Chapter 1

Insect Pest Management

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Abstract

The future of crop production is threatened by the incidence of insect pests. Emergence of pest resistance caused substantial crop losses globally and considered a hurdle for the accomplishment of productivity and poverty alleviation worldwide. Over-reliance on chemicals to control insect pests is associated with ecosystem contamination and additional hazardous health effects. It is now clear that shift approach for pest control is immediately required to elucidate the growing concerns associated with pesticides. Therefore, it is needed to design cropping systems without ecological disruptions and less dependent on synthetic pesticides. Integrated pest management emphasis is on anticipating pest problems followed by simultaneous integration of different approaches, the consistent monitoring of insect pests and their natural enemies and thresholds assessment for decision making. Pest outbreaks and consequently their dynamic and flexible management can only be achieved by restructuring, preventive and therapeutic measures in ways that enhance the crop productivity. In current chapter the focus will be about pest management strategies, the impacts of IPM and its potential contribution to the various crops.

Keywords: Insect pests, Crop losses, Pest control, Preventive, Therapeutic, IPM

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1.1. Introduction

1.1.1. Concepts of insect pests

Man has to compete with insect pests since the start of crop production around 10, 000 years ago for many of his fundamental needs. For this reason, battle lines were drawn right from pre-historic days. A skyrocket increase in the human population (ca. 80 million per annum) (United Nations 1996), changes in nutritional trends especially in the less developed countries towards the quality foodstuffs caused food availability problems. Additionally, decrease in the per-capita crop land availability, poor management and pest-associated losses are also the key repercussions for food safety. From the last few years, food production has been lagging the population growth with only 1% annual increase (1990-97) in grains contrast to 1.6% average population growth in developing countries (Hinrichsen and Robey 2000). There are some other factors including climatic variables (temperature, rainfall, humidity), proper fertilizers, water deficiency, genetic potential of the crop and other organisms which hamper the crop production. These organisms (insect pests) have been identified as a major constraint to increase productivity, especially for high-value crops and considered as serious threats to farmer's efforts in the pre- and post-harvest losses.

Insects play a significant role directly or indirectly and are indispensable part of the agriculture ecosystem. Insects are indeed the most flexible and adjustable form of life as their population far exceed than any other animals on the earth (Offor et al. 2014). For example, many insect species are bio-control agents, some are pollinators, decomposers or producers of valued products in the form of honey or silk. Others can play a significant role to produce pharmacologically active compounds like venoms and antibodies (Offor et al. 2014).

A pest is not only a biological entity rather it is an anthropomorphic categorization which is beneficial and harmful at the same time. For example, termites considered beneficial organisms in forests converting dead trees to organic matter and pests while feeding on wood having high economic value (Capinera 2001).

Crop losses from pests may be quantitative (reduced productivity) or qualitative (decline market value due to artistic features e.g. pigmentation), reduced storage features due to the contamination of the post-harvest products with pests or their toxic products (mycotoxins). Sometimes there is no clear difference between aesthetic and injury level especially in relation to horticultural crops; because a small depression or mark on fruit is insignificant blemish for grower but a conspicuous to down-grade the product for buyer causing significant economic loss to the farmers (Capinera 2001).

The occurrence of insects in every terrestrial and aquatic habitat makes them the most frequent and diverse population present on the planet. In agriculture, pests occur in a variety of groups including animal pests (rodents, insects, nematodes, mites, slugs, snails, birds), plant pathogens (viruses, viroids, fungi, bacteria, chromista) and weeds (undesirable plants). Food crops impairment has been caused by a vast numeric living things with 10,000 species of insect pests, 100,000 diseases (caused by different pathogens), 30,000 species of weeds and about 1000 species of nematodes (Hall 1995). Globally the estimated pre- and postharvest losses due to different insect pests, weeds and pathogens is believed to be 45% (Pimentel 1991) with an estimated worth of USD 500 billion, however, the figure would be more if no control measures had been used (Dhaliwal et al. 2004). The worldwide crop losses due to different pest categories may vary with the crop type, its geographic location, weather conditions, some year and the agronomic practices used. Additionally, the crop losses associated with abiotic factor, particularly the water stress, high temperature and nutrient supply may be reduced by adopting different agronomic practices.

