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INTEGRATED MANAGEMENT OF PESTS IN RICE: APPROACHES AND IMPLEMENTATION

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ABSTRACT

Rice is a primary cereal commodity and a necessary source of nutrition for more than 50% of the global population. The primary objective of sustainable pest control is to make a positive contribution to the practice of sustainable agriculture. IPM exhibits numerous conceptual, ecological, and practical similarities to sustainable agriculture. The pest management tetrahedron consists of four primary elements: the environment, a crop, a pest, and humans. Agricultural practices that combine crop cultivation and insect pest control involve the use of cultural, physical, mechanical, and biological techniques. Conserving these indigenous adversaries is crucial for the efficacy of biological regulation. In agro-ecosystems, the population of natural enemies is increased by manufacturing and releasing large numbers of living organisms to control pest populations and reduce them to levels that do not cause significant damage. The genetic mechanism of resistance has been the most efficient, cost-effective, and dependable method for plant protection for decades. Due to a lack of understanding of the impact of changing climate patterns on pesticide application technology and safety precautions, particularly in relation to the long-term presence and breakdown of chemical pesticides, the stability and sustainability of our agricultural ecosystems will remain at risk from pests. The country's crop yields are approaching a point of decreasing returns at a rapid pace. Therefore, integrated pest management will be crucial in ensuring sustainable and environmentally friendly plant protection.
***Keywords* :** Agro-ecosystems, biological techniques, integrated pest management, natural enemies, pest control.

Introduction

Rice serves as a primary cereal crop and essential nourishment for over 50% of the global population. It is cultivated in around 114 nations, with the majority of them being in Asia and Africa. Global farmers are intensifying their crop densities, resulting in a rise in insect populations to meet the ever-growing demand for increased rice grain output. Consequently, pesticides and herbicides have often been excessively used, leading to severe environmental and economic repercussions. (Bai *et al*., 2013; Liu *et al*., 2014). The persistent application of insecticides, herbicides, fungicides, and the leaching of nutrients into subterranean water, along with the emission of greenhouse gases from agricultural soils, have significantly damaged the natural ecosystem. In India, rice is the crop that uses the second-highest amount of pesticides overall (Kodandaram *et al*., 2013). The farmers employ pesticides without discrimination in order to minimise crop losses, which is the primary concern in agricultural advancement (Reddy, 2013). The extensive use of chemical pesticides presents a significant environmental peril to plant life, animal life, human existence, avian species (Bird Life, 2008), and global groundwater. This could result in a direct negative effect on biodiversity, the decline of crucial farming habitat characteristics, reduced insect diversity (De Zoysa and Inoue 2014). In response to increasing concerns about the negative effects of chemical pesticides on the environment, Integrated Pest Management (IPM) approaches have been consistently implemented to minimise environmental damage (Gill and Garg, 2014).

Historic trends of Insect Pest in rice

For about 9000 years, farmers have been choosing the most productive rice cultivars, which also include kinds that are resistant to insects (Norton & Way, 1990).

- Rice has been native to Asia since it was first cultivated some 6000 years ago (Ponting, 1991). In South Asia, the occurrence of insect pests can be traced back to ancient times. With the increase in international trade, insect pests from many regions of the world have been introduced to this area.
- The discovery of *Eriosoma lanigerum*, often known as the Woolly apple aphid, in India dates back to 1889. It was initially found on imported rootstock of Chinese apple trees(Mishra, 1920)
- In 1937, the Potato Tuber moth was brought to India from Italy and then spread to neighbouring nations (Singh, 2004).
- The ear-cutting caterpillar (*Mythimna separata*) was a significant insect pest in Bangladesh during the 1960s; however, it has become less troublesome in recent times.
- Occurrence of leaf rollers (*Cnaphalocrocis medinalis, Marasmia exigua*) has witnessed a rise since the 1980s, (Sarkar *et al*., 2013).
- During the pre-war times in Japan, the widespread destruction of rice crops was caused by two specific pests: the Borers (*Tryporyza incertulas, Chilo suppressalis*) and the Brown planthopper (*Nilaparvata lugens*) (Kiritani, 1979).
- Asia has had multiple occurrences of rice insect pest epidemics in the last few decades. In 2005, rice planthoppers inflicted substantial harm on East Asian nations such as Vietnam, China, and Japan.
- Resistance to the insecticides Imidacloprid and Fipronil was observed in the Brown planthopper and White-backed planthopper, respectively. (Matsumura and Sanada-Morimura, 2010).
- In September 2008, there was an epidemic of Brown planthopper in basmati rice in Haryana and Western Uttar Pradesh due to ideal meteorological conditions (Bambawale *et al*., 2009).
- In July-August 2018, there was a recent occurrence of rice damage in India caused by the Fall Armyworm (*Spodoptera frugiperda*) and its associated natural enemies (Shylesha *et al*., 2018).

