavailable. Prioritized are safe, effective methods of pest management, such as pheromones that interrupt insect mating or mechanical methods like weeding or traps. Additional techniques of pest management, including targeted spraying of pesticides, may be used if additional monitoring, identifications, and action thresholds show that less hazardous measures are not effective. The use of broad-spectrum insecticides for aerial spraying is reserved for extreme [6].

Because it is the most effective, least costly, and ecologically friendly option, prevention is the primary tool in pest control. To avoid stress and reduce insect issues, choose a healthy plant that thrives in the spot you want it to be, plant it properly, and make sure it has enough water and nutrients. Pests might be drawn to plants that are stressed. Intervention at an early stage is the second most effective method for controlling pests. Early discovery is guaranteed by being present and vigilant in the garden. Less drastic measures are necessary for rapid problem-solving before issues may escalate. Keeping track of garden activities allows a gardener to see trends and make educated choices, making recordkeeping the third most essential tool. You may learn a lot about your garden and its issues by keeping track of things like planting dates, types, purchase locations, problem start dates, weather conditions, management tactics, and the success of those efforts [7].

There are a lot of viable alternatives to spraying that are both safe and effective for plant protection and insect control. Incorporating insecticides with other procedures increases their effectiveness. Gardeners should be knowledgeable with the many kinds of plant pests and their biology in order to use control techniques appropriately and reduce losses. A thorough understanding of the pest is crucial for effective scouting techniques, equipment selection, scheduling, and other aspects of pest control. Cultural, mechanical, biological, and chemical approaches are the four main categories of pest control strategies [8].

Cultural methods

When it comes to preserving the health of plants and warding off invasive species, cultural management is an essential component. When it comes to resistance to pests, healthy plants are more resistant than those with low vigour. In order to effectively suppress insect and mite problems in the landscape, it is vital to engage in regular monitoring, familiarize oneself with prospective issues, and provide early intervention [9]. The preparation of the soil, the selection of plants that are appropriate to the requirements of the site, plants that are not appealing to pests, plants that are tolerant of insects and diseases, rotating crops, interplanting, scheduling planting dates to prevent pests, controlling weeds, and planting "trap" crops are all examples of cultural practices [10].

