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Integrated pest management, progress and future

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Abstract
India has successfully reduced pesticide consumption without adversely affecting the agricultural productivity by appropriate policies that discouraged pesticide use and favored IPM application. Adoption of IPM is low owing to a number of socio-economic, institutional and policy constraints, like lack of commercial availability of biopesticides and inappropriate institutional technology transfer mechanisms. Farmers are aware of technological failure of pesticides to control pests, and their negative externalities to environment and human health exposure. Leading to consequences that the pest risk is too high to conduct experiment with newer IPM approaches. Since, IPM is a complex process and the farmers lack understanding of its approaches and methods of application of new technology components. The socio-economic and the environment of farming is also an important factor in adoption of IPM that works best when applied by the entire community in a synchronized mode. This is unlikely to happen without front-line demonstration and support to farmers. However, many IPM technology programs are based on community approach, and the new IPM policy of India should provide incentives to farmers in future to adopt IPM as a cardinal principle of plant protection. Therefore, in this review we highlight the IPM, its progress and the future strategies to adopt so as to control the yield loss by insect pests.

Keywords: insect, management, control, environment, chemical

Introduction
Crop protection is the study and practice of managing insect pests that damage agricultural crops, forestry and social forestry (Dar, 2017) [12] and thus affect economic value and agri-market (OMICS, 2017; Kumar and Kalita, 2017) [29, 25]. It deals with pesticide-based program including herbicides, insecticides, rodenticides and fungicides. India's population has been growing at an annual rate of 1.9 percent (WBG, 2017) [43], and is expected to touch 1.3 billion mark by 2020. At this rate of population growth, the country would require an additional food grain of about 2 million tons a year (Paroda, 1999) [31]. Although in the recent decades, India has achieved self-sufficiency in food grain production, concerns of food security will remain as ever, as the scope to bring additional land under cultivation is limited and the agricultural production technology has started showing signs of fatigue (Sen, 2017), and has been accompanied by the degradation of natural production of resources (UC-SAREP,2017). Not with standing these facts, the incremental production has to come from productivity increases without damaging the ecological foundations of agriculture. This underlies the need for generation and diffusion of new technologies that produce sufficient food and protect the environment and human health. According to the noted agricultural scientist, M. S. Swaminathan (1999) [37], agriculture production systems in the 21st century need to be based on the appropriate use of biotechnology, information technology and eco-technology.

According to USA Environmental Protection Agency (2017), IPM is an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. A burgeoning literature on insect pest management (IPM) has arisen since 1959 when the term Integrated Pest Control was defined (Stern *et al*., 1959) [36]. The term Integrated control was coined by Bartlett (1956) [4] as the blending of biological control agents with chemical control measures. However, Pesticides should not be relied on as a primary method of pest control. Smith (1976) [36] defined IPM as a multi-disclinary ecological approach to the management of pest population, which utilizes a variety of control tactics compatibly in a single coordinated pest management system. While as, the Dhaliwal and Arora (2005) [14] defined it as a dynamic and constantly evolving approach to crop protection in which all the suitable management tactics and available surveillance and forecasting informations are utilized to develop holistic management programme as a part of a suitable crop production technology. However, based on analysis of 64 defections, Kogan (1998) [22] defined IPM as a decision support system for the selection and use of pest control tactics, singly or harmoniously co-ordinated into a management strategy, based on cost /benefit analysis that take into account the interests of and impacts on producer, society and the environment.

