Chapter 10

Integrated Pest Management, Past, Present and Future in a Changing World

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Abstract

Integrated pest management (IPM) is a sustainable approach to control agricultural crops pests. To evaluate the functionality and efficiency of IPM, the mechanism of plant response to herbivory is the first and foremost principle to understand. The chapter focuses on the past, present and future perspectives of IPM globally. Various sustainable management of insect pests case studies, challenges and success stories have been discussed and elaborated to reach the consequences and outcomes of IPM. The comprehensive litreature studies have proved that integrated pest management is a best practical approach to get sustainability in controlling the insect pests of various crops of economic importance.

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10.1. Integrated pest management- an overview

Integrated pest management (IPM) ranks among the most far-reaching and most comprehensive of crop production tactics being adopted by producers today (Higley and Pedigo 1996). IPM tactics are aimed at producing the highest possible crop yield with a minimum of expense to the producer and the minimum amount of harm to the environment. A major goal of IPM has been to conserve natural enemies and their effects when attempting to suppress pests. Specifically, IPM seeks to maintain crop and control sustainability and environmental quality while improving profits through the proper diagnosis of pests, empirically derived economic thresholds, and specific pesticide applications (Higley and Pedigo 1996). By implementing IPM practices, producers will slow pesticide resistance and reduce environmental contamination, including the reduction of pollution to water systems. Crop producers will be gain value from money spent on pesticides and those concerned with the environment gain comfort from knowing the minimum amount of pesticide is being used and only when substantial losses are predicted.

The idea of IPM was first formally advocated by Stern et al. (1959), but in 1934 a paper by Pierce (1934) posed questions that seemed almost prophetic to the agricultural community in their simplicity. The questions were "Does all damage computed by every single insect is assessable? If not, then when does it become assessable? What is the guarantee of control effectiveness even if the damage is below this point?" Essentially, Pierce was asking if there is a difference between injury and damage. And if there was a difference, where does the injury stop and where does damage begin? He set the stage for the development of Economic Injury (EIs) and Economic Thresholds Levels (ETLs) by asking when control measures are justified.

Pierce (1934) posed the core questions of the issue, but Stern et al. (1959) expanded on Pierce's work by discussing insecticide resistance, replacement, resurgence, residues, and non-target effects of insecticides in their 1959 paper. In order to implement IPM practices Stern et al. (1959) found it necessary to develop the concept of economic injury levels (EILs). They defined an EIL as "the lowest population density that will cause economic damage." This definition is still used in the application of EILs and today refers to the point at which injury inflicted by a pest becomes economic damage.

To minimize confusion, the term "damage" must be defined because damage and injury differ based on their effects on yield of marketable materials. "Injury" is the effect of pest activities on host physiology that is usually detrimental, while damage is an assessable loss of materials or decrease in their characteristics. Thus, damage is often defined as loss to amount of yield, yield quality, or aesthetics (Pedigo et al. 1986).

EILs can be powerful tools for crop producers when making management decisions, but the definition provided by Stern et al. (1959) was not sufficient for producers to adopt this method. Pedigo et al. (1986) refined the definition of EILs to be "the point at which the cost of control (pesticide and application) equals the cost of no control (yield loss)." Pedigo et al. constructed an equation explicitly defining an EIL as:

$$EIL = C/VDIK$$

Where C = management costs per production unit, V = value per unit production, D = damage (yield loss) per unit injury, I = injury per pest, and K = proportion of injury prevented by management.

This definition is a step forward in the evolution of applying EILs to crop production, but it does not take into account the inherent lag time between noticing a pest population pressure that will cause economic loss and taking measures to prevent loss. Because often control measures and the machinery to apply them are not readily available, it may take a week or more for control tactics to be initiated after it has been determined that the EIL has been reached. Thus, for IPM to be successful, pest populations must be managed prior to reaching the EIL.

Stern et al. (1959) addressed this problem by devising the concept of economic threshold (ET). Stern et al. (1959) define ET as the population density at which control measures should be initiated to prevent an increasing pest population from reaching or exceeding the EIL. The use of ETs and EILs are requirements of successful IPM practices, because IPM is often reactionary (based on thresholds) rather than preventative in nature (Pedigo et al. 1986). However, ETs and EILs are useless without comprehensive scouting practices and reliable information defining where the ET and EIL reside for different crops at different growth stages in different growing conditions with different insect pests (Wright et al. 1987; Hutchins et al. 1988; Higley and Pedigo 1996; Culy 2001). Moreover, as the world has become more connected, new invasive pests have emerged, pest species have evolved different life histories, control tactics have caused resistance, global changes in weather patterns and the price for commodities (the "V" which determines thresholds) has become volatile. Given the great need for IPM and the many faceted challenges, an exhaustive review is not possible. However, we hope to provide examples of the challenges so that researchers and practitioners can be vigilant in developing and refining IPM to meet the world's needs for sustainable agricultural production.

