Chapter

Integrated Pest Management: A Paradigm for Modern Age

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Abstract

Integrated pest management is an effective and environmentally sensitive approach for pest management. It plays an important role in sustainable agriculture and quality of food production by providing maximum economic yield to the farmer and also improving human health and environment. Recent developments in agricultural technology, modern communication tools, changing consumer trends, increased awareness for sustainably produced food systems, and globalization of trade and travel, have necessitated the need for the IPM paradigm as appropriate for modern times. Although the concept of integrated pest management originated almost 60 years ago, currently integrated pest management is a robust paradigm of pest control around the globe. This chapter reviews the history of integrated pest management, its main principles, and components of integrated pest management such as host plant resistance, cultural control, behavioral control, mechanical/physical control, biological control, and chemical control.

Keywords: pest management, global losses, sustainable agriculture, new model, control measures

1. Introduction

One of the major challenges of the twenty-first century is to provide food for its ever-growing population. It has pushed food production systems to maximum efficiency and the demand requires farmers to produce more crops on existing farmland that needs continuous improvement of agricultural technologies to minimize crop losses. Although chemical pesticides have played a vital role in providing an abundant and inexpensive food source [1], its persistent overuse has resulted in a number of adverse environmental impacts such as pesticide resistance, resurgence of insect pests, pesticide poisoning, environmental toxicity, elimination of predator species, negative outcomes for other nontarget organisms, disruption in the food web, accumulation of toxins in the food webs, and reduced crop yields [2, 3]. Thus, to feed the future generations and to meet increasing demand for wide spectrum of high-quality fresh products without degrading the resources, strategy must be economically viable and ecologically sustainable. Integrated pest management (IPM) strategy being environmentally friendly pest management is increasingly being adopted in both developed and developing countries for adequate safe and quality food production, improves farmer's livelihood and conserves nonrenewable resources.

1.1 Definition of integrated pest management

Although multiple sources define IPM in diverse ways, previous models primarily focused on the ecological, and to some extent on the evolutionary, aspects of pest management [4]. IPM is a holistic "approach" or "strategy" to combat plant pests and diseases using all available methods, while minimizing applications of chemical pesticides [5]. The basic aim of IPM is not to eradicate pests, but to manage them, maintaining their populations below economic injury levels [6, 7]. IPM is a combination of methods to manage the pest population with considerations of economic efficiency and environmental effects rather than an eradicative method, which was used in traditional practices [8]. The Food and Agriculture Organization of the United Nations (FOA) defines integrated pest management as careful consideration of all available pest control methods and subsequent integration of appropriate measures that deter the development of pest populations and keep pesticides and other interventions to levels that are economically justified and minimize risks to human health and the environment. The United States Department of Agriculture-Agricultural Research Service [9] defines integrated pest management as a sustainable, decision-making process that aims at keeping pest population at below economic threshold levels by employing pest control techniques such as biological, cultural, physical, and chemical methods to identify, manage, and reduce risk from pests and pest management tools and strategies in a way that minimizes overall economic, health, and environmental risks. This strategy avoids undesirable short-term and long-term ripple effects and will ensure a sustainable future [10]. IPM differs from organic agriculture as it allows the judicious use of pesticides, fertilizers, and other materials made from synthetic materials when necessary whereas organic agriculture largely restrict to allowable pesticides made from natural materials only [11].

