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Ecological Engineering as a Pest Management Tool in Horticultural Ecosystems

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INTRODUCTION

Odum (1962) was amongst the first to use the term 'ecological engineering' and 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'. It can be defined as the design of human society with its natural environment for the benefit of both (Mitsch and Jorgensen 1989). Ecological engineering in other terms called as 'Habitat Manipulation' is mainly focuses on reducing the mortality of natural enemies, providing the supplementary resources and manipulating host plant attributes for the benefit of natural biocontrol agents. It aims to provide the natural enemies of pests with resources such as nectar, pollen, physical refugia, alternative prey, alternative hosts and lekking sites. The ecological engineering for pest management has recently emerged as a new paradigm to enhance the natural enemies of pests in an agro ecosystem and is being considered an important strategy for promoting Bio Intensive Integrated Pest Management (BIPM). This approach relies on use of cultural techniques to bring about habitat manipulation and enhance biological control. The cultural practices are executed by knowledge in agro-ecology rather than on advanced pest management options like synthetic pesticides and genetically modified crops. Habitat for sustaining the 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.

Conservation Biological Control (CBC) can be 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). Ecological Engineering or 'Eco Technology' 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 and such ecosystem engineers thereby moderate the availability of resources to other organisms. Various disciplines are allied to ecological engineering are restoration ecology, sustainable agro ecology, habitat reconstruction, ecosystem rehabilitation, river and wetland restoration and reclamation ecology. These sub-sets indicate the range of areas in which ecological engineering has been applied, including the restoration of wetlands, treatment and utilization of wastewater, integrated fish culture systems and mining technology as well as wildlife conservation.

The primary objective in Ecological engineering is to make environment of the Agro-ecosystem suitable for the better survival of natural enemies of pests. Perennial crop systems are potentially more amenable to conservation biological control than are ephemeral annual systems because they are subject to lower levels of disturbance. Thus, resident populations of natural enemies may persist from year to year in perennial crops. Perennial crop systems may be disrupted by unavoidable pesticide applications, so refugia outside the treated area can be critical.

Habitat Requirements

As a general rule, to be useful for pest management, any area maintained for beneficial insect fauna must result in a net gain in beneficial insects and a net reduction in pest insects.

- It must attract beneficial insect populations
- It must improve the health or reproduction of beneficial insects so they can be more effective
- It must allow beneficials to move from the habitat to the crop of interest. The beneficials must eat or parasitize an increasing number of pest insects once they have moved into the crop
- The activity of the beneficials must lead to an economic reduction in pest populations. Preferably, their activity would prevent economic damage to the crop the bottom line for habitat and any other pest management tactic (Landis et al. 2000)

Characteristics of Habitat Manipulation

- 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 natural enemies in biological control
- Developing strategies that induce minimal changes to the natural ecosystem to protect the environment and minimize use of non-renewable resources (e.g. appropriate fertilizer formulations and application patterns)
- Reflecting the utility of the ecological engineering paradigm to agriculture, the term 'agro ecological engineering' has developed currency and this has been viewed explicitly as a way towards sustainable agriculture e.g. multi-storey vegetation giving higher vegetative cover than is typical of monocultures
- Use of cultural techniques to effect habitat manipulation and enhance biological control that most readily fit the philosophy of ecological engineering viz. low inputs of energy or materials, rely on natural processes, practices consistent with ecological principles and refined by applied ecological experimentation
- 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

The Development of Habitat Manipulation

The contemporary habitat manipulation has its genesis in terms of practices that have been used to promote generalist predators in agricultural systems for centuries. Examples includes: age old technique of early habitat manipulation by Chinese farmers is the use of straw shelters to provide temporary spider refugia and overwintering sites during cyclic farming disturbances and another technique, developed in Myanmar is the use of connecting bamboo canes between citrus trees for movement of predatory ants to control caterpillar pests. Beetle banks, field margins, ribbon crops, wildflower strips, trap crops, repellent plants, and refuge crops are the popular approaches.

