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An Updated Integrated Pest Management System: A Footprint for Modern-Day Sustainable Agricultural Practices

Sanjoy Samanta [a*], Atanu Maji [a], Manasij Das [b++], Sampurna Banerjee [c], Anik Bhattacharjee [d], Niharika Pal [e], Priyanka Bhowmik [f], Santanu Banerjee [g] and Sambuddha Mukherjee [h]

[a] *Department of Agricultural Entomology, Uttar Banga Krishi Vishwavidyalaya, Coochbehar-736165, West Bengal, India.*
[b] *Department of Agricultural Entomology, School of Agriculture, Seacom Skills University, West Bengal, India.*
[c] *Faculty of Agriculture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia-741252, West Bengal, India.*
[d] *Department of Agricultural Entomology, Sher-e-Kashmir University of Agricultural Science and Technology, Srinagar, 190017, India.*
[e] *Department of Plant Protection, Faculty of Agricultural Science, Aligarh Muslim University, Aligarh, UP, 202001, India.*
[f] *Department of Entomology, Faculty of Agricultural Sciences, SOADU, Bhubaneswar, Odisha, India.*
[g] *College of Agriculture, Chhatrapati Shahu Ji Maharaj University, Kanpur, U.P., India.*
[h] *Department of Agricultural Economics, Sam Higginbottom University of Agriculture, Technology and Sciences, Uttar Pradesh, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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[++] *Assistant Professor;*
**Corresponding author: Email: sanjoyento2020@gmail.com;*

Review Article

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ABSTRACT

Integrated Pest Management (IPM) stands out as a multifaceted approach, offering efficient, socially acceptable, and environmentally friendly pest management solutions in agriculture. It not only maximizes farmers' financial returns but also fosters environmental and human health benefits, contributing significantly to sustainable food production. However, challenges persist due to farmers' insufficient engagement in IPM technology development and a lack of understanding of its ecological principles. To address these challenges, the traditional ecological perspective of pest management has evolved into a more comprehensive IPM model. This modern approach integrates recent advancements in agricultural technology, leveraging contemporary communication tools, and responding to shifting consumer trends towards sustainably produced food systems. Additionally, heightened awareness of global trade and travel impacts necessitates a reconfiguration of IPM strategies. The enhanced IPM model encompasses four key components: identifying pest management alternatives, synthesizing knowledge and resources to develop effective management strategies, facilitating timely decision-making through information management, and fostering the dissemination of crucial information through outreach efforts. Moreover, the new model recognizes the interplay of human, environmental, social, and economic factors in food production. It places emphasis on the business aspect, involving producers, customers, and sellers, while also addressing sustainability considerations such as economic viability, environmental safety, and social acceptability. By integrating these elements, the revamped IPM approach holds the promise of doubling farmers' income, ensuring food security for all, and promoting overall health and well-being. It represents a holistic solution to pest management challenges, aligning with the broader goals of sustainable agriculture and enhancing the quality of food production for generations to come.

Keywords: New model; IPM; sustainable agriculture; environmental safety; doubling farmer’s income; modern era.

1. INTRODUCTION

The twenty-first century presents a formidable challenge: feeding a rapidly expanding global population while maintaining sustainable food production systems. This necessitates maximizing crop yields on existing farmland through continuous advancements in agricultural technologies to mitigate losses [1]. While chemical pesticides have historically bolstered food production, their prolonged use has resulted in detrimental environmental consequences, including harm to non-target organisms, disruption of ecosystems, toxin accumulation in food chains, and diminished crop yields.

To address these challenges and fulfill future food demands sustainably, a strategy must harmonize economic viability with ecological sustainability. Integrated Pest Management (IPM), a holistic pest management approach, has long been advocated. However, previous IPM models predominantly focused on ecological and evolutionary aspects [2], lacking a comprehensive approach.