Goal, framework, and principles of Integrated Pest Management

Goal: sustainability

The ultimate goal of sustainable pest management (i.e., IPM)) is to contribute to sustainable agriculture (Stern *et al*., 1957. As such, IPM shares many philosophical, ecological, and practical characteristics with sustainable agriculture (Wilken, 1991). The connected components of production, efficiency, stability, and resilience, which are central to sustainable agriculture in general (Fresco and Kroonenberg, 1992), are also essential to IPM. Pest management is meant to sustain yields (qualitative and quantitative); it is intended to contribute to increasing the efficiency of inputs (soil, water, energy, labour, genes, or chemicals) whether these inputs are intended to achieve suitable attainable yield, or to reduce yield losses (and thus, prevent waste of scarce, natural and/or non- renewable resources). Pest management is also intended to stabilise agricultural performance over seasons, and so prevent exceptional crop losses to insects and diseases caused by infrequent populational events. IPM, in many respects, depends on the biological resilience of the systems for which it was developed. The value of IPM recommendations can be judged by the resilience of IPM systems to external events, whether biological (such as uncommon epidemics, outbreaks, or invasions), socio-economical (such as market shifts), or physical (such as exceptional weather conditions, or climate change).

Framework: the pest management tetrahedron

Pest management tetrahedron is composed of four main components: the environment, a crop, a pest, and humans (Zadoks and Schein, 1979). Looking at it from a scientific perspective, the tetrahedron is quite different from the original structure known as the "disease triangle" introduced by Vander plank in 1963. In the disease triangle, only the first three elements (E, C, P) were taken into account, with the last element focussing solely on diseases and not pests in general. With the inclusion of humans in the framework, plant protection preoccupations have taken on a whole new level of complexity. Human beings have significant impacts on Crop-Environment-Pest systems. The new summit, H, acknowledges the role of humans in man-made systems, leading to discussions on the contributions scientists can make to sustainable disease management (pest) (Zadoks, 1989). It is important to note that the fourth summit of the tetrahedron, H, encompasses more than just farmers. It includes farmers' communities, social networks, agro-technology suppliers, food-chain stakeholders, research and extension, as well as policy-makers. Human beings play a crucial and multifaceted role in the following discussion

An important aspect of expansion is the identification of harmful agents, such as insects and pathogens, that can negatively impact the growth of crops. Understanding the genetic diversity of pests and their ability to adapt to different environments is crucial for agricultural scientists. The term "P" no longer refers to a single pest, but rather to the combination of harmful organisms known as crop health syndromes (Savary *et al*., 2011)All of these elements play a role in the overall success of the crop. Incorporating microclimate factors, C also takes into account the potential impact on crop-pest systems. Summit H takes into consideration the indirect impact of crop management on pests, which can be quite significant (Palti, 1981; Zadoks, 1993). Summit H encompasses the involvement of farmers and their decision-making processes, whether they are strategic or tactical in nature (Zadoks and Schein, 1979).

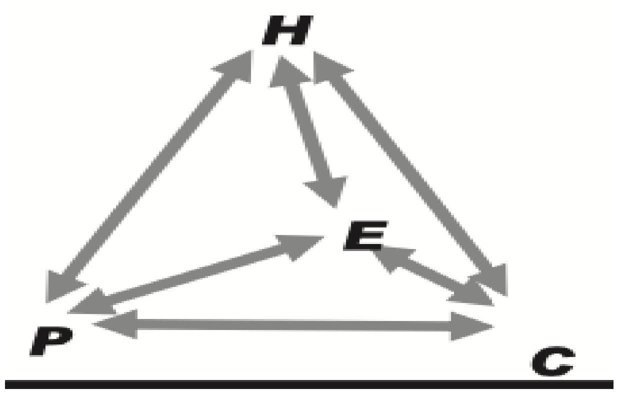

Fig. 1: Pest Tetrahedron. H: Humans; includes individual farmers, farmers communities, agricultural stakeholders (policies), and decisions they make. E: Environment, physical, chemical and biological; includes natural enemies, biological control agents. C: Crop; includes its attributes; genotypes, host plant resistances, physiological, crop density and architecture and the physical microenvironment in the crop. P: Pests; includes pathogens, and animals, especially insects; and vectors of pathogens, with their generic attributes (Savary *et al*., 2011)

First principle: biodiversity

Biodiversity has a significant impact on rice IPM. In many Asian rice systems, the crop and its biological environment have co-evolved for a significant period of time, resulting in stable trophic networks, although they may be relatively simple (Jeger, 2000). Biodiversity forms the basis of ecosystem services that are crucial for human well-being (Millennium Ecosystem Assessment, 2005). When it comes to insect pests, rice-based agrosystems have the potential to offer valuable ecosystem services in terms of preventing herbivores from multiplying and becoming pests. Rice is a temporary habitat that lasts for about 120-150 days and can be vulnerable to invasions by herbivore species once the crop is established. In the rice ecosystem, predators like spiders are already present even before the rice is sown. They thrive on detritivores and other aquatic fauna. Therefore, when herbivores like planthoppers land, they become susceptible to predation. These tiny creatures diligently seek out and destroy the eggs of pests that harm rice plants, helping to keep their populations in check.

