**Ecological engineering: a multidisciplinary and healthy approach to pest management**

**ABSTRACT**

The agricultural revolution has led to ecosystem instability and a lack of natural pest control. The purpose of ecological engineering is to maintain a healthy agroecosystem in which crops and their habitats are manipulated for the well-being and inconvenience of natural enemies and pests. 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. Pest movement has been arrested through windbreaks and trenches, and the population has been managed by applying botanicals, a narrow spectrum, and bio-rational chemicals with the correct time, dose, and amount.

**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, higher 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). Hence, to mitigate the ongoing challenges, the Ecological engineering concept was adopted in pest management.

**2. ECOLOGICAL ENGINEERING FOR PEST MANAGEMENT**

Gurr (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 (Cortez-Madrigal, 2025), physical refugia (Nirwana et al., 2024), alternate prey, alternate hosts (Horton, 2024), lekking sites (Kumara et al., 2021), and pesticides with the correct time, rate, method, technique, and combinations to avoid pesticide-induced mortalities.

**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 is also known as augmentative biological control. Pests are herbivores present at the second trophic level, and natural enemies, such as predators and parasitoids, are carnivorous and are present at the third trophic level. Third-level natural enemies control the second-trophic pest. Control comes from the top. Natural enemies are used for pest control.

Bottom-up control is also known as the resource concentration hypothesis. Crops are herbivores at the first trophic level, controlling pests at the second tropic level. Control from the bottom to the top. Host crop cues are diluted by growing cover and smooth crops. As a result, it becomes difficult for the pest to select a host (Ahmad and Pathanja, 2017).

**2.3 CHARACTERISTICS OF GOOD HABITATS** (Nayak et al., 2018)

The existing habitats are engineered to meet the following requirements.

Net gains of beneficial natural enemies and pest reduction

The habitat should attract more beneficial

Habitats that promote the health and reproduction of natural enemies

The habitat must allow the beneficial insects to move to the crop of interest where the pest is present.

Habitats that increase the killing of pests by natural enemies

The habitat should reduce the pest population and prevent crop damage.

**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).

**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).

**2.7 CRITERIA FOR SELECTING FLOWERING PLANTS (**Horgan et al., 2016)

Plants should grow from the seeds.

The plant should be fast-growing and early flowering.

Plants should require minimum crop husbandry practices.

Plants should attract natural enemies.

Plants should not become hosts to pests.

Plants should provide additional income for farmers.

**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 diversity of flowers is grown along with the main crop. In the name of the chocolate box, nectar and pollen are referred to as the chocolate, and the field is referred to as the box. Floristically diverse vegetation is added to provide nectar, pollen, and a nutritious diet for enemies. In practice, the quality of the floral sources is given more importance than quantity (Polaszek et al., 1999).

**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. The crop debris that provides overwintering sites is destroyed by crop sanitation practices. In ecological engineering, instead of all available cultural practices, target-specific practices are adopted for pest control.

**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 are used as vertical hanging and supporting structures for spiders and birds. To provide nectar and pollen, flowering shrubs, herbs, and annual or perennial forbs are used for ichneumonids and syrphids.

**3. CASE STUDIES**

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 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).

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).

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).

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) in comparison to conventional plots (Yele *et al*., 2022, 2023).

**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.

**5. LIMITATIONS**

In ecological engineering, border crops, guard crops, hedgerows, floral strips, and intercropping are used. These consume more land, time, and labor and require greater effort. Flowering plants were planted along the bunds, resulting in difficulty in passing and favoring the rats. In ecological engineering, crop stubble and weeds are not removed. They leave in the field, leading to the outbreak of other pests and diseases. Yield is also reduced by weed competition. The pest population was not controlled to zero, and the quality and price of the products were reduced due to pest injuries caused by the small number of pests. Some practices are specific to monophagous pests and do not apply to polyphagous pests. When crop cultivation practices like tillage, harrowing, etc. are not followed, the soil's physical and chemical properties get disturbed, leading to an inability to perform for better crop yields.

**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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