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Integrated Insect Pest Management

Hamadttu Abdel Farag El-Shafie

Abstract

Insect pests cause substantial losses to food and fiber crops worldwide. Additionally, they vector human and domestic animal diseases. The dependence on pesticides as a sole method of control has resulted in the development of insect resistance and negative effects on human health, natural enemies, and the environment. The concept of integrated pest management (IPM) originated almost 60 years ago in response to these negative impacts of pesticides. Currently, IPM is a robust paradigm of pest control around the globe. This chapter reviews the history of IPM, its main principles, decision-making rules, the components, and main tactical methods used. Innovative tactical methods such as sterile insect technique (SIT), incompatible insect technique (IIT), and push-pull strategy are discussed. Moreover, challenges of implementation and future prospects of IPM are highlighted.

Keywords: insect pest, integrated pest management, economic threshold, economic injury level, decision rules, ecosystem

1. Introduction

Insects appeared on earth about 390 million years and have diversified into several million species that have adapted to almost all available ecosystems. This large diversity has allowed them to compete with humans effectively since the introduction of agriculture over the last ten millennia [1]. Based on new methods of estimation, there are about 5.5 million species of insects on the earth planet with 1 million identified species, which represent only about 20% of the total estimated number. Previously, the global number of insects was estimated to be 30 million based on host specificity; however, this number seems to be not true [2]. Insects are by far the most successful group of animal on earth and are thus essential component of the ecosystem both economically and ecologically as they make up more than 75% of the world's animal species. Entomology has tremendously developed in recent years and contributed much in the development of other fundamental biological sciences. Today, many insect species are being used as model organisms to study the genomic and proteomic of many organisms. Invasive insect species such as the red palm weevil (*Rhynchophorus ferrugineus*), the fall army worm (*Spodoptera frugiperda*), the spotted drosophila (*Drosophila suzukii*), and the brown marmorated stink bug (*Halyomorpha halys*) are expanding their geographical range and, thus, threatening agricultural crops at a global level [3–6]. According to their mode of nutrition, insects are classified into different categories including herbivores, predators, fungivores, and scavengers. Insects together with weeds and diseases destroy about

40% of the world food production during preharvest phase while approximately 20% is lost during storage [7]. The estimated global losses due to insect pests are 500 billion US\$ and by adopting good pest management practices, the losses can be reduced by 42.6% [8].

Well before 2500 B.C., the Sumerians were using sulfur compounds to control insects and mites. By 1200 B.C., the Chinese developed plant-derived insecticides or what is called botanicals today for seed treatment and fumigation uses. They also used chalk and wood ash for prevention and control of both household and stored product pests. In late 1940s, DDT was discovered as a powerful insecticide announcing a new era of pest control [9]. The heavy use of chemical pesticides caused serious environmental problems without achieving final solutions to insect pest problems. These drawbacks of the unwise use of pesticides inspired entomologist to think of integrated pest management (IPM) in 1959 as a new paradigm of insect control [10].

2. Origin and history of IPM

The concept of IPM emerged about 60 years ago when entomologists from California, USA observed that the sole use of chemical pesticides could not be the solution to insect pests’ problem. Insect resistance to organosynthetic insecticides, resurgence of primary pests, upsurges of secondary pests, and environmental pollution initiated the notion of IPM [11]. It has been emphasized that chemical control should be employed to reduce a pest population only when natural controls are inadequate. Intervention to control pest should also be made when populations rise to levels that cause economic damage. Additionally, the cost of control must cover the amount lost due to the pest damage and negative effect on the ecosystem, due to the application of pesticide, and should be to the minimum [12]. The IPM concept has three basic elements:

- 1. maintaining insect populations below levels that cause economic damage;
- 2. using multiple tactics, in an integrated fashion, to manage insect populations; and
- 3. conserving environment quality.