Second principle: host plant resistance

Understanding the importance of host plant resistance is crucial for effective pest management, both in general and specifically for rice crops (Bonman *et al*., 1992; Kogan, 1998). The range of technologies included in the concept of Host Plant Resistance offers numerous benefits. It is eco-friendly, cost-effective, and has the potential to be highly efficient (Teng, 1994a). Developing effective strategies for deploying resistance genes is crucial for maintaining their long-term effectiveness. Through continuous research, the discovery of new resistance genes has allowed us to effectively utilise host plant resistance in order to control the population of pathogen and insect pests. This has proven to be particularly beneficial in various crops, with rice being a prime example (Bonman *et al*., 1992). By utilising a combination of genetic and ecological methods, along with various tools such as molecular markers and simulation models, there is potential to develop and implement partial resistance on a large scale in the future (Srinivasachary *et al*., 2011).

Third principle: landscapes

Landscapes typically encompass the arrangement of cultivated fields and natural vegetation, along with the ecological systems they are connected to. They play a significant role in rice and highlight the importance of maintaining a balance between harmful and non-harmful organisms in rice-based systems(Way and Heong, 1994; Heong, 2010)

Basics of IPM approach in rice

Integrated Pest Management (IPM) means a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in a compatible manner as possible and maintains the pest populations at levels below those causing economically unacceptable damage or loss

(FAO, 1967). IPM is a knowledge-intensive sustainable approach for managing pests by combining compatible cultural, biological, chemical, and physical tools in a way that minimizes economic, health, and environmental risks with the help of pest scouts. IPM relies heavily on knowledge of pests and crop interaction to choose the best combination of locally available pest management tools.

Table 1 : Components of Integrated Pest Management in rice

1.	Pest Monitoring
2.	Cultural Practices
3.	Genetic management(Pests and disease resistant varieties)
4.	Mechanical Practices
5.	Biological Control Practices
6.	Chemical Control Measures
7.	Nematode Management Practices
8.	Rat Management Practices

Prakash *et al*. 2014

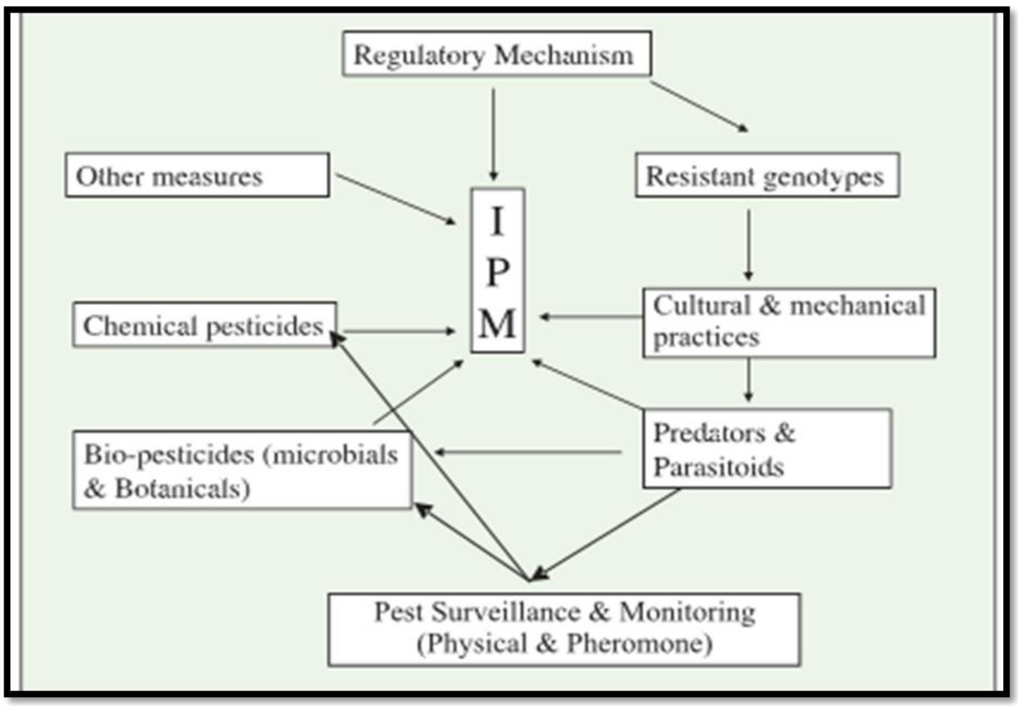

Fig. 2 : Diagrammatic representation of IPM Components (Prakash *et al*., 2014)