1.2 Integrated pest management: a historical perspective

In the 1940s with development of synthetic pesticides, the whole scenario of crop pest management changed. Pesticides played a major role in crop production due to their efficacy, convenience, flexibility, and economy. It began with the introduction of alkyl thiocyanate insecticides, and then the discovery of remarkable insecticidal properties of DDT (dichlorodiphenyltrichloroethane) in 1939 by Paul Muller. DDT was followed by the manufacture of other chlorinated hydrocarbons, including aldrin, endrin, heptachlor and recognition of the herbicidal activity of the phenoxyacetic acids-MCPA (2-methyl-4-chlorophenoxyacetic acid) and 2,4-D (2,4-dichlorophenoxyacetic acid). A number of synthetic inorganic insecticides containing arsenic, mercury, tin, and copper were also developed in nineteenth century. By the 1950s, overuse of insecticides had generated numerous well-recognized cases of pest resistance and destruction of natural enemies of pests [12]. Due to over reliance on synthetic pesticides from the late 1940s to mid-1960s, the period has been called "the dark ages" of pest control. However, in the late 1950s, entomologists began to identify the problems associated with extensive and intensive use, misuse, and abuse of insecticides and pesticide resistance, secondary pest outbreaks, hazards of toxic residues in food commodities and biomagnifications, environmental pollution, and killing of nontarget beneficial organisms. Although many components of IPM were developed long time back through trial and error experiences, farmers had developed a number of mechanical, cultural, and physical control measures of different pests; however, the concept of IPM came into existence only after realizing the harmful effects of chemical pesticides. The term Integrated Pest Control was first used as "integrated control" by Barlett [13] for the integrated use of biological and chemical control to manage insect pests of agricultural crops. The first integrated control program was devised for managing spotted alfalfa aphid, *Therioaphis maculata* (Buckton), on alfalfa grown for hay purposes. It was further elaborated as an approach that applies to the concept of integrating the biological and other controls in complementary ways [7]. The concepts of economic threshold level and economic injury level were also introduced by these authors. Subsequently, it was broadened to include all control methods and all classes of pests (insects, plant pathogens, nematodes, weeds, vertebrate pests, etc.). Shortly after IPM concept first appeared, Rachel Carson's book "Silent Spring" in 1962 was published, which explored the effects of pesticide overuse on environment and nontarget species [14–16]. Hence, the public awareness was raised and thereby the concept "integrated control" became popular in both scientific literature and practice [15, 17]. From past 30 years, IPM has been a valuable paradigm for organizing research and extension efforts worldwide and since then numerous IPM programs are being implemented worldwide. The future aim of IPM programs should not be restricted to only efficient use of pesticides and product substitution; rather these programs should aim at fundamental structural changes through effective understanding of ecological processes and synergy between crops.

2. General principles of integrated pest management

Main proponents of IPM suggest six basic strategies to improve insect management strategies:

2.1 Prevention

The cheapest and most reliable way to avoid many pest problems is to provide an environment that discourages pest activities/infestation. These types of methods include suppression of harmful organisms from becoming problems by planning and managing various options such as:

1. Crop rotation and intercropping.

2. Use of adequate cultivation techniques like seedbed sanitation, management of sowing/planting time and plant densities, under-sowing, conservation tillage, pruning, and direct sowing.

3. Use of resistant cultivars, standard/certified seeds and planting material.

4. Well-balanced nutrient supply and optimal water management.

5. Preventing the spread of harmful organisms through field sanitation and hygiene measures.

6. Protecting and enhancing beneficial organisms.

2.2 Pest identification

Pest identification is one of the foremost strategies to control the pest population. Moreover, when the identity of a pest is not known, then, a strategy built to control the pest at a particular site cannot be transferred to another, as pest species or strain at another site might behave differently. Thus, a solid foundation must be built on pest's systematic, taxonomy, etiology, and spatial distribution [18].

2.3 Establishing a periodic inspection and monitoring system

A pest is an anthromorphic categorization which is beneficial and harmful at the same time. For instance, termites considered beneficial organisms in forests converting dead trees to organic matter are also considered as pests as they on wood having high economic value [19]. Pest inspection includes regular site inspections and trapping to determine the extent of infestation levels and types of pests at particular site. It also includes regular check on the occurrence of species identified properly and considered to be pests or beneficial organisms, the damage caused by the pests, the crop characteristics, and the environmental factors. Monitoring procedure is a key element of IPM programs as it helps early detection, timely information on pest activity, ranking of the severity of infestations, identify its causes, and estimation of future populations. Environment monitoring methodologies must be designed for assessing instantaneous and dynamic aspects of the pest's density, activity, or incidence [18]. Understanding these environmental interactions allows crop advisors to react to changing environmental conditions and helps to determine acceptable pest population levels, effective reduction measures, and breach of the action threshold.

2.4 Determine economic injury and action threshold level of pest activity

The primary objective in integrated pest management is not to eliminate a pest but to bring it into acceptable boundary. FOA defines pest as any species/strain/biotype of plant, animal, or pathogenic agent injurious to plants and plant products, materials, or environments and includes vectors of parasites or pathogens of human and animal disease and animals causing public health nuisance. In IPM, a few pests can be tolerated and it is compulsory to take action when pest numbers reach a certain level, this level is known as threshold. The lowest level of injury to crop plants where the damage can be measured is called the damage boundary and the lowest number of insects that will cause economic damage is referred to as economic injury level (EIL). Economic threshold level (ETL) is defined as the pest density at which control measures should be applied to prevent an increasing pest population from reaching economic injury level. An action threshold level (ATL) is the pest population size that requires remedial action for human-health, economic, or aesthetic reasons and it will vary depending on the site structure and how it is being used (**Figure 1**). As ETL and ATL are pest and site specific, meaning that it may be acceptable at one site but at another site it may