Integrated pest management: The IPM Program collaborates with faculty and Extension educators to develop diverse information serving growers of many crops, the landscape/turf "green" industry, and those looking for home and garden pest solutions (MSU, 2016) [26]. IPM is such a technology whose benefits of adoption are marginally higher than conventional chemical pest control. Insect pests, diseases and weeds are the major constraints limiting the agricultural productivity growth. It is estimated that herbivorous insects eat about 26 percent of the potential food production. Emerging problems of insecticide resistance, secondary pest outbreak and resurgence further add to the cost of plant protection. Annual crop losses due to insect pests and diseases in India are estimated to be 18 percent of the agricultural output (*Helicoverpa* spp. in cotton causes losses up to 50 percent). According to Raheja and Tewari (1996) [32], *H. armigera* (American bollworm) alone causes an annual loss of about Rs1000 crores. The production losses have shown an increasing trend over the years. The most damaging cotton pests are those that attack squares and bolls such as the cotton bollworm, tobacco budworm, pink bollworm, boll weevil, and lygus bugs. Yield losses due to bollworm/budworm complex are typically higher in bloom stage, and bollworm and tobacco budworm can cause yield losses of 67% (Renneberg and Loroch, 2017) [33]. In1983, the losses due to insect pests were estimated worth Rs 6,000 crores (Krishnamurthy and Murthy, 1983) [24], which increased to Rs 20,000 crores in 1993 (Jayaraj, 1996) and to 29,000 crores in 1996 (Dhaliwal and Arora, 1996) [15]. New pests have appeared due to the changes in the cropping patterns and the intensive agricultural practices. Until the beginning of 20th century, farmers relied exclusively on cultural practices such as crop rotation, healthy crop variety, manipulations in sowing dates, etc. to manage the pests. Use of pesticides, although began in 1870s with the development of arsenical and copper-based insecticides, discovery of pesticidal properties of DDT during the World War II revolutionized the pest control. The negative externalities of chemical pesticides, however, started emerging soon after the introduction of DDT. Producers then turned to the more recently developed and much more toxic, organophosphates (OP) and pyrethroid insecticides, which resulted in development of resistant strains e.g., in *Bemisia tabaci* (Naveen, 2017) [27]. With natural enemies eliminated by pesticides, it is difficult to prevent or recovered pest populations from exploding to higher and more damaging levels, and often developing resistance to chemical pesticides. Repeated applications of chemical pesticide repeat this cycle. Indiscriminate, excessive and continuous use of pesticides acted as a powerful selection pressure for altering the genetic make-up of the pests. Naturally resistant individuals in a pest population were able to survive on slaughts of the pesticides, and the survivors could pass on the resistance traits to their generations, therefore making the problem more worse (Gut, 2017) [17].

How IPM works?

IPM is not a single pest control method but, rather, a series of pest management evaluations, decisions, and controls (MSU 2016) [26]. In practicing IPM, growers who are aware of the potential for pest infestation follow a four-tiered approach. The four steps include:

(1) Action thresholds: Before taking any pest control action, IPM first sets an action threshold, a point at which pest populations or environmental conditions indicate that pest control action must be taken. Sighting a single pest does not always mean control is needed. The level at which pests will become an economic threat is critical to guide future pest control decisions.

(2) Monitoring and identifying pests: Not all insects, weeds, and other living organisms require control. Many organisms are innocuous, and some are even beneficial. IPM programs work to monitor for pests and identify them accurately, so that appropriate control decisions can be made in conjunction with action thresholds. This monitoring and identification removes the possibility that pesticides will be used when they are not really needed or that the wrong kind of pesticide will be used.

(3) Prevention: As a first line of pest control, IPM programs work to manage the crop, lawn, or indoor space to prevent pests from becoming a threat; therefore, increasing the total output from the field (Fig 1). In an agricultural crop, this may mean using cultural methods, such as rotating between different crops, selecting pest-resistant varieties, and planting pest-free rootstock. These control methods can be very effective and cost-efficient and present little or no risk to people or the environment.

(4) Control: Once monitoring, identification, and action thresholds indicate that pest control is required, and preventive methods are no longer effective or available, IPM programs then evaluate the proper control method both for effectiveness and risk. Effective, less risky pest controls are chosen first, including highly targeted chemicals, such as pheromones to disrupt pest mating, or mechanical control, such as trapping or weeding. If further monitoring, identifications, and action thresholds indicate that less risky controls are not working, then additional pest control methods would be employed, such as targeted spraying of pesticides. Broadcast spraying of non-specific pesticides is a last resort.

Intensive agriculture and pesticide use in India

Intensive farming or intensive agriculture also known as industrial agriculture is characterized by a low fallow ratio and higher use of inputs such as capital and labour per unit land area. This is in contrast to traditional agriculture in which the inputs per unit land are lower (Anonymous 2016). In India, pesticide use has been increasing at an annual rate of 2.5 percent since early 1970s. About 96,000 tons of technical grade pesticides are currently produced in the country (CARE, 2017) [6], of which two-thirds are used in agriculture (Khader Khan, 1996) [21]. The adoption of the high yielding cereal varieties led to manifold increase in the crop yields. Maintaining higher yields also led to a dramatic increase in the pesticide use; from 5,700 tons in 1960 to 46,195 tons in 2000. India's pesticides consumption is one of the lowest in the world with per hectare consumption of just 0.60 kg compared to US (5-7 Kg/ha) and Japan (11-12 Kg/ha). In India, paddy accounts for the maximum share of pesticide consumption around (26%-28%) followed by cotton (18% -20%) (CARE, 2017) [6]. Indian 'Green Revolution', one of the greatest success stories in the world, with dramatic impact on the food security, was based on principles of intensive agriculture. However, the intensive agriculture has led to the newer problems such as excessive and untimely use of irrigation water, erosion of genetic resources caused by the replacement of rich diversity of the traditional crop varieties with a few high yielding varieties, and inappropriate use of critical inputs such as chemical fertilizers and pesticides (Paroda, 1999) [31]. Thus, with intensification of agriculture and consequent increase in genetic uniformity of crops, the incidence of insect-pests, diseases, nematodes and weeds has increased. In India, the pesticides are broadly divided into five types and the market share of the same is provided in the below charts. Insecticides cover the major part of total consumption i.e. 60% of the market share, whereas Fungicides 18%, Herbicides 16% and the rest 6% by others. Bio-pesticides are an emerging category and are currently a small proportion of the market but have a huge growth potential considering its non-toxic nature (CARE, 2017) [6].