Pest's monitoring:

Field Scouting/survey

The goal of conducting roving surveys is to observe and track the initial growth of pests in places where they are often found. Thus, at the start of the crop season, it is necessary to identify survey routes based on the endemic areas in order to conduct roving surveys. According to the findings of the mobile surveys, the state extension officials need to focus more on block and village levels, as well as collaborate with farmers to start field scouting (Prakash *et al*., 2014).

Objectives of scouting and survey:

- to monitor the initial development of pests in endemic areas. Therefore, in the beginning of crop season survey routes based upon the endemic areas are required to be identified to undertake roving surveys.
- The plant protection measures are required to be taken only when insect pests and diseases cross Economic Threshold Level (ETL) as per results of field scouting.

Roving survey	Field scouting
survey at every 10 km distance at 7-10 days intervals (depending upon pest population). Everyday at least 20 spots should be observed.	Field scouting for pests and bio-control fauna by extension agencies and farmers once in 3-5 days should be undertaken to workout ETL.

Pest monitoring through pheromones/light traps etc.

Majority of insects population in rice can be monitored by fixing and positioning of pheromones or light traps at appropriate stage of crop as per the following details

Pheromone trapping	Light trap	Sweep nets-water pans
5 traps per ha may be used to monitor yellow stem borer and moth population.	Light trap can be operated for two hours in the evening to observe photo-tropic insect pests.	Sweep-nets and water pans may also be used to assess the population of insect pests, and biocontrol agents

Table 2 : List of important insect pests of rice in South Asia

Sl. no	Scientific name	Common name	Stage of infection	Characteristic damage	Stage of rice affected	Economic threshold
1.	*Nilaparvata lugens*	Brown Planthopper	Nymph	Plants wilt and die (hopper burn)	All (from seedling to maturity)	10 insects per hill at veg. 20 insects/hill at a later stage
2.	*Scirpophaga incertulas*	Yellow stem borer	Larva	Death of central shoot(dead heart), white ear, loss of tillers		
3.	*Orseolia oryzae*	Gall midge	Maggot	Central leaf sheath modified to silver shoot, loss of tillers	Growing bud	5% (at the active tillering stage)
4.	*Leptocorisa* sp.	Rice/Gundhi bug	Nymphs, adults	Partial chaffy grains, panicles discolouration with empty or ill filled grains	milk stage of grains.	1 nymph/adult per hill
5.	*Cnaphalocroci medinalis*	Leaf folder	Larvae	Leaf damage, ill filled grains	All(from seedling to maturity)	10% Dead heart or 1 egg mass or 1 moth/m^2
6.	*Chilo spp*	Stem borer	Larvae	Death of central shoot (Dead heart) white ear, Loss of tillers	All (from seedling to maturity)	10% DH or 1 egg mass 1 month/m2
7.	*Sogatella furcifera*	White-backed planthopper	Larva	stunting, fewer tillers, loss grain weight, (hopper burn)	more abundant during the early stage and tillering phase	10 insects per hill at veg. 20 insects/hill at a later stage
8.	*Ripersia oryzae*	Mealy bug	Adult nymph	Stunting, yellowish curled leaves, spots	All stages	1 nymph/adult per hill
9.	*Nephotettix spp.*	Green leafhopper	Nymph Adult	Vector of tungro, plants wilt and die in severe case	Seedling, vegetative stage and growing stages	2 insect/ hill in tungro undemeic area . 20-30 nsects / hill in other areas
10.	*Dicladispa armigera*	Rice hispa	Both the adult and larvae	Scrapes the upper surface of the leaf, Tunnels in the leaf tissues. Eggs inside the leaf tips	All(from seedling to maturity)	35% leaf damage, 1-2 adults/hil
11.	*Spodoptera mauritia*	Swarming caterpillar	Larval	Defoliation and damage to rachillae	Seedling to early tillering stage	1 leaf/hill stray incidence priot to harvesting
12.	*Thrips oryzae*	Thrips		Stunted plant growth , papery distorted leaves	Vegetative, growing and fruiting stages	20% damaged

Modified from Ane & Hussain, 2016; Geddes and Illes, 1991)

