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**Review Article**

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# Ecological Engineering for Pest Management in Agro Ecosystem-A Review

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**A B S T R A C T**

Plants are not capable of running away from their enemies, *i.e.*, the herbivores that may eat them. However, under certain circumstances, plants can rely on the natural enemies of insect herbivores for protection. These natural enemies include other insects that are predators and parasitoids. Habitat manipulation, which is also referred to as "Ecological Engineering", focuses on reducing mortality of natural enemies, providing the supplementary resources and manipulating host plant attributes for the benefit of natural bio-agents. This can be achieved by enhancing the plant diversity and by providing adequate refugia in the agro-ecosystem. In this article we review the use of natural enemies in crop pest management and describe m research needed to better meet information needs for practical applications. Endemic natural enemies (predators and parasites) offer a potential but understudied approach to controlling insect pests in agricultural systems. With the current high interest in environmental stewardship, such an approach has special appeal as a method to reduce the need for pesticides while maintaining agricultural profitability. Habitat for sustaining populations of natural enemies occurs primarily at field edges where crops and edge vegetation meet. Conservation and enhancement of natural enemies might include manipulation of plant species and plant arrangement, particularly at these edges; and consideration of optimum field sizes, number of edges, and management practices in and near edges. Blending the benefits of agricultural and forestry (windbreak) systems is one promising approach to field edge management that has additional benefits of wind protection.

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## Introduction

### The management of nature is ecological engineering (ODUM 1971)

This review is essentially about the management of arthropod pests, though at least some of the principles described will have relevance to other pests, weeds and pathogens. Over recent decades, integrated pest management (IPM) – the combined use of multiple pest-control methods, informed by monitoring of pest densities – has emerged as the dominant paradigm. Each of the specific methodological approaches used in IPM (mechanical, physical and cultural control; host plant resistance; biological control etc; Figure 1) has tended to become a specialised area of research with sometimes only limited communication between researchers across areas. Even sub-areas, such as the four forms of biological control (conservation, classical, inoculation and inundation) recognized by Eilenberg *et al.*, (2001) (Figure 1), have tended to become the domain of specialists. This has led to calls for greater cooperation and exchange of ideas between different sub-disciplines. In the case of biological control, for example, Gurr and Wratten (1999) proposed the concept of 'integrated biological control', which uses conservation biological control techniques to support classical, inoculation and inundation biological control.

Conservation biological control (CBC) has been defined as 'modification of the environment or existing practices to protect and enhance specific natural enemies of other organisms to reduce the effect of pests' (Eilenberg *et al.,* 2001). In practice, CBC is affected by either (1) reducing the pesticide-induced mortality of natural enemies through better targeting in time and space, reducing rates of application or using compounds with a narrower spectrum efficacy, or (2) by habitat manipulation to improve natural enemy fitness and effectiveness.

The second approach often involves increasing the species diversity and structural complexity of agro ecosystems. In the context of CBC, habitat manipulation aims to provide natural enemies with resources such as nectar (Baggen and Gurr, 1998), pollen (Hickman and Wratten ,1996), physical refugia (Halaji *et al.,* 2000), alternative prey (Abou-Awad, 1998), alternative hosts (Viggiani, 2003) and lekking sites (Sutherland *et al.,* 2001). Habitat manipulation approaches, such as those pictured in figure 1, provide these resources and operate to reduce pest densities via an enhancement of natural enemies. For example, 'beetle banks' (Figure 1) are raised earth ridges that typically run through the centre of arable fields and are sown to perennial tussock-forming grasses. During the winter, far higher densities of predatory arthropods shelter on the well-drained, insulated sites than in the open field. In the spring, beetles and other natural enemies emerge from the beetle bank to colonise the growing crop and prevent pest aphid outbreaks (Thomas *et al.,* 1991).When herbivores (the second trophic level) are suppressed by natural enemies (third trophic level) in this manner, control is said to be 'top-down'. Root (1973) referred to pest suppression resulting from this effect as supporting the 'enemies' hypotheses. Importantly, however, within-crop habitat manipulation strategies such as cover crops and green mulches (components of the first trophic level, as is the crop) can also act on pests directly, providing 'bottom-up' control. Root (1973) termed pest suppression resulting from such non-natural enemy effects as the 'resource concentration hypothesis', reflecting the fact that the resource (crop) was effectively 'diluted' by cues from other plant species. These mechanisms are explored in detail in chapter 3, 'The agro ecological bases of ecological engineering for pest management', by Nicholls and Altieri. Though considerable attention has been devoted to testing the relative importance of bottom-up and top-down effects, they are not mutually exclusive and in many systems both are likely to operate (Gurr *et al.,* 1998). Thus habitat manipulation, though it makes a major contribution to CBC, includes a wider series of approaches that may operate independently of natural enemies (Figure 1) and, as discussed below, constitute a form of ecological engineering. Examples of ecological engineering for pest management that operate largely by top-down effects are detailed by Pfiffner and Wyss in chapter 11, 'Use of sown wildflower strips'. Natural enemies use such strips for resources such as nectar and pollen in ways explored by Jervis *et al.,* (Ch. 5, 'Use of behavioural and life-history studies'). The push–pull and intercropping approaches described in the two chapters by Khan and Pickett (ch. 10) and Mensah and Sequeira (ch. 12) employ top-down effects, but the operation of bottom-up effects is also clearly evident.