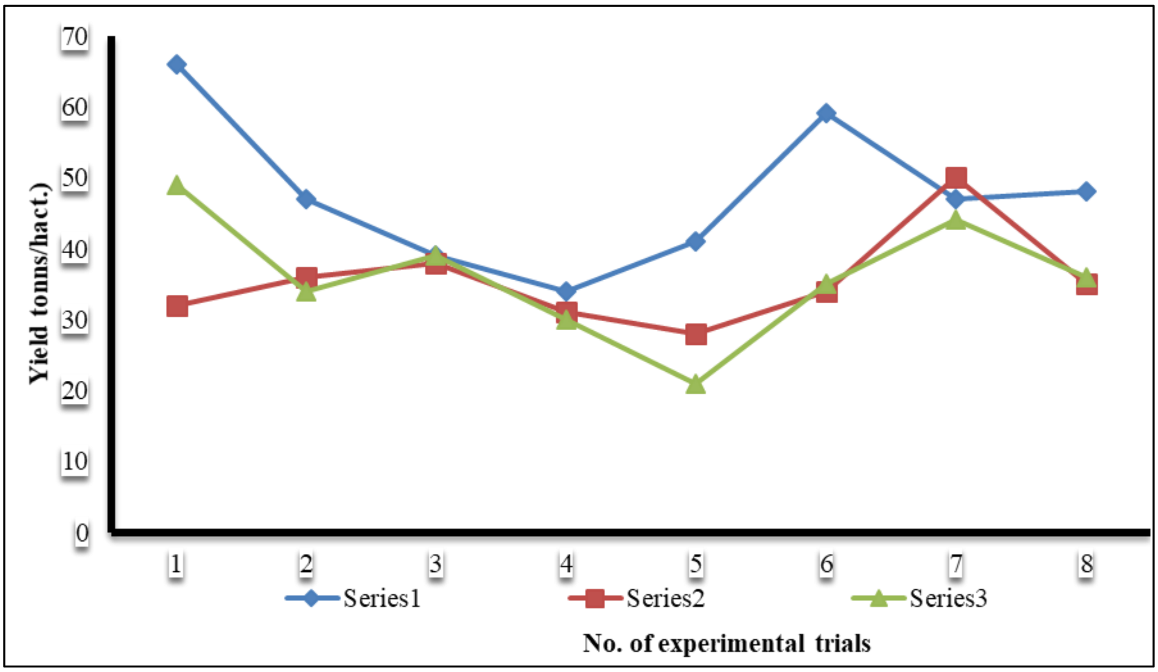

Fig 1: Yield (q/ha) of Basmati rice in IPM trials at different farms, (Baraut, 1998)
[Line 1: Y=0.9048x+31.429; Line 2: Y=-0.7381x+39.321; Line 3: Y=-0.6999+50.771]
IPM (series 1) = integrated pest management, CC (series 2) = chemical control, FP (series 3) = farmers practice
Highest Yield, with Reg. eq. Y=0.9048x+31.429; Logarithmic equation Y=-5.628In(x) + 55.075
Least Yield with Reg. eq. Y= -0.699x +50.77; Logarithmic equation Y= -4.843Ln(x) + 42.42
{The grain yield under both IPM and chemical control treatments was higher compared to untreated control, but the benefit cost ratio was slightly higher in the case of IPM due to lower costs (Garg and Baranwal, 1998)}.