As shown in **Table 1**, the publication of the book “silent spring” is considered one of the most important events that hastened the perception of IPM as a new paradigm of pest control. The adoption and support given to IPM by the FAO in 1967 is a major factor behind the development of IPM. Additionally, the establishment

Date	Event	Reference
Late 1940s	The concept of supervised control	[13]
1959	The concept of integrated control	[10]
1961	The Australian ecologists proposed the term “ <i>Pest management</i> ”	[14]
1962	Publication of the book “ <i>Silent Spring</i> ”	[15]
1966	The term “Pest Management” received recognition in USA	[16]
1967	The term “Integrated Pest Management” was used by Smith and Van den Bosch	[17]
1967	FAO panel of experts accepted the term “Integrated Pest Control” as a synonym for Integrated Pest Management	[18]

Date	Event	Reference
1969	The US National Academy of Science formally accepted the term Integrated Pest Management	[16]
1972	Integrated pest management and its acronym IPM were incorporated into English literature and accepted by the scientific community	[11]
1972	The report <i>Integrated Pest Management</i> prepared by the Council on Environmental Quality was published	[19]
1988	Major IP success in rice systems in Indonesia	[8]
1989	Farmer Field School (FFS) became a preferred extension methodology for IPM	[20]
1992	IPM was recommended for pest management under Agenda 21 of the United Nations Conference on Environment and Development	[21]
1993–2000	IPM initiative of the Clinton Administration	[22]
2011	IPM programs are operational in more than 60 developing and developed countries	[23]
2011	IPM adopted as a policy within sustainable use of pesticides Directive 91/414/EEC in the form of regulation (EC Regulation 1107/2009), which came into force in June 2011	[12]
2014	The EU Frame work Directive on sustainable use of pesticides (Directive 2009/128/EC) requires that all EU Member States develop a National Action Plan, which ensures that asset of eight general principles of IPM are implemented by all professional pesticide users starting from January 1, 2014	[24]

Table 1.
History and chronological development of IPM.

of Farmers Fields Schools (FFS) in 1989 for rice field in Asia, as extension methods, hastened the adoption and application of IPM at farmer level. Recently, the European Union has adopted IPM as a policy for management of insect pests. The integrated pest management is now the ideal system for protection of agricultural crops, domestic animals, stored products, public health, and the structure of human dwellings against the attack of arthropod pests, plant and animal diseases, and weeds [1, 11, 25].

3. IPM definitions

Between 1959 and 2000, 67 definitions of IPM appeared in the literature, most of them included using natural or ecologically sound principles or techniques, preventing pests from reaching the economically damaging levels, and using multiple tactics such as cultural, biological, and chemical. The expression economics, environment, pest populations, and pest control appeared in these definitions of IPM with frequencies of 53.8, 48.1, 40.4, and 38.3%, respectively [25]. All IPM definitions include the following: (i) the appropriate selection of pest control methods and decision rules for selection, (ii) economic benefits to growers and society, (iii) the benefits to the environment, and (iv) considering the impact of pest complex [10, 11, 18, 24].

4. Objectives of IPM

IPM has three main objectives: first, maintaining a balanced sustainable ecosystem and a healthy environment by reducing the use of pesticides and their negative

impacts; second, saving money by reducing chemical pesticides inputs, crop losses due to insect damage and eventually by reducing the pest management cost; and third, protecting human and animal health by providing food and feed that is free of pesticide residues [26].

5. General principles of IPM

According to the EU Framework Directive 2009/128/EC, there are eight principles of IPM that should be strictly followed by all members of the European Union starting from January 2014 [15]. Barzman et al. [27] described these principles as follows:

5.1 Prevention and suppression

The first line of defense in IPM is to prevent and suppress insect pest population through nonchemical methods such as cultural practices, use of resistant varieties, proper irrigation and fertilization, and natural enemies.

5.2 Monitoring

Continuous surveillance and monitoring of insect pests population is essential for assessment of damage and for determining the needs for actions to be taken.

5.3 Decision-making

Management decisions should be based on monitoring and population levels of insect pests, as well as reliable thresholds.

5.4 Nonchemical methods

Sustainable biological, physical, and other nonchemical methods must be preferred to chemical methods if they provide satisfactory pest control.

5.5 Pesticide selection

Selective pesticides, which have minor negative impacts on human health and beneficial insects, shall be used only when needed.

5.6 Reduced pesticide use

Pesticide use should be kept to the minimum through reduction of doses and application frequency without encouraging resistance development in pest populations.

5.7 Antiresistance strategies

Pesticide resistance in insect should be managed carefully using strategies such as application of pesticides with different modes of action.

5.8 Evaluation

The success of control tactics must be measured using indicators based on monitoring of harmful organisms, beneficials, pesticide use, and impact on the environment.

6. Important terminologies in IPM

Pest: any organism that causes damage or inconvenience to human or his possessions [28].

Natural enemy of a pest: a natural enemy of a pest can be predator, parasitoid, nematode, and pathogens (bacteria, viruses, fungi) [29].

