



Integrated pest management: approaches and implementation

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ABSTRACT

Decreasing availability of arable land per unit area due to increasing human population coupled with declining trend observed in the productivity of various crops due to fragmentation of land and decrease in cultivable area exert enormous pressure to meet the required demand of food grains and fibre. It is more evident in the developing world as compared to the developed world. In the present scenario, prevention of losses due to pests is one of the options to meet the challenge of world food security. However, current plant protection practices causes greater danger to environment as well to human health. Implementation of integrated pest management (IPM) technology may be able to address environmental and human health issues, but has not been adopted on large scale. IPM technology has shown promises in reducing pesticide use while improving productivity and profitability, but measuring the success of IPM programmes has become a crucial issue. The decision to adopt a particular IPM activity depends upon the grower's ability and decision to absorb the risk involved in the assessment of prediction of light or severe pest attack. The IPM technology brings not only direct benefits like savings in critical inputs and gains in income in different crops in plant protection measures but also has indirect benefits like improved environment and empowerment of farmers. There is need to make innovative changes in plant protection measures and improve the education of farmers who can fully understand both direct and indirect benefits and risk involved in it. There have been some outstanding development in practical implementation of IPM in the developed world, there remains a critical need for much more appropriate IPM research and its implementation in the developing world. Policy issues such as quarantine and bio-safety and technical gaps such as sound crop husbandry, genetic resistance, biological control, pesticides and availability of critical IPM inputs, research prioritization and popularization may be focused.

Key words: Cultural practices, 'e' pest surveillance, Host plant resistance, IPM, Natural enemies, Pest forecasting, Pesticides

Our agriculture faces two major challenges—production of sufficient food to feed the growing population, and prevention of environmental degradation. Damage by crop pests which include insects, diseases, nematodes and rodents, is one of the major constraints to increase food production. Therefore, reduction in losses caused by pests is the obvious strategy for increased food supply. In addition, quality aspects such as pest-free and residue-free agricultural products are becoming increasingly important in the light of the market liberalization and increasing importance of agricultural exports. Conventional pest control means use of chemical pesticides. However, their excessive and inappropriate use in our agro-ecosystem in the last two decades or so has resulted in degradation of our environment while our pest problems seem greater than ever. There are more and more

reports of resistance of pests to pesticides (Mehrotra 1989, Saini and Jaglan 1998, Alam 2000). Several plant pathogens have also developed resistance against the fungicides and a number of soil fungi (especially the antagonistic ones) and symbiotic bacteria have been adversely affected by misuse of fungicides (Staub and Sozzi 1984). Impact of pesticides on non-target micro-organisms and weed resistance to herbicides is a serious concern, especially because it has developed resistance to different chemical classes (Vaughn 2003). The number of pest outbreaks has increased and many innocuous species have attained the status of serious pests (Elzen and Hardee 2003). The extent of pesticide residues in the environment is also a matter of great concern. Research results have indicated that food commodities are contaminated with persistent pesticide residues (Kalra and Chawla 1981, Agnihotri *et al.* 1994, Agnihotri 1983, Srivastava *et al.* 1995, Arora *et al.* 2006). Hence, there is an urgent need to evolve strategies and technologies that will not only meet increasing demands for food, feed and fibre but also those that will enable us to produce more without

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the problems encountered as stated above.

INTEGRATED PEST MANAGEMENT

The problems of pest control and concern about the indiscriminate use of pesticides in our environment have been the subject of intense debate and discussion. There has been tremendous pressure to devise other methods of pest control that reduce the dependency on synthetic pesticides and reduce residue levels in food commodities. An overarching system that reduces the usage of pesticide is integrated pest management (IPM) that implies to grow high quality produce with minimal impact on human health and environment while providing high economic returns. Agenda 21 of the United Nations Conference on Environment and Development (UNCED) at Rio de Janeiro in June 1992 identified IPM in agriculture as one of the prime requirements for promoting sustainable agriculture and development. The concept of IPM was proposed in sixties (Stern *et al.* 1959) that emphasized the need for simpler and economically safer measures for the pest management (insects, plant diseases, nematodes and weeds) in reducing environmental pollution and other problems caused by excessive and indiscriminate use of pesticides. Strategies of IPM have been developed for the management of major pests of a number of crops. The IPM approaches have succeeded in reducing the use of a number of broad-spectrum pesticides, and studies have shown IPM to be more economical than conventional methods based on chemicals. It aimed at keeping the pest numbers below harmful (economic threshold) levels instead of their eradication, protecting and conserving environment including biodiversity and helped in making plant protection feasible, safe and economical, even for the smaller farmer (Rapusas *et al.* 2009, Dhawan *et al.* 2009, Campbell *et al.* 2009, Sharma *et al.* 2009). Its main advantages are more efficient and low-priced method of management, does not upset the balance in nature, delays the development of resistance and minimizes the residue hazards of pesticides (Stern 1973, Stone and Pedigo 1972). As a part of the sustainable agriculture, IPM must be seen as a component of good agricultural practice (GAP) or integrated crop management (ICM). This essentially includes profitable management of the crop with respect to environment. It is a dynamic system that is suited to local soil, climate and economic conditions. It shall continue to be economical viable in lowering the pest densities in different agro-ecosystems to reduce dependences on pesticide application but future of pest management practices constantly requires a change in landscape or area-wise approaches of IPM (Zalucki *et al.* 2009). Various approaches of IPM are discussed as below.