10.2. Feeding guilds

Because of the variety of crops produced worldwide under different growing conditions and with different potential pests, developing species-specific and region-specific EILs for every species is impossible at least in the short-term. A possible alternative to defining ETs and EILs for each species of insect is to group all species of insects that inflict similar damage and cause similar physiological plant responses into "feeding guilds". In this way, ETs and EILs need only be devised for each guild, not for each insect species (Higley and Pedigo 1996).

Most information available to producers defines thresholds based on average numbers of insects per plant. However, making use of feeding guilds in threshold development and utilization necessitates a different method of quantifying injury because the insect per plant density for one species may not cause the same amount of injury as that same density for another species of insect. For example, 10 flea beetles (Chrysomelidae) per leaf will cause little injury in the absence of plant disease, whereas 10 grasshoppers (Acrididae) will completely defoliate the leaf in a short period. An alternative method that shows promise is the use of injury equivalents (Wright et al. 1987; Hutchins et al. 1988; Higley and Pedigo 1996; Culy 2001). For chewing insects, instead of using number of insects per plant for threshold decision levels, percent defoliation can be used as the unit of injury, making it possible to evaluate the injury of several insect species at the same time.

ETLs and EILs are both based on injury and damage inflicted on the host plant, but not all forms of injury or damage are the same. Boote (1981) classified pest injury into eight classes, six of which can be applied to insect pests: stand reducers, leaf mass consumers, assimilate removers, turgor reducers, fruit feeders, and architecture modifiers. Thus, four of the classes can be used to describe injury and damage by insects on a broad range of crops where the plant leaves are not the product that will be sold (e.g. corn, potato, yam, cassava, rice, wheat). The feeding types applicable to these crops are stand reducers, leaf-mass consumers (defoliators), assimilate sappers, and turgor reducers.

The stand reducers produce an immediate loss in biomass and decreased photosynthesis in the crop (Pedigo et al. 1986). Stand reducers cut a plant's stem and may kill the entire plant. The effects to total yield reduction are influenced by quality and quantity of plants lost throughout the field.

Foliage consumers can also be called defoliators because they consume the leaves of a plant while leaving the stems. It is generally believed that leaf-mass consumption directly affects the absolute photosynthesis of the canopy, however, often has little or no effect on photosynthetic rates of the unit area of the injured leaf tissue (Pedigo et al. 1986). The effect of this type of injury on host plant physiology can be measured by the leaf-mass consumed per unit land area, vertical distribution of the defoliation and timing of leaf consumption (Pedigo et al. 1986).

The assimilate sappers are piercing-sucking insects such as aphids (Aphididae), leafhoppers (Cicadellidae), and rasping insects such as thrips (Thysanoptera). These insects remove plant nutrients after the carbon is taken up by the plant, but before the plant can convert the carbon to tissue (Pedigo et al. 1986).

Turgor reducers can cause injury by girdling the plant stem or boring into the stem. Both of these feeding practices act to influence plant water and nutrient balance. In potato, this group includes insects like *Ostrinia nubilalis* (Hubner) (the European corn borer) (Ziems 2002).

The construction of feeding guilds, ETs, and EILs based on injury equivalents work best for defoliator feeding guilds. Most insect defoliators produce very similar physiological responses in host plants (Poston et al. 1976; Welter, 1989; Higley, 1992; Peterson et al. 1992; Peterson et al. 1996). Although exceptions exist, for example the Mexican bean beetle (*Epilachna varivestis* Mulsant) alters the photosynthetic rates of remaining injured leaf tissue (Peterson et al. 1996). The physiological response of plant hosts to the injury inflicted by piercing/sucking insects is much less clear (Pedigo et al. 1986). It is also important to recognize that an insect's ability to vector viruses or other diseases may make placing a particular insect pest into a feeding guild unrealistic, even if that pest's feeding causes plant responses similar to those caused by other pests (Pedigo et al. 1986).

10.3. Plant response to herbivory

In plants, including those used by humans, growth and development of the crop (biomass production) relates directly to the amount of solar radiation absorbed. The proportion of this biomass that is allocated to the reproductive structures or stored in tubers directly determines marketable yield (Higley 1992). As a consequence, the amount of absorbed radiation determines the productivity of a crop.

Leaves are the primary structures that intercept solar radiation and when leaf tissue is removed, the reduction in light interception is the principle reason of yield losses (Higley 1992). These observations regarding light interception and yield have led to the development of a hypothesis that expects a nearly linear relationship between reduction in light interception and yield loss following defoliation for a variety of crops (Johnson 1987; Waggoner and Berger 1987; Higley 1992).