Population: a group of individuals of the same species in a given area that provides the ecological requirements of the species [10].

Population regulation: the return of a population to an equilibrium density, following departure from that density, because of density-dependent processes [28].

Insect pest complex: the number of insect species associated with a particular crop [28].

Major insect pest (key pest): species of insects, which has a high reproductive potential and is capable of causing economic damage on their host [28].

Minor insect pest: insect species that is not capable of causing damage of economic importance.

Secondary or sporadic insect pest: insect species with population level that occasionally grows beyond its economic injury threshold [28].

Economic damage (ED): occurs when the cost of preventable crop damage exceeds the cost of control. For example, if the wheat is worth \$ 10 a bushel and insecticide cost \$ 15 an acre, then economic damage occurs when insect damage causes a yield loss of 1.5 or more bushels an acre ($Ed = \text{cost of treatment/crop value} = \$ 15/\$ 10/\text{bushel} = 1.5 \text{ bushel}$).

Economic-injury level (EIL): the lowest population density that will cause economic damage. Economic damage is the amount of injury, which will justify the cost of artificial control measures; consequently, the economic-injury level may vary from area to area, season to season, or with man's changing scale of economic values.

Economic threshold (ET): the density at which control measures should be determined to prevent an increasing pest population from reaching the economic-injury level. The economic threshold is lower than the economic injury level to permit sufficient time for the initiation of control measures and for these measures to take effect before the population reaches the economic-injury level [10] (**Figure 1**).

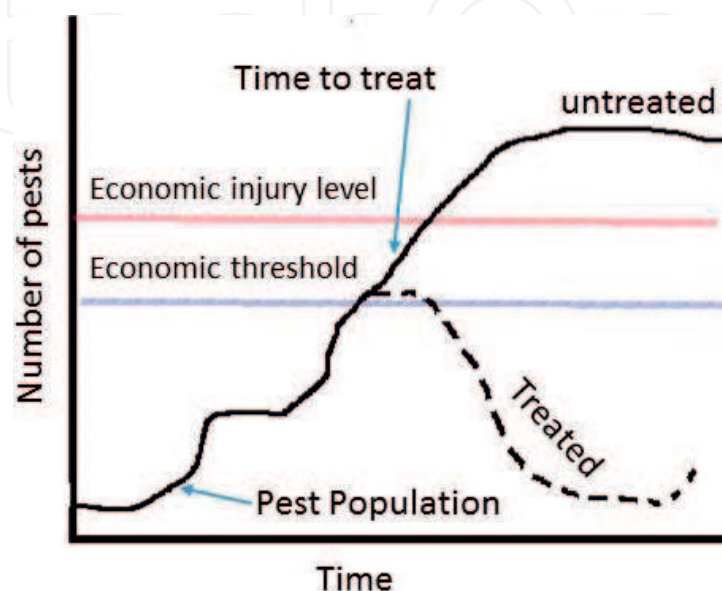


Figure 1.
The economic threshold and the economic injury level.

7. Decision rules in IPM

Identification of pest is essential to gather information about its biology, ecology, and behavior and monitoring population levels. Monitoring includes various activities and procedures that detect and document the presence, growth, and population development or populations levels of an organism. Monitoring is the key to a successful IPM program. Adequate monitoring tools should include trappings using pheromones and light traps, observations in the field as well as scientifically sound warning, forecasting, and early diagnosis systems [27]. Advantages of pest monitoring include early warnings, detection of presence and distribution of pests and their natural enemies, study the impact of weather and other environmental factor on pest/beneficial populations, provision of historical record of the farm, and evaluation of control programs [30]. Visual counts, sweep nets, drop sheets, and vacuum pumps are also useful tools in sampling of field insects.

El-Shafie and Faleiro [31] gave comprehensive accounts on the use of semiochemicals in monitoring and mass trapping of insects. Operational monitoring program is used in IPM to evaluate field situation and should be simple, quick, cost-effective, and adaptable to farmers [30]. There are four methods of sampling insect in the field: random sampling, point sampling, trap sampling, and sequential sampling. More details on sampling of insect pests are given by Flint and van den Bosch [30].