Habitat Manipulation Approaches

Top Down Control: The herbivores (second trophic level) are suppressed by the natural bio-agents (third trophic level) and this type of approach is present in 'augmentive biological control' which is called as 'top down' approach. Russell (1989) has referred the pest suppression resulting from this effect to 'enemies hypothesis'.

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'. 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.

Methods of Ecological Engineering

Above ground Ecological Engineering: Focus is on making the habitat less suitable for pests and more attractive to natural enemies.

- Raising the flowering plants along the border by arranging shorter plants towards main crop and taller plants towards the border to attract natural enemies as well as to avoid immigrating pest population
- Inter-cropping, border-cropping and mix cropping of the flowering plants provide nectar/ pollen as food for

various bio-control agents. Trap crops and repellent crops for pests are also grown as intercrop along with the main crop

- Conservation of weed plants which are growing naturally like Tridax procumbens, Ageratum sp, Alternanthera sp etc as they act as a nectar source for natural enemies
- Avoiding chemical pesticides, when the Pest: Defender ratio is favorable. The compensation ability of the plant should also be considered before applying chemical pesticides

Different types of Plants used in Ecological Engineering

Plants which attract Natural Enemies of Pests

Attractant plants characterized by profuse flowering viz. mustard, sunflower, buckwheat, carrot, marigold, French bean, maize/ corn, cowpea, spearmint etc can be selected based on their availability, prevailing agro-climatic conditions and soil types. The enhanced crop biodiversity by the flowering plants results into increase of parasitoids and predators population due to enhanced availability of nectar, pollen, fruits and insects as an alternate food. The major predators are a wide variety of spiders, ladybird beetles, long horned grasshoppers, Chrysoperla, earwigs, etc. For instance, Cole crops bordered by sunflower, mustard, marigold and coriander have resulted in reduced incidence of aphids due to following nature's manipulations. Sunflower being the tallest crop attracts the Helicoverpa; it is surrounded by two rows of mustard to attract Chrysoperla and Lady Bird Beetle. Coriander crop attracts different natural enemies of main crop pests. Marigold is the preferable crop for egg laying of Helicoverpa. The aphid population on Cole crops was found parasitized by Aphidius, a potential parasite of aphid. This parasitoid can be able to manage the aphid population on Cole crops. The insectary plants majorly belonging to Leguminaceae, Graminaceae, Brassicaceae and Asteraceae families.

Trap Plants

A trap crop is a crop that is planted to lure insect pests away from the main crop.

- Basil and marigold as a border crop (main crop- Garlic) controls onion thrips
- Castor plant as a border crop in Cotton and chilli field, controls Tobacco caterpillar
- Legume as inter/ alternate crops in sugarcane enhances the population of fungal and bacterial biocontrol agents for the management of nematodes and other soil borne diseases
- Inter crop rows of Tridax procumbens in paddy crop enhances the natural parasite and predator populations

Repellant Plants which Repel Harmful Insect-pests

Grown either as border crop or main crop, these repel the pests away from the crop mainly due to the release of volatile repellent plant chemicals.

- Basil repels flies, mosquito and tomato fruit borer
- Garlic repels beetles, aphids, weevils, spider mites and carrot fly
- Radish deter cucumber beetle
- Mint repel cabbage diamond back moth
- Marigold repels beetles, cucumber beetles and nematodes

Barrier/ Border Plants which Attract Insect-Pests and Reduce Pest Population on Main Crop

These protect the main crop against small soft bodied flying insects which migrate from one field to other field such as whiteflies, hoppers, aphids, mealybugs and thrips e.g. Maize, Sorghum, Bajra, Redgram as barrier crops.

How to Choose Plants for Habitat Manipulation

Introduction of plant-derived food is the most important form of habitat manipulation for vegetables and fruit trees which are also suitable sites for breeding and overwintering. There are several agronomic and biological issues that need to be addressed when selecting plant material for use in flower strips.