Many papers in the litreature support the defoliation-light interception hypothesis in soybean and other crops (Higley 1992; Hunt et al. 1994; Haile et al. 1998a, b; Hammond et al. 2000; Peterson and Higley 2001). The leaf area index (LAI) is a ratio of the amount of leaves per unit area of land and ranges from 0 (no leaves present (e.g. start of the growing season) to complete coverage by a full canopy where there are proportionately many more leaves than the land area that they cover (LAI > 5.0). Measuring the LAI of a crop can be a useful tool when used in conjunction with the defoliation-light interception hypothesis. Most crop varieties achieve a LAI between 5 and 6, but maximum light interception (>90%) occurs at an LAI, 4. Expanding on this, maximum light interception should occur until a healthy canopy is defoliated to 20-30% of the maximum LAI. Assuming a tolerant response curve in a crop, this leads to the hypothesis that the critical point (EIL) in the tolerant response curve lies between 20 and 30% canopy defoliation.

Because defoliation damage is common and relatively easy to quantify, it is the most likely candidate for IPM implementation. In addition, the compounding effects of virus transmission are not of concern, although secondary infections of damaged leaves may occur. Once the feeding guilds have been established, the host reaction to defoliation in relation to yield must be examined. Poston (1983) suggests that host plants will show one of three general patterns: a susceptive response, a tolerant response, or an over compensatory response to defoliation events. If the plant exhibits a susceptive response to defoliation, the damage-injury relationship is linear; thus, for every increment of injury inflicted on the host there is a corresponding incremental yield loss. This response is reported often in the litreature, but in most cases the response to injury is only a susceptive response over the range of injury being studied (Poston 1983). Tolerant responses to defoliation are characterized as having a sigmoidal relationship between yield and injury. Tolerant plants will tolerate or compensate up to specific amount of injury without any corresponding production loss until an optimum stage is reached. After this point, the relationship is linear (like the susceptive response) until a lower plateau is reached. The lower plateau begins at the point after which additional injury to the host does not correspond to a yield reduction (Poston 1983). This type of response is probably the most often observed response to defoliation in nature because most plants possess 'extra' leaf area that is not required for maximum light interception and photosynthetic saturation or maximum yield (Hutchins et al. 1987; Higley and Pedigo 1996; Peterson and Higley 2001).

The over compensatory response shows a relationship much like the tolerant response except at low levels of injury; the host is stimulated to regrow leaf materials, or to increase photosynthetic efficiency of remaining tissues resulting in increased yield. At higher levels of injury this response takes on the appearance and attributes of the tolerant response (Poston 1983).

A complicating factor in developing injury guilds for a crop species is the effect of injury timing on plant yield. Typically, early season defoliation results in greater yield loss than later season when a plant has a full canopy. Yield response is also affected by the plant reproductive status as many crops have been found to be more sensitive to injury during the flowering stage. As an example of the effects of timing on guild EIL development, we examine the development of EIL in potato crops.

10.3.1. Defoliator EILs in potato

Throughout the development of EIL for potato defoliators, studies focused on a particular insect in a specific region with little regard for the stage at which injury occurred (Sparks and Woodbury 1967; Hare 1980; Cranshaw and Radcliffe 1980; Wellik et al. 1981; Ferro et al. 1983; Shields and Wyman 1984; Zehnder and Evanylo 1989; Dripps and Smilowitz 1989; Senanyake and Holliday 1990; Senanayake et al. 1993). In 1967, Sparks and Woodbury authored one of the first extension publications to characterize the growth stages of potato. They also made the observation that similar amounts of defoliation at different growth stages caused differing effects on yield with yield being most strongly affected at or around the full bloom stage. Other publications built on this observation when defining EILs for potato.

Yield data exist which show that severe defoliation early or late in the potato life-cycle by Colorado potato beetles had a minimal effect on yield in Manitoba, but defoliation at other stages in the potato life cycle caused a reduction in yield that exceeded 35% (Hare 1980). This publication does little more than validate the work completed by Sparks and Woodbury (1967) 23 years earlier. In fact, almost every study published since Sparks and Woodbury (1967) shows this general trend even though the actual levels of defoliation used to define EILs in each study are different (Cranshaw and Radcliffe 1980; Wellik et al. 1981; Ferro et al. 1983; Shields and Wyman 1984; Zehnder and Evanylo 1989; Dripps and Smilowitz 1989; Zehnder et al. 1995). This information causes problems for producers who are interested in implementing IPM but who are adverse to risk.