7.1 Pheromones as a monitoring tool

Pheromone-baited traps are commonly used for population monitoring and for mass trapping because they have the following advantages:

1. pheromones are species specific and are, thus, easy to use by untrained people;
2. they function at both small and large pest populations;
3. suitable for early detection and delimitation of infestation by invasive pests;
4. can be used in estimation of population size and determination of number of generations; and

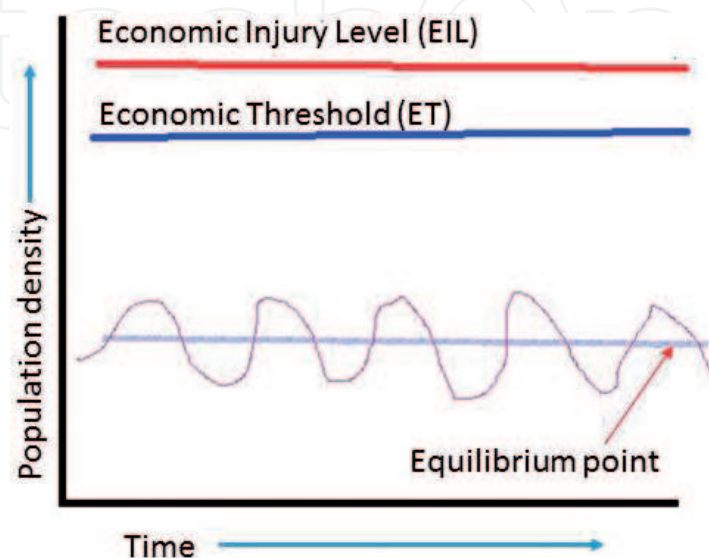


Figure 2.

Equilibrium point is well below the economic injury level. Control action is not needed (modified after Luckmann and Metcalf [33]).

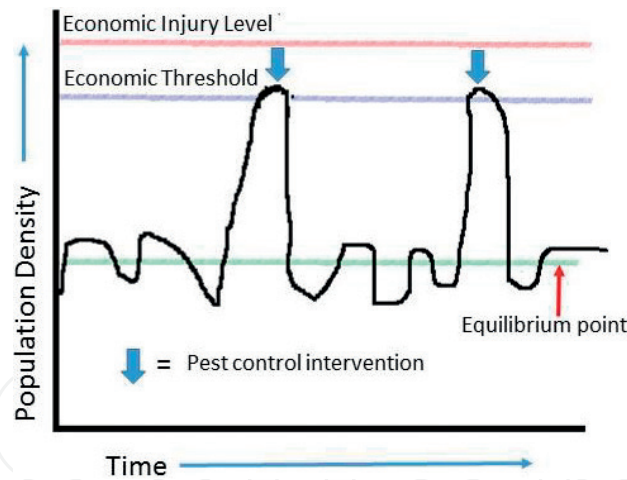


Figure 3.
Equilibrium is below EIL; however, the pest population may reach the ET, and intervention is needed to prevent it from reaching EIT (modified after Luckmann and Metcalf [33]).

5. provide efficient and cheap alternatives to the laborious field scouting.

All of the above make the pheromone-baited traps a useful tool in integrated pest management (IPM) decision-making [32].

In situation where the economic injury level for an insect species is above its equilibrium position (**Figure 2**), the insect is not considered a pest and no decision is needed to control it. However, when the economic injury level is well below the equilibrium position, the insect requires continuous management intervention [33].

Sometimes, the population of the insect pest may reach the economic injury level, even if the equilibrium is well below the economic injury level. In such case, the decision of intervention to control the pest is need to be taken (**Figure 3**). For mathematical calculations of ET and EIL, see Pedigo et al. [34].

8. Components of IPM

The more that you know about a pest, the easier and more successful pest management becomes. Once you have identified a pest, you can access information

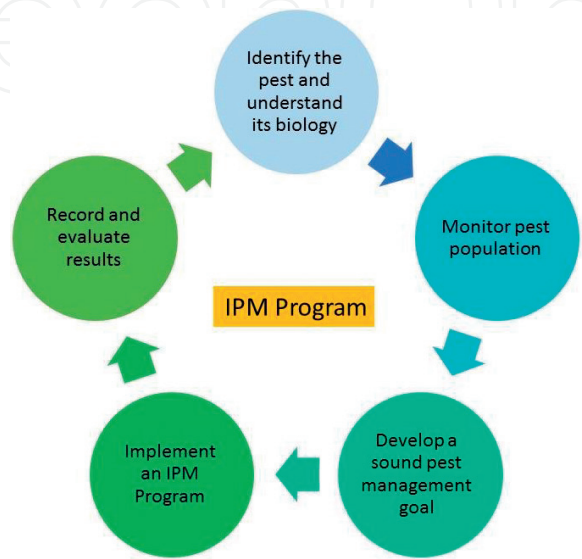


Figure 4.
Components of IPM program.

about its life cycle and behavior, the factors that favor development, and the recommended control procedures. Following identification of an insect pest is monitoring to determine the pest status. If there is a need to control the pest, based on monitoring, then you develop a management program followed by implementation and evaluation as illustrated in **Figure 4**.