1.1.2. Categories of insect pests

There are numerous insect pests and the estimated ratio of insects to humans is 200 million versus 1 and about 40 million insects for each acre of land (Pedigo and Rice 2009). Mostly insect pests can easily be assigned to groups based on characters on their wings or legs and mouth parts. Addition to this, their behaviour, how or where a pest feeds and other aspects of biology are key elements of pest categorization. The insect pests may be categorized based on injury i.e., primary or secondary and direct or indirect (Capinera 2001), frequency of occurrences i.e., regular, occasional, seasonal and persistent; while on population and damage level i.e., key, major, minor, sporadic and potential pests (Dhaliwal and Arora 1998).

1.1.2.1. Primary and secondary pests

Primary pests have potential of complete damage and breed in stable solid grains (e.g. whole healthy pulse and cereal grains) directly at some point during their life cycle. They have the capability to penetrate undamaged seed coat and advances towards the embryo to feed on the endosperm or cotyledons of the seed and reproduce very quickly when the conditions are favorable; grow into a large population and result considerable damage in a short period. Larger and lesser grain borers, rice, bean, pea and maize weevils are considered in stored grain primary pests. However, secondary pests do not attack the undamaged stored products instead generally breed and feed in those commodities that have been already attacked by some mechanical means or other pests (primary pests), bad milling, grinding, handling or other deliberate treatment of the commodity. Among secondary pests red flour beetle (*Tribolium castaneum* Herbst), rice moth (*Corcyra cephalonica* Stainton) and grain mite (*Acarus siro* L.) are important species that account for large proportion of invasion on already damage commodities (Farrell et al. 2002).

1.1.2.2. Direct and indirect pests

Direct pests are distinguished because they usually attack that part of the plant which is harvested for food and the effect, type of injury depends on the mouth parts possess by the insect pests i.e., biting and chewing or piercing and sucking types. Whereas indirect pest damages the other parts of the plant that is usually are not harvested for food purpose and their effect can be noticed in the form of reduced product quality, vectoring of disease and monetary loss. Direct infestation includes the stink bug (*Halyomorpha halys* Stal) feeding on tomato fruit; wireworms (*Agriotes* spp.) feeding on tomato roots and leaf minor on the foliage are considered indirect infestations (Capinera 2001). Although indirect pests are less injurious but a large population can cause a significant damage to the yield.

Regular pests

These pests occur frequently and have a close association with the crop e.g. rice stem borer (*Sciropophaga incertulas* Walk), brinjal fruit borer (*Leucinodes orbonalis* Guenee), pink bollworm of cotton (*Pectinophora gossypiella* Saunders), maize stem borer (*Chilo partell*us Swinhoe), sugarcane pyrilla (*Pyrilla perpusill*a Walker), whitefly (*Bemisia tabaci* Gennadius) and Jassid (*Amrasca biguttula* Ishida).

Occasional pests

The population of these pests is not frequent and have no close relation with the crop. For example, caseworm (*Nymphula depunctalis* Guenee) on rice and mango stem borer (*Batocera rufomaculata* De Geer), gurdaspur borer (*Bissetia steniellus* Hampson) on sugarcane and rice hispa (*Dicladispa armigera* Olivier) are considered occasional pests.

Persistent pests

These types of pests can be found on the crops all over the year and their control measures are much difficult. For example: guava mealy bug (*Maconellicoccus hirsutus* Green), chili thrips (*Scirtothrips dorsalis* Herbst), whitefly (*Bemisia tabaci* Genn.) and fruit fly (*Bactrocera* species).

Seasonal pests

Seasonal pests come during a specific season of the year e.g. mango hoppers (*Idioscopus* spp.) and red hairy caterpillar (*Amsacta albistriga* L.), pink bollworm of cotton (*Pectinophora gossypiella* S.) Citrus psylla (*Diaphorina citri* Kuwayama) and mango mealybug (*Drosicha mangiferae* Stebbins) occurs seasonally.

Based on the infestation percentage pests may be epidemic (abrupt outbreak in a severe form in a region at a particular time) or endemic (presence of pest at a low level regularly and restricted to a particular area).