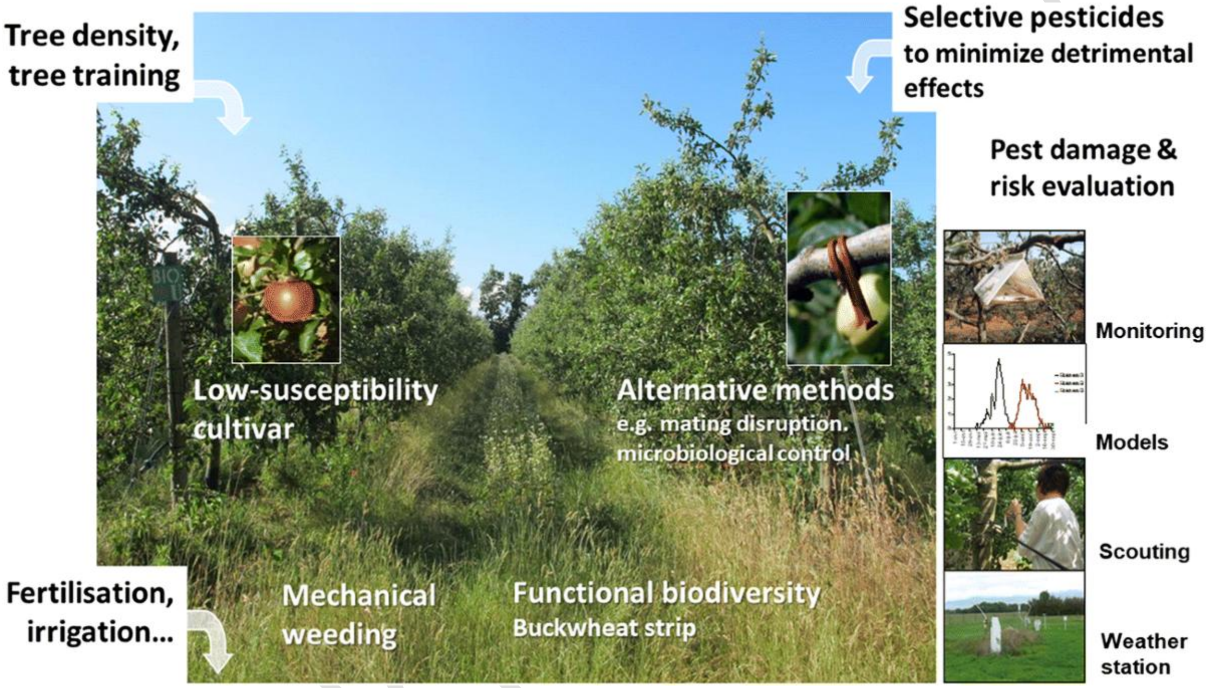


fig . 3Cultural methods

The preparation of soil is vital for a number of reasons, including the promotion of healthy roots, the enhancement of access to water and nutrients, the prevention of stress, and the enhancement of plant resistance to diseases and threats. It is possible to optimize the benefits that the plant receives while simultaneously reducing the difficulties that are associated with the excessive use of fertilizer by doing a soil test and applying just the quantity of fertilizer and lime that is suggested [85]. When the soil is covered with organic mulch, the plant is protected because it reduces the amount of water that is lost from the soil, minimizes the amount of competition from weeds, provides nutrients, and creates an environment that is favorable for earthworms and microorganisms [11].

Even though tilling the soil is harmful to the structure of the soil, it is recommended that it be done in the autumn, when pests are closer to the surface. Tilling in the fall may help eliminate insects that are among crop remnants [12].

The selection of plants should include the use of certified seeds and plants that are free of diseases and insects, as well as the selection of robust plants that have well-developed root systems. Young seedlings may be susceptible to diseases and insects that might begin to

develop in greenhouses or plant beds. When these diseases and insects are transferred into the garden along with the seedlings, it can result in significant losses [13]. Always be sure to get plants from recognized growers who can guarantee that their items are in good health. Ensure that the plants are clean by carefully inspecting them before planting them, and take into consideration planting varieties that have been recognized as being resistant to pests.
Gardeners may prevent typical pest issues by selecting plants with care and attention to detail. For instance, selecting native hollies for beautification, butternut squash for vegetable gardens, or a native downy hawthorn for deer predation are all examples of vegetation that may contribute to the maintenance of a garden that is both healthy and flourishing [14].
Managing diseases and pests in gardens may be accomplished via the practice of crop rotation. It entails growing two crops that are very similar to one another in consecutive years, which might lead to an increase in insect issues. There are several vegetables that are closely linked to one another and share the same illnesses and pests. It is advised that you do not cultivate the same sort of vegetable in the same location year after year in order to decrease the risk of bug infestations. It is recommended that you only plant related crops in a certain location once every three or four years, and you should avoid growing root crops in the same row in consecutive years [15].
Interplantings, which include rotating groups of various plants within rows or patches, may be an effective method for reducing the rate at which diseases spread. As insect repellents, marigolds and garlic are advised; however, the majority of these suggestions have not been demonstrated to be effective [16]. The dates of planting should be set in such a way that the majority of the crop is not exposed to the most severe pest infestations. In order to prevent borers, early squash should achieve maturity before pickleworm appears, and sweet corn seeds or seedlings should be planted as early in the season as feasible. When planting crops that need warm weather, wait until the soil has warmed up before doing so. This will prevent seed and root rots and will encourage strong development [17].
The management of weeds is yet another approach to the control of insect pests. The presence of both harmful and helpful insects may be seen in grasses and weeds. Getting rid of broadleaf weeds that are close to fruit trees can reduce the number of spider mite infestations. Those weeds that are closely connected to the crop plants should be eliminated because they may carry insects that are harmful to the crop [18]. There are a number of pests that have a broad host range, including armyworms, crickets, cutworms, flea beetles, grasshoppers, lygus bugs, slugs, snails, stink bugs, and thrips. These pests often live in weedy regions and have the ability to travel to surrounding plants that are attractive. When planting, it is essential to mow weeds before planting in order to prevent insects from going to the plants that are desired [19].
It is also possible to utilize trap crops for the management of insect pests. Among the crops that may be used as traps for Japanese beetles are soybeans, zinnias, and white roses. Harlequin bugs are drawn to mustard plants, radishes, and turnips. Corn and cabbage maggots are drawn to sunflowers, while Lygus plant bugs are drawn to corn and cabbage [20].
It is necessary for the gardener to engage in early planning in order to successfully implement cultural management for pest control. It is possible that it would be ideal to let the garden lie fallow for a year or two or even longer in locations where there is a restricted amount of land.

When there is a disease issue, there should be raised beds with fresh soil or plants that are grown in containers [21].

Mechanical methods

Insects are an essential component in the process of keeping a garden in good health. In addition, they may be removed from plants at any point, and they can either be useful or damaging to the plants. The chore of hand-squashing insects and egg clusters may be avoided by picking them up by hand instead of doing so [22]. The use of insect traps may be helpful in detecting and managing pests, but their use is restricted, and they may attract unwanted insects to the garden. Despite the fact that light traps, especially black light or blue light traps, are useful instruments for monitoring insects, they provide very little to no protection for agricultural gardens. These traps attract insects that would not otherwise be found in that region, including those that are useful as well as those that are hazardous [23].