9. IPM tactical methods

IPM methods include both chemical and nonchemical means to prevent and control pest populations from reaching economically damaging levels. These prevention and control tactics include biological, mechanical, cultural, physical, genetic, chemical, and regulatory methods. The method to be chosen for IPM depends on many factors, the important of which are nature of target pest, the environment, and economic aspect of the management. Selection of control method should be based on effectiveness and evaluation of any risk that might occur during application of the method.

9.1 Cultural control

Cultural control in cultivated crops include resistant plant varieties, timing of planting and harvesting, irrigation, fertilization, crop rotation, and trap crops. The aim of good cultural practices is to provide congenial environment for the crop while making it unfavorable for pests' development. Thus, cultural control prevents the build-up and outbreaks of pests [28]. Additionally, cultural practices are useful in conservation of beneficial insects, and accordingly, they are essential and effective component of IPM. Tillage practices can destroy pests and their different developmental stages by mechanical injury, desiccation, and exposure to predators and environmental factors [33]. Phytosanitation through collection and removal of crop remains removes many diapausing larvae, eggs, and pathogens. Eradication of infested date palm is a good practice to reduce infestation by the red palm weevil in date palm plantation [3]. Host plant resistance is compatible with other IPM tactics and can provide reasonable degree of protection to plants without causing negative effects on the environment [8].

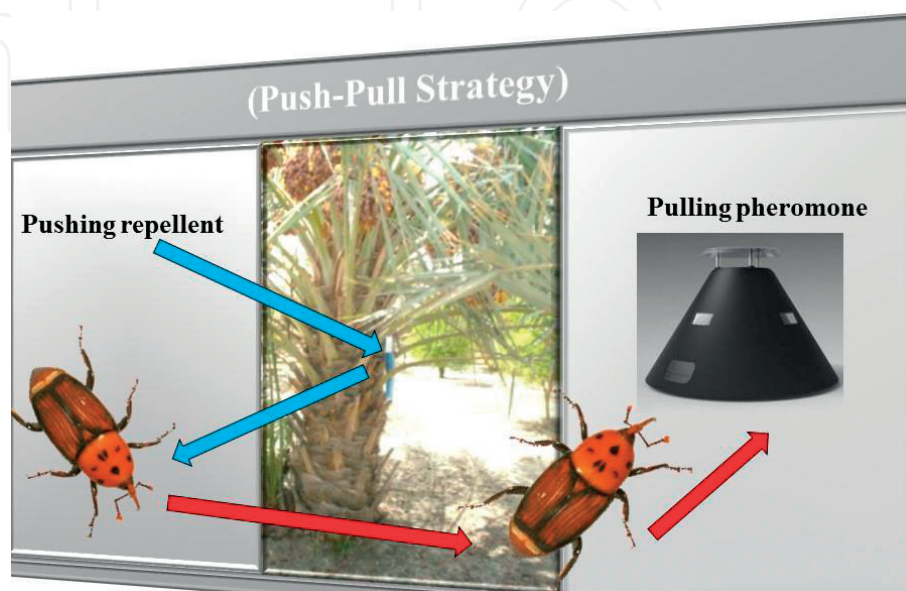


Figure 5.
Push-pull strategy.

9.1.1 Push-pull strategy (PPS)

This strategy is based on intercropping, which fit well under cultural practices section. Simultaneously, it is also based on semiochemicals particularly allomones and kairomones [35]. The pests are repelled or deterred away from a plant (push) through allomones that can be repellents or deterrents and are simultaneously attracted (pull) by kairomones to trap crops where they can be killed or removed [35] (**Figure 5**).

Plants which are effective, so far, in the push-pull tactics include Napier grass (*Pennisetum purpureum*), Sudan grass (*Sorghum vulgare sudanense*), molasses grass (*Melinis minutiflora*), and desmodium (*Desmodium uncinatum* and *Desmodium intortum*). Napier grass and Sudan grass are used for pulling insect pest, whereas molasses grass and desmodium repel or push ovipositing female insects. This strategy has been working in protection of maize and sorghum against damaging stem borers in Africa [36].