## Ecological engineering

Odum (1962) was among the first to use the term 'ecological engineering', which was viewed as 'environmental manipulation by man using small amounts of supplementary energy to control systems in which the main energy drives are still coming from natural sources'. In more recent years, Mitsch and Jorgensen (1989) have defined ecological engineering as 'the design of human society with its natural environment for the benefit of both'. Among, the characteristics of this form of engineering are the use of quantitative approaches and ecological theory as well as the view of humans as part of, rather than apart from, nature. Ecological engineering is a conscious human activity and should not be confused with the more recently developed term 'ecosystem engineering'. This refers to the way in which other species shape habitats via their intrinsic biology rather than by conscious design. For example, termites alter the structural characteristic of soils (Dangerfield *et al.,* 1998), and such ecosystem engineers thereby moderate the availability of resources to other organisms (Thomas *et al.,* 1999). Recently, Parrott (2002) has discussed the ecological engineering field as having evolved to incorporate a growing number of practitioners whose endeavour is the 'design, operation management and repair of sustainable living systems in a manner consistent with ecological principles, for the benefit of both human society and the natural environment'. Possibly, however, the most elegant definition of ecological engineering comes from Chinese approaches where a long history of complex land use systems was, in the closing decades of the 20th century, formalised into a 'design with nature' philosophy (Ma, 1985). The existence of the well-established periodical *Ecological Engineering: The Journal of Eco Technology* is evidence of the level of activity in this research field. This title reflects the synonym for ecological engineering, 'eco technology'. Various disciplines are allied to ecological engineering: restoration ecology, sustainable agro ecology, habitat reconstruction, ecosystem rehabilitation, river and wetland restoration and reclamation ecology (Mitsch, 1991). These sub-sets indicate the range of areas in which ecological engineering has been applied, including the restoration of wetlands, treatment and utilisation of wastewater, integrated fish culture systems and mining technology (Mitsch and Jorgensen, 1989) as well as wildlife conservation (Morris *et al.,* 1994).

Adapting and designing the agricultural system to the environment of the region (e.g. choice of appropriate crop species and cultivars);

Optimizing the use of biological resources in the agro ecosystem (e.g. the use of biological control);

Developing strategies that induce minimal changes to the natural ecosystem to protect the environment and minimise use of non-renewable resources (e.g. appropriate fertiliser formulations and application patterns).

Reflecting the utility of the ecological engineering paradigm to agriculture, the term 'agro ecological engineering' has developed currency (e.g. Hengsdijk and van Ittersum, 2003) and this has been viewed explicitly as a way towards sustainable agriculture in China, where it is said to be thriving (Liu and Fu, 2000). These authors hold that agro ecological engineering produce agricultural systems with multi-components and multi-storey vegetation giving higher vegetative cover than is typical of monocultures. As explored by many authors in the present volume, vegetational diversity plays a central role in habitat manipulation. It could be argued that all pest management approaches (Figure 1) are forms of ecological engineering, irrespective of whether they act on the physical environment (e.g. via tillage), chemical environment (e.g. via pesticide use) or biotic environment (e.g. via the use of novel crop varieties). It is, however, the use of cultural techniques to effect habitat manipulation and enhance biological control (Figure 1) that most readily fit the philosophy of ecological engineering. These cultural techniques typically:

Involve relatively low inputs of energy or materials;

Rely on natural processes (e.g. natural enemies or the response of herbivores to vegetation diversity);

Have developed to be consistent with ecological principles;

Are refined by applied ecological experimentation;

Contribute to knowledge of theoretical and applied ecology (Figure 1).