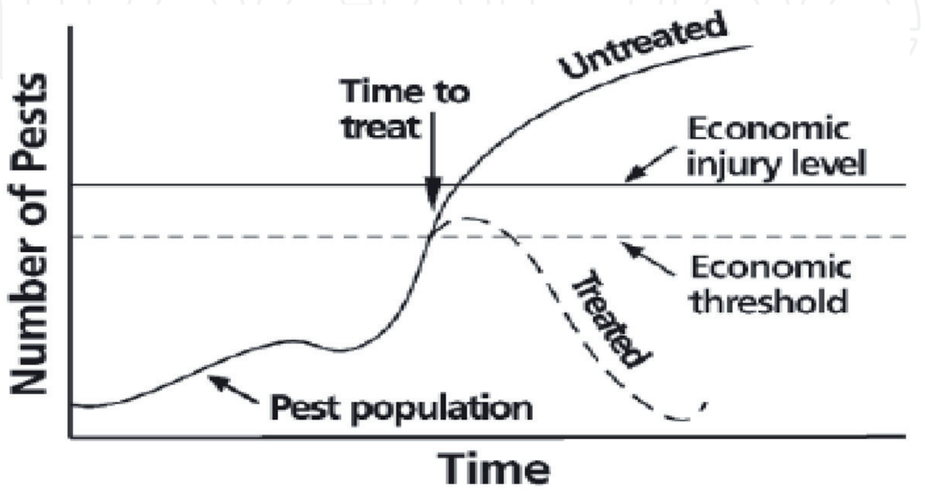

Figure 1.
To make control practice profitable, or at least break even, it is necessary to set the economic threshold (ET) below the economic injury level (EIL). Graphic: National Pesticide Applicator Certification Core Manual, NASDARF.

not be acceptable. Next step involves decision-making process that draws on accurate, timely information to make pest prevention and its management decisions.

2.5 Developing management strategies

In IPM, implementation of treatment strategy involves mechanical, cultural, biological, or chemical controls, or a combination of these strategies. Although using a single strategy may be successful for a short duration but by integration of these practices may provide safe guards against ecological disruptions (pest resistance or destruction of natural enemies) that often develop because of reliance on a single strategy [20]. If all methods have failed and the monitoring system shows that pest population is still beyond action thresholds, then the use of synthetic chemicals should be last resort only, but when used, the least toxic materials should be chosen to minimize exposure to all nontarget organisms. Ultimately, the goal is to control pests with little impact on the environment.

2.6 Evaluating and record keeping

Lastly, evaluation is often considered as one of the most important steps in integrated pest management [21]. A regular evaluation program is essential step to determine the success of the pest management strategies. It is the process of reviewing an IPM program and the results it has generated. Moreover, understanding the effectiveness of the IPM program allows making necessary modifications to the IPM plan prior to pests reaching the action threshold and requiring action again. A record keeping system is essential to establish trends and patterns in pest outbreaks. Information recorded at every inspection or treatment should include pest identification, its population size, distribution, recommendations for future prevention, and complete information on its treatment.

3. Pest management tactics under integrated pest management

The different pest management tactics to suppress pests includes host plant resistance, cultural control, behavioral control, mechanical/physical control, biological control, and chemical control. Each category as discussed below employs a different set of mechanisms for suppressing pest populations.

3.1 Host plant resistance

Host plant resistance approach is the first line of defense in IPM. During domestication of crops many resistance traits have been lost [22, 23]. It involves the use of pest-resistant and pest-tolerant cultivars developed through traditional breeding/genetic engineering [24–26]. The cultivars produced possess physical, morphological, or biochemical characters that reduce the plant's attractiveness for the pest to feed, develop, or reproduce successfully and thus reduce the yield losses. Moreover, it also involves withstanding the infestation/infection of pests to reduced level that they are not large numbers during the plant growth period [27].

3.2 Cultural control

Adopting good agronomic practices that avoid/reduce pest infestations and damage is referred as cultural control. The various cultural practices have been grouped as below:

1. Preparation of nurseries/main fields free from pest infestation by following practices such as removing plant debris, trimming of bunds, treating of soil and deep summer plowing, which kills various stages of pests. Plowing is considered an important control option to destroy the crop residue and expose the soil-inhabiting stages of several vegetable pests [28]. Proper drainage system in field is also to be adopted.

2. Testing of soil for nutrient deficiencies for application of appropriate fertilizers. Use of farm yard manure (FYM) and biofertilizers should be encouraged. High or low nitrogen [29, 30] content in the plant can also contribute to some disease problems.

