

Pest management is a range of methods and practices employed to manage and regulate the population of species classified as pests. These are typical organisms which negatively affect human activities, such as agriculture, residential and commercial environments (Cook et al., 2006). The aim of pest management is to minimize the physical and economic damages caused by these pests.

Table: 1 Lists of some common pests and methods for eco-friendly control.

Pest	Eco friendly Control Method
Aphids	Use of ladybugs or lacewings (Biological Control) Neem oil (Organic Pesticide)
Caterpillars	<i>Bacillus thuringiensis</i> (Bt) (Biological Control), Hand picking (Mechanical Control)
Whiteflies	Yellow sticky traps (Mechanical Control) <i>Encarsia formosa</i> (Biological Control)
Slugs and Snails	Hand-picking and barriers (Mechanical Control), Nematodes (Biological Control)
Colorado Potato Beetle	Crop rotation (Cultural Control), <i>Bacillus thuringiensis</i> (Bt) (Biological Control)
Mice and Rats	Traps (Mechanical Control), Predatory cats or owls (Biological Control)
Mosquitoes	Removing standing water (Cultural Control), <i>Bacillus thuringiensis var. israelensis</i> (Bti) (Biological Control)
Weeds	Mulching (Cultural Control), Hand-pulling (Mechanical Control)
Fungus Gnats	Yellow sticky traps (Mechanical Control), <i>Bacillus thuringiensis var. israelensis</i> (Bti) (Biological Control)
Powdery Mildew	Milk sprays (Organic Pesticide), Resistant plant varieties (Use of Resistant Varieties)

Principles of Eco-friendly Pest Management

Eco-friendly pest management, often referred to as Integrated Pest Management (IPM). It is an approach that emphasizes the use of a combination of strategies to manipulate or manage the pest

populations in a way that is economically viable, environmentally sound, and socially acceptable.

The principles of IPM include:

1. **Monitoring and Identification:** Regular monitoring and accurate identification of pests are essential to determine whether pest management actions are required. Monitoring can help to detect pest infestations prior to significant damage.
2. **Prevention:** IPM emphasizes the prevention of pest problems through various strategies, such as crop rotation, intercropping, and the use of resistant varieties.
3. **Threshold Levels:** IPM is an approach to focused on keeping pest populations below levels those causing economic damage.
4. **Multiple Tactics:** IPM employs a combination of all available pest management tactics, including biological control, habitat manipulation, and the judicious use of pesticides.
5. **Evaluation:** Regular evaluation is conducted to assess the effectiveness of pest management actions and make necessary adjustments (Barzman et al., 2015).

Eco-friendly Pest Management Techniques

Amendment of Cultural Practices

Cultural practices like crop rotation, intercropping, use of pest-resistant varieties, timely sowing, and proper sanitation can disrupt the life cycle of pests, reducing their impact. Altering traditional practices may involve using pest-free seeds or transplants, changing planting dates to avoid peak pest populations, and proper crop residue management. All these changes can lead to healthier crops less susceptible to pest infestations, enhancing productivity while mitigating environmental impact.

Crop Rotation

The practice of growing different types of crops in the same area in sequential seasons, is a

beneficial pest management strategy. It interrupts the pest cycle, making the environment less favorable for pests that are specific to certain crops. Absence of their preferred host continuously, their population is kept under control. crop rotation enhances soil structure, fertility and strengthens the crops' natural defense mechanisms against pests and diseases, ensuring better yields.

Agro-Ecosystem Structure

Agro-ecosystem Structure helps in understanding the entire ecosystem's dynamics, including pests, their natural enemies, and the relationships between different organisms and environmental factors. By promoting biodiversity, farmers can create a more resilient and balanced ecosystem. Planting diverse crops or maintaining natural habitats around the farm can attract and sustain beneficial organisms, such as predators and parasites of pests. These beneficial organisms can help control pest populations naturally, reducing the need for chemical pesticides.

Planting, Sowing and Harvesting Time

Certain pests may be more prevalent and active during specific periods; hence, adjusting the sowing dates can help avoid peak pest activity. Likewise, harvesting at the right time prevents the overexposure of crops to pests, reducing potential damage. An understanding of the pest's life cycle and the crop's growth stages is crucial for this strategy. With proper timing, farmers can exploit the vulnerable stages of pests while protecting the most sensitive phases of crop growth.

Plant Population Density

Closely spaced plants can create a microclimate favorable for certain pests and diseases, due to increased humidity and decreased sunlight penetration. Conversely, very sparse planting can lead to increased weed pressure and make crops more susceptible to pests that prefer isolated plants. Maintenance of optimal plant population density and proper spacing can minimize pest problems. This management approach also ensures that plants are not competing with each other for resources, which can make them more vigorous and less susceptible to pest attacks.

Fertilizer and Water Management

Balanced use of fertilizer and water is another critical strategy in pest management. Over use of fertilization, especially nitrogen, can lead to lush, succulent growth that attracts pests. On the other hand, under use of fertilization can result in weak plants that are more susceptible to pest attacks. Similarly, Over-irrigation can create a favorable environment for pests like fungi and insects that thrive in moist conditions, while under-irrigation can stress plants, making them more vulnerable to pests. Micro irrigation such as drip irrigation and scheduling watering based on soil moisture levels, can help in managing pests effectively.