At times, pheromone traps are used for the purpose of interrupting the mating behaviours of insects or for the purpose of detecting the existence of pests. It is possible for rainfall, chilly temperatures, wind speed, and wind direction to cause harm to the chemical odour that adult females make and discharge. This odour is appealing to males of the same species by attracting them. When the number of pests in a region is low and there is little migration into the area, the chances of success are at their highest [24].

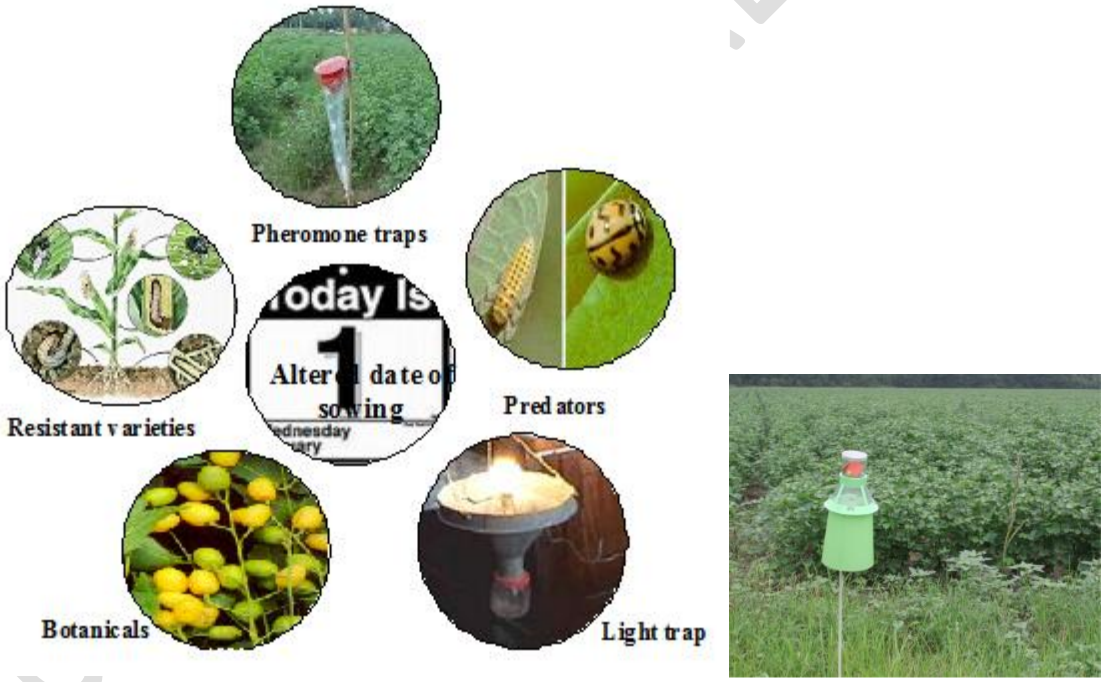


fig . 4Mechanical methods

A shallow can of beer, yellow plastic dishpans filled with soapy water, yellow sticky traps constructed with boards painted yellow and gently coated with oil or grease, and commercial sticky traps are all examples of physical traps that may be created using items that are found about the house. It is possible for mechanical barriers to be efficient in excluding some pests; however, they are ineffective when the pest population is vast [25]. Aluminium foil, reflective mulches, crushed eggshells or hydrated lime spread around plants, copper tape, collars made of cardboard, tin cans, or aluminium foil, screening around potato storage areas, mounding soil around grapevines, cheesecloth screens for cold frames and hot beds, floating row covers of spun polyethylene, sticky barriers on the trunks of trees and woody shrubs, and kaolin clay can form a thin film on leaves and fruit to protect plants from various insects [26]. Cages that are covered with nets and placed over young seedlings assist prevent harm from insects, birds, and rabbits [86]. It is possible that bark-eating animals like voles may cause harm to tree trunks if wire collars were placed around them. For the purpose of preventing birds from eating fruit when it is ripe, bird netting may be stretched over ripening plants. If you want to prevent birds and insects from getting into your ears of corn, you may use paper bags to cover them. However, you should wait until the pollination process is over before you bag the ears [27]. Electric fence barriers are a preventative measure against big creatures eating on plants; nevertheless, the installation of these barriers may be both costly and time-consuming.

Pruning and raking, water sprays and irrigation, and fearing gadgets are all examples of methodologies that might be used for pest control. Controlling pests such as the azalea stem borer and dogwood club gall may be accomplished by pruning affected twigs. On the other hand, raking fallen twigs from shade trees can be effective in preventing twig girdlers and camellia leaf gall. Insects may be dislodged and killed with the use of water sprays and irrigation, while rain is a natural method of controlling spider mites. The incidence of insect issues is decreased when proper watering is performed [28].