3. Selection of clean, certified, pest-resistant/tolerant seeds and treating seeds with fungicide/biopesticides before sowing for seedborne disease control.

4. Proper adjustment of time of sowing and harvesting to escape peak season of pest attack and rotation of host crops with non-host crops.

5. Accurate plant spacing, which makes plants healthier and less susceptible to pests.

6. Proper water management as the high moisture in soil for prolonged period is conducive for development of pests, especially soilborne diseases.

7. Proper weed management as most of weeds besides competing with crop for micronutrients also harbor many pests.

8. Community approach is required for synchronized sowing the crops simultaneously in vast area so that pest may not get different staged crops suitable for its population buildup. If pest appears in damaging proportion, control operation could also be applied effectively in whole area.

9. Crop rotation with nonhost or tolerant crops will break the pest cycles and reduce their buildup year after year. Crop rotation tactic has been used for insect, disease, and weed management in many cropping systems [31–34].

10. Growing trap crops [35] on the borders or peripheries of fields as by growing such crops on the border of the fields develops pest population that can be source of natural enemies providing top-down control [36]. Intercropping/multiple cropping wherever possible as certain crops act as repellents, thus keeping the pest species away from preferred crops results in reduction of pest incidence [37, 38]. For instance, significant disease reduction was seen by interspacing a rice cultivar susceptible to *Magnaporthe oryzae* (causing rice blast) with a resistant one [39, 40].

11. For excellent fruit set in orchards, pollinizer cultivars should be planted in required proportion.

12. Harvesting should be done close to ground level as certain developmental stages of insect pests/diseases remain on the plant parts, which act as primary inoculum for the next crop season.

13. While pruning fruit trees, it is advised to remove crowded/dead/broken/diseased branches and destroy them and large pruning wounds should be covered with bordeaux paste/paint to protect the plants from pest/disease attack.

3.3 Behavioral control

The behavior of a pest can be exploited and controlled through baits, traps, and mating disruption techniques [41–43]. Use of baits containing poisonous material will attract and kill the pests when distributed in the field or placed in traps. Pests are attracted to certain colors, lights, odors of attractants or pheromones. These devices one or more can be used to attract, trap, or kill pests. For instance, pheromone traps involves dispensing large amounts of sex pheromones in plantation area, thereby suppressing the male's abilities to find female conspecifics for mating [44]. Thus, pheromone lures confuse adult insects and disrupt their mating potential, monitoring pest levels, mass trapping, and thus reduce their offspring.

3.4 Mechanical/physical control

This approach refers to the use of a variety of physical/mechanical techniques for pest exclusion, its trapping, removal, or destruction [45–47]. These treatments use equipment, devices, barriers, or extreme temperatures to reduce pests. Mechanical/physical controls include:

1. Agricultural practices like tillage, slash and burn, and hand weeding.

2. Pruning of infested parts of fruits and forest trees and defoliation in certain crops.

3. Mechanical cultivation of soil to kill weeds or overwintering insects.

4. Mowers and brushing equipment for plant control.

5. Setting up of traps for insects, rodents, mollusks, or other pests.

6. Pest exclusion with screens, plants collars, netting, handpicking, or vacuuming.

7. Freezers to control pests in stored products.

8. Flame, hot water, or infrared light for weed control.

9. Noisemakers or other pest repelling devices.

10. Modifying environmental conditions such as heat or humidity in greenhouses, steam sterilization, or solarization.

11. Installation of bird perches in the field for allowing birds to sit and feed on insect pests and their immature stages viz., eggs, larvae, and pupae.

12. Installation of visual or physical bird deterrents such as reflective material or sonic devices or bird scarer in the field as per requirement.

3.5 Biological control

Biological control/biocontrol involves the use of living organisms to manage crop-damaging pests. It is one of the oldest nonchemical control methods used in agriculture [48], and is probably the most well-researched part of the IPM concept. In biological control, arthropod pests are mainly controlled using biological control agent's viz. predators, parasitoids, and pathogens. Biological control agents may provide good control option under certain conditions (temperature, humidity, length of day) or on certain crops. Most biological control agents are highly perishable, so they need to be handled with care and must be released soon they are received. Its release must be planned for the right time and biology must be thoroughly understood as most species are effective on one or a few species of pests. Beneficial insects have been successfully used to control pests in greenhouses [49] and outdoor specialty crops such as strawberries [50]. Most of the intrinsic problems associated with biological control appear mainly in open areas with arthropod agents, which might emigrate from the plantation leaving the pest behind and attack each other (intraguild predation) rather than the target pest [51], or attack nontarget prey [52]. Biological control can be classified into three basic categories namely classical, conservation, and augmentation [53, 54]:

1. Classical biological control involves collection of natural enemies from their native region and releasing them in the new area where their host pest was introduced accidentally [55, 56]. Natural enemies such as predatory arthropods and parasitic wasps can cause significant reductions in pest populations at certain circumstances [57]. In microbial control, disease microorganisms are used to control pests/weeds. For instance, *Bacillus thuringiensis* (Bt), a soil bacterium that contains a chemical toxic to larval insect pests, acts by blocking the larvae from absorbing nutrients in their digestive systems.