Some studies suggest that when defoliated early in the season, plants can compensate for lost leaf area between 10 and 33% (Cranshaw and Radcliffe 1980). Mechanically induced defoliation designed to simulate temporary damage produce similar results (Cranshaw and Radcliffe 1980; Shields and Wyman 1984). Conversely, it was found that season-long defoliation for Manitoba potato fields with low density Colorado potato beetle resulted in significant yield loss and a subsequent lower EIL at first bloom (Senanayake and Holliday 1990) resulting in EILs that are much lower than decision levels for other regions.

All varieties of crops partition nutrients to stems, leaves, roots, and reproductive structures. Early in the growing season, the vast majority of nutrients are partitioned to the stems and leaves of the plant for canopy growth. Later in the growing season, nutrient partitioning is shifted so that reproductive structures (fruits) or storage (tubers) is the primary deposition of nutrients by the plant. Plant varieties may also have an influence and broadly, varieties can be classified as indeterminate or determinate. Indeterminate varieties begin partitioning nutrients to the reproductive or storage structures later and in smaller proportions of total photosynthetic nutrients than determinate varieties. As a result, indeterminate varieties consistently have a larger and more robust canopy while determinate varieties consistently have fruits or tubers with higher dry-matter concentrations than indeterminate varieties.

10.3.2. Conflict in EILs

A growing body of litreature on EILs, pests, and crops grown in different regions, has created more controversy than clarity for growers who wish to adopt IPM. The litreature contains numerous papers that present conflicting conclusions. For example, there are several papers available that discuss the photosynthetic response of the plant canopy to defoliation. Most of the early litreature suggests that insect defoliation causes a reduction in photosynthetic rates of the remaining leaf area (Aldefer and Eagles 1976; Hall and Ferree 1976; Detling et al. 1979; Ingram et al. 1981; Li and Proctor 1984). Most of the more recent litreature suggests that in a number of crops there is no effect of insect defoliation on photosynthetic rates of remaining leaf tissue (Peterson et al. 1992; Peterson and Higley 1996; Peterson et al. 1996; Burkness et al. 1999). There is also at least one paper that suggests that the removal of either partial or entire leaves via insect defoliation increases photosynthetic rates of the plant's left-over leaf tissue because of overcompensation of the remaining leaf tissue (Welter 1989). The conflicting evidences these papers present are most likely a result of utilizing different methodologies; however, considerations of crop variety, growing conditions, region-specific pest attributes must be made.

Solving these problems requires focused research using similar methodology of the experiments that mimics the life history and feeding characteristics of potential pests. With the exception of swarming insects such as locusts, a high level of insect defoliation in the field does not happen in a single day. Thus, in order to accurately define an EIL for insect injury, researchers must mimic the feeding of the defoliator. Most insects defoliate less at the beginning of an infestation and feed progressively more as the development of the insect proceeds from small instars to larger, more destructive instars through molting (Peterson and Higley 2001). Burkness et al. (1998) determined that one-time defoliation of cucumber seedlings had less of an effect on cucumber yield than continuous simulated defoliation (Buntin 2001). Ostlie (1984) found that simulated defoliation conducted in a single day caused less of a yield response in soybean when compared to the same amount of defoliation induced over 12 days. In light of this, some published studies that utilized one-day defoliation methods are inadequate to define EILs and are best suited to model yield loss as a result of weather such as hail (Cranshaw and Radcliffe 1980; Shields and Wyman 1984; Burke et al. 1998).

Methods that characterize the feeding behavior of various insects and use experimentally determined leaf consumption models to dictate daily defoliation amounts are more realistic (Ostlie 1984; Higley and Pedigo 1996). Although, Buntin (2001) found that equal daily defoliation amounts that additively reach the desired end defoliation amount are adequate and are an improvement over one-day defoliation events.

10.4. Challenges to IPM in a changing world

Adoption of IPM will continue to be challenging because of altered growing conditions as a result of human-induced climate change. These changes are a result of increases in carbon dioxide that cause increases in annual temperatures and alteration of rainfall patterns. In addition, increased CO_2 alters plant characteristics while changes in temperatures can result in additional generations of pest species and may alter the interactions of pest species and natural enemies. Global climate change along with globalization also increases the likelihood of introduction and establishment of new exotic pests. Finally, the global market coupled with unpredictable weather patterns will cause rapid changes in the value of crops which is the main determinant of treatment thresholds. Indeed, as a result of projected climate changes, agricultural productivity is expected to decrease by as much as 20% in Africa, Asia, and Latin America with under developed countries facing the most deteriorating effects (IPCC 2007), placing even greater pressures on IPM adoption.