Water may be sprayed at animals such as squirrels, deer, or raccoons using hose adapters that are equipped with motion sensors. This is particularly effective when the adapter is targeted at specific places that need protection. Trees that are not suffering water stress are able to endure root predation from voles and twig predation from deer. Weeds may be naturally outcompeted by a lawn that is provided with enough watering and is in good condition. The larvae of the Colorado potato beetle may be killed on potatoes by the application of heat treatment, which does not result in the death of the plant itself. Flames can be used to eliminate annual weeds. On the other hand, while working with fire in the garden, this should be done with particular care [29].

There is a wide range of efficacy among fearing devices, including reflecting items, noise makers, human or predator effigies, lights, lasers, pyrotechnics, guard animals, and ultrasonic devices. These measures need knowledge of the pest as well as monitoring. Scarecrows and nightlight lights are two examples of scary devices that may be used to get rid of starlings, however they are not very effective against tiny rodents. The employment of scaring is not a strategy that is used in the management of insects since insects do not record sight and sound in the same manner that birds and mammals do [30].

Row coverings and handpicking are two examples of mechanical management systems that have limits, including the amount of time they need and the possibility that they can cause harm to crops. When it comes to successfully controlling insect populations, active monitoring and searching for evidence of harm are both essential components. When it comes to tiny gardens, mechanical techniques, such as row covers, could be more feasible; nevertheless, they would need a large commitment of both time and money. It is possible that handpicking will not be successful after crop damage has been identified; thus, it is vital to engage in active monitoring and observation in order to develop effective techniques for pest control [31].

Biological control

The process of lowering a pest population by the use of predators, parasites, or disease organisms that may normally be found in nature is referred to as biological management system. One of the most important factors that prevents plant-feeding insects from taking over the rest of the globe is the fact that they provide food for other types of insects. Insect and mite populations are often rather concentrated, and as pests grow abundant, parasitoids and predators are drawn to them, which results in a reduction in the number of pest species in that particular region [32,95]. Parasitoids and predators may be purchased via garden catalogues and gardening publications; however, certain insects that are marketed as biological control agents, like as praying mantises and lady beetles, are not particularly successful for amateur gardeners to use. It is far more effective to establish a habitat that attracts and maintains naturally existing predators and parasitoids. This is because the environment is more stable. It is important to be tolerant of some pests in the yard and to consider them as food for the beneficial insects. When beneficial insects are unable to find food, they will relocate to a different place. Reduce the amount of pesticides that are used, since these chemicals may kill both harmful and beneficial insects [33].

Insects and other animals, such as birds, frogs, and spiders, are examples of predators. Predators are creatures that hunt and consume other organisms, which are referred to as prey. Predators typically kill and consume themselves in a single meal. There is a high likelihood that predators are quite active and have lengthy life cycles. A few examples of these kinds of insects include the ground beetle, the lady beetle, the lacewing, the wheel bug, the hover fly, and the predatory mite. In the course of at least one stage of their life, parasites are creatures that live on or inside the body of another living entity, which is referred to as a host. Parasites get their sustenance from the host living organism. In most, they have a life cycle that is rather brief [34].

Cutworms, squash vine borers, pillbugs, grubs, fungus gnats, root weevils, and armyworms are some of the insects that beneficial nematodes consume; they also consume other insects. In order to implement beneficial nematodes in an efficient manner, it is necessary to have knowledge of both the nematode and the insect that needs care. Beneficial nematodes are often distributed by manufacturers in the form of gels, dry granules, clay, and sponges that are filled with water [35]. Nematodes are susceptible to the dangerous effects of heat, UV radiation, and dehydration. Nematodes should be applied in the early morning or late afternoon, when the light and temperatures are lower. This is the optimal time to do so. As a result of the fact that nematodes travel through the soil on the water layer that covers the particles of soil, the area need to be watered either before releasing nematodes or afterward with a mild moisture application. It is recommended by farmers that they refrain from using fertilizer for a period of two weeks either before or after releasing worms. This is because high-nitrogen fertilizer might impair the efficacy of nematodes [36].