Acknowledging the necessity of integrating traditional and modern tools, Stenberg [3] introduced a holistic IPM pyramid framework emphasizing interdisciplinary research. Factors influencing IPM implementation encompass education levels, socioeconomic conditions, environmental consciousness, regulatory frameworks, tool availability, and consumer preferences [4,5,6].

“Despite varied interpretations of IPM, the United States Department of Agriculture-Agricultural Research Service (USDA-ARS 2018) defines it as a science-based decision-making process integrating biological, cultural, physical, and chemical tools to manage pests while minimizing pesticide usage” [7].

Considering the multifaceted nature of crop production, growers adopt diverse strategies to ensure profitability, consumer safety, and environmental sustainability. In light of recent advancements in crop protection, communication technology, and global agriculture, a new paradigm of IPM has emerged [8]. This revised approach encapsulates environmental and social factors, aligning with contemporary agricultural practices and global market demands.

2. PROBLEM STATEMENT

"We consider that despite countless good intentions but also there are harsh realities to face. How IPM has developed over time and assess whether this concept remains suited to present-day challenges, these are the conflicts between IPM concepts, practices, and policies. Inadequate Farmer Involvement in IPM technology development often lack of basic understanding of ecological concepts. IPM research is often lagging and misguided, paying little attention to the ecology and ecological function of agroecosystems" [9]. "Environmental risks in integrated crop protection are an important issue. Pesticides will continue to dominate integrated pest management in developing and underdeveloped countries as the goal is to produce more for food security" [10].

3. AIM OF THIS PAPER

To promote networking among scientists, institutions, extension workers, and farmers, digital technologies and high-speed telecommunications should be implemented. A knowledge-based pest control system should be built to increase IPM communication. Entomologists should collaborate with other agricultural scientists, environmentalists, and farmers to develop and apply innovative IPM tactics aimed at achieving sustainable crop production technologies in the next years. Update and promote the IPM concept according to modern times what is perceived as sustainable. Building consumer trust and education with IPM-based production is the perfect system for all cultures, situations and improve global food security and reduce food-related social inequalities.

4. DIMENSIONS OF MANAGEMENT

"The new IPM model has five major components that address various pest management options, the grower's knowledge and resources to address the pest issue, planning and organising information to take appropriate management actions, and maintaining good communication to acquire and disseminate knowledge about pests and their management" [11].

5. PEST MANAGEMENT

IPM is an integrated 'approach' or 'strategy' for controlling crop pests. The basic goal of integrated pest management is not to eradicate pests, but to control them to keep their population below the level of economic damage. IPM is combination Methods of controlling pest populations in an economical manner environmentally impact, not the eradication method used traditional practice. Good knowledge of general IPM principles. Various management options for all kinds of pest problems important because some are preventive and some are curative.

