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Ecological Engineering: An Important Tool for Sustainable Insect Pest Management

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ABSTRACT

Insect pests are a major constraint to agricultural productivity worldwide, causing significant yield losses and economic damage. Conventional pest management practices rely heavily on chemical pesticides, which have led to problems such as pest resistance, environmental contamination, destruction of beneficial organisms, and health hazards to humans. Ecological engineering offers a sustainable alternative by manipulating agro-ecosystems to enhance natural pest regulation through biodiversity conservation and habitat management. This approach emphasizes the use of cultural practices, habitat manipulation, and conservation of natural enemies to suppress pest populations. Techniques such as floral strip cropping, trap cropping, beetle banks, windbreaks, push–pull strategies, and soil health management play a crucial role in strengthening biological control services. Ecological engineering not only reduces dependency on chemical pesticides but also improves soil health, pollination, and ecosystem resilience. This paper reviews the principles, mechanisms, and applications of ecological engineering for sustainable insect pest management and discusses its constraints and future prospects.

Keywords : Ecological engineering, Biological control, Habitat management, Biodiversity, Sustainable agriculture, Insect pest management

Introduction

Agriculture across the globe has been severely affected by insect pests, leading to substantial crop losses and reduced farm productivity. To address this challenge, farmers have traditionally depended on chemical pesticides as a rapid and effective control measure. However, indiscriminate and prolonged use of pesticides has resulted in pest resistance, resurgence, environmental pollution, and adverse effects on non-target organisms, including pollinators and natural enemies.

Frequent pesticide applications increase production costs and pose serious health risks to farmers and consumers. These limitations of chemical pest management have created an urgent need for environmentally safe and sustainable alternatives that can ensure long-term

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agricultural productivity. Ecological engineering, based on ecological principles and biodiversity conservation, provides an effective framework for sustainable pest management (Odum, 1962). It involves deliberate modification of agro-ecosystems to enhance beneficial organisms that naturally regulate pest populations, thereby reducing reliance on chemical inputs.

Planting hedgerows, blooming strips, or cover crops, for instance, might attract predators such as parasitoid wasps, lacewings, and ladybird beetles, which help suppress pest populations. In addition to improving soil health and resilience, crop variety and intercropping can disrupt insect life cycles and lower the chances of outbreaks. Ecological engineering supports sustainable agricultural production and reduces reliance on chemical pesticides by creating a balanced ecosystem. In addition to controlling pests, these methods also enhance pollination, increase soil fertility, and boost farm biodiversity in general, resulting in a strong and sustainable agricultural system that benefits both farmers and the environment.

Importance of Ecology in Pest Management

Effective pest management requires a thorough understanding of ecological interactions within agro-ecosystems. Pest population dynamics are influenced by abiotic factors such as temperature and humidity, as well as biotic factors including predators, parasitoids, and competitors. Simplification of cropping systems through monocropping and excessive pesticide use often disrupts these interactions, leading to pest outbreaks.

Ecological principles help identify functional relationships among species and enable the design of cropping systems that promote natural pest regulation. By restoring ecological balance, pest populations can be managed below economic threshold levels without excessive chemical intervention.

Mechanism for Habitat Management

Alternate food sources

Many adult natural enemies require nectar, pollen, or honeydew for survival and reproduction, especially during periods of prey scarcity.

Floral resources

Nectar and pollen are provided by plants like Tagetes spp., *Coriandrum sativum*, and *Helianthus annuus*. These sustain the adult stages of helpful insects like *Coccinella septempunctata* (ladybird beetles), *Syrphus spp*. (hoverflies), and *Chrysoperla carnea* (green lacewing) (Powell, 1986).

Extrafloral Nectaries (EFNs)

Extrafloral nectaries are nectar-secreting glands not associated with flowers and are found in crops such as cotton, cowpea, and sunflower. EFNs attract ants and predatory wasps (*Formica spp., Lasius spp.*), which protect plants by deterring herbivorous pests (Bentley, 1977; Heil, 2008).

