4

Concept of Integrated Pest Management

4.1 INTRODUCTION

Though it is not generally recognized, evolution of the concept of pest management spans a period of more than a century (Table 4.1). Many components of integrated pest management (IPM) were developed in the late 19th and early 20th century. The rapidly developing technologies and changing societal values had their impact on the pest control tactics also. The modern concept of pest management is based on ecological principles and involves the integration and synthesis of different components/control tactics into a pest management system (Dhaliwal and Arora, 1994a). IPM, in turn, is a component of the agroecosystem management technology for sustainable crop production (Dhaliwal *et al.,* 1999).

4.2 INSECT PEST MANAGEMENT : FROM TRADITIONAL TO SUSTAINABLE APPROACH

During ancient times, humans had to live with and tolerate the ravages of insects and other pests, but gradually learned to improve their condition through trial and error experiences. Over the centuries, farmers developed a number of mechanical, cultural, physical and biological control measures to minimize the damage caused by phytophagous insects. Synthetic organic insecticides developed during the mid-twentieth century initially provided spectacular control of these insects and resulted in the abandonment of traditional pest control practices. This was followed by the development of high yielding varieties of important crop plants. The intensive cultivation of these varieties, together with the application of increasing amounts of fertilizers and pesticides, has resulted in a manyfold increase in productivity. However, this technology package has also resulted in aggravation of pest problems in agricultural crops as discussed in the previous chapter. The increasing problems encountered with insecticide use resulted in the origin of the integrated pest management (IPM) concept. The history of agricultural pest control, thus, has three distinct phases, viz. the era of traditional approaches, the era of pesticides and the era of IPM (Dhaliwal *et al.,* 1998).

4.2.1 Era of Traditional Approaches (Ancient-1938)

Cultural and mechanical practices like crop rotation, field sanitation, deep ploughing, flooding, collection and destruction of damaging insects/insect infested plants, etc. developed by farmers through experience were among the

Table 4.1 Landmarks in the history of agricultural insect pest management

Period (1)	Landmark(s) (2)
Ancient	The Chinese used chalk and woodash for the control of insect pests in enclosed spaces and botanical insecticides for seed treatment. They also used ants for biological control of stored grain as well as foliage feeding insects. In India, neem leaves were placed in grain bins to keep away troublesome pests. In Middle and Near East, powder of chrysanthemum flowers was used as an insecticide.
900 AD	The Chinese used arsenic to control garden pests.
1690	The tobacco extract was used as a plant spray in parts of Europe.
1762	*Mynah* (a bird) from India was imported for the control of locusts in Mauritius.
1782	"Underhill" variety of wheat reported resistant to Hessian fly in USA.
1831	"Winter Majetin" variety of apple reported resistant to woolly apple in USA.
1848	Derris (Rotenone) reported to be used in insect control in Asia.
1855	A. Fitch reported the role of lady bird beetles, green lacewings and other predaceous insects in the control of insect pests of crops.
1858	Pyrethrum first used for insect control in the USA.
1887	Balfour published his book *The Agricultural Pests of India and of Eastern and Southern Asia.* It was the first publication dealing with agricultural insect pest control in this region.
1889	Biological control of cottony cushion scale on citrus in the USA by use of Vedalia beetle imported from Australia.
1890	Control of grape phylloxera in Europe by grafting of European grapevine scions to resistant North American rootstocks.
1892	Lead arsenate used for the control of Gypsy moth in the USA.
1898	The coccinellid, *Cryptolaemus montrouzieri* Mulsant from Australia was released against coffee green scale, *Coccus viridis* (Green) in India. It established but failed to control the scale.
1911	Cotton Pest Act was enforced in Madras State. Under the Act cotton stalks had to be removed by 1st August every year to minimise the incidence of pink bollworm.
1923	Multiple component suppression techniques involving the use of resistant varieties, sanitation practices and need-based application of insecticides developed for the control of bollweevil in the USA.

Table 4.1 contd....

1931	The cottony cushion scale attacking wattle of commerce, *Acacia decurrens* was controlled in India by release of predatory beetle, *Rodolia cardinalis* Mulsant from California.
1939	• Insecticidal properties of DDT reported by Paul Muller in Switzerland. • Bacillus thuringiensis Berliner first used as a microbial insecticide.
1940	Work on the development of jassid-resistant varieties was undertaken in India resulting in the release of varieties like LSS, 4F, 289F, etc., during 1940s.
1941	Insecticidal activity of Hexachlorocyclohexane (HCH) discovered in France.
1946	Parathion, the first organo-phosphatic insecticide developed.
1948	• Use of DDT and HCH on agricultural crops in India. • "Doom" based on *Bacillus popilliae* Dutky and *B. lentimorbus* registered in USA for the control of Japanese beetle larvae on turf.
1951	• R.H. Painter published his classic book *Insect Resistance in Crop Plants.* • Introduction of first carbamate insecticide, Isolan
1952	First plant to produce HCH established at Rishra (India).
1959	• Concept of integrated control involving integration of chemical and biological control introduced. • Concept of economic injury level and economic threshold developed by V.M. Stern and coworkers.
1962	Publication of the book *Silent Spring* by Rachel Carson which dramatized the impact of misuse and overuse of pesticides on the environment.
1964	Publication of the book *Biological Control of Insect Pests and Weeds* by Paul DeBach, which established biological control as a separate discipline in Entomology.
1973	Development of first photo-stable pyrethroid, permethrin.
1975	• Elcar (*Helicoverpa* NPV) registered for the control of bollworm and tobacco budworm on cotton. • First insect growth regulator (Methoprene) registered for commercial use in USA. • Publication of the book *Introduction to Insect Pest Management* by R.L. Metcalf and W.H. Luckmann which was the first comprehensive treatise on IPM and established the concept on a firm footing.
1980	The interest in botanical pesticides revived and the First International Conference on Neem was held at Rottach-Egern, Germany.

Table 4.1 contd....

1987	Development of first transgenic plant, reported by M. Vaeck and coworkers of Belgian Biotechnology Company, Plant Genetic Systems by transferring *B. thuringiensis* δ-endotoxin gene to tobacco for the control of *Manduca sexta* (Johannsen).
1989	An IPM Task Force was established to garner international support for development and implementation of IPM programmes. A team of consultants appointed by the Task Force reviewed the status of IPM and made recommendations. The Task Force was later reconstituted as the Integrated Pest Management Working Group (IPWG) in 1990.
1992	• Concept of Environmental Economic Injury Levels proposed by L.P. Pedigo and L.G. Higley. • Dr Edward F. Knipling and Dr Raymond C. Bushland were awarded the World Food Prize for developing sterile insect technique. • United Nations Conference on Environment and Development (Rio de Janeiro, Argentina) assigned a pivotal role to IPM in the agricultural programmes and policies envisaged as part of its Agenda 21
1994	A Task Force consisting of FAO, the World Bank, UNDP and UNEP co-sponsored the establishment of the Global IPM Facility with the Secretariat located at FAO, Rome.
1995	Dr Hans R. Herren was awarded the World Food Prize for developing and implementing the world's largest biological control project for cassava mealybug which had almost destroyed the entire cassava crop of Africa.
1997	Dr Ray F. Smith and Dr Perry L. Adkisson were awarded the World Food Prize for their pioneering work in development and implementation of integrated pest management (IPM) concept.

Source : Modified after Dhaliwal *et al.* (1998)

oldest methods developed by humans to minimize the damage caused by insect pests (Smith *et al.*, 1976). This was followed by the use of plant products from neem, chrysanthemum, rotenone, tobacco and several other lesser known plants in different parts of the world. The Chinese were probably the pioneers in the use of botanical pesticides as well as biological control methods for the management of insect pests of stored grains and field crops (Dhaliwal and Arora, 1994a). However, systematized work on many important tactics of pest control including the use of resistant varieties, biological control agents and botanical and inorganic insecticides was done in the USA from the end of the 18th to the end of the 19th century. Remarkable success was achieved in the management of grape phylloxera caused by *Viteus vitifoliae* (Fitch) by grafting of European grape vine scions to resistant North American rootstocks during the 1880s. At around the same time, cottony cushion scale, *Icerya purchasi* Maskell which was causing havoc to the citrus industry in California, USA was successfully controlled by release of the Vedalia beetle, *Rodolia cardinalis* (Mulsant) imported from Australia (DeBach, 1964).