Sustainable agriculture and integrated pest management

The grain yield under both IPM and chemical control treatments was higher compared to untreated control (Omprakash *et al*., 2017; Umina *et al*., 2015) [30, 41]. It was marginally higher in chemical control, but the benefit cost ratio was slightly higher in the case of IPM due to lower costs (Garg and Baranwal, 1998) [16]. The solution to the pesticide externalities lies in the implementation of Integrated Pest Management (IPM), which combines the use of different pest control strategies (cultural, resistant varieties, biological and chemical control). IPM is thus more complex for the producer to implement, as it requires skills in pest monitoring and understanding of the pest dynamics besides the cooperation among the producers *en mass* for effective implementation.

Integrated Pest Management (IPM) is an ecologically based strategy that focuses on long-term solution of the pest through a combination of techniques as biological control, habitat manipulation, modification of agronomic practices, and use of resistant varieties. In the context of crop protection, sustainability refers to the substitution of chemicals and capital with farm grown, biological inputs and knowledge aimed at reduction in the cost of production without lowering the yields (NCC-SAFS, 2017; Swaminathan, 1995) [28, 38]. The systems approach minimizes environmental degradation, sustains agricultural productivity, promotes economic viability in both the short and long run, and maintains quality of the life (Charles and Youngberg, 1990) [7].

Sustainable farming practices commonly include

- Crop rotations that mitigate weeds, disease, insect and other pest problems; provide alternative sources of soil nitrogen; reduce soil erosion; and reduce risk of water contamination by agricultural chemicals.

- Pest control strategies include integrated pest management techniques that reduce the need for pesticides by practices such as scouting/monitoring, use of resistant cultivars, timing of planting, and biological pest controls and increased mechanical/biological weed management.

Tools of integrated pest management

a) Monitoring: Crop monitoring, that keeps track of pests and their potential damage is the foundation of IPM. This provides knowledge about the current pests and crop situation and is helpful in selecting the best possible combinations of the pest management methods. Sex pheromones have been found effective in management of yellow stem borer and for monitoring of brinjal shoot and fruit borer (Dar *et al*., 2017; Dar *et al*., 2017; Dar and Parry, 2017) [9, 12, 13]. Pheromones control the insect through capture and annihilation by either mass trapping or disrupting mating communication. Mating disruption by a single application of slow release formulation of pheromones @ 40g a.i./ha could result in season-long control of stem borer and produce grain yields similar to plots receiving two sprays of conventional insecticides (Hall *et al.*, 1998) [18]. The pheromones are likely to play an important role in rice IPM strategies in future (Krishnaiah *et al.*, 1998) [18] e.g., in brinjal (Dar *et al*., 2017a) [12] and have got advantage over other monitoring tools such as light and sticky traps.

b) Pest resistant varieties: The resistant varieties possess high yield and other desirable agronomic characters, and are being extensively cultivated in the pest endemic areas. For the breeding purpose the screening of varieties is basic component like in Brinjal (Dar, 2012) [12] (Table 1). Breeding for pest resistance is a continuous process and at the same time the insect pests and plant pathogens, co-evolve with their hosts. Thus, gene-transfer technology is useful in developing cultivars resistant to insects (Dar *et al*, 2017b) [12] and plant pathogens. An example of this is the incorporation of genetic material from *Bacillus thuringiensis* (*Bt*) (Dar *et al*, 2017b) [12], in cotton, corn, and potatoes, which makes the plant tissues toxic to the insect pests.

c) Pest tolerant varieties: Have the ability to produce a yield despite attack or injury from insects or diseases. Example: corn varieties that can regrow roots after a corn rootworm attack, or few brinjal varieties (Dar, 2012; Dar *et al*., 2016) [12, 10].

Cultural pest control:

Many practices used in producing crops can also help reduce pest problems. Here are some examples.

a) Tillage. Buries crop residues containing insects, diseases, and weed seeds, and disrupts root systems of perennial weeds. However, the drawback of the studies is that it stimulates the weed seed germination and cause soil erosion.
b) b) Mulching. With plastics or straw controls weeds. Drawback is high cost of equipments and labour
c) Burning. Crop residue reduces diseases. Drawback is, air pollution and the reduced soil cover, which later may lead to soil erosion.
d) Crop rotation. Means growing different crops in sequence to provide better weed and insect control, reduce levels of disease (especially those that survive on crop residue), and improve fertility. Example: rotating corn with soybeans to control corn rootworm.
e) Altering planting or harvest dates. Reduce the impact of pests. Examples: late planting to avoid sunflower midge; cutting alfalfa early during alfalfa weevil infestations. Drawback: possible reduced yields and quality
f) Controlling alternative hosts. Means controlling weeds and crops that harbor pests. Example: weedy grasses in corn attract egg-laying armyworms, stalk borers, and hopvine borers.
   Drawback: Many of these alternative hosts also support natural enemies of the pests
g) Mowing. A mower cuts roadside brush in watersheds. It helps to remove the undesirable plants (weeds) which deprive the soil of nutrients and acts as secondary source of plant diseases and as alternate host of pests.
h) Sound agronomic practices. These promote vigorous crop growth, reduce risk of injury and increase the crop's ability to withstand pests.