Plant	**Scientific name**	**EFNs located**	**Attract**
Cotton	*Gossypium spp.*	Base of leaves	Ants, predatory wasps
Cowpea	*Vigna unguiculata*	Base of stipules	ants
Sunflower	*Helianthus annuus*	Bud bracts	Predatory bugs, parasitic wasps

Plant sap and exudates

Plant secretions and honeydew excreted by aphids provide important food sources for parasitoids such as *Aphidius colemani*.

Shelter for Natural Enemies

Shelters protect natural enemies from predators and adverse climatic conditions while providing sites for mating, reproduction, and overwintering.

Examples- Straw bundles placed along rice field bunds act as artificial shelters for spiders. In orchards, leaf litter, crop residues, and materials such as burlap wrapped around tree trunks provide refugia for predators like spiders, lacewings, beetles, and predatory bugs (Tamaki *et al.*, 1968).

Microclimate modification

Temperature and humidity strongly influence pest and natural enemy activity. Ecological engineering practices help optimize microclimatic conditions to favour beneficial organisms.

Examples- Inter-planting ryegrass in maize fields reduced soil temperature and enhanced the survival of Trichogramma brassicae by improving microclimatic conditions (Orr *et al.*, 1997).

Floral strip cropping

Floral strip cropping involves planting flowering plants within or along crop fields to provide continuous resources for beneficial arthropods. This habitat manipulation strategy enhances biodiversity, increases the longevity and fecundity of natural enemies, and reduces pest outbreaks.

Example- Flowering buckwheat and alyssum increased parasitism by *Dolichogenidea tasmanica* and reduced leaf-roller populations in vineyards (Berndt and Wratten, 2005).

Throughout their life cycles, a variety of natural enemies depend on nectar, pollen, and shelter. Intensively managed monocultures, however, frequently lack these assets. Strips of flowers :

- Attract in helpful insects by offering them food and places to lay their eggs.
- Enhance natural enemies' lifespan and fertility.
- Support biodiversity to lower the chance of insect outbreaks.
- Act as pathways for the passage of natural enemies throughout the terrain.

Trap Cropping

Trap cropping is a diversionary planting technique where a more attractive plant is grown to lure pests away from the main crop.

Types of Trap Cropping

***Perimeter Trap* Cropping** - Around the edges of the main crop trap crops are planted. Examples: In order to reduce infestation in cabbage fields, mustard is used as a trap crop to draw in the diamondback moth (*Plutella xylostella*). (Shelton and Badenes-Perez, 2006).

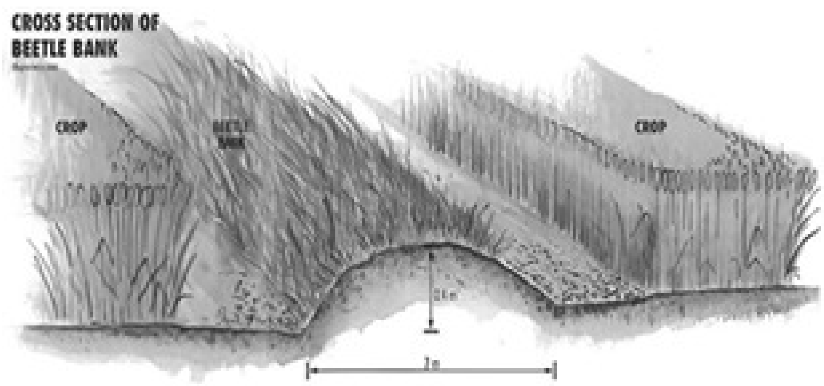
***Sequential Trap* Cropping -** When pests arrive, the trap crop is more attractive since it is planted before the main crop. Examples: Marigold planted earlier than tomato to attract *Helicoverpa armigera* (Kumar *et al.,* 2012).

***Multiple Trap Cropping* -** More than one species or variety are used to trap different pests. Examples: Castor and used alongside cotton to attract *Spodoptera litura* (Dhawan, 1999).