## The development of habitat manipulation

Contemporary habitat manipulation has its genesis in practices that have been used to promote generalist predators in agricultural systems for centuries (Sweetman, 1958). An example of an early habitat manipulation technique, used by Chinese farmers for over 2000 years and still in use today, is the use of straw shelters to provide temporary spider refugia and overwintering sites during cyclic farming disturbances (Dong and Xu, 1984). Another technique, developed in Burma in the 1770s, used connecting bamboo canes between citrus trees to enable predatory ants to move between the trees to control caterpillar pests (van Emden, 1989).

## Habitat manipulation approaches

### Top down control

Here herbivores (second trophic level) are suppressed by the natural bio-agents (third trophic level) and this type of approach is seen in ‘Augmentive biological control’.

### Bottom up control

In this approach, manipulation within crop, such as green mulches and cover crop (first trophic level) will act on pests directly. This type of approach is seen in habitat manipulation of ‘Conservation biological control.

## Possible ways to enhance natural diversity

### Structural and cultural diversity

Trees and other tall vegetation can provide the vertical structure needed by spiders and birds. Flowering shrubs, herbs and annual and perennial forbs can provide for parasitic ichneumonids and syrphids that feed on flower, nectar and pollen. The syrphids are predators of aphids (Leius, 1967) and are more abundant in areas of high floral diversity and abundance (Ruppert and Moltan, 1991). Aphids that feed on goldenrod can be used as alternative prey for ladybird beetles (Coccinellidae) when population of their primary prey is low (Altieri and Whitcomb, 1979).

### Overwintering sites

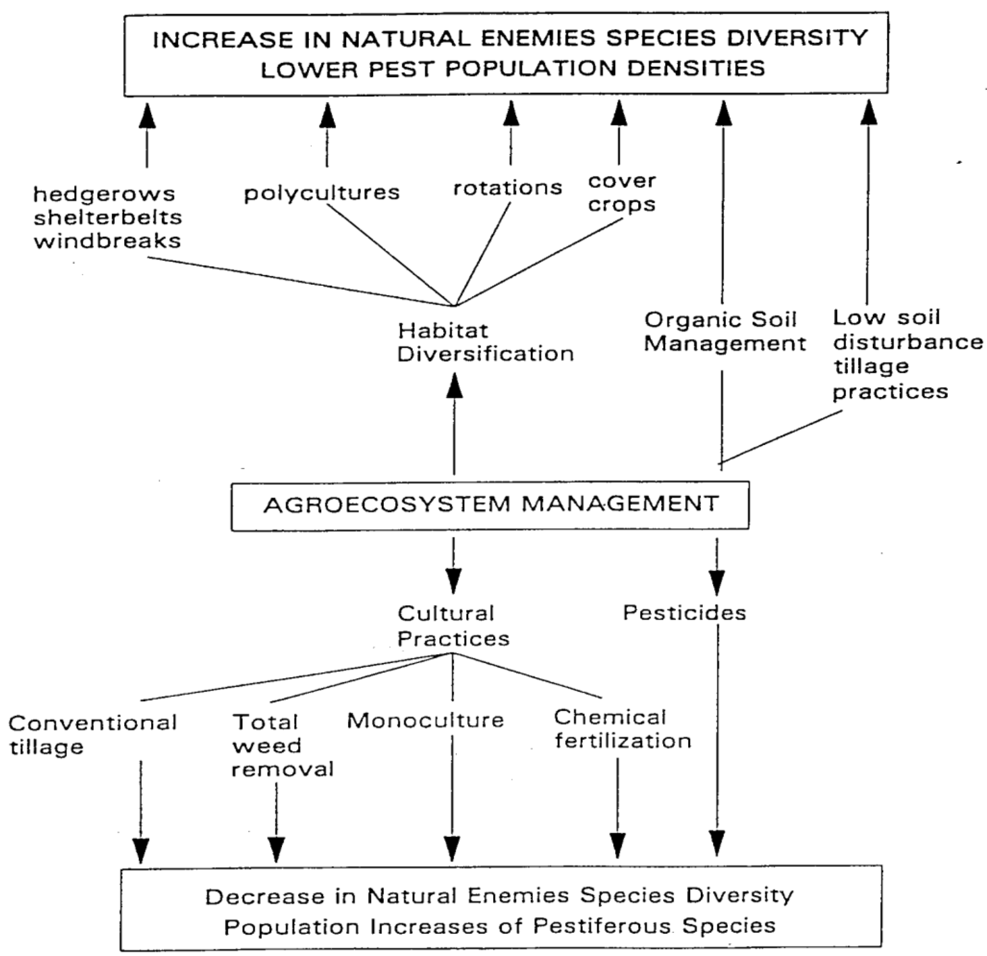
Windbreaks can be used by arthropod predators as overwintering sites if appropriate vegetation is available. In South Carolina, certain species of coccinellids that feed on insect pests of field and orchard crops overwinter at field edges in herbaceous vegetation, grass, and tree litter (Roach and