Different parameters are associated with the level of insect pests population which include general equilibrium position (GEP), economic threshold level (ETL), economic injury level (EIL) and damage boundary (DB). General equilibrium position is the mean pest density over a prolonged period of time during which the pest population tends to vary because of abiotic and biotic factors keeping the permanent environmental conditions constant. Economic threshold level is the population density at which control measures should be initiated to limit the growing pest population that causes economic damage while EIL is the lowest population density that causes economic damage to the crop. Damage boundary is the lowest level of damage which can be measured and provides sufficient time for control measures (Dhaliwal and Arora 1998).

Key pests

These are the most serious and damaging pests. In this category of pests the GEP lies well above the economic injury level. A particular crop may be vulnerable to one or more key pests which may or may not differ regarding the season and area of the crop. Human involvement in the form of control measures may bring the pest population temporarily below the EIL. Being a persistent and high reproductive potential, they can rise back rapidly and for that repeated management practices including environment modifications may be required to lower their GEP below EIL and resultantly minimize crop damage e.g. codling moth (*Cydia pomonella* L.) on apple, cotton bollworms (*Pectinophora gossypiella* S., *Helicoverpa armigera* (Hübner), *Earias insulana* Boisduval, *Earias Vittella* Fabricius (Dhaliwal and Arora 1998) and fruit fly (*Bactrocera* species).

Major pests

In these types of pests, GEP is very close to EIL and sometime at the same level. Thus, there is a possibility of pest population crossing the economic injury level and for that economic damage can be prevented by repeated interventions of control measures. Generally, for most of the crops in most of the areas, major pests remain almost constant throughout the years. However, in some areas, the major pest species complex has been moderately varying from a long period of time e.g., cotton jassid (*Amrasca biguttula biguttula* Ishida), whitefly (*Bemisia tabaci* Genn.), rice stem borers (Dhaliwal and Arora 1998) maize stem borer (*Chilo partellu*s Swin.), sugarcane pyrilla (*Pyrilla perpusilla* Walk.) fall in this category.

Minor pests

The GEP reside below EIL and hardly cross EIL and DB for a short period of time under favourable environmental conditions. They may be restricted to specific crop plants or favour some other plants as hosts. Sometimes, a minor pest of a particular crop in one part of the world may be a major pest of same crop in other part of the globe. Minor pests comply available control measures and even a single application of insecticides is enough to avoid economic damage e.g. cotton strainers (*Dysdercus koenigii* F.), grey weevil (*Anthonomus grandis* Boheman), thrip and mite species (Dhaliwal and Arora 1998), dusky cotton bug (*Oxycarenus laetus* Kirby) and grasshopper species are minor pests.

Sporadic pests

The population of these pests is not significant and generally below GEP but sometimes under suitable environmental conditions at certain places they cross EIL and DB. Many sporadic pests including cutworms, grasshoppers, white grub are polyphagous with some oligophagous pests including sugarcane pyrilla (*Pyrilla perpusilla* Walk.), army worm (*Spodoptera litura* Fabricius) (Dhaliwal and Arora 1998) and gurdaspur borer (*Bissetia steniellus* Hampson).

Potential pests

Potential pests are not serious pests and do not cause any damage except any change in the cropping pattern, cultural practices and in the agroecosystem, that may push the GEP higher and cause economic damage. Based on their basic biology, only a minute ratio of the minor pests is also regarded as potential pests. For example, *Spodoptera litura* (F.) in North India (Dhaliwal and Arora 1998), rice hoppers

(*Nilaparvata lugens* Stal, *Sogatella furcifera* Horvath) and rice leaf folder (*Cnaphalocrocis medinalis* Guenee) are considered potential pest.

1.2. Losses by insect pests in agriculture

Since the beginning of agriculture, crop losses have been attributed to different insect pests. Biotic and abiotic environmental factors are the main cause of reduced plant growth and yield. Both qualitative and quantitative losses occur. Quantitative losses occur because of the reduced plant growth which leads a lower yield per unit area. While qualitative losses include the lower valuable ingredients contents and market value; for example due to aesthetic characteristics, reduced storage characters or the contamination of the harvested products due to pests or toxic products of the pests e.g. mycotoxins (Oerke 2006).