Waterlogged / low lying	Normal Transplanted rice	Direct seeding/ AWD	Saturated / SRI	Aerobic
Stem borer, Case worm, Swarming caterpillar	Stem borer, Gall midge, Leaf folder, BPH, WBPH, GLH Gundhi bug, Whorl maggot, Hispa, Caseworm	Stem borer, Leaf folder, GLH, BPH, WBPH, rodents	Hispa, thrips, defoliators like leaf folder, stem borer, leaf mite	Soil borne pests like nematodes, root aphids
MORE WATER →				LESS WATER

Cultural Practices

Cultural techniques for insect management encompass agricultural activities that serve the dual function of cultivating crops and suppressing insect pests. Farmers have acquired these skills via careful observation and experimentation. Present-day farmers sometimes overlook the insect control aspect of these practices, which have been passed down through centuries. There are two distinct types of cultural control practices: primary and secondary. Primary cultural control practices refer to specific actions used to control insects, such as draining a field when there is a high population of brown planthoppers, planting a trap crop to deter stem borers, or transplanting older seedlings to reduce whorl maggot damage. Secondary practices refer to specific activities carried out in crop husbandry, such as land preparation, weeding, and fertilisation, which also serve to reduce insect population growth.

Cultural Management Practices	
1.	Raise pre-crop kharif grow *Sesbania* or sunhemp and incorporate 45 days old crop in soil during land preparation wherever possible.
2.	Select suitable resistant or moderately resistant variety
3.	Use disease and insect free pure seed.
4.	Seed treatment (for diseases) with carbendazim 50%WP@2g/kg seed or *Trichoderma/Pseudomonas* @ 5-10 g/ha of seed for seed or soil borne diseases and carbosulfan 2 g/kg of seed for root nematodes or as per local recommendations. In termites endemic areas, seed treatment with chlorpyriphos 20% EC @ 10000 ml/ha along with 10% solution of gum arabica or imidacloprid 200 SL (20%) @ 0.25 litre/100 kg seed along with 10% solution of gum Arabica in 3.75 litre of water just before sowing.
5.	Timely planting/sowing.
6.	Pre-sowing irrigation: Many weeds can be controlled by applying pre-sowing irrigation to area where nursery or seedlings are to be transplanted. The emerged weeds can be ploughed under.
7.	Raising of healthy nursery.
8.	As far as possible rice seedling should be free from weed seedlings at the time of transplanting.
9.	Destruction of left over nursery, removal of weeds from field and cleaning of bunds.
10.	Normal spacing with 30-36 hills/ m^2 depending on the duration of the variety.
11.	30cm alley formations at every 2.5to3m distance in plant hopper and sheath blight endemic areas.
12.	Balanced use of fertilizers and micro-nutrients as per local recommendations. Proper water management (alternate wetting and drying to avoid water stagnation) in plant hopper, bacterial blight and stem rot endemic areas. Maintain a thin layer of water on soil surface to minimize weed growth.
13.	In direct sown rice, the crop should be sown in lines at recommended spacing to facilitate inter- weeding operations. Mechanical methods of weed should be practiced after 2-3 weeks and second time if necessary after 4-6 weeks of sowing.
14.	Harvest close to ground level to destroy insect pests present in the internode stubble. This will also expose the insects to birds thus help in natural biocontrol of insect pests.
15.	After harvesting the field should be thoroughly flooded with water and plough with disc rotator to kill hibernating larvae of stem borer present in the stubble. Summer ploughing of fields also exposes larvae and pupae of rice swarming caterpillar or ear cutting caterpillar (climbing cutworm) hidden in the soils to birds and weather factors.

(Prakash *et al*. 2014)

Genetic Management

Genetic mechanism of resistance is the most effective, economic and reliable means for plant protection for centuries (Pasalu *et al*., 2004). Genetic engineers have inserted genes for a variety of desirable agronomic traits into these crops. and crop engineering is presently in the global limelight of agricultural science. 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).

In Indian context, the presence of biotype 4 of the brown plant hopper has been documented in India(Khush and Brar,1991; Mohanty *et al*. in 2017). Three specific genes, namely bph-5, bph-6, and bph-7, have demonstrated resistance against biotype 4, (Behera *et al*., 2013) and (Bentur *et al*., 2021).

Insect pests	**Resistant/tolerant varieties**
Stem borer	Ratna, Sasyasree, Vikas,
Gall midge	Vikram, Shakti, Jyoti, Kakatiya
Brown plant hopper	Sonasali, Rasmi, Neela, Annanga,
White back hopper	HKR 120, HKR 126, HKR 228
Green leaf hopper	Vikramarya, Nidhi, IR 24, Radha, Mahananda and Kunti.
	Prakash *et al*. 2013