Cultural control further includes crop production practices like fallowing, manipulation of plant and row-spacing, adjusting the sowing and harvesting date of crop, and destruction of old crop debris where in pests go for overwintering.

Table 1: Different categories of resistance and screening of brinjal varieties/genotypes to shoot and fruit borer (*Leucinodes orbonalis* Guenee) on number and weight basis under field conditions during 2011 and 2012 (Dar, 2012).

Categories/Genotypes	Rating of infestation(%) level on number basis	Mean fruit infestation on number basis (%)	Rating of infestation(%) level on weight basis	Mean fruit infestation on weight basis (%)	Rating of infestation (%) level on shoot basis	Mean shoot infestation (%)
Entries with Highly Resistant category	0	0	0	0	0	0
Entries with Resistant categories Brinjal-85 Local long	(1-5)	3.30a (11.92) 5.15b (12.71)	(1-5)	3.29a (11.90)	(1-5)	5.37 5.10 4.96 4.60 2.34
Entries with Fairly Resistant categories Shalimar Brinjal purple Round-8 Shalimar Brinjal purple Round-1	(6-10)	8.33c (16.70) 10.08c(16.72)	(6-10)	8.29b (16.65) 6.71b (14.64)	(6-10)	9.1 7.7 7.00 7.60 6.97 6.70

						6.20
Entries with Tolerant categories Shalimar Brinjal Purple Long-42 Shalimar Brinjal Long-208 Shalimar Brinjal Long-217 Dilruba-2Brinjal Purple Long Brinjal Purple Long	(11-16)	11.11^{d} (18.90) 12.50^{d} (19.43) 14.28^{e} (22.07) 16.60^{f} (24.91) 16.63^{f} (24.31)	(11-15)	11.50^{c} (19.81) 12.90^{c} (21.06) 13.50^{d} (21.54) 14.70^{d} (22.53)	(11-15)	0
Entries with Susceptible categories Brinjal oblong Shalimar Brinjal hybrid-2	(17-20)	18.18^{f} (25.20) 20.00^{g}(26.06)	(16-20)	17.00^{e} (24.36) 17.40^{e} (24.57) 18.50^{e} (25.43)	16-20	0
Entries with Highly Susceptible categories Shalimar Brinjal hybrid-1	(>21)	23.07^{h} (28.48)	>21	22.50^{f} (28.26) 21.28^{g} (27.48)	>21	0
Statistics		$CD_{(P=0.05)}$= 1.77		$CD_{(P= 0.05)}$ = 1.83		

Each figure is the mean of three replicate.

Figures in parentheses are arcsine-transformed values in a column, means followed by the same letter(s) are not significantly different by DMRT (P=0.05)

Physical or mechanical controls

These are based on the knowledge of pest behavior. Placing plastic-lined trenches in potato fields to trap migrating Colorado potato beetles is one example of the physical control. Shaking of the pigeon pea plant to remove *Helicoverpa* larvae is a common practice in pigeon pea growing areas. Further this strategy includes the followings.

- Traps for rats, mice, gophers, and birds.
- Light to attract or repel pests; bug zappers
- Sound to kill, attract, or repel pests
- Barriers such as screens in homes and livestock shelters
- Radiation to sterilize or kill pests
- Cold or heat to kill pests. Example: cooling down grain bins over the winter stops activity of grain-infesting insects and molds.

Biological controls

Biocontrol agents fit in very well with most of the other components of IPM.

Bioagents.

a) Predators. Feed on insects. Example: seven-spotted ladybird beetles kill aphid pests of small grains and alfalfa.
b) Parasitoids. Wasps or flies that lay their eggs on insect hosts; the young kill the host as they develop. Example: the wasp *Macrocentrus grandii* lays its eggs on the European corn borer.

Diseases that attack insects often occur in epidemics, killing off large numbers of insect pests. Example: the fungus *Beauveria bassiana* can cause local populations of European corn borers to die off and is also used against rice hispa. *Pandora delphacis* against BPH.

Herbivores. Are insects that feed on weeds. Example: the weevil *Rhyncocyllus* has been introduced to feed on musk thistle seeds.