Thomas, 1991). Woody field edges can provide habitat for birds or small mammals' that feed on insect pests during the winter (Black *et al.,* 1970; Johnson and Beck, 1988).

## Cultural practices

Cultural practices such as plowing, cultivating and harvesting can radically alter the abundance of predators such as spiders, birds, and small mammals. Clean cultivation of a field or around trees may increase crop survival but also can decrease survival of birds, small mammals, spiders, or carabids that use the vegetation for shelter. For example, raking hackberry leaves from lawns removes parasites of the hackberry nipplegall maker. *Pachypsylla celtidismamma* (Fletcher) (Homoptera: Psyllidae) an insect that overwinters in the leaf galls. In rural areas, the leaves are not removed and the parasites control the psyllids (W. Cranshaw, Colorado State University, personal communications). Likewise, crop stubble left in fields might contain overwintering parasitic wasps or may provide cover for predators such as birds, overwintering spiders, or beetles.

**Fig. 1** The effects of agroecosystem management and associated cultural practices on the biodiversity of natural enemies and abundance of insect pests



## Windbreak design

Windbreak design is another method of manipulating natural enemy abundance, and diversity. In North Dakota, carabids and staphylinids (Coleoptera) that feed on crop pests were more abundant at the edge of multi-row wind breaks than in the interior of the windbreak (Katayama, 1980). In single-row elm windbreaks, most of the windbreak is edge; thus, carabid and staphylinid abundance should be relatively constant across the windbreak (Frye *et al.,* 1988).

Conversely, insectivorous birds establish large territories and prefer larger, wider windbreaks. Other species may benefit from curved or undulating windbreak designs that provide greater amounts of edge and less exposure when feeding in fields near the edge (PFRA, undated).

## Pesticides

Although pesticides are the most frequently used method of controlling pests, most pesticides kill not only the target pest but many of its invertebrate natural enemies.

They also may adversely affect vertebrate natural enemies and other non-target organisms and, over time, most insect pests can develop resistance to a pesticide. Minimizing the use of pesticides, proper selection and application of pesticides when needed, and use of other integrated pest management techniques when possible are methods of reducing these adverse effects and conserving natural enemy abundance.

## Providing refugia

Plants, which shelter the natural enemies during unfavourable periods like winter in high altitudes, dry seasons in tropical areas, are called so. Artificially created grasses sown

## Constraints and future prospects

There is basic need to strengthen the research on defining the role of the tritrophic interactions, cultural practices and other practices in improving the efficiency of the natural enemies for important species of natural enemies used in India. Integration of the conservation and manipulation techniques in the IPM modules should be done and be tested for proper pest management practices for different crop pests. A concerted research effort between different disciplines such as Plant Breeders, Agronomist, Soil Scientists, and Chemists and Entomologists is necessary to develop viable technologies with consideration to the conserving of the natural enemies or increasing the efficiency of the natural enemies. Removing the extension gap between the researcher and the farmer is pivotal for the success of the conservation and manipulation techniques. Some of the farmers still believe in ‘clean cultivation’ by burning the residual crops, deep ploughing etc. as the right way of control without being aware of the damage caused to the natural enemies. Periodical training is necessary to educate the extension workers and farmers on biological control incorporating the conservation and manipulation methods. Most of the experiments especially on the use of semi chemicals were conducted in smaller area or in semi field conditions and thus make difficult to draw any conclusions. Studies should be conducted in larger areas so as to generate good amount of data on the use of the semi chemicals.

In conclusion, Habitat manipulation is another form of augmentation and conservation of natural enemies in which cropping system altered successfully to augment and enhance the effectiveness of the natural enemies. Adult parasitoids and predators significantly benefited from source of nectar and the protection provided by refuge (hedge rows, cover crops and weedy borders). Mixed planting increase the diversity of habitats and provide more effective shelter and alternative food source to predators and parasites.

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