- Not all nectar and pollen are accessible for all natural enemies. Accessibility is a function of floral architecture and the morphological structure of insect mouthparts
- The plant species must be attractive and used by the target natural enemy and, to a lesser extent, must be attractive and utilized by potential pest insects
- For perennial crops, the ideal plant may be a species that spreads within or between years and is a good competitor with weeds
- The plant species needs to be easily managed, competitive with weeds and inexpensive
- The plants should quickly become attractive to natural enemies and stay so for the whole cropping season
- The proportion of area planted with flowering nectar plants should not be too large relative to the cropping area, in order to be economically viable
- The plant species should not become a weed problem in the fields
- The establishment of perennial flowering plant habitats may provide similar resources in a more stable fashion over the entire season and for years to come

Below Ground Ecological Engineering for Pest Management

- This focuses on improvement of soil health
- Keeping soils covered round the year with living vegetation or crop residue
- Adding organic matter in the form of farm yard manure,

Vermicompost, crop residue which enhance below ground biodiversity
- Reducing tillage intensity so that hibernating natural enemies can be saved
- Applying balanced dose of nutrients using biofertilizers e.g. applying mycorrhiza and plant growth promoting rhizobacteria (PGPR)
- Applying Trichoderma spp. and Pseudomonas fluorescens as seed/ seedling/ planting material, nursery treatment and soil application

These practices strengthen the ability of crops to withstand pests and also help improve soil fertility and crop productivity. Thus Biodiversity is crucial to crop defenses: the more diverse the plants, animals and soil-borne organisms in a farming system, the more diverse are the pest fighting beneficial organisms on the farm.

Mechanisms for Ecological Engineering

Selecting Resources to Provide

Habitat management should provide natural enemies with suitable resources that are limiting for species and that do not invoke unwanted side effects. The resources that are limiting for natural enemies i.e. extrafloral nectaries, alternative prey, honeydew, flowering weeds etc. depends up on landscape and crop in the field. The attractiveness of food plants is an important factor to consider when selecting plant species for biological control. The nectar feeding on floral resource subsidies by the parasitoid Diadegma insulare in the field can lead to increased gut content of sugars and thus improved longevity and fecundity (Lee and Heimpel, 2008).

Table I

Parasitoid	Pest	Crop	Food Sources
Campoletis chloridae	Helicoverpa spp.	Chickpea	Coriander
Aphelinus mali	Aphids	Apple	Erygium spp.

Alternative Food Sources

Some parasitoids are able to obtain needed resources from hosts others require access to non-host foods. Floral nectar, extra-floral nectar in faba bean (Vicia faba) and cotton (Gossypium hirsutum) are an important food source for adult parasitoids. The presence of honey dew-producing insects and food sprays can also benefit natural enemies, but this approach may be economically viable only in relatively high value crops.

Increased Parasitism due to the Presence of Alternate Food Sources

Shelter and Microclimate

Shelter has been provided by augmenting leaf debris on the orchard floor with peppermint, wrapping the bases of apple trees in vegetable debris held in place with plastic, placing similar debris around the base of smaller trees or by providing on tree refugia of burlap, and aluminum in peach and ryegrass planting (Tamaki et al. 1968). Plants, which shelter the natural enemies during unfavorable periods like winter in high altitudes, dry seasons in tropical areas e.g. artificially created grasses. Refugia can provide food, alternate hosts and overwintering sites.

Floral Strip Cropping

It provides pollen, nectar, shelter and enhances natural enemy fitness. Predators and parasitoids show responses increased longevity, optimal reproduction, female based sex ratio and higher fecundity of parasitoid offspring (Schmidt et al. 2005). The spatial distribution of natural enemies in and around crops flowering buckwheat increases the fecundity and longevity of Dolichogenidea tasmanica a key parasitoid of leaf rollers (Epiphyas postvittana) in vineyard (Berndt and Wratten, 2005).

