**A Review of Ecological Engineering in Pest Management: A Multidisciplinary and Sustainable Approach**

**ABSTRACT**

The agricultural revolution has led to ecosystem instability and a lack of natural pest management. Ecological engineering aims to maintain a balanced agroecosystem by strategically manipulating crops and habitats to enhance the survival of natural enemies while limiting pest populations. Push-pull strategies are adopted in ecological engineering by using semiochemicals and trapping crops. Natural enemies are conserved by providing alternate foods through chocolate-box ecology and beetle-bank feeding and pest movement has been arrested through windbreaks and trenches.

**1. INTRODUCTION**

In crop photosynthetic food reserves, disease-causing pathogens damage some; some are used as sowing material by humans; some are eaten and damaged by pests; and finally, leftovers are for human consumption. Hence, to meet the hunger of the growing human population, The Green Revolution was adopted, which intended to increase food production in developing countries through the large-scale use of pesticides, which led to pest resurgence, secondary outbreaks, pesticide residues, and death of natural enemies, increasing the cost of crop cultivation, a lack of natural control over pests, the development of health hazards, and environmental pollution like biomagnification and eutrophication (Yilmaz and Yilmaz, 2025; Dale et al., 2021). Hence, to mitigate the ongoing challenges, the Ecological engineering concept was adopted in pest management.

**2. ECOLOGICAL ENGINEERING FOR PEST MANAGEMENT**

Gurr et al. (2004) stated that ecological engineering has recently emerged as a paradigm for considering pest management approaches that are based on cultural practices informed by ecology rather than high-technology approaches such as synthetic pesticides and genetically engineered crops. A wide range of approaches are being developed by researchers and employed by practitioners to ensure that appropriate forms of diversity are deployed for pest management via ecological engineering and emerging technology to enhance biological control by preserving or enhancing plant diversity or providing adequate refugia for pests’ natural enemies.

In pest management, ecological engineering involves designing habitats for natural enemies that favor survival, growth, and reproduction, resulting in increased predation. This approach is similar to conservation biological control proposed by Eilenberg (2001), which involves modification of the environment or existing cultural practices to protect and enhance the actions of natural enemies to reduce pest effects.

Conservation biological control is also defined as habitat manipulation that aims to provide natural enemies with resources such as nectar, physical refugia, alternate prey, alternate hosts, lekking sites, and pesticides with the correct time, rate, method, technique, and combinations to avoid pesticide-induced mortalities (Nayak et al., 2018).

**2.1 ECOLOGICAL ENGINEERING PRACTICES**

Ecological engineering for pest management involves habitat manipulation, providing alternate food, shelter, and microclimate to beneficial organisms, and adopting floral stripping, beetle bank, and chocolate box ecology. Implement push and pull strategies, cultural practices, and growing windbreaks around the field (Sen et al., 2022).

**2.2 HABITAT MANIPULATION**

The crop habitat and its surroundings are modified for the benefit of natural enemies using two concepts known as top-down and bottom-up approaches.

The top-down approach, also known as augmentative biological control, involves managing pest populations by enhancing the presence and effectiveness of natural predators and parasites. The term top-down approach implies that pests are herbivores occupying the second trophic level, while their natural enemies, such as predators and parasitoids, are carnivorous and reside at the third trophic level. These third-level natural enemies control second-level pests, meaning that regulation occurs from the top (natural enemies) down to the bottom (pests).

In a bottom-up approach to pest management, instead of directly targeting higher trophic-level pests, the focus is placed on lower trophic-level plants by planting resistant varieties and implementing other cultural practices. Additionally, insect host plant selection behavior can be altered by planting cover crops and smooth crops, where crop cues are diluted, making it difficult for pests to identify their hosts (Fig 1.). The term bottom-up implies that pest management starts from the lower trophic-level plants (bottom) and moves up to higher trophic-level pests (up) (Ahmad and Pathanja, 2017).

**Fig 1. Habitat manipulation**

**2.3 CHARACTERISTICS OF GOOD HABITATS**

In ecological engineering, existing habitats are engineered to attract more natural enemies and promote the health and reproduction of targeted beneficial organisms. Additionally, the habitat must allow beneficial insects to move to the crop of interest where pests are present and enhance pest management. As a result, the overall pest population is reduced (Nayak et al., 2018).