Global changes will affect IPM programs and are likely to alter established thresholds and current practices. Because insects often develop more rapidly at higher temperatures with populations increase at higher rates that causes crop damage more rapidly than current IPM models predict. Insects may have multiple generations per growing season and changes in temperature are likely to favor these insects by increasing their numbers and population growth rates (Bale et al.2002). Thus, treatment decisions based on the number of insects per plant will likely need adjustment to avoid unacceptable losses in yield. IPM programs that incorporate degree days (the accumulated physiological age of insects that grow more rapidly in response to temperatures above developmental minimums) may be less-affected. However, increasing may eliminate frosts in some areas, allowing resident pest species to breed continuously. In addition, elimination of frost may allow subtropical species to establish changing the ecology of natural and managed ecosystems. In addition, changing temperatures can also affect biological control agents.

Consistent and continuous increases in temperature have been observed to reduce the effectiveness of both insect pathogens (Stacy and Fellows 2002) and parasitoids (Hance et al. 2007). Differential effects of temperature on parasitoid and host populations can also result in temporal and spatial separation, reducing effectiveness of these biological control organisms (Ris et al. 2004).

10.4.1. Response of pests to IPM

The Western corn rootworm, *Diabrotica virgifera vigifera* LeConte, offers a case study in the challenges to IPM. This insect has an exceptional ability to adapt and change towards a variety of management strategies (Gray et al. 2009). Historically the western corn rootworm is believed to have originated in Central America where they have been pests of maize (*Zea mays* L.) for about 5000 years (Melhus et al. 1954). The larvae of this pest cause economic losses plus money spent on control at estimated costs of $1 billion annually in the United States (Mitchell et al. 2004) and now it is a pest in Europe and the global estimate exceeds $1 billion (Kaster and Grey 2005, Kiss et al. 2005). Larvae of this pest feed on the roots of a number of grasses and maize (Branson and Ortman 1967, 1970; Clark and Hibbard 2004, Oyediran et al. 2004). It has been reported that the first adaptive change of this pest may have occurred when the Spanish introduced monoculture to Central America. Large areas of monoculture were a big change from the scattered small fields of the small producers that was planted amongst grasses and cucurbits (Branson and Krysan 1981). The western corn rootworm was reported a pest in the western portion of the United States as early as 1867 and then another change occurred with expansion eastward across the Corn Belt (Chaing 1973; LeConte 1868-1869). Maize was grown in monoculture in areas that presumably were supporting low populations of western corn rootworm on grasses, but in the absence in maize (Branson and Ortman 1967; Branson and Ortman 1970; Clark and Hibbard 2004). Reports of this insect pest of maize were on Sweetcorn in Colorado (Gillette 1912). With an increased production of maize, the western corn rootworm continued its expansion eastward and in 1929 it was reported in Nebraska (Tate and Bare 1946) and then Chaing (1973) reported it had expanded and become a pest across most maize production areas of Midwestern United States.

With increased maize production areas, increased monoculture and the introduction of insecticides, the western corn rootworm exhibited another change. Ineffective control of rootworm by insecticides were reported to be observed in 1959 and documented by Ball and Weekman (1963). Areas infested with western corn rootworm were treated with organochlorine insecticides continued to grow until a near crisis occurred. By 1980 nearly the entire Corn Belt had insecticide resistant populations of rootworms (Metcalf 1986). The use of cultural control, by farming practices such as crop rotation has been used as an effective IPM strategy. Soybeans or other non-host crops are a recommended strategy for use for control of the western corn rootworm (Chaing 1973).

The next adaptation or change in western corn rootworm population was selection for survival on the soybean-maize rotation that was reported in 1987 and documented by Levine et al. (1996) and Levine et al. (2002). The extend of rotation-resistant populations of western corn rootworm and the loss of ovipositional fidelity to maize has negated the advantages of crop rotation (Grey et al. 2009). The agricultural landscape of maize-soybean rotation is credited with selecting a variant of the western corn rootworm capable of surviving on both crops. Grey et al. (2009) have reported that the western corn rootworm has continuously adapted the pest management strategies and they give the examples of resistance to conventional insecticides and crop rotation. Transgenic maize crops were produced with insecticidal toxins from the bacterium *Bacillus thuringiensis* (Bt) and because the western corn rootworm has shown the ability to circumvent several management strategies; concern was expressed for the development of engineered maize with resistance to western corn rootworm (Tabashnik et al. 2004; Tabashnik et al. 2008). In 2003, Bt maize was commercially released against the target of the western corn rootworm. The strategy used in the United States to delay resistance to transgenic crops is the refuge strategy. However, Gassman et al. (2011) stated the first example of evolved resistance in the western corn root worm against *Bt* toxin. Clearly, the western corn rootworm has developed tremendous capacity to adapt to maize production practices, starting with the shift from native grasses to maize in monoculture, then the pest status as maize production increased across the United States, this was followed by adaptation and development of resistant populations to multiple insecticides followed by an invasiveness to the soybean-maize crop rotation practices. The last and most recent adaptation of resistance to Bt maize (Cullen et al. 2013).