Beetle Bank

Beetle banks, which are strips of non-crop vegetation established in the middle of fields by creating a raised earth bank sown with perennial grasses for providing suitable overwintering habitat (Wratten, 1992). Non-crop vegetation may be favored by natural enemies as oviposition sites. It has been observed that Coleomegilla maculata (Coleoptera: Coccinellidae) lays more eggs on a native weed, Acalypha ostryaefolia than the sweet corn (Zea mays) crop. They have been used as refuges in arable land to increase the abundance and effectiveness of soil arthropods such as Carabidae, Staphylinidae, Lycosidae, and Linyphiidae protecting them from adverse biotic and abiotic conditions.

Alternative Prey or Hosts

The distribution of predators of Homopteran pests in Apple is determined by the presence of alternative prey on weeds or in surrounding vegetation (Kozar et al., 1994). Organic matter can also be beneficial when applied to the soil surface of field crops. Manure and straw increased numbers of the carabid Bembidion lampros, an egg predator of the cabbage root fly Delia radicum, and increased total carabid populations in cabbage. Prune refuges adjacent to vineyards as well as nearby riparian areas containing Rubus spp. increase Anagrus (Hymenoptera: Mymaridae) parasitism and contribute to control of grape leafhopper Erythroneura elegantula (Irvin et al. 2006).

Avoiding Negative Side Effects

The provision of resources through habitat management can decrease natural enemy attack rates on the pest although the resource is suitable for the targeted natural enemy. In a field cage experiment, provision of flowering buckwheat decreased lacewing densities when aphid availability was high probably because buckwheat primarily benefits the lacewing parasitoid during such conditions. The way to decrease the risk for this type of unwanted side effects is to search for food plants that selectively benefit natural enemies of the pest but not the pest itself or key antagonists (Jonsson et al. 2009). It's well known that most pesticides not only kill the target pest but also 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 need based application of pesticides, and use of IPM helps in minimizing these adverse effects and conserving natural enemy abundance.

Windbreak Design

It is another method of manipulating natural enemy abundance and diversity. The carabids and staphylinids that feed on crop pests are more abundant at the edge of multi-row wind breaks than in the interior of the windbreak. Conversely, insectivorous birds establish large territories and prefer larger, wider windbreaks especially during the winter. Windbreaks can be used by arthropod predators as overwintering sites if appropriate vegetation is available. Certain species of coccinellids that feed on insect pests of orchard crops overwinter at field edges in herbaceous vegetation, grass and tree litter.

Possible Ways to Enhance Natural Diversity i.e. Structural and Cultural Diversity

Trees and other tall vegetation can provide the vertical structure needed by spiders and birds. Flowering shrubs and herbs can provide food for parasitic ichneumonids and predatory syrphids that feed on flower's nectar and pollen. The syrphids are predators of aphids and are more abundant in areas of high floral diversity and abundance and aphids that feed on goldenrod can be used as alternative prey for ladybird beetles when population of their primary prey is low (Landis et al. 2000). Cultural practices such as ploughing, 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. In rural areas, the leaves are not removed and the parasites control the psyllids. Likewise, crop stubble left in fields might contain overwintering parasitic wasps or may provide cover for predators.

Chocolate-Box Ecology

Habitat manipulation for enhanced pest control has been referred to by critics as 'chocolate-box ecology'. Floristically diverse vegetation is added in order to provide adequate nectar, pollen and nutritious diet for natural enemies, this crude approach of 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. These approaches reflect that the quality not the quantity of diversity that is important and requires the selection of 'right kind' of diversity (Gurr et al. 2004).

Push-Pull Strategy

Push-pull strategies involve the behavioural manipulation of insect pests and their natural enemies via the integration of stimuli that act to make the protected resource unattractive or unsuitable to the pests (push) while luring them toward an attractive source (pull) from where the pests are subsequently removed. (Cook et al. 2007).