***Dead-End Trap Cropping* -** The trap crop attracts pests, but because of inappropriate conditions, they are unable to complete their life cycle. Examples: *African nightshade* attracts *Tuta absoluta* but larvae fail to survive. (Smith *et al.,* 2018)

Beetle Bank

In the centre of fields are strips of grasses and other vegetation known as beetle banks. They serve as a haven and home for pest-eating insects' natural enemies, including parasitic wasps, ground beetles, spiders, and predatory beetles. Through the support of natural enemies throughout the crop production cycle, beetle banks, a component of habitat alteration under ecological engineering, improve biodiversity on farms and strengthen conservation biological control. Examples: It has been shown that *Coleomegilla maculata* (Coleoptera: Coccinellidae) lays more eggs on a native weed, *Acalypha ostryaefolia* than on sweet corn (*Zea mays*) crop. Additionally maize plots bordered by *A. ostryaefolia* contained significantly higher *C. maculata* than did plots without a border (Cottrell, 1998).



Origin and Concept

Beetle banks were first proposed in the UK in the late 1980s, mostly as a result of studies conducted by the Game & Wildlife Conservation Trust. Its original goal was to enhance the habitat of carabid beetles, also known as ground beetles, in cereal crop systems. These insects are crucial predators of crop pests like caterpillars, slugs, and aphids.

Structure and Design

- **Location :** To break up the regularity of a vast field, beetle banks are positioned across or along its length, occasionally at different points.
- **Size :** usually extending the entire width or circumference of the field, measuring 0.4 to 1 m in height and 1 to 2 m in breadth.
- **Plant Species :**

✓ Commonly use grasses include perennial ryegrass (*Lolium perenne*), red fescue (*Festuca rubra*), bentgrass (*Agrostis capillaris*), and orchard grass (*Dactylis glomerata*).

✓ Legumes or flowering plants may also be a part of some beetle banks in order to sustain other beneficials, such as parasitoids or hoverflies.

Windbreak

Windbreaks composed of trees or shrubs act as physical barriers that restrict pest movement while providing habitat for natural enemies. They improve microclimate, reduce soil erosion, and indirectly enhance crop yields by strengthening biological control.

Advantages of windbreak design

- Windbreaks serve as physical barriers that prevent flying insect pests including moths, aphids, and whiteflies from entering agricultural areas.
- They lessen pests' capacity to colonize and infest crops by interfering with their flying patterns.
- Natural enemies like as parasitic wasps, spiders, and predatory beetles find refuge and habitat in windbreaks.
- By providing microhabitats and nesting locations, they aid in the preservation and population growth of beneficial insects.
- Windbreaks can provide pollinators and adult parasitoids with nectar and pollen when flowering plants are present.

