Ecological engineering: a new direction for agricultural pest management

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Abstract. Ecological engineering has recently emerged as a paradigm for considering pest management approaches that are based on cultural practices and informed by ecological knowledge rather than on high technology approaches such as synthetic pesticides and genetically engineered crops (Gurr et al. 2004a). This article provides a brief summary of ecological engineering for arthropod pest management and contrasts it with its controversial cousin, genetic engineering. The development of ecological engineering is explored, ranging from a simple first approximation that diversity is beneficial, to contemporary understanding that diversity can have adverse effects on pest management. This requires that the functional mechanisms that lead components of biodiversity to suppress pest activity are better understood and exploited. Pest suppression via ecological engineering is placed in the broader context of 'ecosystem services' provided by farmland biodiversity including nitrogen fixation and the conservation of pollinator species and wildlife.

Keywords: ecological engineering, ecological agriculture, biological control, pest management.

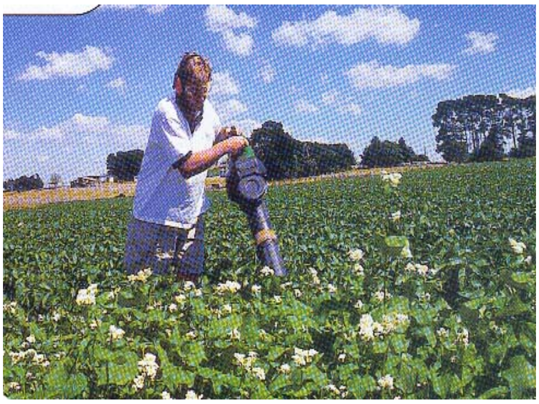
Introduction: paradigms and terminology

Odum (1962) was amongst 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'. Amongst the characteristics of this form of engineering are the use of quantitative approaches and ecological theory as well as a view of humans as a part of, rather than apart from, nature. Ecological engineering has recently emerged as a paradigm for considering pest management approaches that are based on cultural practices informed by ecological knowledge rather than on high technology approaches such as synthetic pesticides and genetically engineered crops (Gurr et al. 2004a). This article provides a brief summary of ecological engineering for arthropod pest management and contrasts it with its controversial cousin, genetic engineering.

Habitat manipulation aims to provide the natural enemies of pests 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 the above listed resources and operate to reduce pest densities via an enhancement of natural enemies. When herbivores (the second trophic level) are suppressed by natural enemies (third trophic level) control is said to be 'top down'. Root (1973) referred to pest suppression resulting from this effect as supporting the 'enemies hypothesis'. 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.

Figure 1. Examples of ecological engineering for pest management

Plate a. Buckwheat strip in the margin of an Australian potato crop providing nectar to the potato moth parasitoid *Copidosoma koehleri* (Hymenoptera: Encyrtidae)



Source: (Photograph, GM Gurr)

Plate b. 'Beetle bank' in British arable field providing winter shelter to predators of cereal pests

Source: (Photograph: GM Gurr)

Root (1973) termed pest suppression resulting from such non-natural enemy effects as 'resource concentration hypothesis', reflecting the fact that the resource (crop) was effectively 'diluted' by cues from other plant species.

Plate c. Strip cutting of lucerne hay stand in Australia provides shelter to within-field community of natural enemies

Source: (Photograph: Z Hossain)

Plate d. New Zealand vineyard with buckwheat ground cover for enhancement of leafroller parasitoids

Source: (Photograph, Lincoln University)

It could be argued that all pest management approaches 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 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 vegetational diversity)

- have developed to be consistent with ecological principles
- are refined by applied ecological experimentation
- contribute to knowledge of theoretical and applied ecology.

Contrasting genetic engineering and ecological engineering

Genetically engineered (GE) crops, otherwise known as transgenic or genetically modified (GM) crops, are becoming an increasingly dominant feature of agricultural landscapes. Worldwide, the areas planted to transgenic crops have increased dramatically in recent years, from 3 million hectares in 1996 to 58.7 million hectares in 2002. Globally the main GE crop species are soybean occupying 36.5 million ha and maize at 12.4 million ha, followed by cotton and canola. Other GM crops available are potato, sugar beet, tobacco and tomato (Hilbeck 2001). In the USA, Argentina and Canada, over half of the area planted to major crops such as soybean, corn and canola is occupied by transgenic varieties. Herbicide tolerant (HT) crops and those expressing insecticidal toxins from the bacterium *Bacillus thuringiensis* (Bt) have been consistently the dominant traits in GE crops, though a range of quality traits has been the subject of much research and these are likely to be used commercially in the near future (Hilbeck 2001).