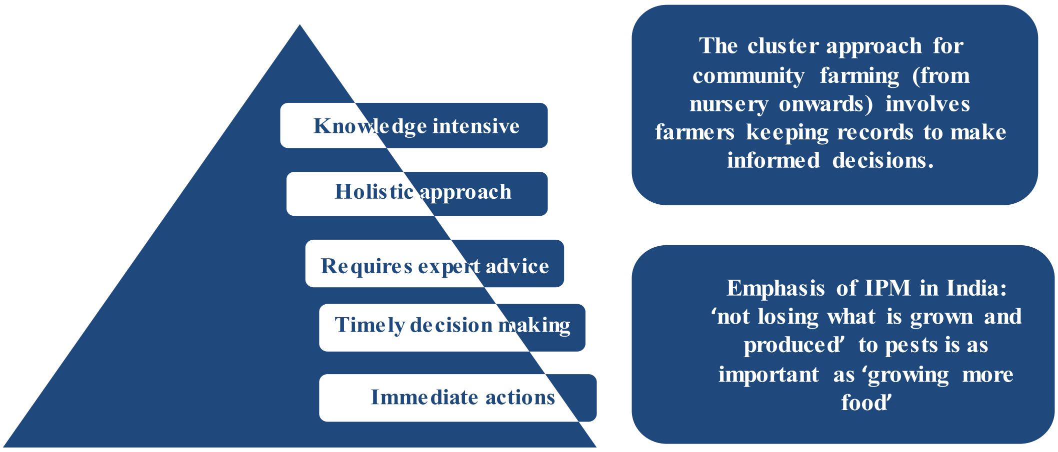

Fig. 1. New IPM model

5.1 Initial Conceptual Initiative in IPM Development

In 1959, UC Berkeley entomologists Vernon Stern, Ray Smith, Robert van den Bosch, and Kenneth Hagen published a seminal paper titled "The Integration of Chemical and Biological Control for the Spotted Alfalfa Aphid. In this paper, they stated the following about integrated control:

To address pest problems, an integrated approach combining biological and chemical control is necessary to correct past mistakes and prevent future ones. These authors' defined terms and concepts commonly used by entomologists, plant pathologists, weed scientists, and IPM practitioners, including economic threshold, economic injury level, and general equilibrium position, Stern et al. [12] provides the following definitions:3

Table 1. conceptual initiative in IPM development

Economic Injury Level	The lowest population density that will cause economic Damage.
Economic threshold	The density at which control measures should be determined to prevent an increasing pest population from reaching the economic injury level
General equilibrium position	The average density of a population over a period of time (usually lengthy) in the absence of permanent environmental change

Integrated control represents a strategic blend of biological and chemical pest management tactics, guided by economic thresholds to prevent pests from inflicting significant economic losses. Originally conceived to address insect pests, the concept of integrated control has evolved into Integrated Pest Management (IPM), encompassing insects, plant pathogens, weeds, and vertebrate pests. However, the initial principles of integrated control, tailored primarily for insect pests, do not seamlessly translate to the management of other pests such as weeds, plant pathogens, and vertebrates.

According to Knake and Downs [13], IPM should adopt an interdisciplinary approach, integrating control measures across various disciplines rather than relying solely on one. Recognizing the interconnectedness of pest populations, Ford [14] delineated three threshold types for plant pathology IPM programs: detection, prevention (with zero injury tolerance), and a standardized economic injury threshold. Similarly, in integrated vertebrate pest control, ecological considerations are paramount, with the destruction of individual vertebrates reserved as a last resort to mitigate animal damage [15].

Implementing pest management strategies necessitates a thorough assessment of their benefits, costs, and associated risks. While increased productivity is desirable, it is crucial to evaluate the environmental ramifications. As noted by Carlson and Castle [16], the true economic impact may be obscured if heightened productivity comes at a significant environmental cost. Higley and Wintersteen [17] caution that relying solely on economic thresholds and injury levels is inadequate for estimating the environmental impacts of insecticide use.

In essence, Integrated Pest Management represents a holistic and adaptive approach to pest control, recognizing the complex interactions among pests, their environment, and management interventions across diverse pest categories.

For the first time in history, humans are exposed to a plethora of hazardous chemicals from conception to death, with synthetic pesticides pervading the global landscape in a remarkably short span of time. It wasn't until 1972 that "integrated pest management" (IPM) gained widespread acceptance within the scientific community. In a February 1972 address to the US Congress, President Nixon highlighted IPM as a component of environmental protection efforts.

Kogan [18] defined IPM as the integration of diverse methods to manage individual pests and their impacts, encompassing organisms that pose threats to human well-being, including invertebrates, vertebrates, pathogens, and weeds. This approach is characterized as multidisciplinary and guided by eco-friendly decision-making principles, with four key elements central to its understanding.

In response to a national review of the US IPM Programme and stakeholder input, the USDA developed the "IPM Road Map" to enhance IPM implementation by various practitioners such as land managers, growers, structural pest managers, and public health officials. The IPM Road Map (2003) aligns with Kogan's historical elements and extends the concept to minimize economic and environmental losses.