APPROACHES

Integrated pest management encourages most compatible and ecologically sound combination of available pest-suppression techniques to keep pest populations below economically damaging levels. The IPM concept is based on

the principle that it is not necessary to eliminate all pests but to suppress pest population to a level at which these pests do not cause significant losses. The first line of defense against pests is prevention through the use of good agronomic practices or cultural methods which are unfavourable for the development of pest problems. Regular monitoring of pest activity is essential for decision making in IPM. Selected management measures to check pest are to be taken at economic threshold level (Stern *et al.* 1959, Stone and Pedigo 1972, Stern 1973), a level of pest density at which control measures should be initiated to prevent the increasing pest population from reaching the economic injury level and it justifies the application of control measures. The term economic injury level was criticized and it was argued that term action threshold would be more logical (Stylen 1968). However, the term economic was retained as it will be more easily understood by farmers and thus more appropriate which is lowest density that will cause economic damage (Stone and Pedigo 1972). There is long list of insect species for which economic threshold values are available which have been developed for different climatic regions. However, these values further need adjustments based on the level of host resistance to pest as well as the potential of naturally occurring biological control agents. An adjustable action threshold levels using larval parasitism of *Helicoverpa armigera* in IPM for tomato has been developed (Walker *et al.* 2010). These can help to avoid unnecessary pesticide application (Smith 1969). The IPM strives to optimize rather than maximize pest management efforts. An integrated strategy for crop pest management includes use of resistant varieties, modifying agronomic practices to reduce pest incidence, biological control and other novel approaches for pest suppression, and only need-based and judicious use of chemical pesticides (Fig 1).

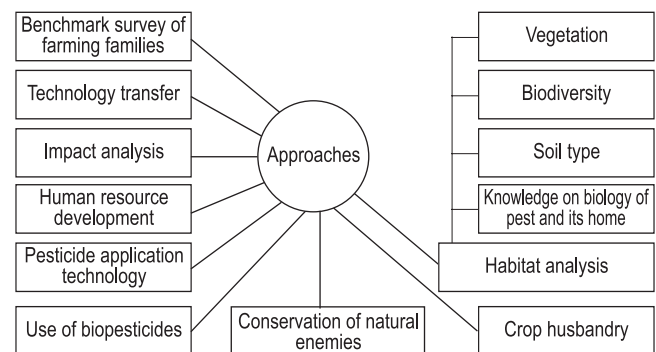


Fig 1 Approaches for successful IPM

Habitat analysis

Severe decline in the crop biodiversity in the intensive modern agro-ecosystem has made it most fragile, unstable and non-sustainable in terms of productivity. There are several evidences of links between insect population stability and plant diversity (Barlow 1983, Rabbinge 1983). The

development of crop habitat management strategies that may conserve and maximize abundance and effectiveness of natural enemies and other beneficial insects and organisms, is crucial in the bio-intensive integrated pest management of crop pests (Kogan 1998). The conservation of natural enemies by the direct enhancement of vegetative diversity has been a subject of intense study for many years. In developing strategies for crop habitat management with a view to conserve beneficial flora and fauna, it is necessary to contrast agro-ecosystems (human dominated) and natural ecosystem. Aggressive use of chemicals has deteriorated soil health, which has to be restored with the help of organic inputs. Natural ecosystems are self-perpetuating, whereas agro-ecosystems are not. Studies of agro-ecosystems during the last four decades have led several agricultural scientists to question commitment of modern industrial agriculture with high intensity of monocultural production. The change in food, shelter, water and intra-species competition in space and time has created numerous environmental problems including pest and their management strategies. Habitat analysis provides an appropriate framework to help understand and perhaps manipulate IPM to provide guidelines for the development of improved strategies (May and Hassel 1988).

Monitoring and forecasting of pests

Pest forecasting provides opportunity to farmers for preparedness and for taking timely action to apply bioagents and pesticides which ultimately cut down cost of production and serve as a tool in precision farming. Pest-forecasting through mathematical and computer-based models deals with perception of the future activity of the biotic agents which adversely affects crop production. Pest forecasting models are essential tools and pre-requisite of IPM, as the insect population and disease incidence levels are deciding factors in the pest management. One of the earliest forecasting works on plant pest was the forecasting of late blight of potato [*Phytophthora infestans* (Mont.) de Bary] by Everdingen (1926) which considered several climatic factors together such as dew during night (at least 4 hr), minimum temperature at night (less than 10°C), mean cloudiness on the following day (more than 0.8) and rainfall in the next 24 hr (minimum of 0.1 mm). In India, one of the earliest works on pest forecasting was started by Pradhan 1967 when he gave the concept of biotic theory of locust population explosion. According to him, temperature is one of the most important factors which determine duration of various stages in insect life-cycle and number of generations. The development of biograph had seen one of the important findings to show the rate of development on different temperature regimes. Later, various other models were developed such as wheat stem rust (*Puccinia graminis tritici* Eriks. E.Henn) rules based on climatological parameters. The main requirements for development of pest forecasting

models are data on weather parameters, pest-population, natural enemies and crop phenology that forms corner-stones in pest management programme (Trivedi and Rajagopal 1989, Rajagopal and Trivedi 1992). An ideal surveillance team should include entomologists, pathologists, nematologists, agricultural meteorologists, modelers and production scientists for collection of data on various aspects. Monitoring of pest population at regular intervals round the year provides quantitative and qualitative data.