Table 1. Comparison of ecological engineering with genetic engineering in agriculture

Characteristic	Ecological engineering	Genetic engineering
Units engineered	Ecosystems	Organisms
Tools for engineering	Species	Genes
Principles	Ecology	Genetics/ molecular biology
Biotic diversity	Maintained/enhanced	Potentially threatened
Maintenance and development costs	Moderate	High
Public acceptability	High	Low
Level of current use in agriculture	Limited uptake in developed countries, though reflected in many traditional agricultural systems	Widespread in some 'developed' countries.

Source: Adapted from Mitsch and Jorgensen 1989

Transnational corporations, the main proponents of biotechnology, argue that carefully planned introduction of these crops should reduce crop losses due to weeds, insect pests, and pathogens. They hold that the use of such crops will have added beneficial effects on the environment by significantly reducing the use of agrochemicals (Krimsky and Wrubel 1996). It has been suggested that 'if adequately tested', GE crops may promote a sustainable environment (Braun and Ammann 2003). This view is, however, not universal and environmental organisations such as Greenpeace oppose GE crops for a variety of reasons (see below). Scientists have become intensely involved in investigating the possible adverse effects of GE crops and the literature in this field is large and expanding dramatically. Some, such as Herren (2003) and Krebs *et al.* (1999), question whether we have learnt sufficiently from the past, particularly from the naïve optimism with which pesticides were initially embraced in the mid-20th century.

At a recent conference, Tappeser (2003) presented statistics showing the very small fraction, three per cent or less, of biotechnology budgets spent on biosafety or biodiversity studies. Wolfenbarger and Phifer (2000) concluded that the key experiments on environmental risks and benefits of GE crops are lacking.

Many authors have explored such risks and benefits of GE crops as environmental impact (Hails 2003; Jank and Gaugitsch 2001, Dale *et al.* 2002), ecosystem services (Lovei 2001), farm biodiversity (Firbank and Forcella 2000; Firbank 2003; Watkinson *et al.* 2000) changes to plant community structure resulting from gene flow (Pascher and Gollmann 1999) and ethical considerations (Robinson 1999). An extensive literature has developed also on the utility and challenges of Bt crops on target Lepidoptera (e.g., Edge *et al.* 2001; Cannon 2000; Shelton *et al.* 2002) in crops such as cotton and corn.

The opportunities for, and risks to habitat manipulation of GE crops-effectively the interface of genetic engineering and ecological engineering are two approaches with many points of contrast (Table 1). Experience over the last 10 years during which GE crops have been grown widely and investigated intensively suggests some significant advantages over conventional crops. This view is, however, actively contested and many commentators have expressed concerns. The use of GE soybean, corn, canola and cotton has been estimated to have reduced pesticide usage by 22.3 million kg of formulated product (Phipps and Park 2002). Such reductions are, given the widespread acceptance of the environmental impact of pesticides, likely to have had a beneficial effect on biodiversity. In particular, reductions in pesticide use will reduce the pesticide-induced mortality of natural enemies – an aspect of conservation biological control (Barbosa 1998; Gurr et al., 1998) with consequent benefits to pest management. This effect is one of several possible synergistic effects of GE crop use on ecological engineering approaches for pest management explored by Altieri et al. (2004).

Ultimately, if GE crops are able to make crop production more efficient, the requirements of society for food and fibre will be met with a reduced need for an expansion of croplands into natural and semi-natural areas. This will increase scope to conserve, or reintroduce into farm landscapes, areas of non-crop vegetation. Such vegetation can have desirable consequences for pest management (Gurr *et al.* 2004a), value in wildlife conservation (Kinross *et al.*, 2004), as well as catchment stability, water purification, recreation and aesthetics. However, on farmlands where genetically engineered crops are grown there are likely to be at least some adverse effects for biodiversity (Altieri et al. 2004) and the use of this technology will, for the foreseeable future, remain controversial with consumers. As a consequence, ecological engineering approaches merit greater research attention. Not only are these often effective and sustainable, the approaches that use are unlikely to meet resistance from the general public (Gurr et al. 2004a)

Ecosystem services

Farmers are increasingly aware of the ecosystem services performed by agricultural biodiversity. These include pest suppression, conservation of pollinator species and wildlife, fixation of atmospheric nitrogen, nutrient cycling and so on (Costanza et al. 1997). Indigenous and peasant farmers in the developing world have always relied on biodiversity for agroecosystem function. Others have been influenced by broader regulatory schemes such as 'set-aside' (Crabb et al. 1998), the conservation reserve program (Frawley and Walters, 1996), 'LEAF' (Linking Environment and Farming) (Drummond 2002) and various payment systems that have been proposed to reward farmers for 'producing nature' (e.g., Slangen 1997; Musters et al. 1999). The 2001 foot and mouth epidemic in Britain raised awareness amongst farmers and the broader public and policy makers, of the direct economic value of farmlands for various amenity uses including farm-based tourism.