**2.4 ALTERNATE FOODS**

Many hymenopteran and dipteran parasitoids benefit from alternative foods (Han et al., 2024; Josephrajkumar et al., 2022). Alternative foods for beneficial insects include nectar, pollen, and honeydew. The parasitization rate is enhanced by consuming floral nectar (Geerinck et al., 2025) and honeydew (Syropoulou et al., 2025). Some adult parasitoids relied completely on nectar, pollen, and honeydew. The application of an alternative food supplement known as Envirofest attracted several beneficial insects of the Coccinellidae and Melyridae (Coleoptera); Lygaeidae and Nabidae (Hemiptera); and Chrysopidae (Neuroptera) in cotton fields (Mensah, 1997). In apple plantations, predator abundance was determined by the availability of alternate food-providing weeds (Kozár et al., 1994).

**Fig 2. Alternate foods for natural enemies**

**2.5 PROVIDE SHELTER AND MICROCLIMATE**

Abiotic factors affect the rate of parasitization and predation. Deviation from optimal conditions such as high temperature and low humidity may constrain the activities of natural enemies (Wu et al., 2022). Shelters are provided by augmenting leaf debris on the floor and wrapping tree bases with vegetable debris to change the microclimate and protect natural enemies from high temperatures and humidity (Orr et al., 1997).

**2.6 FLORAL STRIPPING**

A strip of flowering plants is grown between the main crops this process is known as floral stripping. Floral strips provide pollen, nectar, and shelter to natural enemies. Floral stripping increases the longevity, sex ratio, reproduction, and fecundity of natural enemies (Alcalá Herrera et al., 2022). The availability and spatial distribution of natural enemies in and around the field have also increased (Berndt and Wratten, 2005).

In a Meta-analysis study, Jachowicz and Sigsgaard, (2025) stated that adopting floral strips to increase natural enemy population has a positive effect when diverse floral strip species are used, compared to a single species of floral strip, which showed no significant effect. In a multivariate model, there was a 48% ± 20.9 increase in natural enemies, and the natural enemy population increased by 4.1% ± 0.64 for every additional floral plant species added to the main crop.

Results of the five-year experiment at Xinhua, Zhejiang province, in eastern China, showed that the overall biodiversity of the rice ecosystem, biological control of pests, and biological stability of the ecosystem were increased when ecological engineering practices such as habitat manipulation based on growing nectar providing flowering plants (preferably sesame), combined with trap plants on the bunds, and also the number of natural enemies such as *Anagrus* sp., damselflies, and frogs were significantly increased by fourfold, and the number of insecticidal spays was reduced by 75% in the ecologically engineered rice plots compared with conventional plots (Lu et al., 2015).

Arthropod diversity consists of 78 insects with 9 natural enemies and 3 pests, 50 insects with 2 natural enemies and 1 pest at 45 DAS (Days After Sowing), 41 insects with 7 natural enemies and 6 pests, and 32 insects with 7 natural enemies and 2 pests at 65 DAS were recorded in ecologically engineered rice plots (by growing white-flowered *Turnera subulata* and yellow-flowered *Turnera trioniflora* along bunds) and conventional plots (Amzah *et al*., 2018).

Among the ecologically engineered black gram plots with border crops of cowpea, red gram, lab-lab, green gram, cluster bean, and French bean, the highest coccinellid beetle 3.72/plant, with a pest defender ratio of 1:24, and an occurrence ratio of 1.84, and the lowest *Aphis gossypii* 3.63/terminal shoot, preference ratio of 0.94, and maximum BC ratio of 1:4.35 were recorded in the black gram and cowpea border cropping systems (Lokesh et al., 2017).

In ecologically engineered rice plots grown with a border cropping system of aroma (Pusa Basmati-1, Pusa Suganth, and Jeeraga Samba) and non-aroma varieties (BPT 5204, ADT 36, and ADT 43), the highest mirid bug predator population, *Cyrtorhinus lividipennis*, was 7.24/hill, with an occurrence ratio of 1.16, and a BC ratio of 1:1.50, recorded in the border cropping system of rice with the Pusa Basmati variety (Chandrasekar et al., 2017).