Trichogramma spp., *Trichoderma* spp., *Verticillium* spp., *Aspergillus* spp., *Bacillus* spp., and *Pseudomonas* spp. that attack and suppress the plant pathogens have been successfully exploited as biological control agents in integrated pest management programme. Unlike in other crops, use of bio-control agents through inundative or inoculative releases in rice ecosystem has provided sporadic success.

Chemical controls:

In USA on August 31, 2016, under Ontario Regulation 63/09 of the Pesticides Act (O. Reg. 63/09), one of the requirements to buy and use Class 12 pesticides is that a person must successfully complete the Integrated Pest Management (IPM) Course to become certified. But in the developing countries like India these chemicals have adverse effects on human health and the environment; and owing to continues use the pests continue to develop resistance to hazardous chemicals. Sustainable and effective agricultural pest management will require continued development and increased use of alternative pest management strategies, such as integrated pest management (IPM). Some IPM practices yield significant environmental and economic benefits in certain crops, and IPM can lead to better long-term pest management than chemical control alone.

Pesticides are used to keep the pest populations below economically damaging levels when the pests cannot be controlled by other means, therefore need-based application of insecticides is an economical and practical way to ensure higher yields. Pesticides include both the synthetic pesticides and plant-derived pesticides botanical pesticides are used as raw crushed plant leaves, extracts of plant parts, and chemicals purified from the plants. Among these botanical pesticides neem formulations including, neemax, rakshak, econeem, neemazal and neem gold are safe to major natural enemies (Dar *et al*., 2016c) [12] like water bug (*Microvelia douglasi atrolineata*), egg parasitoids of stem borer (*T. japonicum*) and mirid bug (*C. lividipennis*), etc. (Jhansilakshmi *et al.*, 1998) [20]. Pyrethrum, tobacco, garlic, and pongamia formulations are some other examples of botanicals.

Legal control

Actions can be taken under federal, state, or local laws to slow or stop the spread of certain plant pests, especially those that are brought in from other areas. These actions include quarantine, inspections, compulsory crop or product destruction, and eradication of pests (Dar *et al*., 2017b) [12]. Example: legal controls against the Mediterranean fruit fly have included insect eradication programs and quarantine and embargoes on affected fruit.

Pest management in India

India has a history of pest outbreaks resulting in extensive losses in rice production systems (Atwal *et al.*, 1967); therefore, the need of chemical pesticides was realized when damage due to gall midge outbreak in Kerala was estimated worth Rs 6 crores. The introduction of 'Green Revolution' technologies, viz. high yielding crop varieties, chemical fertilizers and pesticides coupled with assured irrigation and improved agronomic practices put India into an era of food self- sufficiency, with food security still need to be more assured (Sharma, 2017) [35]. However, this kind of intensive cropping was accompanied by the increasing problems of insect pests, disease and weeds. Farmers were motivated to adopt prophylactic control measures with emphasis on chemical pesticides. But the indiscriminate and injudicious use of pesticides resulted in several adverse effects, viz. development of resistance in pests to pesticides, resurgence in pests, pesticides residues in food, fodder, soil and water, pesticides poisoning, and health hazards to human beings, wild-life and livestock. To realize the economic and environmental objectives of IPM, the Government of India has taken a number of measures for the promotion of IPM.

National policy on IPM

The Government of India is signatory to the Agenda 21 of the United Nations Conference on Environment and Development 1972, which accepts IPM as an effective way to reduce the use of chemical pesticides to reduce the risk of damage on environment and human health and therefore adopted IPM as the main plank of plant protection strategy in 1985. Since then, a number of initiatives have been taken to promote IPM which are discussed as below:

- Setting up of 26 Central IPM Centers (CIPMC) under the Directorate of Plant Protection, Quarantine & Storage for promotion of IPM in all States and Union Territories. New CIPMCs in the north-eastern states of Arunachal Pradesh, Meghalaya, Manipur and Tripura are already set up.
- Assistance to state governments for setting up of 29 biocontrol laboratories and for production and release of biocontrol agents
- Allocation of 50% state funds on plant protection to promote IPM and human resource development
- Organize season-long IPM training programmes for the training of trainers.
- Setting up of Farmers' Field Schools (FFS) to train Agricultural Extension Officers and farmers in IPM skills.
- Demonstration of field tested IPM practices and Policies for firm support.
- Phasing out subsidies on pesticides and diverting the resultant savings for promotion of IPM.
- Phasing out/banning/restricting the use of hazardous pesticides.
- Liberalized criteria and procedures for the registration of biopesticides.
- Emphasis on production and use of biocontrol agents, biopesticides and pheromones in addition to other technological facilities.