During the last several years, forecasting model of various pests such as potato tuber moth [*Phthorimaea operculella* (Zell.)] (Trivedi 1989, Trivedi *et al.* 1994 a), aphid [*Myzus persicae* (Sulzer)] (Trivedi *et al.* 2002), American bollworm [*H. armigera* (Hubn.)] (Das *et al.* 2001), mustard aphid [*Lipaphis erysimi* (Kalt.)] (Chattopadhyay *et al.* 2005, Bhattacharya *et al.* 2007, Dhaliwal *et al.* 2007) have been developed and for other polyphagous pests need to be fine-tuned based on the local factors before field application. Most of the diseases in which forecasting service has helped the farmers (Singh *et al.* 2004) are late blight of potato [*P. infestans* (Mont.) de Bary], blast of rice (*Pyricularia oryzae* Cavara), stripe rust of wheat (*Puccinia striiformis* Westend.), leaf rust of wheat (*Puccinia recondita* Roberge ex Desm.), downy mildew of grapevines [*Plasmopara viticola* (Berk. & Curtis ex de Bary) Berl. & de Toni] and apple scab [*Venturia inaequalis* (Cooke) Winter in Thum.]. Such simpler forecasting models are of immense use in preparedness for executing plant protection decisions by small-size farmers in developing world in comparison to expert system or decision support systems developed for large-size farmers in the developed world which are of little use (Day *et al.* 1996).

Biological approach

All pests have natural enemies which limit their reproduction, growth and population. Conservation of these natural enemies is the essential part of the strategy of biological control. Additionally, there are methods to augment these natural enemies in the agro-ecosystems. This is done by mass producing and releasing biotic-agents to suppress pest population to desired non-damaging levels. The commonly used bioagents include parasitoids, such as *Trichogramma* sp. and predators, such as *Chrysoperla* sp. and coccinellid beetles. The management of natural enemies to reduce pest population and its effect is one of the most important components of our pest management strategy.

Conservation and augmentation of natural enemies: The conservation of natural enemies is the most important consideration in biological control because if they are conserved, the need for other control measures is greatly reduced (Thompson 1956). Conservation means avoidance of measures that destroy natural enemies and promote measures that are conducive for their reproduction and development. Avoiding indiscriminate use of broad-spectrum

pesticides over large areas, adjusting spray schedules so as to cause minimum harm to natural enemies and encouraging natural enemy activity, and growing plants that attract natural enemies are some of the methods of conservation. This was amply demonstrated by adjusting the spray schedule which permitted vedalia beetle [*Rodolia cardinalis* (Mus.)] to regain control of cottony-cushion scale [*Icerya purchasi* (Mask.)] (Caltagirone and Douth 1989). The killing of predacious mites on many crops by the application of pesticides encouraged the phytophagous mites to become pest (Huffaker *et al.* 1969). One of the most successful examples of conservation of natural enemies is the collection and preservation of *Epiricania melanoluca* (Fletcher), which is a potential nymphal and adult parasite of sugarcane leaf hopper (*Pyrilla perpusilla* Walker), at the end of the season and augments its releases at the beginning of the next season (Pawar *et al.* 2002). With this method large number of parasites are conserved, which otherwise perish due to non-availability of food during long dry hot summer. Sowing coriander (*Coriandrum sativum* L.) or marigold (*Tagetes* sp.) in vegetable fields increases the activity of syrphid flies which predate oil aphids and other soft-bodied insects. Conservation of spiders and other natural enemies by avoiding pesticides use is the most important aspect of IPM in rice (*Oryza sativa* L.). While planning of implementation of biological control strategies, natural mortality factors may be identified by developing life-table of a pest that provide insight into its survival potential (Birch 1948a, 1948b, Dempster 1956, Trivedi *et al.* 1994b).

Biorationals: Natural products have enormous potential as safe and biodegradable pesticides. The main feature of biorationals is their increased specificity to avoid non-target mortality and other associated problems. The use of biorationals is an important component of our IPM strategy. Other than margosa or neem (*Azadirachta indica* A. Juss.) which have been shown to be effective against a number of pests (Kumar and Parmar 1998) are nuclear polyhedrosis virus (NPV) and *Bacillus thuringiensis* Berliner which has gained importance in suppressing pests in crops like cotton (*Gossypium* sp.) and vegetables (Emden and Peakall 1996, Bateman and Thomas 1996). The production technology for many of the botanicals and biopesticides is available and the efficacy of these in management of various pests and diseases has been demonstrated in large-scale field trials.