The strategies involve the combined use of intercrops and trap crops, using plants that are appropriate for the farmers and that also exploit natural enemies. Stem borers are repelled from the crops by repellent non host intercrops, particularly molasses grass (M. minutiflora), silverleaf desmodium (D. uncinatum), or Greenleaf desmodium (D. intortum) (push), and are concentrated on attractive trap plants, primarily Napier grass (Pennisetum purpureum) or Sudan grass (Sorghum vulgare sudanense) (pull). Molasses grass, when intercropped with maize, not only reduced stem borer infestation, but also increased parasitism by Cotesia sesamiae. Desmodium produces with large amounts sesquiterpenes which suppress the parasitic African witchweed (Striga hermonthica) (Khan et al., 1997).

Multiple Mechanisms

Habitat management may benefit natural enemies by the simultaneous operation of more than one mechanism. For example Eriborus terebrans, the primary parasitoid of Ostrinia nubilalis in maize in Michigan showed that females were most frequently captured in maize fields close to wooded field edges and that parasitism of O. nubilalis was higher in these areas. The wasps were shown to be more active on hotter days which could result in their leaving crop habitats to find shelter in adjacent wooded areas. It was suggested that wooded edges benefited E. terebrans by providing both a source of adult food i.e. nectar, honeydew and shelter to access a moderated microclimate (Dyer and Landis, 1996).

Types of Habitat Management

Trap Cropping

Trap crops have been deployed or manipulated to attract, divert, intercept and retain insect pests in order to reduce their damage within the main crop. Once the pest is aggregated in a trap crop, it can be managed by the use of much more localized applications of pesticides or by the physical destruction the pest along with infested portion. The attractiveness of the trap crop and its spatial coverage/arrangement are critical in successful and effective pest management schemes. In dead-end trap cropping, the selected trap plants are attractive to insects on which their offsprings cannot survive for a long time, making it not necessary to use of pesticides for the control the pests aggregated on the trap crop. Pest management using trap cropping has been commonly used to target Coleoptera, Diptera, Lepidoptera, Thysanoptera, Orthoptera, Hemiptera, and Homoptera pests. Amongst these orders the Plutella xylostella L. is the most studied insect.

Cover Cropping

Cover cropping or living mulch is an important agro-ecological pest management practice of planting annual or perennial herbaceous plants before or after the main crop and used to cover the soil for a single season or the whole year viz. Rye, Secale cereale L., Sunn hemp, Crotalaria juncea L., marigold, Tagetes patula L. Cover crops can increase the habitat complexity in the cropping system, enhancing the abundance of natural enemies. In China, groups of farmers have used a chickweed species, Ageratum conyzoides L., as a ground cover in citrus orchards aiming at conserving predatory mites, such as Amblyseius spp. and Panonychus citri McGregor. Similarly, the Red clover, Trifolium pratense L. has been used as a cover crop in cucumber, Cucumis sativus L. to reduce populations of the striped cucumber beetle, Acalymma vittatum F. and the melon aphid, Aphis gossypii Glover, by enhancing populations of generalist predators such as the big-eyed bug, Geocoris spp. Fallén, the minute pirate bug, Orius spp. Wolff and ladybird beetles (Coleoptera: Coccinellidae), compared to monocultural practices without cover crops.

Intercropping

Intercropping acts on herbivores by partitioning their population between the crop and the intercrop, reducing pest pressure in the main crop (Root 1973). It also helps to deter or repel pests because non-crop visual or chemical cues change insect behavior, potentially reducing pest damage. This form of habitat management also acts by creating a physical barrier, restricting inter-plant pest movement or providing floral resources for the pests' natural enemies. For example, intercropping celery, Apium graveolens L., in cucumber fields reduced the population of the whitefly, B. tabaci by repelling the pest and deterring oviposition.

Multiple Cropping

This form of intercropping or trap cropping is created with two or more crop species grown together. It can either enhance the efficiency of trap crops while managing several insect pests at a time or provide different phonological crop stages to enhancing the attractiveness of insect pests at different times. The use of multiple cropping systems viz. sunflower (Helianthus spp.), tomato (S. lycopersicum) and marigold (Tagetes spp.) in crucifer fields can also reduce populations of aphids.