9.2 Mechanical and physical control

Mechanical and physical controls prevent pests from accessing their resources by making the environment unsuitable for them. They also negatively affect important biological parameters of pests such as feeding, reproduction, dispersal, and survival. Physical control methods may include heat and steam sterilization of soil, which are commonly used in the management of greenhouse insect pests. Insect pests can be excluded from plants by using screens, barriers, fences, and nets, as well as light trapping (**Figure 6**). Mechanical and physical controls are carried out purposely for pest control, which differentiate them from cultural practices [28].

9.3 Biological control

Biological control is defined as the action of parasites, predators, or pathogens on a host or prey population, which produces a lower general equilibrium, position than would prevail in the absence of these agents [10]. A good biological control agent should be characterized by the following traits: specialization on the host, compatible with other natural enemies, capable of rapid reproduction, adapted to the environment where the host exists, and efficient in finding prey at low densities. There are three major types of augmented biological control: classical, inoculative, and inundative. These are distinguished by the input needed to create a balance between the pest and natural enemy populations. These three categories are defined as follows:

Classical biological control involves introducing natural enemies from a pest's native range into a new area where native natural enemies do not provide control.

Inoculative biological control means releasing natural enemies periodically or seasonally to reestablish a balance that has not been maintained naturally or has been disrupted by other control methods.

Inundative biological control involves the massive production and release of natural enemies to control the pest quickly.

Control of cottony cushion scale (*Icerya purchasi*—Maskell) by vedalia beetles (*Rodolia cardinalis*) imported from Australia in 1888 was the first great success and it had greatly benefited the California citrus industry and ignited interest in this practice in the State [37]. Nine species of *Trichogramma* parasitoid are reared in private- or government-owned insectaries around the world and released annually on an estimated 80 million acres of agricultural crops and forests in 30 countries [38]. In Germany and Austria, the control of the Indian meal moth, *Plodia interpunctella* (Huebner), and the Mediterranean flour moth, *Cadra kuehniella* (Zeller), in food



Figure 6.
Solar-powered insect light trap.

processing facilities is achieved by releasing large quantities of *Trichogramma evanescens* Westwood using the inundative release strategy [39].

Manipulations of insect reproductive systems techniques such as sterilized insect technique (SIT) and incompatible insect technique (IIT) provide innovative and environmental-friendly methods for IPM. These techniques are considered as part of the biological control and thus are discussed in this section (**Figure 7**).

The SIT involves the mass release of sterilized males, which mate with wild females. Sterilization of males using ionizing radiation causes dominant lethal mutation in the sperm. The mating of sterile males with wild females results in zero offspring. The sterile insect technique (SIT) has been successfully used for the management of some major insect pests [5]. According to Barnes et al. [40], successful application of SIT depends on the following factors:

1. the target insect pest should be characterized by low population levels;
2. knowledge on the bionomics and genetic of target insect pest;
3. the availability of techniques for mass rearing, releasing, and monitoring of large numbers of viable sterile insects;
4. the release of sterile insects over a wide area to cover the whole population; and
5. the released sterile insects should not be harmful or harmless to humans and the environment.

Another radiation technique is partial male sterility technique (IS), which is used mainly for lepidopterans because full sterilization affects their performance under field conditions. The mating of partially sterilized males with wild females results in sterile male-biased offspring [41].

Wolbachia is an endosymbiont bacterium that is capable of manipulating the reproduction of its host insect. It increases the frequency of *Wolbachia*-infected