10.4.2. Unintended consequences of genetically modified organisms

The role of IPM and the integration of insect-resistant genetically modified (GM) or (GMO) crops into management strategies and the potential effects on non-target organisms has been discussed by O'Callaghan et al.(2005). Extensive research has been conducted to address the impacts of introduction of GMO plants as a strategy for addressing major insect pests of crop plants (Kennedy 2008). Also, the present and future role of GMO maize in IPM systems has been reported by Hellmich et al. 2008. There have been both intended consequences and unintended consequences in both conventional breeding of crops and genetically modified crops (Cellini et al. 2004). Much concern has focused on environmental and human safety with focused attention to integrated pest management(IPM) developed as a strategy to deal with insecticide failure and now a second strategy which utilizes GMO crops with some of same concerns for environment and human safety (Romeis et al. 2008). It should be noted that both the use of insecticides and GMO's violate a basic concept in IPM and that is one of monitoring and integration of strategies only use after a pest has reached an EIL.

10.4.3. GMO and IPM

Because GMO are used regardless of pest pressure, they strongly select for resistance even when pest densities are below EILs. When one uses GMO plants as a strategy for management of insect plants, then one weighs the possibilities that pest protection may be being purchased even in the absence of the pest. Currently, insect protection is being purchased without regard to economics, environmental safety and Insect Resistance Management (IRM) (Hellmich et al. 2008). A strong environmental concern is the possible adverse effects of GMO's on non-target plant feeding species, natural enemies, and beneficial insects such as pollinators (O'Callaghan et al. 2005)

10.4.4. IPM challenges in Pakistan

Despite the fact that Integrated Pest Management (IPM) has been applied in several crops in Pakistan, the transfer of this approach remained a bottleneck. Due to diversity in Pakistan, monoculture and strip cropping systems are common. The pest population problems and outbreaks are more in monocultures than in mixed cropping systems. This has led to overwhelming use of chemical pesticides.

Cotton crop in Pakistan is vulnerable to many kinds of insect pests and mites which cause 20-40% losses in this crop. Approximately, 46000 tons of pesticides were used during the year 2000, of which 60% of the pesticide was use in cotton. This high use of chemicals has resulted in resistance to many pests to these chemicals, health issues and residues in food chain (Mallah and Korejo 2007). Depending heavily on chemicals for pest management has also resulted in several socio-economic problems. Creating monocultures and depending only on chemicals for controlling pests along with zero tillage practices have facilitated the use of modern farming system to produce more. However, using natural enemies as control methods for pest population is not the primary control methods used by the farmers in Pakistan.

Relying only on one control strategy of pest management is not sufficient to overcome the losses. Rather, a broad ecological attack is needed in which several controlling methods work together to control and manage pest populations. Integrated Pest Management (IPM) is a decision based system keeping in view the cost/benefit, its impact on society, producers and on environment (Marcos 1998). IPM technique works collectively using cultural, biological, chemical methods as well as resistant and tolerant varieties (Sarwar 2004). Furthermore, it also reduces the hazards related to pests and pest management techniques (Thomas 2009). Integrated pest management is not only helpful in increasing productivity and sustainability but also reduces the non-judicious use of pesticides in developing countries (Systemwide 2010). Using IPM technique, a 70% decrease in the pesticide use while 42% increase in yield has been reported (Pretty 2006). To safe guard the non-target organisms and environment, it is critical to have knowledge about the correlation between crops, pests and environment.

Lack of knowledge about IPM, information, operative difficulties, higher costs and risks, intensive labor and time, quantity and quality of yield also contribute to limited adoption of IPM technology (Alston and Reding 1998).

Pakistan lacks the true enforcement of regulations for a sustainable crop production. The regulatory body, Pakistan Environmental Protection Agency (Pak-EPA) has the responsibility to promote research and development of science and technology, identifies the needs and provides information and guidance to public for the sustainable development. The regulatory bodies also ensure safety for consumers and environment by agricultural commodities, use of agrochemicals and by genetically engineered crops. These all measurements are meant to improve the quality and quantity of food produced. The commercialization of any chemical involves high cost thus enabling agrochemical industry to invest more and utilization of the available resources wisely (CropLife, 2003). However, in Pakistan, due to small agrochemicals industry, there is a lack of company owned stewardship of the products. Majority of the used agrochemicals are based on old chemistry which are more damaging to humane health and environment. With the development of export market and increase in profit margins, it is important to address and enforce regulations for pesticide use and policies that will favor IPM.