According to the IPM Road Map (May 2004), IPM is defined as a science-based decision-making process aimed at mitigating pest risks and implementing management strategies. This program leverages pest biology, environmental data, and technology to prevent pest damage while minimizing risks to human health, property, natural resources, and the environment. It prioritizes cost-effectiveness and offers a versatile strategy for pest management across various settings, from urban and residential areas to wild lands. IPM represents a comprehensive, low-risk approach to safeguarding resources and human well-being from the impacts of pests.

5.2 Types of Pests

The relationship between a pest and its host greatly influences the strategy and components of an IPM programme. IPM practitioners recognise four pest types: sub economic, occasional, perennial, and severe [19].

1. Even during population peaks, a sub economic pest's equilibrium position remains below the level of economic injury. Insects in this category may cause direct losses, but if crop values are low and pest densities are low, it may not be necessary to implement control measures that cost more than the host damage.
2. In most cases, an occasional pest's equilibrium position is below the economic injury level, but population peaks may exceed it. The occasional pest is a common pest. Although present on or near a host almost every year, it rarely causes economic damage.
3. Perennial pests have a general equilibrium position below economic injury levels, but peak populations occur frequently, resulting in annual economic damage.
4. Severe pests have a general equilibrium position that exceeds the level of economic injury, resulting in economic damage to hosts. Perennial and severe pests are the most damaging and difficult to manage in an IPM programme.

A pest management strategy encompasses all steps taken to eliminate or reduce a pest problem, whether real or perceived. The biology and ecology of the pest, as well as its interactions with the host or environment, greatly influence the development of a specific strategy. Pest management aims to reduce pest status. To improve pest control, it's important to address both the pest and the host. Pedigo & Rice [19] identify four types of strategies. There are four options for pest management based on their characteristics and economics: doing nothing, reducing pest numbers, reducing host susceptibility to pest injury, and combining reduced pest populations and reduced host susceptibility. After creating a pest management strategy, it's time to determine how to implement it. Pest management tactics refer to various methods used to implement a management strategy. There are four options for pest management based on their characteristics and economics: doing nothing, reducing pest numbers, reducing host susceptibility to pest injury, and combining reduced pest populations and reduced host susceptibility. After creating a pest management strategy, it's time to determine how to implement it. Pest management tactics refer to various methods used to implement a management strategy.

5.3 Do Nothing Strategy

Pest injury does not result in economic loss for hosts. Many hosts, including plants and animals, can tolerate minor injuries without causing economic harm. Insect injuries can often be mistaken for more serious ones. This is most likely to happen when pest population density is not linked to an economic threshold. If pest density is below the economic threshold, a do-nothing strategy is recommended. Otherwise, control efforts may not yield a net benefit. The do-nothing strategy is commonly used when insects cause indirect harm to a host or when a successful pest management programme reduces the pest population and only surveillance is required. While no tactics are used in the do-nothing strategy, it does not mean that no effort is required or that pest suppression is not taking place. To determine if the do-nothing strategy is effective, it's necessary to sample the pest population. Environmental factors may also impact the population, leading to pest suppression.

5.4 Reduce Pest Populations

The most common pest management strategy is to reduce pest densities to address or prevent problems. According to Pedigo and Rice [19], this strategy can be used as a preventive measure or for therapeutic purposes when populations reach a certain economic threshold.

To reduce pest densities, two objectives may be beneficial. If a pest's long-term average density falls below the economic threshold, reducing population peaks is the most effective approach. This action won't significantly alter the pest's equilibrium, but it can prevent damage during outbreaks.

If the pest population's general equilibrium is near or above the economic threshold. Lowering the general equilibrium position prevents peak populations from reaching the economic threshold.

5.5 Reduce Host Susceptibility to Pest Injury

Reducing host susceptibility to pest injury is a highly effective and environmentally friendly strategy. This strategy does not affect the pest population but rather the host or host's Changes are made to the relationship and interaction with pests to reduce their potential damage. This strategy involves developing plant or animal cultivars with tolerance, which allows them to be more resistant to pests than their non-tolerant counterparts. Tolerance does not reduce pest populations, but it reduces the harm caused by pests to the host. Examples of this strategy include moving livestock indoors to reduce exposure to pest insects or adjusting crop planting dates to create an asynchrony between pest and susceptible plants.