Varieties with resistance to more than one pests	
Variety	Resistance to
Udaya	Brown plant hopper, gall midge, green leaf hopper
Suraksha	Gall midge, green leaf hopper
Vikramarya	Gall midge, brown plant hopper
Shaktiman	Gall midge, brown plant hopper
Rasmi	Gall midge, Brown plant hopper
Daya	Gall midge, brown plant hopper, Green leaf hopper
Samalei	Gall midge, brown plant hopper
Bhuban	Gall midge
	Prakash *et al*. 2013

Mechanical Practices

Traditional techniques for managing rice pests are some of the earliest and most labour-intensive treatments. These methods diminish in popularity as labour prices increase and more cost-effective alternative methods become accessible. Countries with socialist systems that are capable of mobilising huge groups of inexpensive workers are more likely to engage in such practices. Manual methods of insect control may be overlooked despite being equally laborious as manual weed control practices (Maxwell-Lefroy 1906). Manual insect management methods are particularly suitable for high-value crops that have inexpensive labour, concentrated insect pests, and where the gathered insects can be utilised as food or have economic worth (Isely, 1951).

Mechanical Managemental Practice	
Sl.no	
1.	Collection of egg masses and larvae of pest to be placed in bamboo cages for conservation of biocontrol agents
2.	Removal and destruction (burn) of diseased/pest infested plant parts.
3.	Clipping of rice seedlings tips at the time of transplanting to minimize carryover of rice hispa, case worm and stem borer infestation from seed bed to the transplanted fields.
4.	Use of coir rope in rice crop for dislodging case worm, cut worm and swarming caterpillar and leaf folder larvae etc. on to kerosinized water (1 L of kerosene mixed on 25 kg soil and broadcast in 1ha).

Biological Control Practices

Every pest has its own set of natural enemies that help keep their numbers in check, preventing them from reproducing and spreading too rapidly. Preserving these natural enemies is crucial for the success of biological control. In agro-ecosystems, natural enemies are augmented by mass producing and releasing biotic agents to suppress pest populations to non-damaging levels. Managing natural enemies to decrease pest populations and minimise their impact is a crucial aspect of our pest management strategy.

Conservation and augmentation of natural enemies:

Conserving natural enemies is of utmost importance in biological control, as it significantly reduces the need for additional control measures (Thompson 1956). Conservation involves refraining from actions that harm natural enemies and instead implementing practices that support their growth and reproduction. Implementing targeted pest control measures, optimising spray schedules to minimise harm to beneficial organisms, and cultivating plants that support natural enemies are effective strategies for conservation.

Conserving spiders and other natural enemies by avoiding the use of pesticides is crucial in the realm of IPM in rice (*Oryza sativa* L.). When considering the implementation of biological control strategies, it is important to identify the natural mortality factors of a pest. This can be done by developing a life-table that provides valuable insights into the pest's survival potential (Birch 1948a, 1948b, Dempster 1956, Trivedi *et al*., 1994b).

Biorationals

There is great potential in natural products as pesticides that are both safe and biodegradable. Biorationals are known for their heightened specificity, which helps prevent unintended harm to non-target organisms and minimises related issues. Using biorationals is a crucial part of our integrated pest management (IPM) strategy. There are certain natural substances, such as Margosa or neem (*Azadirachta indica* A. Juss.), that have proven to be quite effective in combating various pests.

The details of biological control practices taken up under rice are given below

Sl.No	**Biological control measures**
1.	*Trichogramma japonicum* and *T. chilonis* may be released @ 1 lakh/ha on appearance of egg masses / moth of yellow stem borer and leaf folder in the field.
2.	Natural biocontrol agents such as spiders, drynids, water bugs, mirid bugs, damsel flies, dragonflies, meadow grasshoppers, staphylinid beetles, carabids, coccinellids, *Apanteles, Tetrastichus*, *Telenomus*, *Trichogramma, Bracon, Platygaster* etc. should be conserved.
3.	Collection of egg masses of borers and putting them in a bamboo cage-cum-percher till flowering which will permit the escape of egg parasites and trap and kill the hatching larvae. Besides, these would allow perching of predatory birds.
4.	Habitat management: Protection of natural habitats within the farm boundary may help in conserving natural enemies of pests. Management of farmland and rice bunds with planting of flowering weeds like marigold, sun hemp increases beneficial natural enemy population and also reduce the incidence of root knot nematodes. Provide refuge like straw bundles having charged with spiders to help in build up spider population and to provide perch for birds
5.	Mass trapping of yellow stem borer male moths by installing pheromone traps @ 20 traps/ha with lures containing 10-15 mg pheromone at 20 days after transplanting.