**2.7 CRITERIA FOR SELECTING FLOWERING PLANTS**

In ecological engineering, selected flowering plants should be grown from seeds. In comparison to the main crop, they require fewer crop husbandry practices, grow quickly, and flower early. Additionally, they should attract more natural enemies and should not attract pests. Apart from this, the selected flowering plants should provide extra income to farmers **(**Horgan et al., 2016).

**2.8 BEETLE BANKS**

Beetle banks are raised earthen structures with perennial grass that provide overwintering and ovipositional sites (Molina and Vazquez Pugliese, 2022). A coleopteran coccinellid predator, *Coleomegilla maculate*, lays more eggs on the weed *Acalypa ostryifolia,* and fields bordered with weeds contain more predators than controlled plots (Cottrell and Yeargan, 1999). The beetle bank represents the conservation of beneficial beetles on the bank, similar to the raised earthen structure of perennial grass.

**2.9 CHOCOLATE BOX ECOLOGY**

In chocolate-box ecology, a variety of flowering plant species is grown along with the main crop, which attracts more predators and parasites. When floristically diverse vegetation is added to the main crop, it provides nectar, pollen, and a nutritious diet for predators and parasites, leading to increased parasitism and predation. We assume that in the term chocolate box, the word chocolate refers to nectar and pollen, which are as sweet as chocolates, and the word box refers to the field where the flowering plant species are present-similar to a box containing chocolates. In practice, while selecting diverse flowering plant species, preference is given to quality, which means the flowers to which the targeted natural enemy is most attracted (Polaszek et al., 1999).

The population of insect pests of rice, such as BPH and WBPH, and the damage caused by leaf folder and whorl maggot were less, and the population of natural enemies, such as spiders and mirid bugs, was higher in ecologically engineered rice plots (by growing field crops such as sesamum, sunflower, and soybean, and flower crops such as marigold, balsam, and gaillardia around the rice fields) (Table 1.) in comparison to conventional plots (Yele et al., 2022; Yele et al., 2023).

**Table 1. Pest and predator populations in conventional and ecological engineering paddy plots (Yele et al., 2022; Yele et al., 2023)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Year | Name of insect | Nature | Conventional plot\* | Ecological engineering plot\* |
| 2019 | WBPH | Pest | 2.35 ± 0.48 | 0.66 ± 0.25 |
| 2020 |  |  | 2.17 ± 0.69 | 0.83 ± 0.44 |
| 2019 | Leaf folder | Pest | 2.45 ± 0.22 | 0.64 ± 0.11 |
| 2020 |  |  | 2.81 ± 0.58 | 0.54 ± 0.35 |
| 2019 | Whorl maggot | Pest | 7.47 ± 1.20 | 5.00 ± 0.93 |
| 2020 |  |  | 7.13 ± 2.19 | 3.76 ± 1.90 |
| 2019 | Stem borers | Pest | 1.8 ± 0.2 | 0.9 ± 0.08 |
| 2020 |  |  | 1.7 ± 0.2 | 0.6 ± 0.03 |
| 2019 | BPH | Pest | 9.8 ± 3.9 | 5.2 ± 1.8 |
| 2020 |  |  | 14.4 ± 5.1 | 9.4 ± 3.6 |
| 2019 | Spider | Predator | 1.8 ± 0.2 | 2.5 ± 0.3 |
| 2020 |  |  | 1.1 ± 0.1 | 2.4 ± 0.2 |
| 2019 | Mirid bug | Predator | 1.8 ± 1.1 | 3.3 ± 1.9 |
| 2020 |  |  | 0.5 ± 0.1 | 1.4 ± 0.4 |
| 2019 | Rove beetle | Predator | 0.1 ± 0.0 | 0.2 ± 0.00 |
| 2020 |  |  | 0.1 ± 0.0 | 0.2 ± 0.1 |

\*Each valve (Mean ± SE) is a mean of ten replications

WBPH- no. of hoppers/hill

Whorl maggot- no. of leaves infected/hill (%)

Leaf folder- no. of folded leaves/hill (%)

Stem borers- no. white ears at preharvest stage (%)