Identifying the type of losses caused by different insect pests is always complicated because insect pests when pass through various life cycle stages (instars) may damage different parts of the crop including roots, foliage, blossoms and fruits. Sometimes insect may not complete its typical damage because it may be disturbed from its location by a human activity, animals, strong winds or a bird might eat it. The resulting incomplete damage may provide an initial access to other organisms (e.g. bacterial rots) causing further damage or the scarred tissues continues to develop. The mouthparts of insect pests have a significant effect on type of damage; and is comprises on complicated toolkit of feeding with the basic elements the unpaired front labrum, a median hypopharynx behind the mouth, a pair of laterally attached mandibles and maxillae and a labium forming the lower lip. These component parts have been modified into a remarkable diversity of forms and well adapted over time that allow the insects as a group to exploit an extraordinarily wide range of food sources (Simpson 2013).

Although different species produce same type of damage but their mouthparts differs; hence the damage they have caused may serve as useful tool for the identification and classification of the pest. The mouth parts may be in entognathous condition in which the mouthparts lie in a cavity of the head produced by the genae, which extend ventrally as oral folds and meet in the ventral midline below the mouthparts (e.g., Collembola, Diplura and Protura). In some insect orders like Orthoptera, Coleoptera, Odonata and Lipedoptera etc the condition is ectognathous in which the mouthparts are not enclosed in this way, but are external to the head. The shape of the mouthparts is associated to diet, but two basic types can be well recognized: one modified for chewing and biting of solid food and the other adapted for sucking the cell sap (Simpson 2013). The types of damage to various crops can be direct or indirect. Direct injury done to the plants by eating on roots, leaves, flowers, seeds, burrows in stems and on fruits.

1.2.1. Damage to roots and tubers

About ninety percent of all insect pests spend at least some part of their lives in the soil (Gaugler 1988; Villani and Wright 1990; Kaya and Gaugler 1993) as it is considered as ideal niche and provides protection from extreme weather conditions and other natural enemies. These pests, irrespective of which group they fall, are members of several insect orders including Coleoptera, Lepidoptera, Diptera etc and others of equal importance. Some of the insect pests spend time in the dirt habitat several times during every season; some are constantly present, while others visit only once a year. Depending on the crop, soil insects can cause damage directly to the underground parts such as carrots, potatoes, sugar beets, onions, radishes, cereals and ornamental bulbs. The common soil pests which are vulnerable to below ground parts include wireworms, leather jackets, chafer grubs, cutworms, millipedes, vine weevil (*Otiorhynchus sulcatus* F.) larvae, cabbage root fly (*Delia radicum* L.), some species of slugs and snails and some other species of equal importance that cause damage from sowing to harvest (Wood and Cowie 1988). These insect pests enter and consume the fine root system, which directly kills the plant or indirectly decrease yield by lowering translocation of water and nutrients. Attack on root system can also enhance susceptibility to pathogens or lodging of mature plants. Because of tunneling in the roots, the lodging of plants especially the grains when touches the ground, soil fungi such as aspergillus may invade it. Similarly, root galling by several weevil species and roots swellings with root-knot nematodes resulted yellowing, wilting and ultimately lead to plant death (Offor et al. 2014).

1.2.2. Damage to leaves

Insect pests with chewing mouth parts may defoliate the plants by eating portion or whole leaves resulting skeletonize, notched, shot holed or shredding of leaves; while some other pests feed internally to the leaves or bore into the roots or stems. For example, the most common defoliating pests are locusts, grasshoppers, some species of weevils (Curculionidae), leaf beetles and some slugs and snails which feed on leaf margins and produce notches and in case of severe infestation the entire leaf lamina may be consumed. Similarly, the caterpillars, of several families (Noctuidae, Bombycidae, Gracillariidae, Hesperiidae etc.,) skeletonize, making tunnel mines or blotches and cut the lamina or making a leaf roll, respectively. While in case of pests with sucking mouth parts they usually cause foliage discoloration, curling, sooty mold production or twisting of young stems. For instance, aphids (Aphididae), whiteflies, mealy bugs (Pseudococcidae) and scale insects are regular sap feeders, retard the growth and ultimately lead to collapse of plants (de Jesus Jr. et al. 2001; Lopes and Berger 2001).