Botanicals as arthropod toxins (insecticides, nematicides, feeding deterrents, growth and metamorphosis disrupt), allelochemicals and phytoalexins are well established (Pickett *et al.* 1997). Several living systems such as nerve axons and synapses (pyrethrum, nicotine, rotenoids), hormonal balance (jurabione, farnesal, sesamin, sesamol as JH analogues; polypodine, ptersterone, precocenes I and 11 as JH-antagonists and plumbagine as moulting hormone), reproduction (B-arrone), behaviour (engenol-attractant; bixin-repellent; aziracitin-antifeedant) are reportedly affected

by them, underlying their potential that has been highlighted in view of the alliance of various undesirable effects such as pest resistance, outbreak of secondary pests, pest resurgence, adverse effects on non-target organisms, the problems of residues, user and consumer hazard (Ridgeway *et al.* 1990). Pyrethrum (Asteraceae), rotenone (Leguminosae) and nicotine (Solanaceae) obtained, respectively, from *Chrysanthemum*, *Derris* and *Nicotiana* species have been the most extensively used botanicals in the past. All the three of these compete for space and with other cultivated groups for their production. This limits their availability and use in practical pest control. Of the 59 plant families shown to have potent anti-insect activity, the Meliaceae has received most attention, particularly the neem tree, which is widely grown in India. Its active constituent, azadirachtin, is a limonoid with antifeedant, growth regulatory and reproductive effects. Margosa or neem has offered itself to be the most viable botanical alternative for pest management (Mordue and Blackwell 1993). It has all the attributes of an ideal input in the IPM. The key limitation in the use of botanical pesticides are poor raw material base, lack of agro-technology, cost-prohibitive products and technology, product standardization, lack of multi-spectrum use, inadequate research and development, IU defined role in IPM and unclear policy.

Use of sex attractants or pheromones, insect-growth regulators and repellents, are some of the other novel approaches. Pheromones offer interesting new possibilities in pest management. Besides monitoring the changes in pest populations and assisting in timing of application of pesticides, they are also now being used for pest management as mating disruption lures also known as PBW Ropel for American boll worm [*H. armigera* (Hubn.)] and pink bollworm (*Pectinophora gossypiella* Saunders) in cotton-growing areas of the world (Patil *et al.* 2007). They need to be promoted, so that the spray of pesticides can be reduced down. The pheromones are also used in traps to lure and destroy insects. The pheromone-mediated field application technology has been amply demonstrated (Minks and Kisch 1998) in several instances such as fall armyworm [*Spodoptera litura* (Fabr.)], diamond-back moth [*Plutella xylostella* (L.)], yellow-stem-borer [*Scirpophaga incertulas* (Walker)], pink bollworm (*P. gossypiella* Saunders) and *H. armigera*. The use of pheromones has been instrumental in increasing the effectiveness of both monitoring insect populations and in providing adequate information to enable implementation of cost-effective control. At least, 46 different types of pheromones are available commercially for use in pest management (Cropping 1998).

Host plant resistance and transgenic crops and varieties

Cultivating plant varieties which are less prone to pest attack is an important strategy in IPM. These resistant varieties reduce production cost; require less control by limiting the damage throughout the crop season. Though there is no

detailed estimates of the economic benefits of pest-resistant crops, numerous such crop-specific examples exist that envisage their economic benefits (Painter 1951) barring a few insect biotypes may develop capability of survival and damaging resistant varieties which are otherwise resistant to populations of some pest species. With the development of resistance by the pests to pesticides and failure in adoption of developed and validated IPM technologies there is renewed interest of the scientific community in breeding resistant cultivars to pests and it has contributed immensely to sustainable crop production world-wide (Khush and Brar 1991). Host plant resistance along with natural enemies and cultural practices can play a major role in implementation of crop-specific IPM technologies (Dhaliwal and Singh 2004). Contribution made by resistant material in avoiding yield losses is quite significant and cannot be written off, especially in case of cereals, oilseeds and pulses (Dhaliwal and Singh 2004). Use of resistant varieties not only helps us to avoid losses but also encourages the survival of natural enemies in terms of both microbes (fungal and bacterial) and insects (Sharma and Ortiz 2002). Developing single or multiple gene-based resistances against key pests got priority over other parameters (Prins and Zadoks 1994). However, there may be problems if we rely exclusively on plant resistance for insect control, for example, high level of resistance may be associated with low yield potential or undesirable quality traits, and resistance may not be expressed in every environment wherever a variety is grown.

Recent breakthroughs in biotechnology and genetic engineering have opened new vistas for developing resistant cultivars. The introduction of novel genes for pest resistance into crop plants from unrelated plants and micro-organisms is an exciting development. Protocols are now available for transformation in many crops. The best known example is the incorporation of genes which produce *Bt* endotoxins into crops like cotton (*Gossypium* sp.), rice, maize (*Zea mays* L.), tobacco (*Nicotiana* sp.), tomato (*Solanum esculentum* L.) and potato (*Solanum tuberosum* L.). Biotechnology is globally recognized as a powerful tool of plant and animal genetic modification (GM) that holds promise of improving productivity, profitability and sustainability of farm production systems, including those existing in small and poor farming situations (Cohen 2005, Brookes and Barfoot 2006). Performance of *Bt* cotton, bred through biotechnology tools showed that the number of sprays required for bollworm management was much lower for *Bt* plots, i.e. 1.44 for *Bt* versus 3.84 for non-*Bt* during 2002 and 0.71 for *Bt* versus 3.11 for non-*Bt* (Bennett *et al.* 2004, Bambawale *et al.* 2010), besides cutting the cost of cultivation and savings on-farm labour and environment degradation. In China, net revenue increase from cultivation of *Bt* cotton ranged from \$357 to \$549 over a three-year study period (Pray *et al.* 2001). Application of GM technology for commercial crop production is confronted with a number of issues and

challenges, the most important being safety of environment, human and animal health (Philippe 2007). These concerns are based on the argument that recombinant DNA-based GM technology differs from traditional breeding in that totally new genes using potentially risky technology are transferred between widely unrelated organisms, and the location of these genes on the recipient genome is random, unlike when gene transfer takes place through conventional breeding. These differences demand that adequate laboratory safeguards are used and plants developed by GM technology are rigorously assessed. Some specific concerns associated with transgenic flow include development of new weeds, erosion of genetic diversity in wild and weedy relatives of crop plants and development of antibiotic resistance in pathogenic microorganisms (Snow and Palmer 1997). In spite of the concern raised about the GM crops, the global area under cultivation of GM crops has now increased significantly from 1.7 million ha in 1996 to 125 million ha in 2008, with 25 countries growing GM crops including 15 developing countries and 10 industrial countries (Qaim 2009). Past experience with toxic pesticides has made many developed and developing countries fearful and there is renewed concern about the safety of GM crops worldwide.