5.6 Combine Reduced Pest Populations with Reduced Host Susceptibility

Developing a pest management programme involves combining previous strategies to achieve common goals. A multifaceted approach leads to greater consistency than relying on a single strategy or tactic. Research indicates that a single strategy is more likely to fail when a single tactic fails, whether gradually or quickly. The multifaceted approach ensures that if one tactic fails, others can be used to mitigate losses. An IPM programme relies on a variety of strategies and tactics.

5.7 Funding IPM Research and Implementation

Since the 1970s, the USDA, EPA, and NSF have been key supporters of IPM research and extension programs, offering competitive and formula-based funding. The majority of IPM research and extension initiatives are carried out by investigators at land-grant universities, in line with the Morrill Land-Grant Acts of 1862 and 1890. Notable IPM pilot efforts include the Huffaker (1972–1979) and Adkisson (1979–1984) projects, receiving substantial funding from EPA, NSF, and USDA, amounting to $US 13 million and $US 15 million, respectively [20]. It's important to note that implementing IPM may not always lead to significant reductions in pesticide usage, as observed in some cropping systems. Over time, political support for older IPM programs may wane in favor of newer initiatives. Assessing the success and impact of IPM implementation can be challenging, and IPM leadership may encounter difficulties in clearly articulating its objectives. Additionally, there is a growing trend towards organic production practices. The United Nations Development Programme (UNDP) and World Bank established the Global IPM Facility to support IPM implementation through increased lending operations [21]. However, the impact of this facility has been described as "mixed" by Schillhorn van Veen (2003).

The Integrated Pest Management Collaborative Research Support Programme (IPM CRSP), initiated in 1993 with financial support from USAID, is another significant organization promoting IPM worldwide. Current sites include Albania, Bangladesh, Ecuador, Guatemala, Jamaica, Mali, the Philippines, and Uganda. Collaboration between scientists from US institutions such as Virginia Tech, Ohio State University, and Purdue University, alongside host institutions, has led to successful IPM programs in various cropping systems globally [22]. Furthermore, CGIAR centers have made substantial contributions to enhancing crop pest resistance on a global scale. These centers play a crucial role in implementing IPM programs in target regions such as Africa, Asia, and Latin America, as noted by James et al. [23],

5.8 Information and Communication Technology-Based Pest Surveillance and Advisory for IPM and Awareness on IPM: Key to Success

IPM is a sustainable pest management approach that combines cultural, biological, chemical, and physical tools while minimising economic, health, and environmental risks. IPM is a multi-method approach to pest management that considers crop and pest interactions to select the most effective combination of locally available tools. ICAR-NCIPM regularly offers training programmes, refresher courses, and workshops for master trainers at crop-based ICAR institutions, State Agricultural Universities, Krishi Vigyan Kendras, State Agricultural Department, industry personnel, non-governmental organisations, and crop growers involved in plant protection. The goal is to educate and train on recent developments in IPM to raise awareness and promote implementation.

5. EXAMPLES OF SUCCESSFUL IPM IMPLEMENTATIONS

6.1 Integrated Pest Management in Cotton at Ashta Village, Maharastra

6.1.1 Cotton protection scenario

Ashta farmers primarily used monocrotophos (17.35%), followed by endosulfan (12.26%), dimethoate (10.8%), cypermethrin (9.95%), and fenvalerate (7.35%). Endosulfan + dimethoate was the most popular pesticide combination, with 56.5% of farmers using it. 13.5 percent of farmers used a combination of cypermethrin, monocrotophos, and dimethoate. Methomyl and Neemark accounted for 23.66% adoption. Pest problems, such as bollworms and grey mildew, were caused by a combination of practices and environmental factors. Seed cotton yield ranged from 0.75 q/ha to 3.75 q/ha, with an average of 2.20 q/ha, despite farmers' heavy reliance on chemical pesticides.The village provided ample challenges and opportunities for implementing the IPM approach [11].