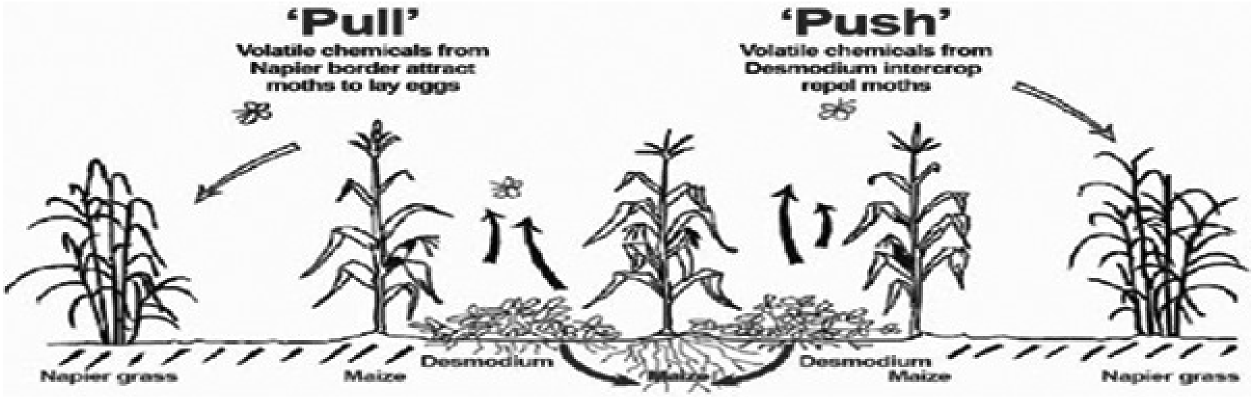
- By reducing wind speed across fields, windbreaks shield crops from physical harm such lodging or shredding leaves.
- By preserving soil moisture and lowering evaporation, they aid in the maintenance of a good microclimate.
- By lessening the influence of strong winds on bare or farmed land, windbreaks effectively reduce soil erosion.
- They can directly increase crop yields by lowering wind-related stress and damage, and indirectly by improving insect control.
- Windbreaks lessen the demand for chemical insecticides by lowering pest pressure and increasing biological management.
- Some windbreak plants, like casuarina or neem, might offer further advantages like lumber, fuelwood, or pharmaceuticals.
- Additionally, windbreaks enhance the farming landscape's aesthetic appeal and ecological balance.

Examples- In the border of multi-row wind breaks had higher populations of carabids and staphylinids (Coleoptera), which consume crop pests, than the centre of the windbreak. Carabid and staphylinid abundance in single-row elm windbreaks is often comparatively consistent across the windbreak. (Frye *et al.*, 1988).

Push-Pull Strategy

The push–pull strategy combines repellent intercrops (push) with attractive trap crops (pull) to manipulate pest behaviour and enhance biological control (Cook *et al.*, 2007).

Example- In maize-based systems, *Desmodium spp.* repel stem borers while Napier grass attracts them, resulting in reduced pest infestation and suppression of Striga weeds (Khan *et al.*, 1997).



Ecological Engineering for Pest Management-Above Ground

- To attract in natural enemies and deter migratory pest populations, grow taller plants near the orchard boundary and shorter plants toward the main crop to increase the number of flowering plants and appropriate cash crops along the orchard border.
- Planting flowering plants on the internal bunds inside the orchard.
- *Tridax procumbens*, *Ageratum spp.*, *Alternanthera spp.*, and other naturally occurring weed plants should not be removed because they serve as a source of nectar for natural enemies.
- Avoid using insecticides with broad spectrum chemicals. Prior to using chemical pesticides, the capacity of the plant to compensate should also be taken into account.

Ecological Engineering for Pest Management-Below Ground

- Throughout the year, cover soils with crop residue or living vegetation.
- To improve biodiversity below ground, add organic matter in the form of crop residue, vermicompost, and farm yard manure (FYM).
- To preserve dormant natural enemies, lessen the degree of tillage.
- Use biofertilizers to apply a balanced dose of nutrients.
- Plant growth-promoting rhizobacteria (PGPR) and mycorrhiza should be applied.
- Use *Trichoderma spp.* and *Pseudomonas fluorescens* for soil application, nursery treatment, and seed, seedling, and planting material.

Constraints and Future Prospects

- Research identifying the function of cultural practices, tritrophic relationships, and other practices in enhancing the effectiveness of natural enemies has to be strengthened.
- Requirement of integration with IPM modules.
- To create farmers friendly technologies that take into account the preservation or enhancement of natural enemies' effectiveness, a concentrated effort is required.

- For conservation and manipulation strategies to be successful, the extension gap between researchers and farmers must be closed.
- Need for large-scale field validation.
- Strengthening extension and farmer training programs.

Conclusion

Ecological engineering applies ecological principles to modify agricultural environments for sustainable pest management. It reduces reliance on chemical pesticides, conserves biodiversity, and enhances ecosystem services. When integrated with biological control strategies, ecological engineering forms the basis of integrated biological control, offering durable and environmentally sound pest suppression.

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