Crop husbandry

Cultural control is the oldest and the most effective method of pest suppression. Cultural methods such as deep ploughing and burning of crop residues; soil solarization; synchronous planting of crop fields; planting trap crops (Shelten and Badenes-Perez 2006), cover crop (Atanassov *et al.* 2002), crop rotation, tillage; and use of pest-free seeds and planting material are effective methods to reduce pest load (Fig 2). Protection of high-value or small-area crops by fencing or screening is a common practice. Physical methods of pest control involve manipulation of temperature, humidity, use of energy and sound. Growing different crops in a rotation helps in reducing the build-up of certain pests, especially those in the soil, such as root feeders, fungal pathogens affecting the root system and nematodes (Singh *et al.* 2002). Crop rotation also breaks the pest cycle, reducing the incidence of insect pests and diseases. Lower incidence of insect pests was found on legumes intercropped with maize. Intercrops of spinach (*Spinacia oleracea* L.) and tomato (*Lycopersicon esculentum* Miller nom.cons.) reduced the incidence of cabbage aphid (*Brevicoryne brassicae* L.), and mustard as a trap crop decreased the incidence of diamond-back moth in cabbage [*Brassica oleracea* L. convar. *capitata* (L.) Alef. var. *capitata* L.] / cauliflower [*B. oleracea* L. convar. *botrytis* (L.) Alef. var. *botrytis* L.] substantially (Srinivasan and Krishnamoorthy 1991). Incidence of pod borer (*H. armigera*) got reduced in tomato growing marigold as trap crop (Srinivasan *et al.* 1994) and also in chickpea (*Cicer arietinum* L.) when grown in association with barley (*Hordeum vulgare* L.), mustard (*Brassica* sp.), linseed (*Linum usitatissimum* L.)

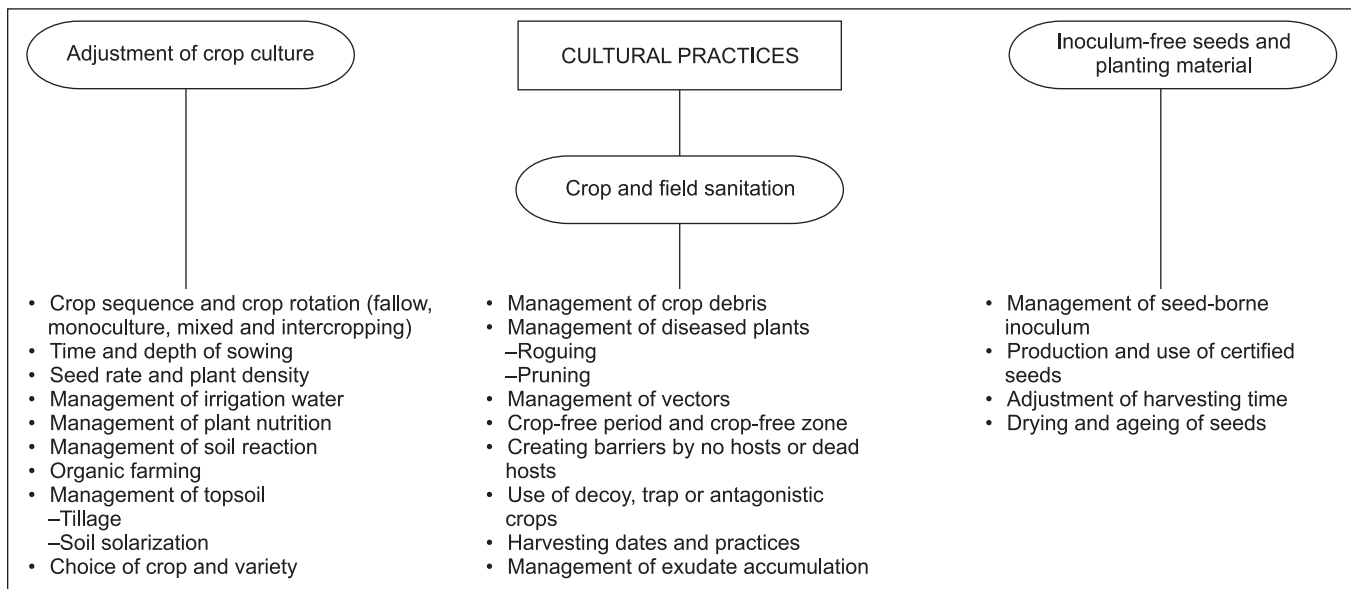


Fig 2 Disease management through cultural practices

or coriander. Incidence of chickpea wilt and root rot of pea were considerably reduced when planting was delayed.