Disease-causing organisms, such as viruses, bacteria, and fungus, are referred to as pathogens. Pathogens are capable of either killing or incapacitating their hosts. The employment of bacteria to eliminate caterpillars is the kind of biological management that has shown to be the most advantageous [37]. The bacteria known as Bacillus thuringiensis (Bt) is responsible for the production of a toxin that causes the midgut of an insect to be destroyed. There are a number of formulations that are available that are capable of providing efficient control of over 400 different types of insects without causing damage to consumers or domestic animals. Make certain that you are using the appropriate strain for the pest that is being managed [38].

fig . 5Biological control

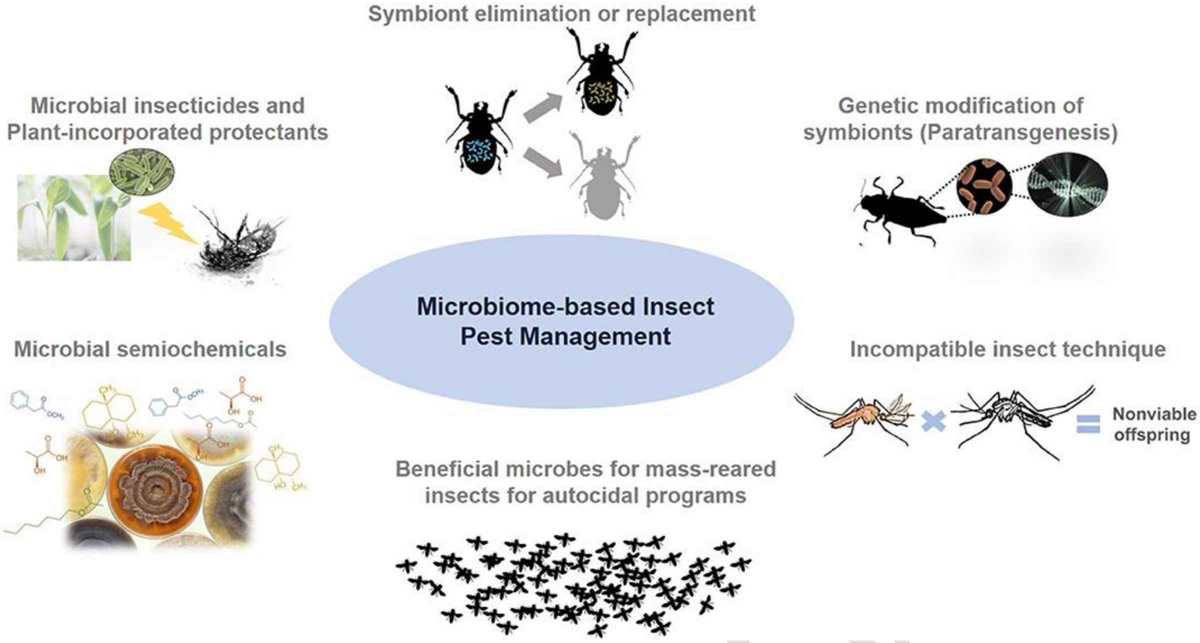
With regard to the management of grasshoppers, the disease organism known as Nosema locustae has some potential. These fungal microsporidium are said to have the potential to be effective for a period of up to five years after the original application process. There are several regions where this disease may be purchased commercially under a variety of different trade names. To make substantial claims about its usefulness in home gardens at this point in time would be completely premature [39,94].

When it comes to biological management, one of the limitations is timeliness. It is possible to identify pests for which a predator is commercially accessible; but, by the time the predator arrives and the plant is treated, an unacceptable amount of damage may have already been done. Due to the fact that they have a tendency to roam away from the region in which they are released, natural predators that are purchased are often only effective for a brief periods of time [40].

Biocontrol agents

When it comes to controlling common greenhouse insect pests, biocontrol agents include predators such as Amblyseiusswirskii, Delphastuscatalinae, and Dicyphushesperus, as well as parasitoids such as Encarsiaformosa, which is the most extensively employed parasitoid for whiteflies [41]. It is possible to release parasitoids once every one to two weeks, and they are effective at temperatures greater than 70 degrees Fahrenheit. Aphidoletesaphidimyza, Ladybird Beetle, and Gall Midge are examples of predators that are able to consume a wide variety of aphid species. These predators are most effective when the temperature is between 68 and 80 degrees Fahrenheit and the relative humidity is between 70 and 80 percent [42,93]. A minimum of eight weeks is required for predators such as the Green Lacewing, also known as Chrysoperlacarnea, to develop a substantial population. These predators feed on greenhouse whitefly. Predators such as Amblyseiusswirskii consume larvae of both the first and second instars, are able to withstand greater temperatures than Neoseiuluscucumeris, and will also consume the eggs and nymphs of whiteflies. Neoseiuluscucumeris is the most common predatory mite employed to control western flower thrips. It feeds on the larvae of the first instar and releases itself early on in the crop development cycle [43,92].

Fig .6 Symbiont elimination



In addition to feeding on the larvae and adults of western flower thrips, the minute pirate bug, also known as Orius spp., may also feed on aphids and whiteflies. With ornamental pepper plants, which may be used as banker plants, this insect can be used. More costly than utilizing Neoseiuluscucumis, it is best effective when temperatures are higher than sixty degrees Fahrenheit and the duration of the day is more than twelve hours [44]. The predatory mite known as Stratiolaelapsscimitus, which lives in the soil, is capable of killing up to thirty victims every day. These prey may include western flower thrips pupae or fungus gnat larvae. Biological control methods for common greenhouse insect pests include parasitoids such as Encarsiaformosa, predators such as Amblyseiusswirskii, predatory mites such as Neoseiuluscucumeris, and soil-dwelling predatory mites such as Stratiolaelapsscimitus [45]. It is important to note that other biological control agents are also available. Controlling the development and spread of these pests in greenhouses is made easier with the aid of these agents [46].