Flower Strips or Insectary Plants

The establishment of flower strips is one of the most common habitat management techniques that can promote conservation biological control, and other ecosystem services such as pollination, weed control and aesthetics. The efficiency of biological control agents such as predators and parasitoids can be enhanced by diversifying the landscape through the maintenance of selective floral habitats that provide nectar and pollen to the natural enemies but enhance pest 'fitness' to a lesser extent by acts as a trap crops sometimes. Yellow flowers are frequently used to attract beneficial insects e.g. yellow rocket, Barbarea vulgaris acts as a trap crop for the diamondback moth, P. xylostella and as a floral food source for the hover fly, Sphaerophoria scripta. Whereas, the insectary plants are plant species that attract or accumulate natural enemies or pests by providing SNAP (Shelter, Nectar, Alternative prey and Pollen) or by releasing volatile compounds e.g. sweet alyssum for hoverflies against aphids and buckwheat to promote the parasitoid, D. tasmanica of leaf roller complex in fruit orchards.

Weed Strips

A 'weed' refers to an unwanted plant species, which grows within the main crop, directly competing with it for nutrients and harboring insect pests and diseases, and thus limiting crop yield. Herbicides are commonly used for weed management in conventional farming systems. However, the complete removal of weeds from an agricultural area can be detrimental to arthropods, as pest outbreaks are more likely to be associated with weed-free plots than weed-rich plots. However, certain weeds, if appropriately managed, may provide non-host food resources such as pollen, nectar, and microhabitats for the natural enemies. Weed strips managed in apple orchards increased populations of aphidophagous hoverflies and spiders (Araniella spp.), improving the biological control of aphids as a consequence. Similarly, survival of the ladybird beetle, Cycloneda sanguinea L. was increased in weed (beggar-tick, Bidens pilosa) strips in tomato fields, reducing the numbers of tomato aphids.

Manipulation of Field Margins with Flowering Non crop Vegetation

Field margins are an important and underrated potential habitat for bio control agents, because they can offer food or shelter in adverse biotic or abiotic conditions. Nectar-rich flowering non-crop plants in field margins such as F.

esculentum and C. sativum increased the fitness of the parasitoid, Copidosoma koehleri Blanchard, promoting the biological control of the potato tuber moth, Phthorimaea operculella Zeller. Similarly, tall vegetation can also be used by polyphagous predators for shelter during unfavorable conditions, such as when pesticide sprays occur, at crop harvest. Deployment native vegetation in crops can potentially increase the abundance and diversity of beneficial arthropods, improve conservation biological control and deliver a range of other ecosystem services. Pandey et al. (2018) demonstrated that the longevity of Diaeretiella rapae McIntosh, Cotesia glomerata L. and Diadegma semiclausum Hellen (Hymenoptera: Ichneumonidae), which all are parasitoids of P. xylostella, were increased in the presence of Australian native plants, such as Westringia fruticosa (Wild.) Druce (Lamiaceae), Mentha satureioides R. Br (Lamiaceae), and Lotus australis Andrews (Fabaceae), compared with the non-native buckwheat, F. esculentum.

Dry Mulches

Mulch materials such as straw, other organic mulches or plastic in agriculture can provide suitable habitat for natural enemies and can reduce disease pressure. Straw or organic mulch can also improve soil fertility, soil organic matter, earthworm activity and soil water-holding capacity. In North-west China, farmers used vegetable debris and plastic mulch at the base of apple trees to enhance the biological control of the apple pest mite Eotetranychus pruni by increasing the activity of the predatory mite, Metaseiulus occidentalis Nesbitt.

Strip Cutting (Strip Grazing or Alternate Harvesting)

Strip cutting or strip grazing (i.e., leaving a small portion of crops in a field during harvesting to provide natural enemy refuges) in lucerne can reduce the dispersal of natural enemies by providing temporal or spatial stability in agroecosystems. Full crop harvest can remove shelter or food sources for natural enemies, whereas alternate harvesting of lucerne can provide habitat for predators such as Dicranolaius bellulus and Coccinella transversalis to suppress populations of Helicoverpa spp. Hubner and Merophyas divulsana Walker, while enchancing parasitism rate by Trichogramma egg parasitoids. Thus, alternate harvesting can lead to predators moving from harvested plots to non-harvested ones, reducing their mortality by providing shelter.