A number of synthetic inorganic insecticides containing arsenic, mercury, tin and copper were also developed towards the end of the nineteenth and the beginning of the twentieth century. With the development of these insecticides, the focus of research in entomology slowly shifted from ecological and cultural control to chemical control, even before the development of synthetic organic insecticides (Perkins, 1980).

4.2.2 Era of Pesticides (1939-1975)

The synthetic inorganic insecticides were broad spectrum biocides and were highly toxic to all living organisms. These were followed in due course by the synthetic organic insecticides like alkyl thiocyanates, lethane, etc. The era of pesticides, however, began with the discovery of the insecticidal properties of DDT [2, 2-(*p*-chlorophenyl) –1, 1, 1-trichloroethane] by Paul Muller in 1939. The impact of DDT on pest control is perhaps unmatched by any other synthetic substance and Muller was awarded Nobel Prize for this work in 1948.

DDT was soon followed by a number of other insecticides like HCH, chlordane, aldrin, dieldrin, heptachlor (organochlorine group) ; parathion, toxaphene, schradan, EPN (organophosphorus group) and allethrin (synthetic pyrethroid) during the 1950s and a large number of other popularly used organophosphates and carbamates in the ensuing decade.

Due to their efficacy, convenience, flexibility and economy, these pesticides played a major role in increasing crop production. The success of high yielding varieties of wheat and rice that ushered in the 'green revolution' was partially due to the protection umbrella of pesticides (Pradhan, 1983). The spectacular success of these pesticides masked their limitations. The intensive and extensive use, misuse and abuse of pesticides during the ensuing decades caused widespread damage to the environment. In addition, insect pest problems in some crops increased following the continuous application of pesticides. This, in turn, further increased the consumption of pesticides resulting in the phenomenon of the pesticide treadmill (Altieri, 1995). The combined impact of all these problems together with the rising cost of pesticides provided the necessary feedback for limiting the use of chemical control strategy and led to the development of the IPM concept.

4.2.3 Era of IPM (1976 onwards)

Although many IPM programmes were initiated in late 1960s and early 1970s in several parts of the world, it was only in late 1970s that IPM gained momentum. The first major IPM project in USA, commonly called the Huffaker Project, spanned 1972-78 and covered six crops, *i.e.* alfalfa, citrus, cotton, pines, pome and stone fruits, and soybean. This was followed by another large scale IPM project called CIPM, the Consortium for Integrated Pest Management (1979-85), which focussed on alfalfa, apple, cotton and soybean. The average adoption of IPM for four crops was claimed to be about 66 per cent over 5.76 million ha. In 1993, the US Government set up the National IPM Initiative and submitted that implementing IPM practices on 75 per cent of the nation's crop area by 2000 was a national goal.

The national IPM programmes were launched in late 1980s and early 1990s in several developing countries. The most outstanding success has been the FAO-IPM programme for rice in Southeast Asia. By the end of 1995, 35,000 trainers and 1.2 million farmers had been exposed to IPM through this programme.

The recent development at FAO in support of IPM is the establishment of the Global IPM Facility, co-sponsored by UNDP, UNEP and the World Bank. The concept is in response to the UN Conference on Environment and Development, held at Rio de Janerio, Brazil in 1992, which assigned a central role for IPM in agriculture as part of "Agenda 21". The Facility will serve as a coordinating, consulting, advising and promoting agency for the advancement of IPM worldwide (Kogan, 1998).

4.3 ORIGIN OF IPM CONCEPT

Basic tactics of IPM were proposed and used to protect crop plants against the ravages of pests long before the term was coined. In the absence of modern synthetic pesticides, crop protection specialists during late nineteenth and early twentieth centuries, relied on pest biology and cultural practices to propose multitactical approaches, that could be considered as precursors of modern IPM systems.

The idea of integrated control first appears to be conceived by Hoskins *et al.* (1939) when they said "... biological and chemical control are considered as supplementing to one another or as the two edges of the same sword...nature's own balance provides the major part of the protection that is required for the successful pursuit of agriculture...insecticides should be used so as to interfere with natural control of pests as little as possible...".

The credit for using the term 'integrated control' for the first time goes to Michelbacher and Bacon (1952), who while working on the control of codling moth, *Cydia pomonella* (Linnaeus), stressed "the importance of considering the entire entomological picture in developing a treatment for any particular pest... . All effort was directed towards developing an effective integrated control program of the important pests of walnut". Subsequently, Smith and Allen (1954) stated that "integrated control...will utilize all the resources of ecology and give us the most permanent, satisfactory and economical insect control that is possible". Following this, it was the series of papers that established integrated control as a new trend in entomology.

The integrated control was first defined by Stern *et al.* (1959) as "applied pest control which combines and integrates biological and chemical control". This definition stood through late 1950s and early 1960s, but began to change soon in the early 1960s as the concept of pest management gained acceptance among crop protection specialists.

The idea of managing insect pest populations was proposed by Geier and Clark (1961) who called this concept as "protective population management", which was later on shortened to "pest management" (Geier, 1966). By the mid-1970s both integrated control and pest management coexisted essentially as synonyms. However, a synthesis of two expressions had already become available when Smith and van den Bosch (1967) mentioned "The determination of insect numbers is broadly under the influence of total agroecosystem and a background role of the principle elements is essential to integrated pest population management."

It was, however, in 1972 when the term 'integrated pest management' was accepted by the scientific community after the publication of a report under the above title by the Council on Environmental Quality (CEQ, 1972). In creating this synthesis between integrated control and pest management, no obvious attempts seemed to have been made to advance a new paradigm. Much of the debate had already taken place during 1960s and by then there was substantial agreement on the following issues (Kogan, 1998) :

- 'Integration' means the harmonious use of multiple methods to control single pests as well as the impacts of multiple pests.
- 'Pests' are any organism detrimental to humans, including invertebrate and vertebrate animals, pathogens and weeds.
- 'Management' refers to a set of decision rules based on ecological principles and economic and social considerations. The backbone for the management of pests in an agricultural system is the concept of economic injury level (EIL).
- 'IPM' is a multidisciplinary endeavour.

4.4 DEFINITIONS OF IPM

Since the first definition of integrated control (Stern *et al.,* 1959), more than 65 definitions of integrated control, pest management or integrated pest management have been proposed. A broader definition was adopted by FAO Panel of Experts (FAO, 1967) : "Integrated pest control is a pest management system that, in the context of associated environment and population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest populations at levels below those causing economic injury". It is not simply the juxtaposition or superimposition of two control techniques but the integration of all suitable management techniques with the natural regulating and limiting elements of the environment. According to National Academy of Sciences, IPM refers to an ecological approach in pest management in which all available necessary techniques are consolidated in a unified programme, so that pest populations can be managed in such a manner that economic damage is avoided and adverse side effects are minimized (NAS, 1969).

Most of other contemporary definitions perpetuate the perception of an entomological bias in IPM because of the emphasis on pest populations and economic injury levels, of which the former is not always applicable to plant pathogens, and the latter is usually attached to the notion of an action threshold often incompatible with pathogen epidemiology or many weed management systems. Smith (1978) defined IPM as a multidiscipilinary ecological approach to the management of pest populations, which utilizes a variety of control tactics compatibly in a single coordinated pest management system. In its operation, integrated pest control is a multi-tactical approach that encourages the fullest use of natural mortality factors complemented when necessary by artificial means of pest management. In other words, IPM seeks to integrate multidisciplinary methodologies to develop pest management strategies that are practical, effective, economical and protective of both public health and the environment (Smith *et al.*, 1976). IPM has also been defined as a pest population management system that utilizes all suitable techniques in a compatible manner to reduce pest populations and maintain them at levels below those causing economic injury (Frisbie and Adkisson, 1985). Dr Ray F. Smith and Dr Perry Adkisson have been awarded the 1997 World Food Prize for their pioneering work in development and implementation of IPM concept.

IPM is a systematic approach to crop protection that uses increased information and improved decision-making paradigms to reduce purchased inputs and improve economic, social and environmental conditions on the farm and in society (Allen and Rajotte, 1990). IPM is a comprehensive approach to pest control that uses combined means to reduce the status of pests to tolerable levels while maintaining a quality environment (Pedigo, 1991). IPM is also defined as the intelligent selection and use of pest control tactics that will ensure favourable economical, ecological and sociological consequences (Luckman and Metcalf, 1994).