Policy developments

Apart from major policy, the central government of India from time to time convenes meetings of the senior executives of the state governments, and scientists of the Indian Council of Agricultural Research, and State Agricultural Universities for formulating policies for proper implementation of the IPM programmes.

The national plan of action on IPM has following objectives

a) Financial assistance from the central government should be channelized through plant protection division to facilitate effective implementation of IPM for achieving the desired results
b) Every state government should identify a nodal officer of the rank of Joint Director Agriculture, for proper planning and implementation of IPM
c) IPM packages developed at the national level should be fine-tuned to meet the local needs of a state
d) Pest surveillance and monitoring should receive top priority at the state level for timely forewarning of pest and disease situations
e) Biological control laboratories need further strengthening through joint ventures associating central/ state governments and industry.
f) Encouragement of production of sufficient quantity of biocontrol agents/biopesticides and equipping biocontrol laboratories with adequate facilities
g) Incentives to private entrepreneurs may be provided as one time grant for the establishment of biopesticides and biocontrol units
h) Financial assistance to the tune of 75 percent on the cost of biopesticides, biocontrol agents and pheromones should be provided by the Centre/States to promote IPM.
i) Biocontrol agents/biopesticides, pheromones, etc. should be exempted from excise and custom duties, and sales taxes.
j) Quality control standards for biopesticides already developed may be used for monitoring their quality.
k) Registration requirement for biopesticides and pheromones need to be further simplified and bringing all biopesticides/biocontrol agents under the purview of Insecticides Act, 1968.

Activities of the CIPMCs are

- To undertake pest surveillance and monitoring on major *Kharif* and *Rabi* crops to forewarn pest and disease situation.
- To issue pest and disease situation/forewarning bulletins to all the concerned authorities of state departments of agriculture and horticulture for need-based adoption of plant protection measures.
- To popularize biological control of pests by introducing exotic biocontrol agents, mass rearing and field releases, and conserving biocontrol agents against major pests and weeds.
- To extend technical help to state governments in establishing the biological control laboratories.

To train extension workers, farmers, cooperatives, and other organizations in mass rearing/conservation of biocontrol agents, to organize Farmers Field Schools (FFS) and demonstrations for popularizing IPM among the state extension functionaries and farmers.

The Government of India reviews the toxicity and residues of the pesticides registered under the Insecticides Act, 1968. Based on the expert opinion, the pesticides are being banned or recommended for restricted use. Biopesticides like neem-based formulations, *Bacillus thuringiensis*, *Trichoderma* have been registered for commercial use by the farmers to promote IPM. Also other biopesticides like NPV, GV, entomogenous fungi, etc. have been brought under the provision of Insecticides Act, 1968 so that farmers get quality biopesticides.

State facilities

Most of the state governments have intensified their efforts to popularize IPM through demonstrations and trainings of the extension personnel and farmers. The Central Government, Indian Council of Agricultural Research and State Agricultural Universities are extending technical assistance for the training. The state governments are also strengthening their facilities for biocontrol production units. The State Departments of Agriculture, Horticulture, and Agricultural Universities have a strong network of extension set up at village, block and district levels providing 50 percent subsidy on the plant protection chemicals including biopesticides to the farmers. Now, a few NGOs have also started Krishi Vigyan Kendras (KVKs) with the assistance from the Indian Council of Agricultural Research, and a few biopesticides production units with the assistance of Department of Biotechnology, Government of India. The private plant clinic centres also help in promotion of IPM programmes in various states.

Progress of IPM training

A three-tier training programme namely season-long training courses, establishment of Farmers' Field Schools and IPM demonstrations has been designed to train farmers and extension functionaries. The resources for training courses in IPM have come from international organizations like FAO, ABD-CABI and UNDP. The IPM training-cum-demonstration commenced since 1981 by organizing demonstration in 40ha farmers' rice fields for the entire crop season. The major emphasis in these trainings is on recognition of the friendly insects and spiders by the farmers and extension workers. Biopesticides like *Bacillus thuringiensis*, *Trichoderma*, and neem-based pesticides have been registered and are now available commercially for use by the farmers. To supply quality biopesticides to farmers even NPV, GV antagonistic fungi and bacteria and entomogenous fungi have been brought under the purview of Insecticides Act 1968.