1.2.3. Damage to fruits and flowers

A diverse group of insect pests including caterpillars, aphids, weevils, moths, flies etc cause different type of damages to fruits reducing both yield and quality. For instance, larvae of mango weevil (*Sternochetus mangiferae* F.) and codling moth bore towards the core of mango and apple, respectively and cause severe damage (Sorensen 1988). The attack of pear midge on pear lefts fruitlets swell and cannot be developed properly and in most cases, drop prematurely. Similarly flower buds are often bored by caterpillar species (Noctuidae, Tortricidae) and eaten partially or completely by various grasshoppers. Sometime adults and larvae of beetles (Scarabaeidae, Chrysomelidae) causing ragged tiny holes to appear in the flower petals. Similarly, thrips (*Thrips tabaci* L.), earwigs (*Forficula auricularia* L.) and capsids attack on flowers resulting perforation and scruffy appearance to petals. In indirect type of damage, insects cause very little or no harm to the crop directly but spreads bacterial, viral or fungal diseases to the crops. For example, aphid transmits the viral diseases of sugar beets and potatoes (de Jesus Jr. et al. 2001; Lopes and Berger 2001).

Crop production may be enhanced in different areas of the world by introducing high-potential varieties, better soil and water management practices, fertilization and better agronomic techniques, application of pesticides, use of various biological and non-chemical control methods. Despite all these efforts to prevent injury, global crop losses to insect pests remain matter of concern. Pre-harvest pests account for an average loss of 35% of potential crop production around the globe (Oerke 2006). Moreover another 35% of the produce was lost during pre-harvest handling; transport, packaging, storage, processing and marketing (IWMI 2007). Total estimated crop losses may vary by context and scope. Loss may be differentiated into various levels, e.g., primary, secondary, direct losses, exhibiting that pests not only menace for crop production and diminish the net income of farmers but can also disturb the food supply and the economic status of individuals and even countries (Zadoks and Schein 1979). In context of food security, crop losses to pests may signify the comparable of food needed to nourish over 1 billion people globally (Birch et al. 2011). Although the losses vary among crops, locations and years; the aim of protection measures to minimize the damage and for that the available quantitative data on the effect of different categories of pests on different crops is very limited. Crop losses to various pests globally were first estimated by Cramer in 1967 and later on detailed losses assessment was done by Oerke et al. (1994) for major crops of the world. Regardless of crop protection measures, assessment of crop losses needed to be explained to develop future strategies to keep pest populations below damaging levels. While the productivity effects of such high crop losses are significant and over the past three to four decades the losses in all major crops have increased in relative terms.

Because of the paradigm shift in the new crop production technologies especially the crop protection approaches, Oerke (2006) and Popp et al. (2013) has revised the crop losses data for major cash and food crops for the period of 2001-03. Even though the actual losses due to various pests have been reduced considerably during the last few decades, however, the potential losses rate much higher in different cash and food crops (Table 1). In 2001-03 the estimated losses for soybean, wheat and cotton were 26-29% and 31, 37 and 40 per cent for maize, rice and potatoes respectively. Comparison to actual loss the potential loss rate was higher and for 2001-03 about 50-68% in wheat, soybean and maize, while 75, 77 and 82% were recorded in potato, rice and cotton respectively (Table 1.1). Although the number of crops covered in this analysis were limited, but giving some order of magnitude of losses for the future scenario of crop management in agriculture ecosystem. Pests were responsible for almost 50% losses of the crops in tropical region as compared to just 25-30% losses in Europe and the United States (Yudelman et al. 1998). Reasons for this greater level of damage in tropics is that pests are year-round problem moreover, farming community is often poorer and do not have access high yielding varieties of plants, effective and safe pesticides and adequate irrigation.