Chemical Control Measures

Refining pesticide application recommendations to minimise their use is the top priority in Integrated Pest Management (IPM) programs that control the use of pesticides. The most crucial aspect is ensuring the safe and responsible utilisation of pesticides. Typically, pesticides are used as a precautionary measure rather than a strategic response, especially when farmers have sufficient funds to buy them. This can lead to a cycle of dependency on pesticides, (Collins *et al*. 1992, Litsinger *et al*.1980). Ensuring the quality control of pesticides, whether in their technical form or in the ready-to-use stage, is crucial for the success of plant protection operations. It is crucial to pay close attention to pesticide application techniques. Many spray application methods that are commonly used, while effective, can be wasteful and inefficient. Implementing effective pesticide application techniques can significantly decrease the quantity of pesticides used, safeguard against soil and water contamination, and ultimately mitigate potential risks to the environment and human health.

For the successful implementation of Integrated Pest Management, the thorough understanding of the concept of economic threshold Level.

Table 3: Economic threshold level(ETL) of major pests of rice crop stage wise (Prakash *et al*. 2013)

Crop Stage	Pest	Economic Threshold Levels (ETLs)
Nursery	Yellow stem borer	1 egg mass/m^2
	Root knot nematode	1 nematode/g soil
Early to mid-tillering stage	Leaf folder	2 Fully damaged leaves (FDL) with larva/hill
	Stem borer	2 egg mass/m^2 or 10% dead heart or 1 moth/m^2 or 25 moths per trap/week
	Gall midge	1*et al* gall/m^2 or 10% silver shoot
	Brown plant hopper/WBPH	10-15 hoppers/Hill
	Rice case worm	2 fully damaged leaves /hill
	Swarming caterpillar	1 damaged tiller/hill or 2 larvae /m^2
Panicle initiation to booting	Stem borer	2 egg mass/m^2 or 1 moth/m^2 or 25 moths/trap/ week
	Leaf folder	2 FDL/hill
	BPH/WBH	15-20 hoppers/hill
Flowering to milky grain	Gundhi Bug	2 bugs/hill

Chemical Management of Rice Pests	
Pests	**Pesticides**
I. INSECTS	
Nursery	
Gall midge	Carbofuran 3% CG @ 25000-66600 g/ha or carbosulfan 6% G @ 16700 g/ha or carbosulfan 25% EC @ 800-1000 ml/ha.
Stem borer	Cartap hydrochloride 4% granules @ 18750 g/ha or cartap hydrochloride 50% SP @ 1000 g/ ha.
Vegetative stage	
Stem borer	Carbofuran 3% CG @ 25000-66600 g/ha or cartap hydrochloride 4% granules @ 18750-25000 g/ha or cartap hydrochloride 50% SP @ 1000g/ha or monocrotophos 36 % SL @ 625-1250 ml/ ha.
Leaf folder	Spray cartap hydrochloride 4% granules @ 18750-25000 g/ha or cartap hydrochloride 50% SP @ 1000 g/ha or monocrotophos 36 % SL @ 625-1250 ml/ha or chlorpyrifos 1.5% DP @ 25000 g/ha.
Brown plant hopper/White backed plant hopper	Spray of imidacloprid 70% WG @ 30-35 ml/ha or imidacloprid 30.5% m/m SC @ 60-75 ml/ha or ethofenoprox 10% EC @ 500-750 ml/ha or acephate 75% SP @ 666-1000 g/ha or buprofezin 25% SC @ 800 ml/ha.
Flowering	
Brown plant hopper/White backed plant hopper	Spray of imidacloprid 70% WG @ 30-35 ml/ha or imidacloprid 30.5% m/m SC @ 60-75 ml/ha or ethofenoprox 10% EC @ 500-750 ml/ha or acephate 75% SP @ 300-500 g/ha or buprofezin 25% SC @ 800 ml/ha.

Nematode Management Practices

Rice has been documented to be associated with over 200 species of plant-parasitic nematodes (PPN) on a global scale (Prot 1994). The root-knot nematode (*Meloidogyne graminicola*) is a significant issue in rainfed, upland, and lowland rice production areas. In contrast, the rice root nematode (*Hirschmanniella* spp.) only affects lowland rice in South and Southeast Asia. The root-knot nematode is particularly problematic in rice-based production systems (Prot *et al*., 1994). Nematodes have the ability to cause a significant reduction in rice yield, with certain production areas experiencing losses of up to 50%.

Nematode pest of rice and management	
Nematode	**Managemental measures**
White tip nematode (*Aphalenchoides besseyi*)	• Sun drying of seeds for 6 hours for 4 days. • Pre-sowing of nursery bed treatment with carbofuran 3% CG @ 50000 g/ha, if nematode population crosses the ETL.
Root knot nematode (*Meloidogyne graminicola*)	• Rotation with the crops like sweet potato, sunflower, cowpea, sesamum, and onion. • Soil application of carbofuran 3% CG @ 50000 g/ha.