Future of integrated pest management in India

IPM research

National Centre for Integrated Pest Management (NCIPM) of Indian Council of Agricultural Research (ICAR), India was established in February, 1988 to cater to the plant protection needs of different agro-ecological zones of the country. In spite of a large expert workforce across different plant protection disciplines, there are still epidemics of pests on different crops in the recent past with the chronic pest problems assuming serious proportions. The Centre has a strong institutional network in place to take on the challenges of plant protection in the country in a harmonized manner.

Pesticide effectiveness and insect resistance

The effectiveness of chemical pesticides in reducing the pest-induced losses has diminished in recent years. Number of pests has developed many fold resistance to insecticides. Further, destruction of natural enemies of insect pests, a number of new pests have emerged. These imply that intensive use of chemical pesticides is leading to increased cost of pest control and reduced farm profitability. Under such a situation, alternative technologies such as biopesticides could provide some solutions. Research has generated a number of technologies using plants and pathogens. Many of these have, however, not been commercialized perhaps due to lack of their proven economic feasibility, short shelf-life, slow effect and incompatibility with chemical pesticides. Technologies such as, *Trichogramma chilonis* and *Crysoperla carnea* despite their proven effectiveness, do not find favor with industry as well as farmers because of their short shelf-life, sensitivity to chemical pesticides and higher cost of application. Plant-based pesticides are often slow in action. This suggests that the research should target overcoming these technological problems. Genetic manipulation of seed varieties for pest resistance is an important constituent of plant protection strategy. Genetically modified varieties of some crops, such as cotton and rapeseed-mustard, have been developed but these are surrounded by controversies regarding their long-term effect on the environment, biodiversity and human beings. Nevertheless, genetic resistance could be an effective tool in pest management (Dar and Wani, 2017) [12].

Public-private sector interface

While most of the technologies have been developed by the public sector, private sector does not find investment in commercial production mainly because of their short shelf-life and stochastic pest behaviour. Most of the biopesticides are produced by the public sector firms. These hardly comprise 2 percent of the agrochemical market (Dar and Padder, 2016) [10].

Economic feasibility

Scientists claim are based on controlled experimental evidences and its wide scale testing under field conditions is yet to prove its (IPM) economic feasibility. It's environmental and health benefits are well recognized. But farmers in the developing countries have a myopic view, and heavily discount the environmental and health benefits. They adopt a new technology only if it generates as much economic returns as the current technology

Area-wide adoption

There is hardly any information available on area protected with IPM. Estimates based on production statistics of biopesticides indicate that only about 1 % of the gross cropped area receives application of IPM inputs (see review by Dar and Padder, 2016) [10]. The future of IPM would largely be determined by the community participation. There is a need to devise an 'incentive system' for the farmers who participate in community pest management e.g., fruit fly management on area wide basis using gamma radiations (Dar *et al*., 2016) [10]. Involvement of local administrative units (*Panchayats*) and Non-Governmental Organizations (NGOs) could be of great help in pushing IPM forward

Agricultural extension

India has a well-developed agricultural extension system. It has, however, not been tuned to the emerging technological requirements of the farmers. Extension personnel often lack awareness on the IPM inputs in terms of their technological characteristics, application rates and method of application.

Funding

The current efforts to promote IPM are largely on account of the initiatives of the Government of India through its Central Integrated Pest Management Centers. The state governments are required to allocate at least 50 per cent of the plant protection funds for promotion of IPM.

Regulations

The production of biopesticides is controlled by the same regulations as applicable to that of chemical pesticides. It is, therefore advisable to relax registration norms for biopesticides considering their environmental and health benefits. Banning hazardous pesticides would help for emergence of bio-pesticide industry.

Food security and quality

Food security has been an over-riding policy concern until now. Now with sufficient stocks of food grains, this has dissipated. A few years back it was apprehended that reduction in pesticide-use would adversely affect the production of food as well as non-food crops. And this might endanger the food security. Recent evidences, however, have indicated that gradual reduction in pesticide-use may not have much adverse effects on overall agricultural productivity.

Summery and Conclusion

Integrated Pest Management (IPM) is a systematic plan which brings together different pest control tactics into one program and reducing the emphasis on pesticides by including cultural, biological, and mechanical controls. The concerted efforts made since 1990 have resulted in development of political will, bureaucratic commitment, research support and acceptability of IPM by the farmers. All these attempts have helped in vertical expansion of IPM to some extent. For reaching the masses, it is essential to promote lateral spread of IPM by associating farmers and Self Help Groups by organizing community IPM programmes. In this connection IPM-trained farmers can be gainfully utilized to scout and monitor the fields, recognize abnormal conditions and identify their causes, understand the different control methods available, and determine the economic costs and benefits.

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