Financial constraint is the major one among many other limiting factors in achieving any developmental objectives. Pakistan like any other developing country also lacks the funding for Integrated Pest Management (IPM) development and deployment. The agriculture research and extension work thus is affected directly due to low funding. Furthermore, to keep the IPM community updated with the recent findings and improvements within and outside the country, it is important to have strong communication structure. Print and electronic media play a key role to disseminate the desired information to stockholders. Developed countries are well equipped with facilities of telecommunication and media to share the knowledge and information. However, developing countries like Pakistan has not only the poor availability but also poor reliability of the limited communication sources. The big cites more often have such of the facilities but remote areas don't have. The researchers and extensionists are working in areas like Pakistan, where 70% of its population is engaged in agriculture, they lack the fundamental facilities. Internet facilities will prove to be very useful for IPM accessing various databases or through Global IPM facility. Thus, Government needs to address and provide this weakly telecommunication aspect of IPM. The socio-economic position of the farmers is another important aspect that needs attention. Off-farm working in farmers to improve their livelihood results in poor agricultural practices and labor shortage as well.

Public sector agricultural research and extension is not up to mark in Pakistan due to lack of facilities, and operational funds. This scenario causes the capable scientists to work in private sector or to move abroad for better opportunities. Several international agencies invest their funding through projects but due to limited time period for these projects create hindrance in characterizing, identifying and testing the IPM. Gender imbalance is also of importance especially when women are actively involved in crop management (Bruin and Meerman 2001).

Developing countries own 60% of its population engaged in off-farm employment in agriculture (Bongaarts, 2002). Particularly when male young adults in a family prefer working in urban areas that results in the old and female agriculture work force behind (Pingali 2001).

Conservation and elevation along with effectiveness of the natural enemies requires a long-term planning. The local prevalence and diversity in predators could be increased with increased habitat diversity that will be useful for biological control of pests. The protection and maintenance of natural enemy has been found critical and difficult especially in their native ecosystems. Modification in pesticide use in a way that requires application only when needed can also be helpful in conservation. Similarly, changing active ingredients, application rates and formulations may also help in conserving the natural enemies. Judicious use of pesticide can increase the use of biological control in any IPM system. In case where key pests are not manageable through biological, cultural or host plant resistance then relying on chemicals are essential to achieve goals of IPM (Sarwar 2012).

An estimated 26-40% loss in yield of food and cash crops has been reported around the globe (Oerke 2006). A 30 % in pre-harvest losses due to insects, weeds and pathogens while 10-20% post-harvest losses have been reported due to insects and rodents (Oerke 2006). The current world food problems and increase in the population do not allow such losses.

Major goal of IPM is to keep pest populations below threshold using beneficial control agents and lesser use of chemicals. Use of chemicals if necessary must be in a way that will cause least amount of harm to beneficial arthropods.

Growth stage is another important factor in IPM. For instance, injury during reproductive stage is more detrimental than at vegetative stage of plant. Thus, recognition of developmental stages is very important for growers and IPM practitioners. This is also important because growth stage of plants determines the response of insects and that economic threshold are also dependent on growth stages.

Majority of the farmers in Pakistan are unable to identify the insect pests correctly. The correct identification of insects is very crucial before implementing any sort of control measures. Field crop pests are generally classified based on type of injury they cause. Certain types of the insects consume leaf tissues, hence termed as defoliators. Examples include beetle, caterpillar and grasshopper. Insect pests like corn ear worm, *Helicoverpa zea* (Boddie) constitute the pod feeders group while stem feeder insects feed on stem (hopper). The injury caused by these groups reduce yield significantly. Besides these pests, there are numerous other pests which are not major pests like mites, maggots and grasshoppers but need attention from researchers and IPM practitioners.

Measuring the injury level requires proper sampling that depends on type of insect and growth stage of plant. For the accurate count of insects, most of the IPM program use ground or shake cloth or sweep net methods at the time when plant attains sufficient size. The measurement of injury is done more often by estimating the defoliation levels, percent injury of the pod or percentage in the reduction of stand. Plant injury and insect sampling is helpful identifying the potential pests.

Integration of various disciplines is an important philosophy under IPM umbrella (diseases, weeds, and nematodes). Another barrier to the full integration of or implementing the IPM is the lack of an understanding of the type of injury and plant reaction towards that injury. Determining that injury from an insect pest, disease and weed might possibly affect the physiology of the plant that further go far in development the truly integrated approaches to pest management. Now, the researchers have been begun to understand the various types of injuries, their causal organisms and their interaction to find out the impact of injury from all pests on the plants' physiology, so that the unified approaches to the pest management can be established. System of IPM has demonstrated high impact on crop productivity and great adaptability in their application.