Sanitary and phytosanitary measures

Pest problems are often induced by human activity. The increased movability of people and goods bring with it an increased likelihood of movement of species around the planet, either deliberately in the form of commodities such as livestock, pets, nursery stock, and produce from agriculture and forestry, or inadvertently as species are transported as unwitting passengers in packaging, ballast, and on the commodities being traded. This has resulted into introduction of alien species tearing down the natural barriers (Wittenberg 2005). Some of them become harmful and pose threat to environment and human population. These so called invasive alien species are increasingly recognized as potential threat to biodiversity. Weeds are predominant group of invasive alien species known to cause economic problems as well as deleterious effect on the environment. Interestingly alien insects and diseases despite their diversity have also been shown to have adversely affected the environment as well agriculture. Quarantine laws and other regulations have been promulgated in many countries including India to overcome these problems. Constant vigilance is needed to keep off pests which do not occur naturally. A list of measures has been suggested to ward-off from the dangers posed by invasive alien species (Wittenberg and Cock 2001). Not all alien species are harmful, some of them are economically beneficial for the mankind, and therefore the effective risk analysis for bilateral and multilateral agreed standards is essential for agricultural development. There has been great interest in sanitary and phytosanitary measures (SPS) under the world trade agreement. The infrastructure and SPS measures for

quarantine stations with the help of the FAO have been further improved and the process is on for improvement in various countries. Borlaug Global Rust Initiative for world's vulnerability to stem rust, yellow and leaf rust of wheat is one of the important initiatives to check spread of rust. A list of pest species that are potential threat to world's biodiversity has been prepared that can be used to ensure pest-free trade (Panetta *et al.* 1994).

Pesticides and their management

There has been considerable debate on the role and need for pesticides. In fact emotional pronouncements and demands for legislation to ban the use of pesticide have left the public confused regarding the role of pesticides in agriculture and public health and their effect on environment. The pesticide problem is the result of man having placed excessive demands on a finite environment. It is a typical example of pollution—the cause being the number of people and the standard of living they demand, and the symptom being damage to ecosystem from persistent synthetic chemicals. Synthetic organic chemical pesticides are biological poisons and none is absolutely specific, therefore they have harmful side-effects when released into the environment and risk arising out of their use must be properly understood (Higley and Wintersteen 1992). The possible effects are direct toxicity to applicator or consumer, development of strains or pests resistant to pesticides (Brown 1968, Metcalf 1980, Bhatia 1988, Kranthi *et al.* 2002), resurgence of pest species, outbreak of secondary pests such as mealy bug in cotton (Jeyakumar *et al.* 2008), destruction of non-target organisms such as parasites and predators, honeybees and other pollinators, fishes, birds and other wildlife; and accumulation of harmful residues on crops, humans, animals, wildlife and the

environment including soil and water.

The detection of high amounts of pesticide residues in our environment is alarming. Many food commodities are contaminated with persistent pesticide residues (Shah *et al.* 2000, Kole *et al.* 2002, Cesnik *et al.* 2009, Islam *et al.* 2009). Widespread contamination of bovine milk, butter, milk products, brands of baby milk powder, vegetables and even mothers' milk with DDT and HCH residues above the maximum residue limits were encountered (Kalra and Chawla 1981, Agnihotri *et al.* 1994, Agnihotri 1983, Rupa *et al.* 1989a, Rupa *et al.* 1989 b). This is very disturbing. The main reasons are misuse and malpractice of pesticides, including unwanted and unwarranted spraying; poor equipment and poor or no training in safety procedures; and finally the inability of the enforcement agencies to prevent the sale of spurious material in the market. Because of these reasons, demand for synthetic pesticides has been declining globally; the growth of the synthetic pesticide market has also been marginally affected due to the introduction of biopesticides. Global pesticide market was worth \$27 144 million in 2003 that declined to \$24 205 million in 2010 (Thakore 2006).

Management of pesticide use is an integral part of IPM. Our priority is to refine the pesticide application recommendations to reduce their use to the absolute minimum. Safe and judicious use of pesticides is the most important. Often the pesticides are used routinely as a form of insurance rather than a graduated response, where yields are relatively high and predictable, because farmers have enough disposable income to purchase pesticides forcing entry into pesticide treadmill (Collins *et al.* 1992, Litsinger *et al.* 1980). Quality control of pesticides both as technical products and in the ready-to-use formulated stage is vital for the success of any plant protection operations. Economic threshold is a dynamic process and is mainly dependent on cost, plant protection and commodity (Pedigo and Higley 1986, Pedigo *et al.* 1986). Therefore, the suggestive threshold levels are indicative for decision-making. Careful attention must be given to pesticide application techniques. Most spray application methods conventionally used though quite effective are wasteful and inefficient. Good pesticide application techniques can reduce amounts of pesticides applied, prevent contamination and pollution of soil and water, thus minimizing the danger to environment and health.