In our view, IPM is a dynamic and constantly evolving approach to crop protection in which all the suitable management tactics and available surveillance and forecasting information are utilized to develop a holistic management programme as part of a sustainable crop production technology (Fig. 4.1). Here it needs to be emphasized that the aim of future IPM programmes should not be restricted to mere efficient use of pesticides and product substitution (biorationals and botanicals in place of conventional insecticides), within an agricultural system that essentially remains unchanged (Table 4.2). Rather, these programmes should aim at fundamental structural changes through a better understanding of ecological processes and synergy between crops (van Veldhuizen and Hiemstra, 1993).

Kogan (1998) carried out a numerical analysis of various definitions spanning the last 35 years and found that most of the authors depended on the following issues to capture the essence of IPM concept :

- The appropriate selection of pest control methods, used singly or in combination ;
- The economic benefits to growers and to society ;

- The decision rules that guide the selection of the control action ; and
- The need to consider impacts of multiple pests.

Taking into consideration all the above points and the current thought, Kogan (1998) put forth his definition : "IPM is a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society and the environment".

This chapter focuses on some of the important but neglected aspects of IPM, viz. monitoring of insect pests, decision making and implementation strategies.

4.5 MONITORING INSECT PESTS AND NATURAL ENEMIES

Monitoring phytophagous insects and their natural enemies is a fundamental tool in IPM for taking management decisions. Monitoring requires estimation of changes in insect distribution and abundance, information about the insects, life history and the influence of important biotic (natural enemies) and abiotic (climatic) factors on pest population. Depending on the objectives, monitoring may be undertaken on an areawide basis or at the farm level (Shelton and Trumble, 1993).

4.5.1 Regional Monitoring

Large scale monitoring programmes fulfil a number of important functions.

- Monitoring is undertaken at quarantine stations to detect exotic pests which pose a threat to agriculture.
- Repeated surveys over a wide area are undertaken to detect new species or to document distribution and population trends of known indigenous species.
- Movement surveys are undertaken to develop a better understanding of ecological, climatological and biological factors which influence insect movement. This information is used to develop predictive models which are used to forewarn the farmers regarding pest outbreaks.
- Large scale programmes are also undertaken to determine emergence patterns and generation peaks for important insect pests. These are most useful for helping to time further sampling schemes or to initiate management strategies.
- Monitoring programmes are also undertaken to detect the development of insecticide resistance in important pests.

4.5.2 Localized Sampling

Localized sampling at the farm level serves to provide information on the followng aspects :

- Many serious pests move freely between crops within a localized region and the spatial aspects of population change can play a major role in the timing and intensity of pest outbreaks on certain crops. Monitoring helps to detect the intercrop movement of target pests.

- Within field sampling helps to determine the pattern of infestation in the specific area.
- Sometimes, only a part of the plant is sampled to reduce costs. Such sampling is possible only when a predictive relationship has been established between the whole plant counts and the subsamples.

A detailed account of sampling techniques has been given in chapter 2.

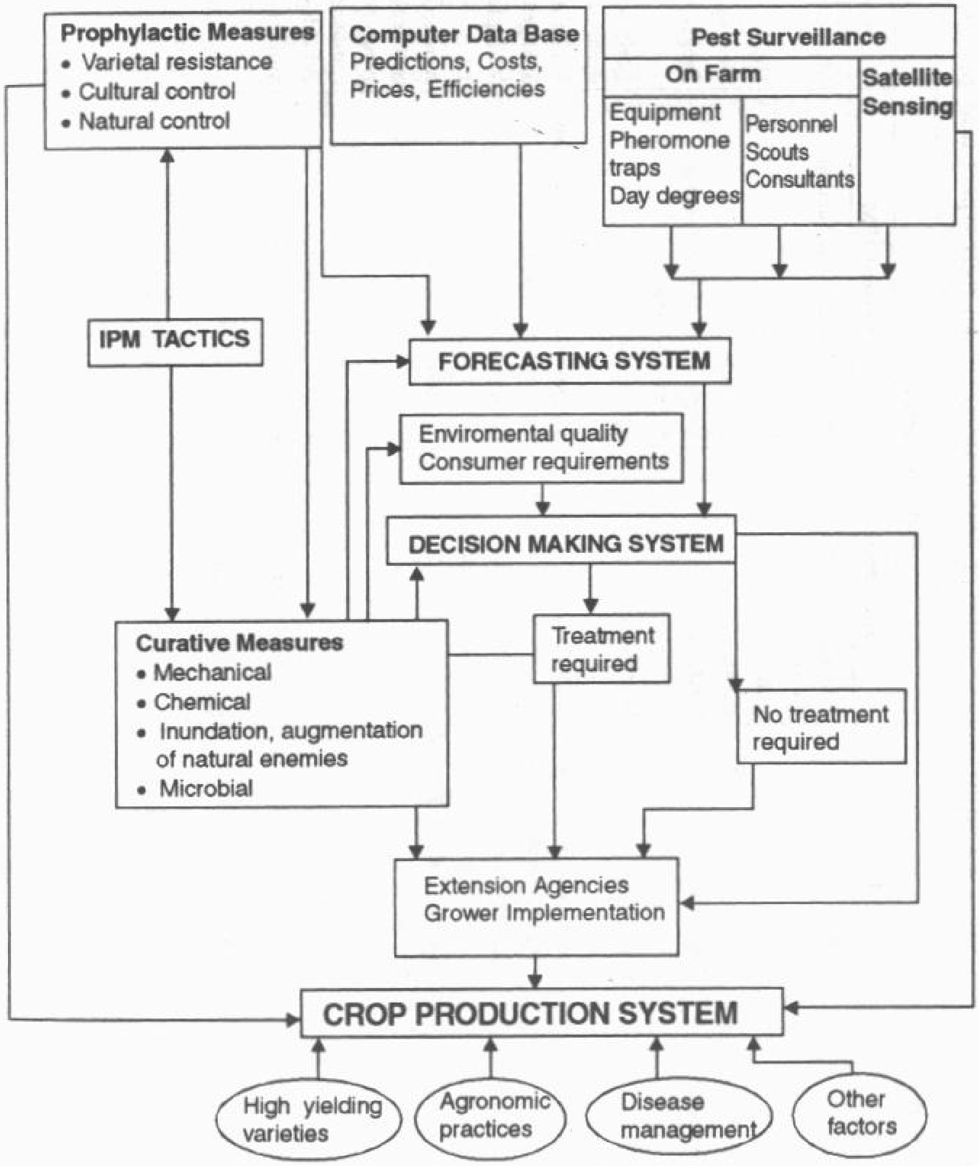


Fig. 4.1 Major components of a pest management system and their inter-relationships (Modified after Dhaliwal and Arora, 1994b)