Table 1.1 Global estimates of actual and potential crop losses due to pests of major crops

Crop	Actual loss rate (%)			Potential loss rate (%)		
	1988-90	1996-98	2001-03	1988-90	1996-98	2001-03
Cotton	38	29	29	84	82	82
Rice	51	39	37	82	77	77
Potato	41	39	40	73	71	75
Maize	38	33	31	59	66	68
Soybean	32	28	26	59	60	60
Wheat	34	29	28	52	50	50

Source: *Oerke et al. (1994), Oerke and Dehne (2004), Oerke (2006), Popp et al. (2013).*

1.3. Overview of pest management strategies

1.3.1. Pre-insecticide era

Pest dilemma is as old as the beginning of crop cultivation and actions to alleviate these problems started right from the pre-historic days. Some traditional approaches including cultural and mechanical practices (ploughing, crop rotation, flooding, field sanitation etc.) were among the oldest pest control methods developed by farmers with their own experiences (Smith et al. 1976). These were followed by use of sulfur with stored grain, about 2500 B.C. by Sumerians. Both Egyptians and Chinese were presumably the pioneers in the use of botanical pesticides for the protection of seeds, stored grains and other field crops. However, about 300 B.C., some advancements were occurred in pest control including the timely planting of crops to avoid losses and the use of natural enemies to control pests (e.g., in China ants were used to control leaf beetles on citrus). Some new developments were recorded in pest control strategies until about 1000 A.D. and later 1100 A.D. insecticidal soap were used in China. While in 1600's tobacco infusions, arsenic and some herbs were applied against insect pests and late during 1700's, some plant resistance to insects was progressed in Hessian fly, *Mayetiola destructor* (Say) in the USA. In 1705, mercuric chloride was used as a wood preservative and about hundred years later the inhibition of smut spores by copper sulfate was proposed by Prevost. Later, in 1850's very important natural insecticides rotenone and pyrethrum were developed from different plant parts and used for a longer period of time. To control gypsy moth (*Lymantria dispar dispar* L.) lead arsenate was used in 1892. During the late 1800s and early 1900s, there was rapid development in synthetic insecticides and pest control focus was slowly shifted from ecological and cultural to chemical control. In the beginning, the insecticides were expensive, hazardous to apply, phytotoxic and were not efficient compared to today which are well targeted and goal oriented.

1.3.2. Insecticidal era

The discovery of the insecticidal properties of DDT (dichlorodiphenyl trichloroethane) during the late 1930s by Swiss chemist Paul Muller marked the beginning of insecticidal era and had a great impact on insect pest control. In its early days, it was acclaimed a miracle due to its toxicity to wide range of insect pests, persistent nature, inexpensive, effective and easy to apply (Pedigo and Rice 2009). After worldwar II, there was diverse and rapid development in the insecticide industry to increase food production and for that several insecticides such as hexachlorocyclohexane (HCH), aldrin, dieldrin, parathion, schradan, toxaphene, chlordane, heptachlor (organochlorine group) and allethrin (synthetic pyrethroid) and other organophosphates and carbamates in the following periods. Many petroleum companies have been involved in the development of chemicals and during the 1950s other organophosphates and carbamates entered the insecticide industry. The first organophosphorus insecticide developed was Malathion having a relatively very lower toxicity to mammals. Phenoxyacetic acid herbicides were also discovered during the same time period. An important breakthrough in the field of plant chemotherapy occurred in late 1960s with the introduction of some new effective systemic fungicides in the market. Most of the 1950s chemical industries and farmers were not fully aware of the health hazardous problems associated with the use of pesticides. However, indiscriminate use of pesticides was the main reason of the problem and in 1962 these were pointed by Rachel Carson in her book "Silent Spring". The book recounted how the DDT residues in the food chain can be dangerous for the living organisms. In the meantime, along with these developments, the number of insect species showing resistance to insecticides including DDT, organophosphates, carbamates and pyrethroids had been increased rapidly with the passage of time. The ubiquitous use of pesticides in the ecosystem, their high residue levels in food products and the rising cost provided the necessary action for the limiting pesticide use and open the doors for the safest and more environment friendly idea of pest management (Pedigo and Rice 2009).