Chemical management

For the purpose of controlling pests in gardens, chemical management is a last choice since it may result in the death of all insects that are susceptible to the active components. This can then lead to the development of resistance in the pests to the chemicals. When pesticides are used improperly, they may also cause outbreaks of secondary pests and have negative effects on creatures that are not intended to consume them, such as insects or leaves that have been polluted with pesticides [47]. During stormwater runoff, pesticides have the potential to be transported into streams, where they might produce unexpected effects.

In a nutshell, chemical management is a complicated procedure that requires integrating background knowledge about a pest issue with a plan that is tailored to the specific circumstances. The following are the five phases that make up an integrated pest management strategy (IPM): 1) Observe, 2) Identify, 3) Evaluate, 4) Put into action, and 5) Appraise the results [48].

It is vital to carry out a comprehensive survey that encompasses the identification of all plants, including cultivars, in order to successfully manage a garden. It is recommended that a "monitoring kit" be used in order to record any changes that occur in the landscape, including either general conditions or any anomalies [49]. Before concluding that there is a pest issue, it is important to examine the watering schedule, fertility, soil pH, and any other elements that might be responsible for the change in appearance of a plant that is not in accordance with the standards that are considered acceptable [50].

The worth of the plants, the amount of time that is available, the life cycle of the pest, and the degree of expertise of the observer should all be taken into consideration when developing an IPM strategy. As an example, the plan for monitoring a privacy hedge would be conducted less often than the plan for planting roses that have won awards [51].

In order to effectively tackle an issue, it is essential to correctly diagnose the pest in question. For the purpose of both the control of the pest that is causing the problem and the usage of the chemical on the particular kind of plant that is going to be sprayed, the chemical that has been chosen must be labelled. Each and every user is legally obligated to adhere to the directions that are printed on the label of the pesticide, which include the quantity and the time of the application [52,91].

fig . 7Chemical management

At the end of the day, chemical management is a complicated process that calls for meticulous preparation and execution. It is possible for gardeners to properly control pests and maintain the health and well-being of their plants if they follow these procedures [53].

The third step is to evaluate.

Before selecting whether or not to pursue treatment for a plant issue, it is important to take into account a number of different aspects. Some of the factors that are taken into consideration include the expense of treating the issue, the worth of the plant, and the possibility that the disease may spread to other plants. In many, plants are able to survive defoliation before major issues arise [54]. This is because sunlight that penetrates a hole at the top of the plant reaches a lower leaf, which in turn enhances the amount of photosynthesis that occurs in that leaf. As opposed to heavy feeding in the early autumn, when leaves are ready to fall anyhow, heavy feeding on woody ornamentals early in the season is more detrimental to plants than excessive feeding in the early autumn. The amount of damage that a plant is able to sustain without suffering harm that is considered undesirable is referred to as a threshold, while the amount of damage that the owner considers to be unacceptable is referred to as an aesthetic threshold [55].

Property owners have the ability to establish their own criteria by defining the degree of damage that is considered to be acceptable to the plant's health and aesthetic appeal. Next, it is necessary to make an estimate of the number of pests that are responsible for the amount of damage that homeowners are willing to bear [56]. In order to arrive at this estimation, it is necessary to do monitoring, keep a record of the number of pests, and determine if the damage is unacceptable or whether the pest population is planning to reach levels that are destructive [57]. There are certain pests that produce many generations in a single year, while others produce just a few generations or perhaps just one generation. For the purpose of determining whether or not the population levels of the pest will expand until the food sources are depleted or whether or not the weather conditions could restrict the development of the population, it is essential to precisely identify the pest. The treatment of diseases is distinct from that of insects due to the absence of treatments that may be administered. Nevertheless, tolerating moderate levels of sickness is a reasonable course of action. The degree of tolerance that one has for weeds and the aesthetic thresholds that one has are mostly determined by personal choice [58].

Although the majority of landscaping plants are not necessarily in danger of dying as a result of defoliation, it is an ugly condition. Even under these circumstances, thresholds can be different. When compared to plants that are located on the side of the yard, for instance, a foundation plant that is located close to an entry would most likely have a lower aesthetic threshold. Certain plant species, such as roses, which are very vulnerable to a wide variety of pests, do not lend themselves well to threshold restrictions [59].

Implementation is the fourth step.