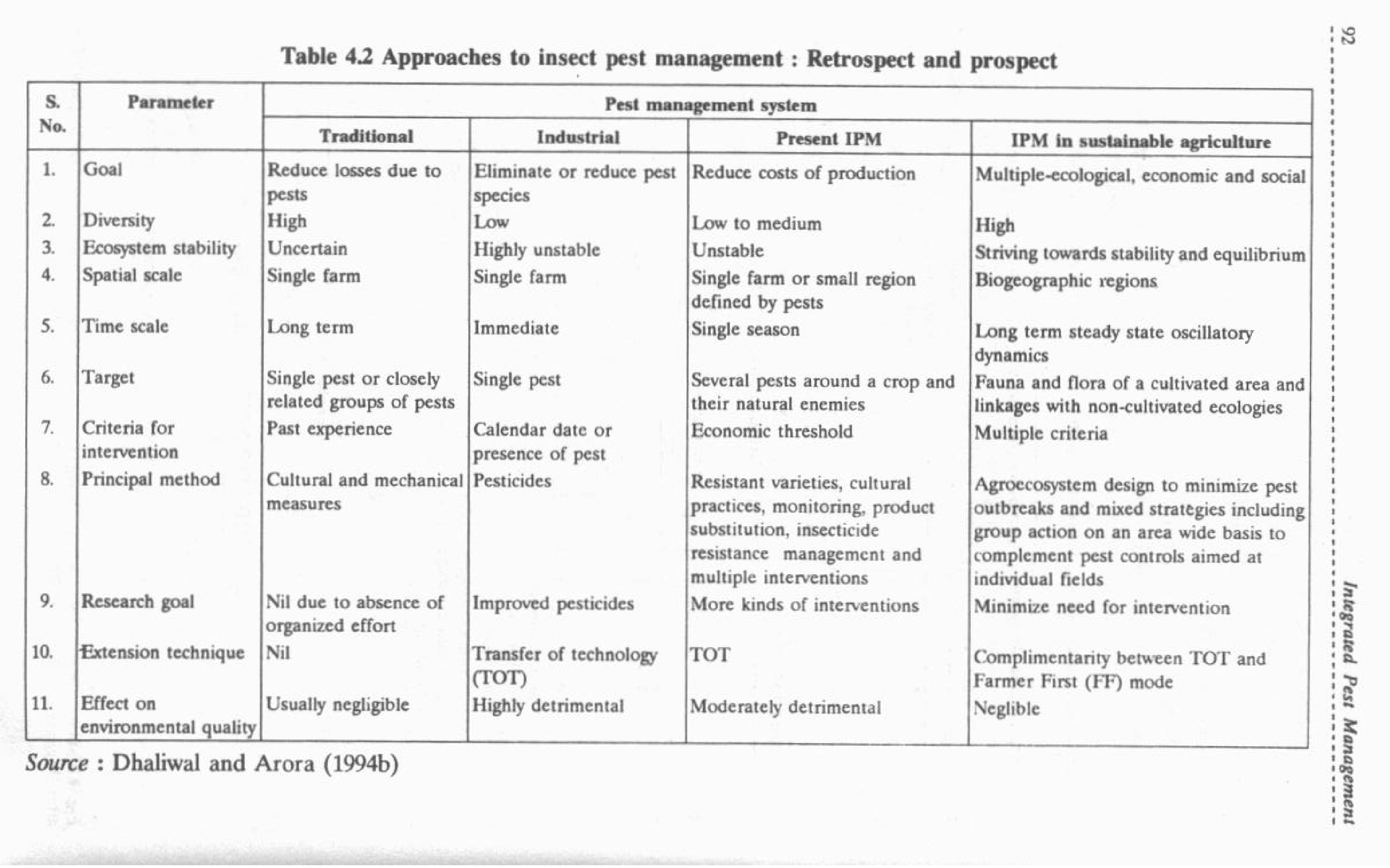


Table 4.2 Approaches to insect pest management : Retrospect and prospect

S. No.	Parameter	Pest management system			
		Traditional	Industrial	Present IPM	IPM in sustainable agriculture
1.	Goal	Reduce losses due to pests	Eliminate or reduce pest species	Reduce costs of production	Multiple-ecological, economic and social
2.	Diversity	High	Low	Low to medium	High
3.	Ecosystem stability	Uncertain	Highly unstable	Unstable	Striving towards stability and equilibrium
4.	Spatial scale	Single farm	Single farm	Single farm or small region defined by pests	Biogeographic regions
5.	Time scale	Long term	Immediate	Single season	Long term steady state oscillatory dynamics
6.	Target	Single pest or closely related groups of pests	Single pest	Several pests around a crop and their natural enemies	Fauna and flora of a cultivated area and linkages with non-cultivated ecologies
7.	Criteria for intervention	Past experience	Calendar date or presence of pest	Economic threshold	Multiple criteria
8.	Principal method	Cultural and mechanical measures	Pesticides	Resistant varieties, cultural practices, monitoring, product substitution, insecticide resistance management and multiple interventions	Agroecosystem design to minimize pest outbreaks and mixed strategies including group action on an area wide basis to complement pest controls aimed at individual fields
9.	Research goal	Nil due to absence of organized effort	Improved pesticides	More kinds of interventions	Minimize need for intervention
10.	Extension technique	Nil	Transfer of technology (TOT)	TOT	Complimentarity between TOT and Farmer First (FF) mode
11.	Effect on environmental quality	Usually negligible	Highly detrimental	Moderately detrimental	Neglible

Source : Dhaliwal and Arora (1994b)

4.6 CONCEPT OF INJURY LEVELS

Most crops harbour wide variety of insects. Crops like cotton and sugarcane have been reported to be attacked by more than 1000 species of insects worldwide. Potentially, most of these could cause havoc but actually only a few of them damage the crop. The critical factor which determines the damaging capacity or otherwise of an insect is its population level. The concept of injury levels was propounded to enable us to identify the population level at which an insect could cause damage to a crop. Most popular terms used in this connection are the economic injury level (EIL) and the economic threshold level (ETL). But a number of other terms like action threshold, action level, threshold level, inaction threshold, control threshold, insect injury threshold, critical injury threshold and critical population threshold have been suggested as alternatives to EIL and ETL (Pedigo *et al.*, 1986).

4.6.1 Economic Injury Level

Insect colonization and feeding often cause injury to the plants. The injury does not necessarily result in damage. The latter refers to a measurable loss of host ability most often including yield quantity, quality or aesthetics. The lowest level of injury where the damage can be measured is called the damage boundary (DB) (Fig. 4.2); while the lowest number of insects that will cause economic damage is referred to as economic injury level (EIL) (Pedigo, 1991).

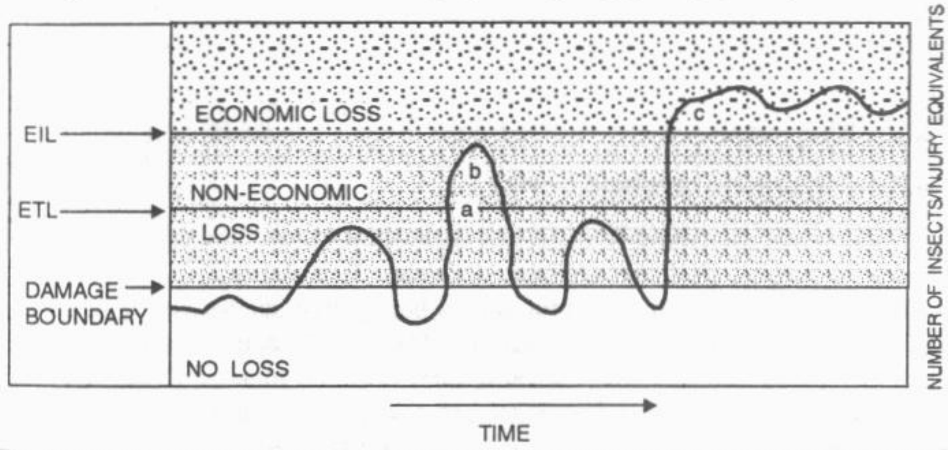


Fig. 4.2 Graph showing relationship between damage boundary (DB), economic threshold level (ETL) and economic injury level (EIL) for a hypothetical insect pest population. (Modified after Dhaliwal and Arora, 1994b). As the increasing insect population approaches ETL (at a), control measures are initiated, so that the population is unable to reach EIL (b) and economic loss is avoided. In case no control measures are undertaken, the increasing insect population crosses DB, ETL and EIL (c) resulting in economic loss.

Even before the advent of synthetic organic insecticides, questions were raised regarding the level of damage at which control measures should be initiated against insects. However, the concept of EIL was developed by Stern *et al.* (1959) to overcome problems, viz. insecticide resistance, pest resurgence,

insecticide residues and non-target effects, caused by indiscriminate use of DDT and other broad-spectrum synthetic organic insecticides.

Although expressed as numbers of insects per unit area, as its name implies, the EIL is, in reality, a level of injury. Because injury is difficult to measure in a field situation, however, number of insects are used as an index of that injury. There have been suggestions that the name should be changed to critical population density. Alternatively, it may be more useful to express the EIL in standard units of injury. The standard units of injury are the injury equivalents, *i.e.* amount of injury that could be produced by one pest through its complete life cycle; and equivalency, *i.e.* total injury equivalents (for a population) at a point in time (Pedigo *et al.*, 1986). If management action (insect suppression) can be taken quickly and loss averted completely, the EIL may be expressed as follows (Pedigo, 1991) :

$$\text{EIL} = C/VID \qquad ...(1)$$

EIL = No. of injury equivalents per production unit (insects/ha).
C = Cost of management activity per unit of production (Rs/ha)
V = Market value per unit of product (Rs/tonne)
I = Crop injury per pest density
D = Damage per unit injury (tonne reduction/ha).