The FAO-EU Regional Project in Pakistan proved very useful for extension field workers of Agricultural Extension Department and farmers through IPM-FFS program to grow ecofriendly cotton crop. The FAO-EU funded cotton IPM program suits into the ground realties of the Pakistan and genuine interest to introduce agro ecological sound IPM practices. This program resulted in strengthening farming community and environmentally safe agriculture. Farmer field schools (FFS) also strengthened the knowledge of farmers. This knowledge has resulted in the less use of pesticides and with more production and profitability (Godtland et al. 2004). The FFS is a training model developed primarily by FAO in which farmers gain the decision-making power regarding use of agrochemicals at their field. This unique extension approach is action-learning oriented where farmers are allowed to observe, analyze and make alternative decision about their crops (FAO 2004). Conventional farmers usually do not follow the right criterion and do not consider alternatives to chemical use. These practices and conventional agriculture where pesticides are the major component used has resulted in health hazards, environment degradation, food quality issues and damage to soil structure (Country report 2002). In this scenario, Government should take steps and collaborate with international agencies to promote IPM (Dasgupta et al. 2007).

10.5. Global challenges to IPM

Adoption of IPM will continue to be challenging because of altered growing conditions as a result of human-induced climate change. These changes are a result of increases in carbon dioxide that cause increases in annual temperatures and alteration of rainfall patterns. In addition, increased CO_2 alters plant characteristics while changes in temperatures can result in additional generations of pest species and may alter the interactions of pest species and natural enemies. Global climate change along with globalization also increases the likelihood of introduction and establishment of new exotic pests. Finally, the global market coupled with unpredictable weather patterns will cause rapid changes in the value of crops which is the main determinant of treatment thresholds. Indeed, as a result of projected climate changes, agricultural productivity is expected to decrease by as much as 20% in Africa, Asia, and Latin America with less developed countries facing the most-negative effects (IPCC 2007), placing even greater pressures on IPM adoption.

Global changes will affect IPM programs and are likely to alter established thresholds and current practices. Because insects often develop more rapidly at higher temperatures, populations will increase more rapidly and crop damage may occur more rapidly than current IPM models predict. Insects may have multiple generations per growing season and changes in temperature are likely to favor these insects by increasing their numbers and population growth rates (Bale et al. 2002). Thus, treatment decisions based on the number of insects per plant will likely need adjustment to avoid unacceptable losses in yield. IPM programs that incorporate degree days (the accumulated physiological age of insects that grow more rapidly in response to temperatures above developmental minimums) may be less-affected. However, increasing may eliminate frosts in some areas, allowing resident pest species to breed continuously. In addition, elimination of frost may allow subtropical species to establish changing the ecology of natural and managed ecosystems. In addition, changing temperatures can also affect biological control agents.

Continuous and constant increases in temperature have been observed to reduce the effectiveness of both insect pathogens (Stacy and Fellows 2002) and parasitoids (Hance et al. 2007). Differential effects of temperature on parasitoid and host populations can also result in temporal and spatial separation, reducing effectiveness of these biological control organisms (Ris et al. 2004).

10.6. Recommendations and management

The conclusions drawn from several studies of IPM can be used to suggest recommendations for the adoption of IPM technology at farm level. Some recommendations have been suggested below to boost the adoption of IPM technology.

1) The adoption of IPM technique can be accelerated promoting the cultivars which are insect resistance (Hussain et al. 2011). The host plant resistance is another non chemical and environmental friendly way to avoid pest populations (Sarwar 2011). This would also apply on the harvested grain where insect pests also cause significant damage (Ali et al. 2011).
2) Cultural practices and tactics could have used to support IPM. Controlling the planting dates could result managing the overwintering pests like beetles and caterpillars.
3) Tillage modifications can have left crop residues about 30 % in the field that can further help to change the habitat for pest population dynamics.
4) Other strategies will make more use of cultural practices like cover crops, trap crops, resistant cultivars, and other cultural practices, which the grower might employ specifically for pest management.
5) Use of predators, parasites and pathogens is an effective way to reduce pest populations (Sarwar 2012).
6) Education plays an effective role in the adoption of IPM technology. Hence, it is recommended that government may take actions to upgrade the education as well as training programs for crop producers.
7) Elder farmers do not adopt the innovative technologies like IPM. Hence, it is suggested that government may mediate to create awareness about IPM technology among elder farmers. Incentives should be given to young farmers in crop production.

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