1.4. Insect pest control paradox

Pest outbreak is one of the most serious problems in agriculture and the analysis over the past few decades had showed that the proportion of crop losses to insect pests increased significantly. Historically pest management has been studied both pragmatically and theoretically and in most of the cases pesticides have been used to suppress the pest population. There is a very interesting scenario of rising pesticide use, rising crop losses to pests and most significantly the increase of crop production. Experiments in Pakistan concluded that the use of herbicides had prevented 23 percent crop losses (Qureshi 1981), while some crops would have been destroyed without use of chemical pesticides (Farah 1994). According to another analysis, global losses would have been raised from 42 to 72 percent in the absence of pesticides (Oerke et al. 1994). However, pesticides have been effective at certain times to suppress pest population but can be an outbreak for the insect pests other times (Matsuoka and Seno 2008) resulting in a population well beyond the crop's economic threshold. This situation has been to refer as paradoxical phenomenon of increased pesticide use and often considered as pest resurgence. Many investigations had been carried out regarding pest resurgence (DeBach et al. 1971; Gerson and Cohen 1989; Hardin et al. 1995; Cohen 2006) that could be due to the development of resistance in the pests against pesticides or by the decrease of its natural enemies affected by the pesticides (Morse 1998). The timing of the application of pesticides is the key (Li Charles and Young 2013), however a regular application is not a good control option to suppress the pest population (Hamilton 2008). The answer to the paradox of increased pesticide use and rising crop losses to pests lies in the integrated management which was originally coined to define the blending of biological control agents with synthetic insecticide control options (Bartlett 1956). Certainly, the use of pesticide is an important tool to suppress pest population and many pest management programs depends on pesticides use. Geier and Clark outlined the idea of pest management and called this concept protective population management in 1961, and it was later termed as pest management (Geier 1966). Pest management varies from previous approaches which were focused on control rather than to manage the pest populations and bringing the injury to a tolerable level. Since its commencement in 1972 the term integrated pest management was recognized by the scientific community after the report publication by the council on environmental quality (CEQ 1972).

1.5. Concepts and components of sustainable pest management

We consider simply the sustainable agriculture is the food production using farming techniques that balance with the environment and favorable both to humans and other species (Harwood 1990). For a sustainable pest management system, these farming techniques must be economically viable and contribute to a healthy environment for long term. The key approach for pest regulation that we predict is the consistency with these goals for sustainability as it is clearly obvious in integrated pest management programs. There are many definitions for Integrated Pest Management (IPM) suggested by different authors. Pest management is the selection and the use of pest control multiple tactics that will ensure the favorable ecological, economic and socioecological consequences. The basic hypothesis is that IPM is very important for sustainable management of animal pests, plant pests and weeds which cause threats to the quality and quantity of agricultural products. The principles of pest management clearly emphasize conservation that contains both cropping and nonagricultural environments (water, air, soil, wildlife etc.,) (Pedigo and Rice 2009). Moreover, the IPM success largely depends on farmer's knowledge about the awareness of pests' biological and ecological processes that are much critical to use different options to solve the problem (James et al. 2010).

Agro-ecosystems is considered a habitat of less diversity of animal and plant species compared to natural ecosystems e.g., forests and meadows. Agricultural ecosystems can be more susceptible to pest attacks and resurgence due to lack of diversity both in plant and insect pest species compared to natural ecosystem. However, much can be gained through the manipulation of different production techniques to minimize pest problems and for that a considerable knowledge requires about the pests and factors that affect their populations. For insect pest management, planning should anticipate pest problems to follow the ways to avoid them (Pedigo and Rice 2009).

Different authors have proposed pest management practices differently with slight variations. Geier (1966) suggested the following management practices: (1) how the pest life system can be modified to reduce its population below economic threshold level (2) applying biological knowledge and current technology to achieve the modification and (3) development of pest control procedures suited to current technology and compatible to economic and environment aspects. Similarly, Apple et al. (1979) listed the components of pest management as follows; (1) pest identification to be managed (2) specify management unit (3) development of pest management strategy (4) development of monitoring techniques (5) establishment of economic thresholds and (6) develop descriptive and predictive models. A pest management approach is the plan to mitigate or eliminate a pest problem and is always depends on the insect biology and the cropping system involved.

There are different types of strategies suggested by Pedigo and Rice (2009) that can be followed: (1) no intervention or involvement, (2) diminish pest numbers, (3) decrease crop vulnerability to pest damage, and (4) reduction in crop susceptibility along with pest number. The use of multiple strategies is a basic and key principle of designing insect pest management programs. However, the appropriate strategy primarily depends on the status of insect pest in the production system. Broadly speaking, the major subdivisions of insect pest management programs are preventive and therapeutic practices. Integrating these tactics in a comprehensive manner has been essential for sustainable pest management but with a few limitations associated to these practices. Although using a single tactic may be successful for a short duration but by integration of these practices might provide safe guards against ecological disruptions (pest resistance or destruction of natural enemies) that often develop because of widespread reliance on a single strategy (Pedigo and Rice 2009).