Rat Management Practices

Rodents have significant economic importance due to their role as destructive pests that can cause damage to crops, fruit gardens, orchards, and stored food grains. Additionally, they inflict harm on numerous types of properties, leading to significant economic losses (Pradhan and Talmale, 2011). In India, the amount of grain lost to rats after harvest is estimated to be between 25-30%. This results in a cost of at least US$5 billion every year for stored food and seed grain (FAO, 1999). Historically, there have been significant reports in India regarding the considerable influence of rodents on rice fields (Rao and Joshi, 1986).

Management of rat in rice	
Sl. no	**Management measures**
1.	Application of bromodiolone (0.005%a.i) in baits six weeks after transplantation
2.	Residual live burrows may be treated with second application of bromodiolone(0.005%).
3.	control operations with rodenticides except Zinc phosphide (as rodents develop bait shyness) may be repeated if the rodent population exceeds working index.

Issues in implementation of IPM

- 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.
- The adoption of IPM practices by growers has fallen short of the expectations of the IPM developer.
- There are several challenges associated with the use of botanical pesticides. These include a limited supply of high-quality raw materials, a lack of advanced agricultural technology, expensive products and technology, difficulties in standardising products, limited versatility in their use, insufficient research and development, an undefined role in integrated pest management, and an unclear policy framework

Future Thrust Area

Studies on pest control methods and ecological balance should investigate the effects of different Integrated Pest Management (IPM) tactics on the overall stability of agricultural ecosystems. Crop varieties designed to possess insect resistance can significantly enhance the effectiveness of Integrated insect Management (IPM) initiatives in impoverished nations. Conducting fundamental research is essential for responding questions regarding improving pest control for long-term effectiveness. However, it is also important to consider research that is based on the practices of farmers. It is important to introduce education on Integrated Pest Management (IPM) in schools due to the restrictions set by the World Trade Organisation (WTO) about pesticide residues in food and the changing focus on environmental safety. In order to tackle the problem of inadequate execution of Integrated Pest Management (IPM) activities, the utilisation of sophisticated technologies such as expert systems, information and communication technology, and simulated weather information can streamline the decision-making process for producers and enhance the rate at which IPM measures are implemented. Farmers that adopt Integrated Pest Management (IPM) approaches and successfully achieve higher crop yields should get suitable incentives.

Key focus areas for Integrated Pest Management include:

- **Pest control tactics and ecological stability**: Research on pest management techniques and ecological stability should examine the impact of various Integrated Pest Management (IPM) strategies on the overall stability of agroecosystems. The findings of this research have implications beyond academia, as they can inform practical approaches to maintaining the stability of agricultural systems. There is a need for quantitative field studies to examine the ecological consequences of different strategies, both in the short and long term. These studies should focus on disturbances caused by the tactics and the time it takes for the ecosystem to recover from these perturbations.

- **Engineered Crops**: Future IPM programs in developing countries can greatly benefit from crops engineered for pest resistance. Nevertheless, it is crucial for researchers to carefully consider the advantages of their work in light of any potential negative consequences. Instead of focussing on the speed of developing new transgenic plants with pest resistance, the priority should be on maximising the plants' longevity in reliable deployment systems while minimising any negative consequences.
- **Farmers' participatory Research**: While conducting fundamental research is crucial for addressing enquiries related to optimising pest control for optimal long-term outcomes, it is equally vital to consider research that is based on the practices of farmers (Fujisaka 1991). It is important to understand the knowledge and practices of farmers (Bramel, 1980) is required for successful implementation of IPM.
- **IPM in the classroom**: Education regarding Integrated Pest Management (IPM) should begin in schools, given the WTO regulations regarding pesticide residues in edible commodities and the evolving landscape of environmental security. According to Wearing (1988), education outreach, farm size, and farm ownership are considered to be the primary elements that influence the successful application of Integrated Pest Management (IPM).
- **Utilization of expert systems**: To address the issue of poor implementation of IPM practices, the use of advanced technologies like expert systems, information and communication technology, and simulated weather information can simplify IPM decision making for growers and increase its implementation rate (James and Edwin 1995). Establishment of kiosks in villages can serve as discussion forums for farmers, where they can receive information about IPM technology. Simulated weather information enables growers to efficiently utilise precise, up-to-date, location-specific weather data in their daily decision-making process, eliminating the need for costly and time-consuming on-farm weather monitoring systems. Software for decision making, such as pesticide advisor, has been developed and is currently being utilised for the purpose of making prudent decisions (Singh *et al*. 2006).
- **Incentives**: Farmers that implement Integrated Pest Management (IPM) techniques and achieve increased crop yields should get appropriate incentives. Greater emphasis should be placed on providing further coverage of Integrated Pest Management (IPM) in both print and electronic media. There is a growing trend of establishing more contact centres to provide convenient assistance to farmers in addressing their issues regarding plant protection.

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 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. 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.

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