These primary variables are affected by a number of complex variables.

In instances, where some loss from the insect is unavoidable, the relationship becomes :

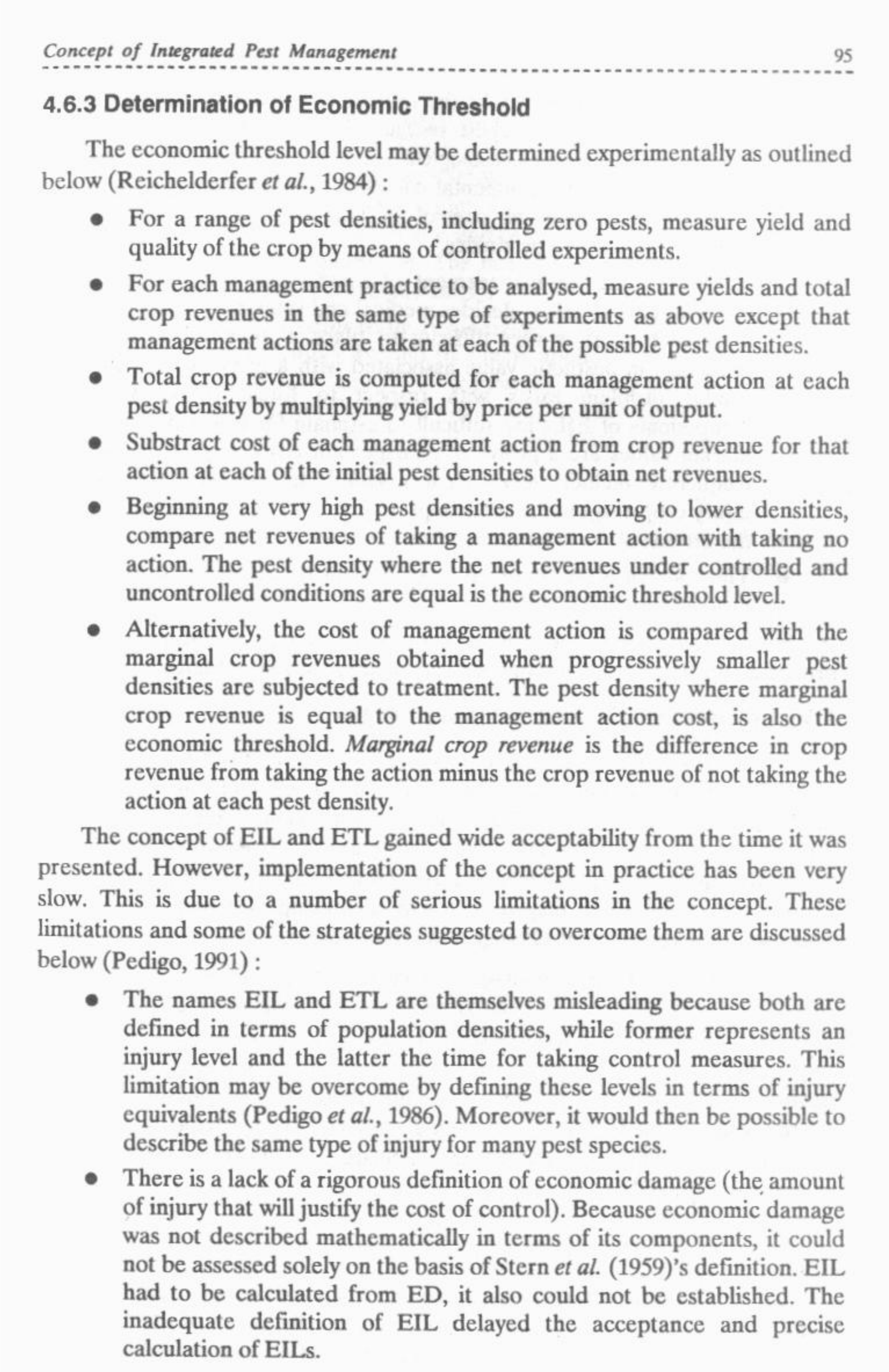
$$\text{EIL} = \frac{C}{V \times I \times D \times K} \qquad ....(2)$$

where K represents proportionate reduction in injury (*e.g.* 0.6 for 60%).

4.6.2 Economic Threshold Level

Economic threshold level (ETL) is the best known and most widely used index in making pest management decisions. It is defined as the population density at which control measures should be initiated against an increasing pest population to prevent economic damage (Fig. 3.2). Although expressed in insect numbers, ETL is, in fact, a time parameter, with pest numbers being used as an index for when to implement management strategies. Just as with EILs, ETLs also can be expressed in insect equivalents (Pedigo, 1991). In economic terms, ETL is defined as the level to which a given pest population should be reduced to achieve the point where marginal revenue just exceeds marginal costs (Mumford and Norton, 1984).

ETL is a complex value based on the EIL, population dynamics of the pest, weather forecasting and the pests' potential for injury. The relationship between EIL and ETL is shown in Fig. 3.2. When no action is taken at ETL, the population exceeds EIL; while when management steps for pest suppression are taken as the population crosses ETL, the population is forced down before it could reach EIL.



4.6.3 Determination of Economic Threshold

The economic threshold level may be determined experimentally as outlined below (Reichelderfer *et al.*, 1984) :

- For a range of pest densities, including zero pests, measure yield and quality of the crop by means of controlled experiments.
- For each management practice to be analysed, measure yields and total crop revenues in the same type of experiments as above except that management actions are taken at each of the possible pest densities.
- Total crop revenue is computed for each management action at each pest density by multiplying yield by price per unit of output.
- Substract cost of each management action from crop revenue for that action at each of the initial pest densities to obtain net revenues.
- Beginning at very high pest densities and moving to lower densities, compare net revenues of taking a management action with taking no action. The pest density where the net revenues under controlled and uncontrolled conditions are equal is the economic threshold level.
- Alternatively, the cost of management action is compared with the marginal crop revenues obtained when progressively smaller pest densities are subjected to treatment. The pest density where marginal crop revenue is equal to the management action cost, is also the economic threshold. *Marginal crop revenue* is the difference in crop revenue from taking the action minus the crop revenue of not taking the action at each pest density.

The concept of EIL and ETL gained wide acceptability from the time it was presented. However, implementation of the concept in practice has been very slow. This is due to a number of serious limitations in the concept. These limitations and some of the strategies suggested to overcome them are discussed below (Pedigo, 1991) :

- The names EIL and ETL are themselves misleading because both are defined in terms of population densities, while former represents an injury level and the latter the time for taking control measures. This limitation may be overcome by defining these levels in terms of injury equivalents (Pedigo *et al.*, 1986). Moreover, it would then be possible to describe the same type of injury for many pest species.
- There is a lack of a rigorous definition of economic damage (the amount of injury that will justify the cost of control). Because economic damage was not described mathematically in terms of its components, it could not be assessed solely on the basis of Stern *et al.* (1959)'s definition. EIL had to be calculated from ED, it also could not be established. The inadequate definition of EIL delayed the acceptance and precise calculation of EILs.

- The EIL concept overlooks the influence of other production factors that can affect the crop/pest system. The externalities left out include interseasonal dynamics, biological relationships with other pests and natural enemies, environmental contamination by pesticides, resistance to pesticides, effect of control in neighbouring fields and health problems relating to pesticides.
- Decision levels for management of some types of pests can not be determined with EILs. Besides medical and veterinary pests, it includes most vectors. It is very difficult to place a monetary value on the reduction in aesthetic value associated with a given type of injury. A similar problem exists with respect to forest pests. Almost all components of EILs are difficult to estimate for forest pests; accurate market values are a problem; management costs may vary greatly and frequently include mere environmental and social costs and the injury/crop-response relationships may be difficult to determine because the growth of the crop spans many years.
- The concept is unsuitable in case of attack of multiple pests on a single crop at the same stage.

However, in spite of these limitations, the EIL concept continues to offer a practical approach to pest-related decision making in a broad sense.