Plants that are in good health are better equipped to fight off pests. Pest issues may be caused by a number of factors, including the selection of the incorrect cultivar, unsuitable location, or inadequate upkeep in many metropolitan contexts. The elimination or reduction of insect issues may be facilitated by alterations to the landscape that boost plant health [60]. The goal is to prevent pests from obtaining everything they need, including food, housing, the right temperature, and other components. For integrated pest management to be effective, it is essential to have a solid understanding of the biology, behaviour, and ecology of pests. Depending on the pest, there are natural enemies that may be developed, improved, or maintained in an area, or they can be acquired for release. These natural enemies can be either predators or parasitoids [61,96,97]. Established plants that attract beneficial insects also limit the usage of pesticides, which kill both the species that are beneficial to the environment and the pests that they feed on. There is no such thing as a ual effort when it comes to the deliberate release of predators and parasitoids; success demands meticulous research [62].

Satellite Technologies for IPM

Satellite technologies offer a solution for remote crop monitoring, allowing farmers to check any farm field on a daily basis. EOSDA Crop Monitoring is a digital platform that allows farmers to monitor crops remotely, regardless of their size or location. Scouting in integrated pest management involves regular field inspections for deviations in crop development, promoting grounded decisions. EOSDA Crop Monitoring provides a valuable scouting feature that allows farmers to detect vegetation decline, set tasks, assign tasks, and receive a comprehensive report with inspection details [63].

The platform also allows for the planning and monitoring of integrated pest management (IPM) agricultural activities on individual fields. Users can select the activity type, set the timeline, and monitor its status. Regular scouting can show if the integrated pest management practices are bringing desired results [64].

EOSDA Crop Monitoring uses vegetation indices to monitor crop state in the field and detect changes. If problem areas do not recover after applying integrated pest management components, it indicates potential pest population's increase, indicating the need for another integrated management option [65].

Remote sensing can be integrated into current business processes, allowing for before-after comparisons of single field changes over two dates. This helps confirm the beneficial effects of fertilizers or other IPM agrichemicals. However, if the agrichemical does not prove useful, further improvements are needed before introducing the product to the agri-market [66].

(a) (b)

Fig . 8Satellite Technologies for IPM

Principles behind IPM

Integrated Pest Management (IPM) uses agronomic, mechanical, physical, and biological concepts to prevent pests. Control methods must include a variety of answers to last. Instead of individual crops, IPM applies to cropping systems throughout time and space. The "Holy Grail" IPM requires no crop protection once set up. IPM is used by farmers that gradually integrate novel ideas over multiple years. Stepwise improvements with farmers may help researchers and farm advisors expand crop protection across greater geographical and temporal boundaries to create sustainable methods [67,87].

Farmer social and economic conditions are non-technical implementation elements.

Advanced ecology shows that increasing genetic variety in a cycle is beneficial, but market, agri-environmental programs, and retail chain procurement techniques determine whether to introduce a new cultivar or crop species. If market forces fail, alternative economic incentives may work. Swiss agriculture policy promotes sustainable integrated production via incentives. Environmentalism and low-input techniques may be explained by farmers' social capital and professional networks [68,89].

Farm advice services facilitate multi-actor interactions, information flow, and locally relevant IPM expertise. They help conventional and organic farming communities share knowledge and assist multi-actor groupings of farmers, advisors, researchers, and other stakeholders. Switzerland, Hungary, Denmark, France, Germany, and the UK have effectively deployed collective advisory models [69].

The eight IPM principles do not address social and economic issues or agricultural advice service organization. However, these non-technical aspects are useful levers. Economic factors, farmer social milieu, agricultural consulting services, and collaborative multi-actor techniques affect IPM adoption [70,90].

Member States must demonstrate how their National Action Plans implement the eight IPM basic principles under Framework Directive 2009/128/EC. These concepts help farmers make rational decisions. Intelligent implementation of the concepts may minimize pesticide use and innovate [71].

Principle 1 (Prevention and suppression) covers cropping system design and efforts to limit pest outbreaks. After the cropping system is in place, Principles 2 (Monitoring) and 3 (Decision-making) provide a succession of control alternatives to examine, beginning with the least preoccupying. Principle 8 (Evaluation) closes the loop by requiring users to evaluate their activities to improve the process [72].

Control strategies and a multi-pest strategy are more effective and sustainable than single tactics. Research and extension must integrate plant genetic resistance, crop diversification, crop management techniques, and landscape influences into pest control tactics. The FP7 PURE project examined alternative approaches in maize-based farming systems, decreasing pesticide inputs by at least 30% and suppressing pests as well as existing chemical methods.

Crop rotation is essential for pest control and prevention. Crop rotation is the best agronomic alternative to synthetic pesticides in organic arable farming. Altering winter and spring-summer crops in arable crop rotations disrupts the insect life cycle more effectively than winter or summer crops alone [73].