Organic farming, for instance, can benefit wildlife such as birds (Beecher *et al*. 2002) but, as pointed out by Vickery (2002), such whole-farm approaches are in the minority. Alternative strategies that can readily be incorporated into conventional farming systems are important. These do exist and examples of farming practices and landscape features that favour biodiversity have been reviewed comprehensively by Paoletti (1999) and include the following:

- hedgerows,
- polycultures,
- agroforestry,
- herbal strips within crops,
- appropriate field margins,
- small fields surrounded by hedgerows.

It is practices such as these that are used in ecological engineering for pest management for this approach is inexorably entwined with the pragmatic use of biodiversity to perform the ecosystem service of pest suppression. Consequently, the pursuit of this practical outcome (i.e. reduced crop losses) may simultaneously lead to other benefits such as wildlife conservation, conservation of pollinators, nitrogen fixation and so on.

Any simplistic notion, however, that pest management is achieved simply by increasing on-farm biodiversity is incorrect. Biodiversity is undeniably a powerful tool for pest management; but is not consistently beneficial. The discipline of ecological engineering is in the process of moving from a 'first approximation', the simplistic assumption that diversity per se, is beneficial (Gurr et al. 2004b). In a landmark review of the relevant literature, Andow (1991) determined that pests tended to be less abundant in polycultures than in monocultures in 48.5 per cent of cases in annual crops systems and 60.5 per cent of perennial crop cases. In the remaining cases (close to half of those in the literature) pest population densities were either unchanged, responded variably or were increased in polycultures. Further, as would be expected, a suppressive effect of polycultures on polyphagous pest species was far less commonly reported than was the case for monophagous pests. Combining statistics for annual and perennial crop systems, lowered pest densities were apparent in 63 per cent of monophagous pests species but in only 23 per cent of polyphagous pests. Clearly, vegetational diversity is no guarantee of lowered pest densities.

'Chocolate-box ecology'

Habitat manipulation for enhanced pest control has been referred to by critics as 'chocolate-box ecology' because of the picturesque nature of some of the tools used; strips of flowers are an example. In some cases, floristically diverse vegetation is added without prior testing and ranking of the candidate plants, but this crude approach is not universal and habitat manipulation researchers now more commonly screen plant species to determine optimal species or use a range of selection criteria to determine appropriate botanical composition (Gurr et al., 1998, Pfiffner and Wyss 2004). These approaches reflect the notion that it is the quality, not the quantity, of diversity that is important (Polasezek et al. 1999) and this requires the selection of the 'right kind' of diversity. This is illustrated by work the of Tooker and Hanks (2000) that showed that parasitic Hymenoptera tended to visit only a limited number of food plants – a mean of 2.9 plant species per parasitoid species. Therefore, providing nectar to a parasitoid of a key pest could fail unless an appropriate food plant species is identified by appropriate research. 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 (Gurr et al. 2004 a, b).

Conclusions

Ecological engineering is a human activity that modifies the environment according to ecological principles. Accordingly, it is a useful conceptual framework for considering the practice of habitat manipulation for arthropod pest management. This form of ecological engineering presents an attractive option for the design of sustainable agroecosystems and, though it and genetically engineered crops are not mutually exclusive options, ecological engineering may be less risky. Genetically engineered crops are likely to have profound effects on agriculture as they become still more widely used, especially in developed countries. The net effect may or may not be beneficial, and whether the risks of proceeding outweigh the potential benefits is currently actively debated. As explored by Altieri et al. (2004), genetically engineered crops do offer at least some scope to work synergistically with ecological engineering techniques but negative effects may outweigh the benefits. The risk of negative consequences for farm biodiversity from generically engineered crops increases the need for farm landscapes to incorporate features that will favour wildlife. Often, such ideas as conservation corridors can fulfil this function, as well as providing pest management benefits (Kinross et al. 2004). However, optimal outcomes for wildlife species require a better understanding of the ways in which these animals respond to manipulation approaches and of the implementation of optimal strategies. This supports the notion of directed approaches for pest management referred to above.

As methods and theory are integrated and more widely used, ecological engineering will evolve into a rigorous branch of ecology. Whether or not genetic engineering and ecological engineering achieve synergies or become entrenched as alternative paradigms for pest management, the development of the latter discipline into a more rigorous branch of ecology will allow it to contribute to the challenge of meeting the needs of humankind for agricultural products in a sustainable fashion.

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