4.6.4 Environmental Economic Injury Levels

The challenge of attempting to decrease pesticide inputs further can be met by developing environmentally-based EILs and their concomitant ETLs. An environmental EIL is an EIL that evaluates a management tactic based on not only its direct costs and benefits to the user but also its effect on the environment. The EIL equation (equation 2, Section 4.6.1) integrates many management elements, each of which may have a role in making pest management most environmentally sustainable (Pedigo and Higley, 1992) :

(*i*) **Assigning realistic management costs (C).** Component C of the EIL equation represents costs associated with taking management action against a pest population (PC) and increased costs cause EIL to increase proportionately. Generally, C does not take into account the environmental costs associated with environmental risks; it is possible to include these costs in variable C of EIL. Methods for computing the environmental costs (EC) of pesticides are discussed in Section 10.4. These are utilized for calculating the environmental economic injury levels (En. EIL) :

$$\text{En. EIL} = \frac{PC + EC}{VDIK}$$

(*ii*) **Manipulating crop market value (V).** This could be achieved by putting a higher market value for a pesticide-free produce. The extent of increase would depend on the consumers' willingness to pay for a safer product.

(*iii*) **Reducing damage per pest (D).** Reducing D implies that less loss of yield occurs for a given amount of injury. This is possible if plant is able to tolerate and compensate for injury. Plants that can tolerate or compensate for injury do not place selection pressure on pest populations. Therefore, the benefits of tolerance and compensation in plant are sustainable and permanent. Even partial tolerance will increase EILs (by decreasing D). The need for pesticides and the risk to environment will be reduced correspondingly.

(*iv*) **Developing environmentally responsible K value.** Modified K is the proportion of total pest injury averted by timely application of a management tactic. Increasing the EIL to improve environmental quality implies that we are willing to tolerate more pests. But this is not always the case. By reducing D or K, EIL can be increased even without causing increased losses or costs.

4.7 INTEGRATION OF TACTICS

The pest management tactics are either preventive or therapeutic. *Preventive practices* utilize tactics to lower environmental carrying capacity (reduce the general equilibrium position) or increase tolerance of the host to pest injury. Prevention relies on an intimate understanding of the pest's life cycle, behaviour and ecology. The preventive tactics involve natural enemies, host resistance and cultural practices. In addition, quarantines are also an important component of preventive tactics. *Therapeutic tactics* are applied as a correction to the system when necessary. The objective of therapy is to dampen pest population below the economic injury level. The only widely used therapeutic tactic is the use of conventional insecticides but other approaches like microbial agents, augmentation of natural enemies, use of growth regulators, etc. may also play a vital role (Pedigo, 1991).

Actual integration involves proper choice of compatible tactics and blending them so that each component potentiates or complements the other. Probably, the earliest example of integration of techniques was the use of a combination of resistant varieties and sanitation practices as prophylactic measures combined with application of calcium arsenate at high population level in case of bollweevil on cotton in USA during first quarter of the twentieth century. Similar programmes were being developed for other pests also but the advent of synthetic organic insecticides intervened and these techniques were relegated to the background. The misuses and abuses of insecticides have again focused our attention on integrated control measures. Some of the possible ways in which different tactics may be integrated have been discussed in respective chapters.

4.8 ESSENTIAL REQUISITES FOR DECISION MAKING IN IPM

IPM is a knowledge intensive system and a lot of background information regarding the pest, abiotic and biotic factors, agroecosystem and management tactics is required for taking decisions regarding execution of IPM programmes.

Identification of insect pest(s). Proper identification of the insect pest causing damage in a given situation is essential for collecting further information

about the pest as well as for undertaking necessary control measures. Corect identification will lead to published information on the insects' life history, behaviour and ecology which are important in the development of suitable control measures.

Correct identification may help to direct biological control workers to know the area of origin of the pest. On the other hand, wrong identification of the target organism in the native habitat may lead to the introduction of the wrong natural enemy, which may also fail to get established in the new area. Such mis-identification was one of the reasons for repeated failures in the biological control of California red scale. *Aonidiella aurantii* (Maskell) which was misidentified as a species of *Chrysomphalus*, a genus believed to be of South American origin.

Life history and behaviour of the pest. In addition to the information obtained from literature, it is essential to study the life history of the pest including duration of different developmental stages, fecundity and number of generations per year, in the target area. Host range of the insect pests including the sequence of crops, non-cultivated plants and weeds should also be known.

Behaviour of the pest including mode of feeding, plant parts (roots, foliage, reproductive parts, etc.) attacked, external or internal feeding behaviour and mobility of the pest are also important considerations for undertaking control measures.

Natural regulating factors. Most of the insects occurring on a crop are held in check by natural regulating factors. It is essential to know the biotic (parasitoids, predators, pathogens, etc.) and abiotic (temperature, moisture, etc.) factors which regulate the population of important insect pests on a particular crop. Correct identification of natural enemies is also important in order to manipulate them for their utilization in IPM.

Need for control measures. Insects are ubiquitous in agricultural as well as natural ecosystems. The need for taking control measures against a particular insect pest depends on a large number of interacting factors including number of insects, crop value, type of damage, idiosyncracies of the consumer and economic and environmental costs of the control measures. In IPM, location specific environmentally based economic injury levels may be used for taking decisions regarding the need for control measures.

Timing of control measures. Timing of application of control measures is a critical factor in IPM decision making. The application must be made at a time at which the pest is present at a susceptible stage. For instance, it is important to apply insecticides against early instars of *H. armigera* before they bore into the pod or fruit where they are difficult to control. Timing may also be important in relation to augmentative releases of parasitoids. Parasitoids should not be released before a pest population is large enough to allow natural enemy establishment but not too late that they cannot exert sufficient levels of control before damage is caused. Where a combination of measures is used, for instance, pesticides and natural enemies, then the timing of pesticide application needs to be adjusted to minimize the harm to populations of natural enemies and other beneficial organisms.

Selection of suitable control measures. An array of control measures is usually available for use against a particular pest. The prophylactic meaures have to be taken well in advance of the appearance of the pest or even before the time of sowing of the crop. These include resistant varieties, cultural control measures and environmental manipulations for strengthening of natural control. The curative control measures including the use of chemical and biologically based pesticides may be undertaken based on economic injury levels. It is important that appropriate control measures are selected that are compatible and their combined use is practicable and effective. The selection of chemical or biological pesticide depends on its efficacy against the pest, formulation and method of application, cost of application, residual effectiveness, effect on non-target organisms, environmental cost, etc. Pest management ratings, contingent valuation and environmental impact quotient are some of the parameters used for selecting pesticides for use in IPM (Section 10.4).

4.9 DECISION MAKING SYSTEMS

Pest management is a combination of processes that include decision making, taking action against a pest, and obtaining the information to be used in reaching these decisions (Ruesink and Onstad, 1994). In assessing, evaluating and choosing a particular pest control option, farmers are likely to take three major factors into account (Fig. 4.3) :

- Farmers' perception of the problem and of potential solutions is the most important factor. Here, the farmer's ability to identify pests, his assessment of likely and potential pest losses, and his opinion regarding the efficacy of different control options will affect the decision process.
- The way in which control options are assessed will depend on the farmers' objectives. Subsistence farmers may opt for a guaranteed food supply while commercial farmers are more concerned with profit.
- The number of options that a farmer can feasibly use, would depend on the constraints set by the resources available.

Various alternative pest control options could be evaluated for their cost effectiveness (Reichelderfer *et al.*, 1984) :

- Determine from experimental results both the per hectare cost and a measure of effect of each alternative practice. If effectiveness can be measured in terms of output (yield and/or crop quality), use partial budgeting or other analytical techniques to evaluate alternatives. If effectiveness cannot be measured in these terms, proceed with determination of cost- effectiveness.
- Using the same units in which effectiveness is measured (*e.g.* reduction in pest numbers or damage), specify an effectiveness target that is

appropriate, given the experimental data and information at hand (*e.g.* a 50% reduction in pest population).

- Multiply the cost of each practice times the effectiveness target, then divide that product by the actual level of effectiveness achieved by the practice. This gives a set of relative cost-effectiveness figures in rupees per hectare.
- Compare the cost-effectiveness of alternative practices. The practice that has associated with it the least cost to achieve the effectiveness target is the most cost-effective practice.