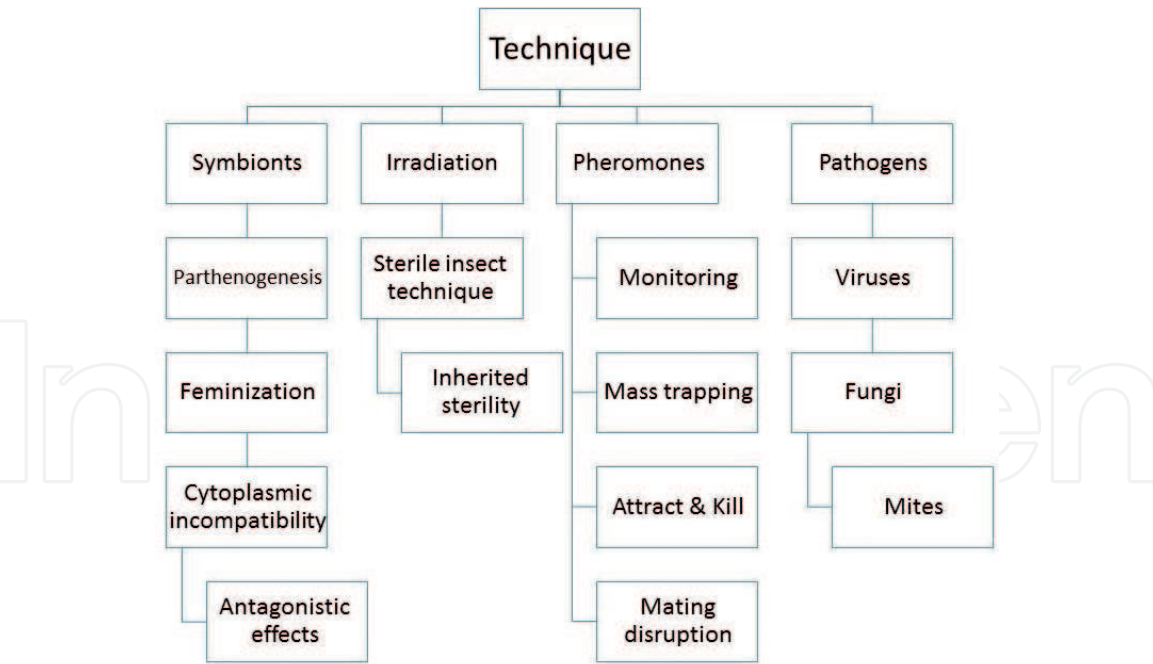


Figure 7.
Techniques of manipulating sexual reproduction of insect pests for their management (modified after Harari et al. [32]).

females in the host populations by causing feminization, parthenogenesis, male killing, and cytoplasmic incompatibility [42]. The cytoplasmic incompatibility (CI) is also called incompatible insect technique (IIT) and has been used against insect pests and disease vectors such as med fly, tsetse fly, and mosquitoes. A strain of *Wolbachia* was taken from *Drosophila melanogaster* and introduced into the mosquito *A. albopictus*, the vector of the dengue virus, in order to control the disease. Consequently, the mosquitoes become unable to transmit the dengue virus [43]. The infected males produce no offspring after mating with local females (CI), followed by a decrease in the local mosquito populations and a relative increase in *Wolbachia*-infected females that do not transmit the virus [44].

Both SIT and IIT can be combined together, and they are compatible with conventional biological control using parasitoid, predators, and pathogens. SIT allows both sexes to be released, while in case of IIT, only males should be released. The release of *Wolbachia*-infected females may result in production of viable offsprings if the released females are compatible with either wild or released males [5].

9.4 Chemical control

Pesticides should only be used when necessary to keep pest populations below that cause economic damage. Selective pesticides, which have the least negative effects on the environment, should be used according to principles 5, 6, and 7 of IPM. Botanicals and microbial (biorational) pesticides should be given priority in selection. The efficacy of these biorational pesticides may be increased when applied together [27]. A variety of selected pesticides must be applied precisely in the field and at right doses to prevent the development of insects' resistance [26].

10. AW-IPM

The integration of a number of different control tactics into IPM systems can be done in ways that greatly facilitate the achievement of the goals either

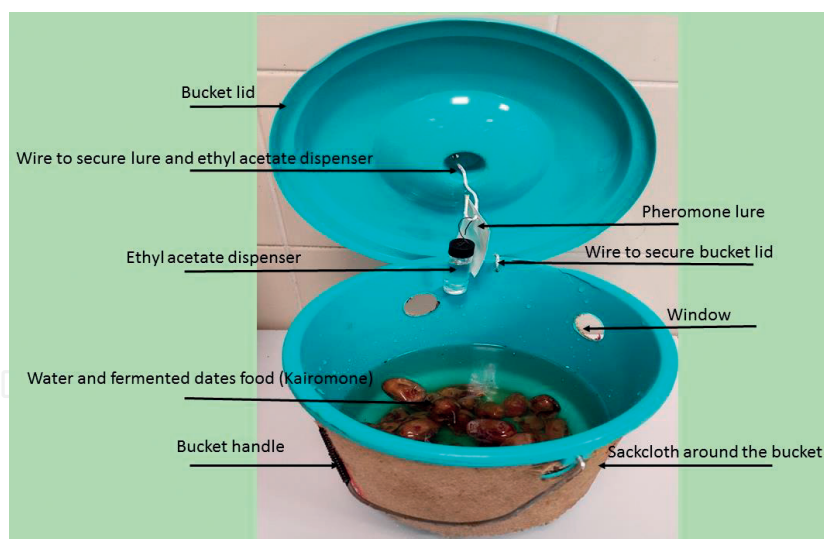


Figure 8.
Pheromone-baited trap for monitoring and mass trapping of red palm weevil.