1.5.1. Preventive strategy

Preventive strategies are primarily used for insect pests that cannot be controlled effectively after injury and for that action should be taken before they become an economic problem. These practices often employed without the knowledge of pest presence or status of the pest population. Prevention can be accomplished by focusing either on the pest or the host. In most of the times available practices focus on the pests to reduce average population density or general equilibrium position of pest and afterwards level of crop damage to a below economic injury level. Most of the above mentioned agronomic practices are critical in pest management, since the intensity of the pest problem is often directly related to these practices. Majority of the techniques that accept and utilize ecological factors are compatible with other for integrating into an overall preventing pest management program. It is also very important to know that making decisions of insect pest management should be placed in context with other factors e.g., natural enemies of pests (predators, parasitoids and pathogens), weather etc. Therefore, the estimation of insect pest densities and/or the amount of crop injury should be accompanied by evaluation of the potential impact of natural enemies and impending weather conditions.

The other area of preventive pest management is the crop itself in which efforts can be made to reduce losses by making the host less vulnerable or tolerant to insect pest population. The sowing of plant tolerant varieties to pest injury is a tactic which has been often ignored by the breeders, since it is an important method to develop ability in plant to withstand despite injury. Plant tolerance in integrated pest management programs with the existing cultivars can be achieved by growing healthy plants through proper agronomic practices e.g., irrigation, fertilization. Additionally, plant and animal quarantine is a key component of preventive pest management and play an important role by preventing spread of pests from infested to uninfested areas.

1.5.2. Therapeutic strategy

In ecological based pest management strategies, therapeutics may have a noteworthy role and recognized as a key component of IPM programs to cure a chronic crop disorder and to prevent future losses. Instead of primary lines of defensive therapeutic controls should be regarded as backup components. Curative strategies usually focus on timely assessment of pest populations and reaction to them with the use of therapeutic materials, if the density of an insect pest population has reached or exceeded the economic threshold level. As therapeutics, synthetic natural products and living organisms can be regarded as an efficient tool, however, whether product is nontoxic or natural based does not inevitably mean it is less disruptive than synthetic products. The key is to work in an integrated way as much as possible and for that number of therapeutic products (e.g., biopesticides, semiochemicals and natural enemies) are prevailing and many more are being advanced with new technological measures (Lewis et al. 1997). However, all suitable non-chemical control options should be implemented before pesticides are recommended. There are number of tactics that can be applied in pest management therapy including selective pesticides, fast-acting nonpersistent biological controls (microbial insecticides), early harvests and mechanical removal of pests (Pedigo and Rice 2009). Of these available practices, pesticides are by far the most important in pest management treatment. For the development of pest management program, both preventive and therapeutic tactics should be integrated in a way that ensures the economically and ecologically sound outcomes.

1.6. Conclusion

Crop pests, pathogens and weeds are considered significant challenge to world food security, poverty alleviation and agricultural earnings. It has been well recognized that the modern-day agriculture cannot withstand the current crop production levels and standards with the exclusive use of pesticides. Increasing pest problems and ecological backlash can only be corrected using holistic pest management practices including preventive and therapeutic tactics. Recent expeditions are for effective, safe and long-term pest management strategies which have been targeted principally towards the advanced and improved products attributed as a substitute of existing conventional toxic synthetic pesticide. To increase the yield and to address the future production demands IPM, will be considered the most attractive pest management approach when pesticides repercussions are taking into account. Although, the results of integrated pest management sometimes variable and insidious. However, this approach can better exploit the modern science and the traditional agricultural systems based on indigenous farming practices for the sustainable crop production. The primary goal of integrated pest management is to increase the rate of new findings to address both chemical and non-chemical research areas and develop the farming practices that are compatible with ecological and conservation systems and scheming the cropping pattern that certainly limit the advancement of any organism to become a pest. Understanding the agro-ecosystem, integration of new management skills and the new concepts for pest management must be encountered so that we can protect our environment smartly and make sure the uninterrupted safe and nutritious food supply for the growing world population.

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