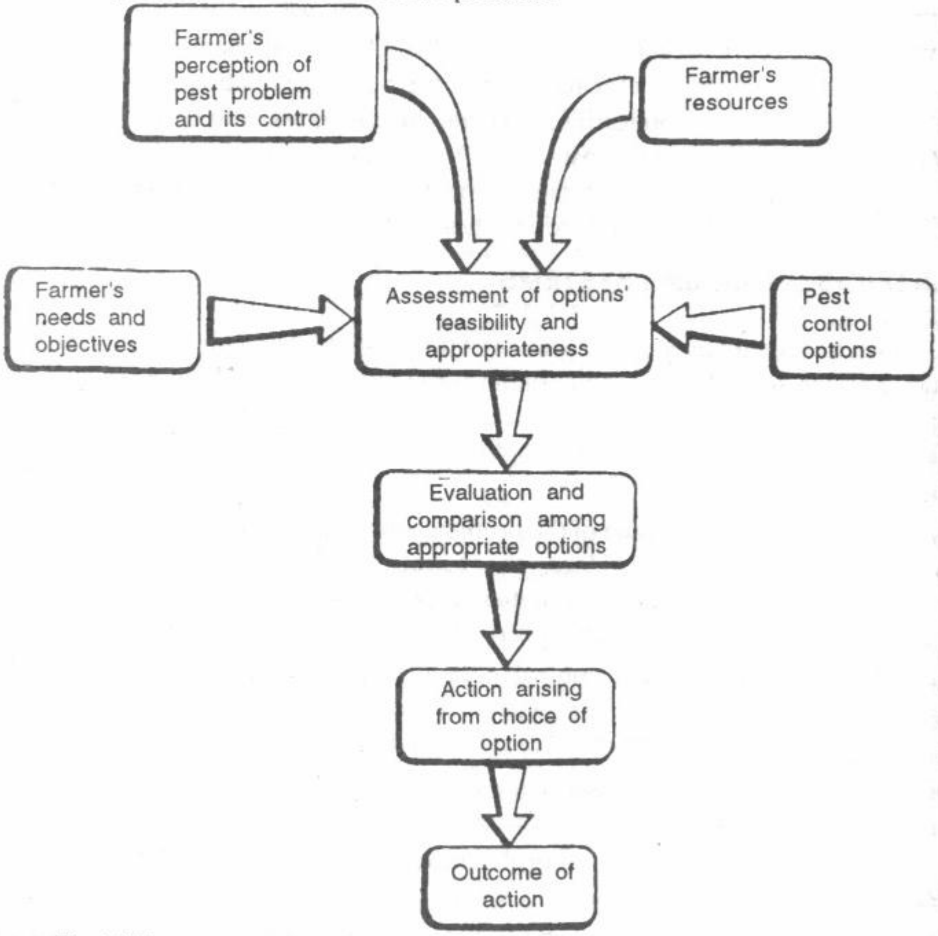


Fig. 4.3 The process of decision making in IPM (After Reichelderfer *et al.*, 1984)

4.10 IMPLEMENTATION

Although IPM has been accepted in principle as the most attractive option for the protection of agricultural crops from the ravages of insect and non-insect pests, yet implementation at the farmers' level has been rather limited. Some of the important constraints to wider adoption of IPM and suggested measures to overcome them are discussed in this section.

4.10.1 Constraints in IPM Implementation

The Consultant Group of the IPM Task Force has conducted an indepth study of the constraints on the implementation of IPM in developing countries, which can be categorised into the following five main groups (NRI, 1992; Alam, 2000) :

(*i*) **Institutional constraints.** IPM requires an interdisciplinary, multi-functional approach to solving pest problems. Fragmentation between disciplines, between research, extension and implementation, and between institutes, all lead to a lack of institutional integration. Secondly, both the national programmes of developing countries and the donor agencies have lacked a policy commitment to IPM in the context of national economic planning and agricultural development. This has resulted in a low priority for IPM from national programmes and donors alike. Thirdly, the traditional top-down research in many cases does not address the real needs of farmers, who eventually are the end-users, and who select to adopt or reject the technology based on its appropriateness. Institutional barriers to research scientists in national programmes conducting on-farm research in developing countries are real, and need to be addressed.

(*ii*) **Informational constraints.** The lack of IPM information which could be used by the farmers and by extension workers is a major constraint in implementation. In a recent study regarding implementation of IPM in Haryana, India, it was found that more than three fourth of the farmers were not even aware of the concept of IPM. Even those aware of the concept reported that they lacked the skills necessary to practise IPM (Alam, 2000). While the individual control techniques are well known, little knowledge is available on using these in an integrated fashion under farm conditions. The lack of training materials, curricula and experienced teachers on the principles and practice of IPM is another major constraint. In many cases, the field level extension workers are not sufficiently trained in IPM to instil confidence in the farmers.

(*iii*) **Sociological constraints.** The conditioning of most farmers and farm level extension workers by the pesticide industry has created a situation where chemicals are presented as highly effective and simple to apply. This acts as a major constraint in IPM implementation. There appears to be a direct conflict between industry's objective of more sales, and the IPM message of rational pesticide use, in the eyes of farmers. There is a need for private industry and public sector extension agencies to work in a more complementary manner. A majority of the farmers in a recent study in Haryana, India, expressed their lack of faith in IPM. They considered IPM practices to be risky as compared to the use of chemical pesticides.

(*iv*) **Economic constraints.** A major constraint, even if IPM is adopted in principle, is the funding for research, extension and farmer training needed for an accelerated programme. IPM must be viewed as an investment, and as with other forms of investment, requires an outlay. In the long run, IPM programmes may become self-generating due to savings on resource inputs for production. A majority of the farmers purchase pesticides on credit and depend on shopkeepers and pesticide dealers for information about the pest control methods.

(*v*) **Political constraints.** The relatively low status of plant protection workers in the administrative hierarchy is a constraint to general improvement in plant protection. Associated with the above are the morale and financial standing of these workers. The continuance of pesticide subsidy by the government for political reasons and its tie up with the government-provided credit for crop production, acts as a major constraint to farmers' acceptance of IPM. Various vested interests associated with the pesticide trade also act as a political constraint on the implementation of IPM.

4.10.2 Strategies for IPM Implementation

Acceleration of IPM implementation in developing countries requires farmers' participation, increased government support, improved institutional infrastructure and favourable environment.

(*i*) **Farmers' participation.** It will not be an exaggeration to say that the dawn of civilization started with farmer innovation. Ever since that day, farmers have improved ways of growing crops through successive innovations. Prior to the emergence of crop protection sciences and even before the broad outlines of the biology of pests were understood, farmers evolved many cultural, mechanical and physical control practices for the protection of their crops from insect and non-insect pests. Farmers' innovations were the only source of improvements in crop production and protection technology until formal research by on-station scientists started complementing it during the late eighteenth and nineteenth century (Haverskort *et al.*, 1991).

Unfortunately, with the advent of modern high-tech agriculture comprising of HYVs, fertilizers and pesticides, the farmers have been completely displaced from the research and development process. Instead this role has been usurped by the private industry and the government agencies. The technology generated by the farm scientists is being transferred through the extension agencies to the farmers. The new technology package has created a number of ecological and environmental problems. The alternative path of sustainable agriculture requires farmers' participation at every step of the research and development process in order to draw on his understanding of the local conditions and constraints, his innovativeness and his skills at making the best possible use of limited resources.

Placing the farmer at the centre of development process is wholly consistent with the IPM goal of making farmer a confident manager and decision maker, free from dependence on a constant stream of pest control instructions from outside. The role of researchers, extension workers and non-government organizations (NGOs) is to act as consultants, facilitators and collaborators, stimulating and empowering the farmers to analyze their own situation, to experiment and to make constructive choices. A number of terms have been proposed for the new approach. These include : 'Farmer- first-and-last', 'farmer participatory research', 'farmer first', 'approach development', 'people-centred technology development (PCTD)', 'participatory technology development (PTD)' (Chambers *et al.*, 1991; Haverskort *et al.*, 1991). PTD serves to improve the experimental capacity of farmers and helps in development of locally-adapted improved technologies.