Tillage

Tillage, the process of preparing soil for planting through mechanical agitation, can significantly influence pest populations. It can disrupt the life cycle of pests by exposing overwintering pests to harsh weather and predators, destroying their habitat, and burying crop residues that might harbor pests or diseases. On the other hand, minimum tillage or zero tillage farming can also contribute to pest management. By preserving soil structure and moisture, zero tillage farming can encourage beneficial soil organisms that help control certain pests.

Mulches

Mulches create a physical barrier that prevents pests from reaching the crops. Mulches can effectively reduce a variety of pests, including insects, nematodes, and weeds. Organic mulches, such as straw, leaves, or compost, can enhance soil health by adding nutrients and improving soil structure, promoting the growth of beneficial microbes that can suppress soil-borne diseases. In contrast, reflective mulches can repel certain insects and reduce the spread of virus diseases transmitted by these pests.

Biological Control

The use of living organisms-predators, parasites, and pathogens to control pest populations are included in biological control. Predators, such as lady beetles and spiders, directly consume pests. Parasites, like parasitic wasps, lay their eggs inside or on pests, eventually killing them. Pathogens,

including certain bacteria, fungi, and viruses, cause diseases that can reduce pest populations (Eilenberg, Hajek, & Lomer, 2001).

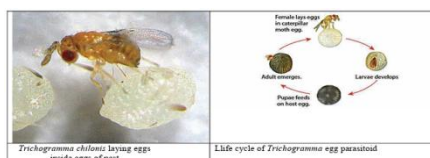
Biological Control Agents

Predators: Predators like Coccinellid beetles in vegetable ecosystem, Spiders in rice ecosystem, dragon flies, damsel flies, lady bird beetles, lacewings, birds etc., have proved helpful in protecting crops.



Ladybird beetles - grubs and adults feed on aphids and other soft bodied insect pests. *Cryptolaemus montrouzieri* feeds on mealy bugs on citrus, guava, grapes, coffee, mango, custard apple and green shield scale on mango, guava. Ground beetles target Coconut black headed caterpillar and rice brown plant hopper. The larvae of Green lace wing (*Chrysoperla carnea*) feed on soft bodied insects like aphids, jassids, white flies, mealybug etc.

Parasitoids: Parasitoids are small insect which feed on larvae of insect and complete their life cycle within them. It includes a



number of species of wasps, fly etc. which lay eggs in or on the bodies of their insect host, and complete their life cycles on host bodies ultimately killing the host. Parasitoids may be of different types viz., egg, egg-larval, larval, pupal, adult depending on the developmental stage of the host in/on which it completes its life cycle. Examples are different species of *Trichogramma*, *Bracon*, *Chelonus*, etc. Egg parasitoids deposit their eggs in the eggs of the host and whose progeny emerge from the host eggs. *Trichogramma chilonis* is used against sugarcane borer pests, rice leaf folder.

Cultural Control: Cultural control techniques include crop rotation, intercropping, and sanitation (Cook et al., 2006). Crop rotation has been successfully used to control pests like the corn rootworm, which relies on continuous corn planting. By rotating corn with other crops, farmers can break the rootworm's lifecycle and reduce its populations. Intercropping, such as planting legumes in cereal crops, can disrupt pest colonization and reduce pest densities.

Table 2: Cultural Operations for controlling pests

S. No.	Techniques	Pest can be Managed
1	Crop rotation	Corn Rootworm
2	Hand Picking	Tomato Hornworm
3	Use of Resistant Varieties	Colorado Potato Beetle
4	Interplanting	Cabbage Moth
5	Sanitation (removal of diseased/infested plant matter)	Peach Borer
6	Mulching	Squash Bug
7	Proper Water Management	Mosquito Larvae
8	Soil Solarization	Nematodes
9	Timely Harvesting	Fruit Flies
10	Planting Time Adjustment	Bean Beetle
11	Companion Planting	Aphids
12	Use of Pest-Resistant Seed Varieties	Stem Borers
13	Fallowing	Cutworms
14	Cover Cropping	Soil-Dwelling Pests
15	Mechanical Weed Control	Various Weed Pests
16	Proper Fertilizer Application	Various Soil Pests
17	Synchronized Planting	Various Crop Pests
18	Destruction of Infested Plant Debris	Various Overwintering Pests

Challenges in Implementing Eco-friendly Pest Management

Major challenges of Implementing Eco-friendly Pest Management is the cost. While it can be cost-effective in the long run, the initial costs can be high, deterring farmers from adopting them. The availability of resources, both human and material, is another hurdle. For example, biological control methods require a thorough understanding of pest biology and ecology, and may require specialized materials or organisms that are not readily available. Gaps in knowledge pose a significant challenge. Knowledge of pest biology and ecology, as well as the long-term impacts and effectiveness of various control methods.

Conclusion

Eco-friendly pest management is vital for sustainable agriculture and environmental conservation. Despite challenges in implementation,

the potential solutions and emerging trends promise a positive future.

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