BPH, Spider, Mirid bug, Rove beetle- Population no./hill

**2.10 PUSH AND PULL STRATEGY**

The proposed method is based on behavioral modification of targeted insects using stimuli. Push means keeping the pest away from the crop through repellents and deterrents and using stimuli that mask the host’s appearance; pull means attracting the pest to stimuli (Cook et al.,2007). This approach involves the combined use of intercrop and trap crop fields. Intercrops masked crop stimuli (push) and trap crops attracting the pest (pull) (Czarnobai De Jorge et al., 2024). Stem borers are repelled by non-host intercrops such as molasses grass (*Melinis minutiflora*), silverleaf (*Desmodium uncinatum*), and greenleaf (*Desmodium intortum*). They are attractive to trap plants such as, Napier grass (*Pennisetum purpureum*) and Sudan grass (*Sorghum vulgare sudanense*).

**2.11 CULTURAL PRACTICES**

Tillage, weeding, and crop sanitation are not only harmful to pests but also to beneficial insects. Beneficial insects in the soil are disturbed by excessive tillage. The weeds that provide nectar, pollen, ovipositional sites, and lekking sites are destroyed by weeding. In ecological engineering, instead of all available cultural practices, target-specific practices are adopted for pest control. In coffee plantations, crop sanitation helps reduce coffee berry borer populations, but at the same time, it reduces their availability as prey or hosts for parasitoids and predators (Johnson et al., 2020).

The mean population of predators (62.60 ± 1.60) and parasitoids (14.01 ± 0.74) was higher when the mango orchard was grown with the weeds. In contrast, the mean population of predators (59.27 ± 1.60) and parasitoids (7.25 ± 0.74) was lower when the mango orchard was grown without weeds, indicating that weeds can attract and serve as insectary plants for beneficial insects (Kleiman and Koptur, 2023).

In a two-year study conducted by Lu et al. (2022), it was found that the mean densities of natural enemy populations were higher in both no-tillage (20.48 individuals/m2) and reduced tillage (19.73 individuals/m2) compared to conventional tillage plots (11.22 individuals/m2). The study concluded that conservation agriculture practices, such as no-tillage and reduced tillage, could facilitate and enrich the distribution of natural enemy populations.

In search of the significance of weeds in pest management, Pugh et al. (2022) found that When diamondback moth-infested cabbage plants and *Lepidium virginicum* plants (a weed) were placed in the field for 48 hours, more spiders and parasitized DBM larvae by *Cotesia vestalis* (a parasitoid) were recovered from *L. virginicum* (56%) than from cabbage (27%). Hence, these findings suggest that the presence of *L. virginicum* in cabbage agroecosystems could be beneficial by diverting DBM oviposition away from cabbage and promoting predator and parasitoid populations.

**2.12 WINDBREAKS**

Windbreaks attract natural enemies and provide shelter, support structures for the hanging of beneficial spiders, and a woody habitat for the nesting of hymenopteran parasitoids. Trees and tall vegetation serve as vertical hanging and supporting structures for spiders and birds. To provide nectar and pollen, flowering shrubs, herbs, and annual or perennial forbs support ichneumonids and syrphids. Additionally, windbreaks help control pest movement.

Vineyards with adjacent or planted trees can reduce insect pest damage by increasing the abundance of predatory insects and insectivorous bats, which has been shown to increase the rates of parasitism and predation (Favor et al., 2024)

**3. LIMITATIONS**

In ecological engineering, border crops, guard crops, hedgerows, floral strips, and intercropping are used. These practices consume more time and labor and require greater effort. Flowering plants were planted along the bunds, making passage difficult and favoring the growth of the rat population, especially in paddy fields where pathways are highly important. In ecological engineering, the pest population was not reduced to zero, and the quality and price of the products declined due to minor pest injuries caused by the remaining pests.

**4. CONCLUSION**

In ecological engineering, instead of using a single input, complex and multiple strategies are deployed for pest management. As a result, resistance or resurgence will not occur. Ecological engineering reduces pesticide reluctance and promotes natural pest control, which is economically, ecologically, and environmentally feasible for pest management. This approach offers immense opportunities for pest management using nonchemical methods. These techniques are also not high-tech and are simple to practice.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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