2. Conservation biological control is aimed at promoting the survival and activity of natural enemies at the expense of pest populations [48]. For instance, ecological strips can be deliberately created consisting of selected non-crop plants to provide food sources, overwintering shelters, and protection of local natural enemies from pesticide disturbances [58, 59].

3. Augmentative biological control is the periodic release of large numbers of mass reared natural enemies with the aim of supplementing natural enemy population/inundating pest population with natural enemies [54, 60]. The practice of augmentation is based on the knowledge or assumption that in some situations there are not adequate numbers or species of natural enemies to provide optimal biological control, but that the numbers can be increased (and control improved) by releases. This relies on an ability to mass-produce large numbers of the natural enemy in a laboratory or by commercial companies.

3.6 Chemical control

Chemical pesticides are the last resort when all other methods fail to keep the pest population below economic level. The four major problems encountered with chemical pesticides are pest resistance, toxic residues, secondary pests, and pest resurgence [10]. Chemical control includes synthetic chemicals as well as chemicals of microbial (avermectin and spinosad) or botanical origin (azadirachtin and pyrethrins). Pesticides that are generally highly toxic and are known to have toxic residual effects should not be recommended off hand. The use of natural pesticides and organophosphates being more environmentally friendly is encouraged and synthetic pesticides

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should only be used as a last resort or only used as required and only at specific times in a pest's life cycle. Chemical pesticides are categorized into different groups based on their mode of action [61] and rotating chemicals from different mode of action groups is essential to reduce the risk of resistance development [62]. Pests can also develop resistance to botanical and microbial pesticides if they are overused [63]. Thus, use of pesticides should be judicious, based on pest surveillance and economic threshold level. While going for chemical control, we must understand thoroughly what to spray, when to spray, where to spray, and how to spray.

4. Integrated pest management certification

Pest control operators, farmers, grounds managers, crop consultants, wildlife management specialists, and others can have their products certified under a variety of programs that use IPM as a requirement. Certification means that a product/service meets a well-defined standard.

5. Pros and cons of an integrated pest management program

The key benefits of integrated pest management to farming and society include:

- IPM emphasizes understanding the agroecosystem, integration of new management skills and the new concepts for pest management to protect our environment and make sure the uninterrupted safe and nutritious food supply for the growing world population.
- IPM, besides sustaining biodiversity, slows the development of resistance of pests to synthetic pesticides.
- It improves profitability to farmer as pest management costs are reduced.
- It reduces risk of crop loss by a pest and long-term answers to pest problem.
- It protects environmental and human health by restricting broad spectrum pesticide use.

In spite of benefits of IPM stated so far, there are also some drawbacks to it:

- IPM involves more technicalities and decision-making.
- An IPM program requires a higher degree of planning and management.
- It is more time and energy consuming.
- It requires more resources as a substitute to pesticides.

6. Conclusion

In agriculture sector, increased pest resistance and ecological backlash can only be corrected by effective, safe, and sustainable pest management strategies. IPM can be expected to continue to be dominant theme in the future as it can better exploit the modern science and the traditional agricultural systems based on indigenous farming practices. Overall, IPM addresses all the economic, environmental, and social aspects and provides safe and affordable food to the consumers and profits to producers and sellers along with maintaining environmental health. Moreover, to develop IPM programs for the twenty-first century, further research and, more importantly, field studies and on-farm validation are needed to advance these approaches for a pest-free crop and pesticide-free product.

Conflict of interest

No conflict of interest is indulged.

Abbreviations

IPM	integrated pest management
FOA	Food and Agriculture Organization of the United Nations
DDT	dichlorodiphenyltrichloroethane
MCPA	2-methyl-4-chlorophenoxyacetic acid
2,4-D	2,4-dichlorophenoxyacetic acid
FYM	farm yard manure
EIL	economic injury level
ETL	economic threshold level
ATL	action threshold level
Bt	*Bacillus thuringiensis*

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