PRACTISING IPM

Crop- and region-specific IPM programme have been developed and practised world-wide where different control tactics have been combined to suppress pest densities (Ahuja *et al.* 2009a, Naved *et al.* 2008a, 2008b, Sharma *et al.* 2008). The potential strength and contributions of the IPM are often not realized. Policy-makers, donor representatives, researchers and the users of IPM are not always satisfied with the actual achievements in terms of demonstrable and quantifiable results. It is primarily due to the limited knowledge about the

economic and environmental impacts of the adoption of IPM. Since many IPM initiatives involve public funds that have opportunity costs, one needs to show that investment in IPM programmes pay-off. This raises the question of what components should be in an IPM initiative, i.e. to what degree farm level activities should be complemented by policy measures. The IPM technology would bring not only direct benefits like savings in critical inputs and gains in income in different crops in plant protection measures but also indirect benefits like improved environment and empowerment of farmers (Antle and Pingali 1994, Cornejo 1998). But the most common economic analysis of integrated pest management practices at the farm level focuses on the choice of alternative for pest control. Profitability is the most important factor in choosing IPM programme. The decision to adopt a particular IPM activity depends upon the producer ability and decision to absorb the risk and in the assessment of prediction of light or severe pest attack. For example, if a farmer is risk averse and is unduly skewed towards severe pest attack, he may still choose the spray approach in spite of the fact a large number of studies have shown that IPM programme can reduce pesticide use while improving productivity and profitability (Ahuja *et al.* 2009b, Prasad *et al.* 2009, Pandey and Singh 2008, Dash *et al.* 2006, Singh *et al.* 2007). Hence, the question of measuring success of IPM programmes becomes crucial. To achieve this objective, the primary data need to be collected from adopted IPM villages with the help of questionnaire and rapid rural appraisal (RRA)/ participatory rural appraisal (PRA) techniques. This would help in understanding production system and practices adopted by farmers of that region and the problems related to plant protection. Impact assessment studies bring out factors responsible for non-adoption of IPM technology at farm, household, village, institution levels. Constraint analysis may help in suggesting policy measures for empowerment of farmers and policies for promotion of IPM at the national level. Then impact assessment studies for calculation of indirect benefits should also be done for IPM technology for socio-economic factors, changes in biodiversity and environment. The studies on biodiversity and environment will also be of great value in assessing the socio-economic impact of the technology.

EMERGING ISSUES

The identification and diagnostic services of pests and their hosts with the support of GIS, biotechnological tools, ELISA kits (Mumford 1982) and e-pest atlas are some of the important areas that need to be developed for larger application and practice. Since pesticide application technology and safety measures have not been well understood in the changing climate patterns, especially with reference to persistence and dissipation of chemical pesticides, particle size, drift and impact on non-target animals, need a thorough understanding. The status of pest and natural enemies in protected cultivation

under greenhouse and polyhouses has not been fully studied; therefore attention of researchers and managers is required.

Education and training

In view of the WTO requirements concerning pesticide residues in edible commodities and in the context of changed scenario of environmental security, people need to be educated about IPM at all levels right from school stage. Among different factors affecting the adoption of IPM, education outreach, farm size, and farm ownership of the end-users generally regarded as the key issues in successful implementation of the IPM (Wearing 1988). A recent study conducted in India, indicated that information seeking behaviour, land holding, socio-economic status, extension participation, risk orientation, economic motivation, management orientation and innovativeness were found important factors in adoption of IPM programme (Yadav *et al.* 2007). Farmers' participatory trainings (FPTs) have had greater success in achieving IPM implementation (Way and Emden 2000). In India also training through farmers field school (FFS) tend to change the attitude of farmers which indicated that farmers trained through FPT tend to adopt IPM technology and have favourable attitude towards IPM in comparison to untrained farmers (Krishnamurthy and Veerabhadraia 1999). User-friendly software on IPM, i.e. Pest Management Information System (PMIS), needs to be developed for training of master trainers and farmers, IPM resource manual for village institutions, diagnostic services for pest and natural enemies on farmers' channels in television on prime time; and emphasis should be given on higher returns to farmers.

Research

There are many tracking technologies that have shown promising results for management of individual pest problems in different crops but there is a need to synergize, simulate, develop and validate all research findings into adoptable modules. World over, there are many examples of successful implementation of IPM module in cotton (Dhawan *et al.* 2009, Amara 2009), rice (Rapusas *et al.* 2009), vegetables (Cameron 2007, Loehr *et al.* 2000, Sharma *et al.* 2009, Rahman *et al.* 2006), pigeonpea (Kumar *et al.* 2008), fruits (Bentley 2009) and oilseeds (Virupakshapp *et al.* 1999). Adoption of IPM module resulted in drastic reduction in pesticide application and higher profitability. In India a series of generic IPM modules have been developed which can be assessed logging to <http://dacnet.nic.in/ppin/ipmpakpra.htm>. Since IPM is knowledge-intensive, its successful implementation requires education, forecasting of pest epidemic, skill in pest monitoring and understanding of pest dynamics. Also as a result of changing climate, pest risk analysis (PRA) has become important as several new commodities will enter market globally under the new WTO regime sanitary and phytosanitary issues are important and

need to be studied (Kheterpal and Gupta 2003). Research efforts are to be made to develop appropriate cultural tools, i.e. deep summer ploughing alone has been found to be effective for management of several pests such as wire worms, cutworms or root grubs (Robertson 1993), fruit flies in various guards (Joshi *et al.* 1989) or adjusting the date of planting as observed in rapeseed-mustard (Karoly *et al.* 1996) or to conserve and promote natural enemies of pests as evident in case of management of *Pyrilla perpusilla* in sugarcane by conserving *Epiricania melanoleuca* (Pawar *et al.* 2002). Biopesticides have been gaining steadily during the decade from insignificant share of 0.2% in the world pesticide market to 4.2% in 2010 as these offer several advantages over traditional chemical/synthesized pesticides in terms of safety, specificity in targeting the pest, decompose quickly, and also techniques for mass production, storage, transport, and application of pesticides have been developed (Thakore 2006). Greater efforts on researches like detection of development of resistance in pests to pesticides through molecular, biochemical and immuno-chemical approaches offers discrete advantage over the traditional method of detecting resistance in insects (Karoly *et al.* 1996). Developing on-line pest-forecasting systems by taking into account biological inputs, crop phenology, natural enemies and weather, and IPM news, should be researchable issue and need to be undertaken on priority (James and Edwin 1995).