The approach has been used for implementation of IPM programmes in Indonesia (Matteson *et al.*, 1994). In this method, farmers are divided into small groups to monitor the crop and then each group analyzes the field situation by identifying the key factors. Group members then decide whether any action is required. At a combined meeting, each group presents and defends its summary to the trainees. The trainer facilitates by asking leading questions or adding technical information if necessary. This process allows farmers to integrate and practise their skills and knowledge, and gives trainers an opportunity to evaluate the trainees' ability. Thousands of farmers have been trained utilizing this approach and it is being tried on a pilot scale. A survey among these farmers during the first post-training season revealed that they really decreased their frequency of pesticide sprays to a level consistently lower than that of non-IPM farmers. The percentage of farmers not applying pesticides was also significantly higher among the trained ones. Inspite of lower pest control expenditures, these farmers obtained higher yield than the non-IPM farmers (Sections 13.2, 13.3).

(*ii*) **Government support.** Both the national programmes of developing countries and the donor agencies must have a policy commitment to IPM in the context of national economic planning and agricultural development. The costs to developing countries of not bringing their policies in line with the objectives of IPM are relatively greater than the costs to developed countries. National policies to promote IPM require close regulation at all stages related to the importation and/or manufacture, distribution, use and disposal of pesticides. In the case of pesticides which do not meet prescribed standards for safety, persistence, etc., import and manufacturing bans should be enacted. At a minimum, the conditions laid out by the *FAO Code of Conduct on the Regulation, Distribution and Use of Pesticides* should be adopted. Pesticide subsidies need to be eliminated in order to make IPM an attractive alternative.

The funds so saved may be utilized for the implementation of IPM. Funds may also be diverted from some of the current research programmes to IPM-oriented plant protection programmes. Additional monetary resources may be generated through cooperation with bilateral/multilateral agencies willing to support such programmes (NRI, 1992).

(*iii*) **Legislative measures.** IPM is an information system and its adoption reduces pest control costs. The alternative to IPM is the indiscriminate use of broad spectrum synthetic organic pesticides. Unfortunately, while pesticide manufacturers and users (farmers) derive the full benefits from the use of these chemicals, they pass on the environmental and ecological costs of their use to the society as a whole. If they are made to bear the full cost of the use of these toxicants, they may find IPM a more economical and attractive alternative. This could be achieved by enforcing suitable legislative measures.

Secondly, the success of an IPM programme in any geographical region depends upon its implementation by all the farmers in the area. Ideally, farmers may voluntarily adopt an IPM programme but some farmers may hold out. Such farmers called 'spoiler holdouts' may impair the success of a programme by failing to adopt a necessary practice thus causing damage to adjacent areas. Besides these, some farmers may free-ride and thus shift the costs of implementing and managing a programme to a group of participating farmers. To overcome 'spoiler holdouts' and 'free riders,' it may be necessary to impose a programme upon an unwilling minority through suitable legislative measures (Tarlock, 1980).

(*iv*) **Improved institutional infrastructure.** IPM cannot be implemented unless there is a basic infrastructure for plant protection in a country. There is a need to develop and support national programme capabilities for on-farm testing and technology extrapolation. At the international level establishment of *IPM Working Group* to coordinate and monitor funding of IPM projects is bound to provide impetus to the implementation of IPM.

IPM is predominantly a knowledge technology, the use of which requires training of the many groups involved. There is currently little training material for most of these groups including farmers, extension personnel and researchers. If IPM is to become the major approach for pest management in the developing world, this deficiency must be remedied urgently (NRI, 1992).

Another aspect requiring greater attention is co-ordination of effort within and between countries, between national research, training and implementation institutes/programmes, and amongst international development agencies.

Lack of a reliable database has also hampered progress of IPM programmes. A reliable source of accurate information on the status of crops and pests in farmers' fields is necessary for many IPM activities. Most of the successful IPM programmes both in developed and developing countries have a reasonably accurate system of monitoring and evaluating various biological and environmental parameters is the agroecosystem. A reliable data base on crop yield and pest losses is required for planning and resource allocation at the national and international level. Systems analysis has been used as a problem diagnosis tool for IPM in developed-country cropping systems and may be used in the developing countries as well.

(*v*) **Improved awareness.** Increased education and awareness regarding the objectives, techniques and impact of IPM programmes are required at all levels including policy makers, planners, farmers, consumers and general public. The importance and benefits of pesticides are being overemphasized by a multibillion dollar industry utilizing the services of not only their salesmen but also agricultural scientists, administrators and planners. There is not yet a strong market in IPM information. Policymakers and planners need to be convinced that without IPM current agricultural production systems are not sustainable. Similarly, much important information which might induce a farmer to adopt IPM is not immediately observable and is, therefore, not sought by him. A manufacturer has no incentive to recommend a programme that uses less pesticides, or even selective pesticides that kill a limited range of pests (Tarlock, 1980).

Consumer groups and general public may also be able to support the implementation of IPM programmes by demanding residue-free commodities. There is now a distinct market for organically produced food and other products. Non-government organizations (NGOs) and consumer groups need to be strengthened in developing countries, so that there is a public-oriented movement for implementation of IPM.

4.11 POTENTIAL OF IPM

Initially, IPM programmes evolved as a result of the pest problems caused by repeated and excessive use of pesticides and increasing cases of pest resistance to these chemicals. It is only during the past few years that economic and social aspects of IPM have also received increasing attention (Fig. 4.4). Some of the important advantages offered by IPM over the pesticide-based plant protection programmes are listed here (NRI, 1992).

(*i*) **Sustainability.** It is now being increasingly recognized that modern agriculture cannot sustain the present productivity levels with the exclusive use of pesticides. Increasing pest problems and disruptions in agroecosystems can only be corrected by use of holistic pest management programmes.

(*ii*) **Economics.** If the environmental and social costs of pesticide use are taken into account, IPM appears to be a more attractive alternative with lower economic costs.

(*iii*) **Health.** Production, storage, transport, distribution, and application of pesticides involves greater health hazards than the safer inputs used in IPM. In developing countries, it is almost impossible to implement residue limits or waiting periods for pesticides on food products and other commodities. This endangers the safety of the entire population of these countries.

(*iv*) **Environmental quality.** The IPM programmes, do not endanger non-target organisms, nor do they pollute the soil, water and air. The clean air, water and soil are now being recognized as non-renewable resources which once polluted are almost impossible to purify.

(*iv*) **Social and political stability.** The pesticides used by the farmers are obtained from the corporate houses and even from other countries. The inputs used in IPM are usually based on local resources and outside dependence is minimized. This helps in maintaining social and political stability.

(*vi*) **Local knowledge.** IPM builds upon indigenous farming knowledge, treating traditional cultivation practices as components of location-specific IPM practices. This is especially important for the farmers in developing countries where traditional agricultural systems are based on indigenous farming practices. The incorporation of IPM into these practices helps the farmers to modernize while maintaining their cultural roots.

(*vii*) **Export of agricultural commodities.** The presence of pesticide residues is affecting our exports of agricultural and horticultural commodities. There is a growing demand for organically cultivated, fresh and processed fruits and vegetables. The current consumption of organically produced fruits and vegetables at the global level is valued at US $ 27 billion. The Agricultural Producers Export Development Agency (APEDA) of the Union Commerce Ministry, Government of India has proposed to export organically produced fruits, vegetables and their products to a value of Rs 5200 crores annually during the eighth five year plan period. The pesticides in beverages like tea and coffee have affected our exports of these commodities during the last few years. Similar is the case for Vanaspati. There is also a considerable export market for cotton fabrics and garments devoid of pesticide residues in Japan and western countries. Residue-free *basmati* rice is also highly prized in the international market (Jayaraj *et al.*, 1994). Thus, implementation of IPM in these crops will give boost to export of fresh and processed agricultural commodities from India and other Asian countries.

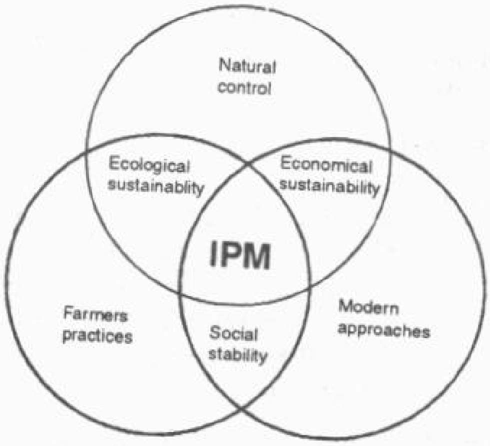


Fig. 4.4 Role of IPM in ecosystem stability (After Dhaliwal and Heinrichs, 1998)