6.1.2 Features of IPM implementation

1. They followed Bio intensive module
2. Monitoring and Scouting for Crop Protection Decisions.
3. The Farmer Field Schools (FFS) approach to IPM implementation

❖ The overall impact of the Ashta IPM are as follows:

- Enhance natural predator and parasite activity.
- Reduce chemical insecticide use.
- Enhance environmental safety by increasing bird population in crops.
- Achieve compensatory yields and higher net returns.

6.1.3 Validation of IPM for Basmati rice, New Delhi

A basic IPM module for integrated crop management was developed based on pest prevalence and available literature. IPM strategies include incorporating green manure (Sesbania/Vigna radiata) into soil, using balanced fertilisers with a focus on potash and zinc, managing biotic stress through regular crop and pest monitoring, conserving natural enemies, using bio-pesticides, and applying chemical pesticides based on need (economic threshold level) [24-31].

6.1.4 Features of IPM implementation

- Farmer field schools
- Availability of quality bio agents
- Pest monitoring
- Communication
- Empowerment and skill development for IPM.

6.2 Intensive Application of IPM for Increasing Production of Pulses

6.2.1 Integrated pest management strategies

For Pigeonpea

- To prevent foliar diseases like powdery mildew and Cercospora leaf spot, remove undecayed plant/crop residues in the pigeonpea field.
- To promote crop health and resistance, apply 20 kg/ha of Sulphur (via SSP, Gypsum, or elemental) and Zn (as $ZnSO_4$) to the soil.
  To reduce Phytophthora blight, choose fields with no water logging, a good drainage system, or ridge-sowing. Use certified seed of a recommended variety that is resistant to key insect pests and diseases.
- Use recommended plant-to-plant spacing and row distance based on variety and location. Encourage larger row spacing for both late and transplanted pigeonpea [11].

Chickpea

- To prevent soil-borne diseases like wilt, black rot, and soft rot, remove un-decayed plant/crop residues from the field.
- Apply Sulphur to the soil at a rate of 20 kg/ha (via SSP, Gypsum, or $ZnSO_4$) to promote crop health and resistance.
- Use certified seeds from recommended varieties that are resistant to key pests and diseases.

- Use recommended plant spacing and row distances based on variety and location.
- Increase spacing between rows and plants to prevent foliar (Ascochyta) and floral (Botrytis) diseases. Encourage inter-cultivation of "Coriander/Linseed" [25].

Mungbean and Urdbean

- Encourage field sanitation, deep summer ploughing, and application of de-oiled neem cake at 5 q/ha.
- Use balanced fertiliser dosages, including K, to ensure pest tolerance in crops.
- Use varieties with resistance for foliar diseases (yellow mosaic virus, powdery mildews).
- For disease management, apply Carbendazim @ 1g/kg seed or Trichoderma (4 g/kg seed) + Carboxin (1 g/kg seed). For early stage insect pest management, apply imidacloprid or thiomethoxam 70WS @ 5g/kg seed or apply Imidacloprid 0.3G @15kg/ha to the soil [11].

7. CONCLUSION

Effective, safe, and sustainable pest management strategies are crucial in the agriculture sector to address increased pest resistance and environmental impact. IPM is expected to remain a dominant theme in the future because it allows pests, weeds, and diseases in agricultural crop and animal husbandry production to better exploit modern science and traditional agricultural systems based on indigenous farming practices. Overall, IPM addresses all economic, environmental, and social aspects, ensuring that consumers have safe and affordable food, producers and sellers profit, and the environment is protected. Further research, field studies, and on-farm validation are necessary to develop IPM programmes for the 21st century, resulting in pest-free crops and products.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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