Popularization

Implementation of IPM practices by growers has been less than expected by the developer of IPM. The key may be the difficulty the grower face in obtaining the information they need to make IPM decisions and interpreting the desired information and the difficulty the growers have in integrating and interpreting the information when it is obtained. New technologies such as expert systems, information and communication technology and simulated weather information can make IPM decision making easier for growers and its implementation popular (James and Edwin 1995). Information and communication technology (ICT) is an umbrella term that includes any communication device or application, encompassing electronic communication. It includes use of radio, television, cellular phones, computer and network hardware and software, satellite systems and so on, as well as the various services and applications associated with them, such as videoconferencing and distance learning. Crop-based software such as PMIS (pest management information system) have been developed and released for use by researchers, master trainers, training organizers and extension workers as an instructional and educational media. Kiosks may be opened in villages to function as the Discussion Forum for farmers for dissemination of information on IPM technology. Simulated weather information allows growers to effectively use, accurate, timely, site-specific weather information in their day-to-day decision making without the

cost and time required to operate their own on-farm weather monitors. Truxall and Travis (1994) have found that the simulated weather information results in same management of apple scab as provided by on-site weather monitoring units. Decision making software such as pesticide advisor for their judicious use has also been developed and is being used (Singh *et al.* 2006). Farmers adopting IPM and getting higher yields need to be suitably rewarded. More coverage on IPM needs to be given in print as well as electronic media. More and more call centres may be opened for easy access by farmers for sorting out their problems related to plant protection. Other core issue involved in IPM popularizing with farmers is the availability of critical inputs to them at the appropriate time.

Prioritization

The ample knowledge support, generic IPM modules for the management of pest, and mass multiplication technology for bioagents are available but a wide gap is visible between technology generators and users. Therefore, the strategic approach with multi-institutional support is essentially to be strengthened for the development of IPM practitioners in different agro-ecological regions. The challenge is to identify commercially viable technologies and to make them available to end-users for adoption leading to development in a much faster way. The process of technology dissemination for wider adoption includes developing the capacity to harness potential technologies of production and protection, achieving quality improvement with setting-up of referral laboratories for pesticide residues. To make IPM relevant, issues of education and training, IPM research, IPM popularization, availability of quality inputs and appropriate policy framework are extremely important (Way 1977). The labelling of food and food products grown under IPM umbrella has yet to be started, so that farmers can get the premium price for their produce on the lines of approach being followed for organic farmers. The stability of effectiveness of plant products as pesticides, establishment of biocontrol units, increase in shelf-life of bioagents and market network for biopesticides need to be improved considerably. As the pest management has been mainly based on tritrophic levels (host, pest, and natural enemies), the four-tiered approach (action thresholds, monitor and identify pest, prevention and control) would be effective for increasing the profitability and cutting down the cost of pest management. The IPM net calendar and the institutions dedicated to IPM are the National Centre for Integrated Pest Management (India), IPPC (USA) and British Crop Protection Centre (Europe) .

CONCLUSION

The sustainability and stability of our agro-ecosystems will continue to be threatened by pests. Increases in crop yields in the country are rapidly reaching a stage of diminishing returns. The pest scenario in the years to come

is expected to undergo considerable changes. The factors that are likely to govern such changes are intensification and diversification of agriculture, climate change, introduction of exotic plants and cultivars and genetic manipulations for development of new plant types across gene barriers. Economic consideration may result in crop shifts, increased seed imports and also increased use of chemicals per unit area. Liberalized seed policies may lead to introduction of low levels of resistance to biotic stresses. Though it may not be possible to foresee the exact pest scenario with respect to any specific crop, the current trend indicates that the complexity of pests will increase and pest outbreaks are likely to be more frequent in the future. The resurgence problems, specially in the case of sucking pests such as aphids, white-flies and jassids, will increase with continued use of pesticides and nitrogenous fertilizers. The problem of resistance to pesticides is likely to become even more acute. Hence, integrated pest management will, therefore, be the key to provide sustainable and environmentally sound plant protection. It may be understood that adoption is not a discreet and dichotomous event by which one move from non-adopter to adopter by a single step but involves series of steps.

The basic approaches in pest management in future are not likely to change, though the balance may shift. These are, quarantine, sound crop husbandry, genetic resistance, biological control and pesticides. Future pest control technologies will essentially be refinements or modifications of tactics presently available to us such as biological, cultural and chemical. New techniques that are emerging from research in molecular biology, including the ability to selectively move genes among organisms, provide opportunities for manipulating desirable properties in living organisms in such a way as to greatly increase their usefulness in biological-based methods of pest control. Therefore, biotechniques can be expected to increase the number of situations in which biorational will be able to provide competitive and acceptable methods of managing pests.

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