of field-by-field pest management, or of area-wide (AW) pest management, which is the management of the total pest population within a delimited area [1]. Knipling [45] used simple population models to demonstrate that small insect pest population left without management can compromise the efforts of containment of pest population in a large area. AW-IPM programs should be coordinated by organizations rather than by individual farmers to insure full participation in the program [46]. Pheromone-based control tactics including mass capturing of using pheromone traps (**Figure 8**) proved to be effective against a variety of insect pests in area-wide IPM programs. The pests' behavior and ecology including their natural enemies should be considered when planning future AW-IPM programs [32].

11. Implementation of IPM program

Successful IPM depends mainly on basic research on ecosystem and the understanding of interactions among hosts, pests, and their natural enemies [11]. The following steps should be taken before implementing an IPM program:

- identify the pest;
- specify the goal of the program;
- set up a monitoring program;
- know the pest level that triggers control;
- know what control methods are available; and
- evaluate the benefits and risks of each method.

The socioeconomic factor is important in the implementation of IPM. For example, the decision to include a new variety resistant to insects may also depend on

the market value of that variety. A suitable extension methodology such as Farmer Field School (FFS) can help disseminate the IPM among farmers. Preparation of guidelines that include the principles of IPM for different crops is essential during the implementation phase. Moreover, the continuous evaluation of IPM programs provides feedback for future adjustment and improvement [27].

12. Indicators of measuring impact of IPM

It is extremely important to record and evaluate the results of your control efforts. Some control methods, especially nonchemical procedures, are slow to yield measurable results. Other methods may be ineffective or even damaging to the target crop, animal, treated surface, or natural predators and parasites. Pesticide use by volume, pesticide use by treatment frequency index, reduction in use of more toxic pesticides, and environmental impact quotient have been used as IPM impact evaluation indicators [22].

13. Future prospects of IPM

Since 1959, no major departures from the basic notion of IPM have occurred [11]. In the future, major advances in IPM are expected in decision-making techniques as well as tactical options for control methods. Combination of technologies and tools, simulation, modeling, BD, remote sensing data, Geographical Information System (GIS), Automatic Weather Stations (AWS), and internet of things (IoTs) can be used to promote the implementation of IPM. New generation of GPS, sensors-fitted farm equipment, e-tablets, and mobile applications (*Plantix*) could be used for future pests and diseases identification and monitoring [47]. Since implementation of IPM programs depends largely on information, it is anticipated that a giant step being taken in areas such as principles of insect sampling, computer programming and mathematics, understanding of pests biological and ecological aspects, and simulation techniques and modeling [11]. Additionally, meteorological and geostatistical computer models can revolutionize forecasting and monitoring of insect pests, which, eventually improve decision-making for IPM. Novel tactics such as silencing of pest gene or RNA interference (RNAi) and endosymbionts hosted by insect pests could be used as potential new tools for future management of insect pests. Continuous training and education of farmers represent the cornerstone for establishment of solid and effective IPM program in agroecosystems.

14. Conclusions

Due to its importance, the European Union has adopted IPM as a policy for management of insects and other pests. Manipulating reproduction of insect pests with pheromones, irradiations, *Wolbachia*, and pathogens will provide a variety of innovative tactical methods for IPM. Transgenic plants resistant to insect pest are also important tactical methods for future implementation of IPM. The information and communication technology (ICT) and nonprint media such as projectors, tablets, laptops, and mobile cell phones are expected to play a vital role in disseminating IPM knowledge among illiterate farmers, in their languages, in developing countries. In this respect, Julia and Robert [48] started a university-based scientific

program called scientific animation without borders (SAWBO) to deliver IPM strategies in the tropics. The SAWBO App helps trainers to use IPM-animated videos, in different local languages, to educate farmers efficiently. The advancement in semiochemical-based tactics could provide great support for area-wide IPM (AW-IPM), which will gain importance in the coming years due to the increasing numbers of invasive insect pest species.

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