Continuous maize production shows how crop rotation reduces pesticide use and manages the invasive Western corn rootworm Diabroticavirgifera and other noxious weeds. By rotating maize to a variety of non-maize crops, farmers may prevent a "rotation resistant" Western corn rootworm that oviposits in non-maize crops [74].

Crop management methods, frequently unrelated to pest control, greatly affect cropping systems' pest susceptibility. Mechanical weeding damages crop tissue and promotes illnesses, whereas fertilization impacts sap-sucking insects, mites, plant pathogenic fungus, and bacteria. Tillage systems affect weed populations and soil-borne illnesses. Conservation tillage is a good practice, although its significance in IPM is unclear [75].

Crop protection is focusing on increasing inter- and intra-specific diversity in and around the cultivated area. Mixed cultivars, composite cross-populations, intercropping, living mulches, and semi-natural vegetation boost spatial diversity. Planting diverse crops together reduces disease severity and improves insect control. Prevention techniques that build healthy, strong agricultural systems need efficient agronomic lever integration to limit pesticide usage. Beyond prevention, abandoning pesticides requires monitoring hazardous species at regular intervals or after local alerts. Ideally, all farms would monitor pest numbers and employ forecasting tools before controlling. Not all nations can afford warning and forecasting systems for all crops. Denmark, Germany, Switzerland, and France have good support systems [76].

Weeds seem identical when management choices are required, therefore farmers are hesitant to monitor them. End-of-season weeds or tiny untreated field plots might be used to create weed maps due to gradual population shifts. Monitoring, warning, and forecasting techniques differ by pest and local resources [77].

Monitoring and thresholds are key to IPM Principle 3. Weeds and diseases may have long-term effects on crop types and production settings, therefore these criteria may not apply. Weed and disease threshold-based judgments must be proven and revisited.

Weeds' spotty spread and long-term influence make economic criteria difficult to set. However, thresholds may not apply to tolerant types with obvious disease signs that may not affect yield. It is unreasonable to expect strong and scientifically sound economic harm thresholds for all key pests in all crop types and production settings [78].

Effective pest management requires prioritizing non-chemical alternatives above chemicals. Determining "satisfactory pest control" is challenging and may not be sustainable. A comprehensive IPM approach with many protective techniques helps control pests. Soil solarization and biological control may work together to manage pests [79].

Live natural enemies are a promising non-chemical IPM technique. Biological control agents are well-developed in protected crops, but they have great potential in arable crops. Innovative screening techniques that concentrate on criteria outside effectiveness will provide access to potential microorganism taxa outside the biodiversity pool [80].

In conclusion, IPM principles stress observation, good decision rules, and all principles. IPM reduces pesticide usage, yet selective pesticides are needed when preventive and alternative control fail. Pesticide selection must minimize health and environmental impacts. To optimize IPM and reduce pest control interruption, solutions compatible with beneficial arthropods are preferred. For this, examine the IOBC Pest Select Database, the IPM Impact Side-effects database, the University of Hertfordshire's Pesticide Properties DataBase, and the French Ministry of Agriculture's E-phy catalogue online [81].

Another IPM concept that reduces health and environmental concerns is pesticide reduction. National pesticide strategies aim to minimize consumption quantitatively and over time. Crop protection specialists disagree on whether pesticide levels should be decreased.

Anti-resistance measures are especially crucial in IPM since pesticide-resistant organisms are rising and threatening numerous goods. The link between pesticide dosages below the label, sublethal effects, the hormesis effect, and pesticide resistance is debated. The need for lower pesticide doses is not supported by crop protection specialists [82].

Evaluation helps farmers to evaluate their crop protection systems, another important part of effective management. Traditional evaluation techniques might hinder alternative development, but new IPM-adapted performance criteria and standards of reference could combine these aspects at the cropping system and agroecosystem level [83].

Conclusion

In conclusion, the adoption of Integrated Pest Management (IPM) strategies represents a crucial step towards maximizing yield and ensuring sustainability in horticulture crop production. By embracing a comprehensive approach that integrates various pest management techniques, growers can effectively mitigate pest pressures while minimizing adverse impacts on the environment and human health. The success of IPM lies in its ability to balance economic considerations with environmental stewardship, promoting long-term resilience and profitability in agricultural systems. Furthermore, by reducing reliance on chemical pesticides and fostering ecological balance, IPM not only enhances crop yields but also preserves biodiversity and ecosystem health. As we continue to confront the challenges posed by pests and climate change, the principles of IPM offer a roadmap for achieving sustainable agriculture that meets the needs of both present and future generations. Through continued research, education, and collaboration, growers can further refine and implement IPM strategies to maximize productivity, profitability, and environmental sustainability in horticulture crop production.

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