Ecological Engineering in Horticultural Ecosystems: Case Studies/ Success Stories

Ecological Engineering in Cabbage Ecosystem (NIPHM, Hyderabad)

A study demonstrated that cabbage crop grown by farmers with intensive use of chemical pesticides could be successfully grown by adopting Agro-eco System Based Analysis (AESA) based IPM in conjunction with Ecological Engineering for Pest Management. This was by continuous monitoring of the crop, increasing biodiversity in the crop ecosystem by Ecological Engineering with special focus on mustard as a trap crop which attracted leaf webber and to some extent aphid population onto it. The combination of these practices resulted in reducing pest density upto 60 days after transplanting which helped in maintaining favorable P:D ratio. Whenever unfavorable P:D ratios were observed during mid-crop growth stage, appropriate bio intensive management tactics were adopted such as release of natural enemies, as well as application of botanical pesticides. The study showed that Bio intensive approaches in cabbage crop ecosystem not only reduce cost of cultivation but also minimize pesticide residues in crop produce, conserve and increase natural enemies and protect the environment.

Habitat Manipulation in Apple Orchards of China

It seems to be an effective strategy to attract aphidophagous predators that actively search for flowering plants as a food source during adulthood, namely lacewings and syrphid flies. This practice can possibly increase the presence of other relevant aphid predators, such as ladybirds and anthocorids, and generalist predators such as spiders. There is evidence that these insects have the capacity to move back and forth from flowering habitats to apple trees and exert higher levels of aphid biocontrol. Besides this, it is also known to increase the abundance of tortricid moth (codling moth and leaf roller) predators, particularly earwigs and predatory bugs. Habitat manipulation in apple orchards seems to be an effective strategy to attract predators that feed from flowering plants during adulthood i.e. lacewings and syrphid flies and possibly increase the presence of other relevant aphid predators, such as ladybirds and anthocorids.

Habitat Management in Citrus Orchards of China

Citrus growers in China are reported to have planted or conserved ‘weeds’ principally Ageratum conyzoides L., on 135,000 ha of orchards. These plants are beneficial to natural enemies of the citrus red mite, Panonychus citri, primarily Amblyseius spp., through the provision of alternative food in the form of pollen. A similar case is evident for citrus growers in Queensland, Australia where A. victoriensis is important in the management of eriophyid mites. Encourage the flowering of Rhodes grass during the fruit-growing season to provide pollen as an alternative food for the predatory mite. Doing so typically involves mowing alternate inter-rows every three weeks, allowing time for the grass to produce pollen while maintaining a neat orchard. Further, between 30 and 50 percent of growers used Eucalyptus torelliana trees in windbreaks, making use of its hairy leaves to intercept grass pollen and provide an alternativerefuge for the predator.

Considering Ecosystem Dis-services in Habitat Management

Habitat diversity can increase the provision of floral resources that may increase the fitness of natural enemies, reducing pest populations. However, if pests also prefer to feed on and dwell in flowering plants, this could lead to more damage, increasing ecosystem dis-services as a result (Gurr et al., 2017). For example, the population of the potato pest, P. operculella and its damage in potatoes were increased close to flower strips compared with potatoes 20 m from these strips. Deploying new plants in agroecosystems can lead to pest accumulation, potentially limiting the expected ecosystem service of biological control that is sought. For example, when Alyssum sp. was added to radish crops in Nepal, the soybean hairy caterpillar, Spilarctia casigneta (Lepidoptera: Erebidae) feed on Alyssums, reducing its abundance and presumably reducing its effectiveness.

Constraints and Future Prospects

Not with standing the multiple benefits provided by habitat management techniques, its adoption is lagging in large-scale farming systems across the globe and also the subject to the considerable debate and poor public acceptance. An overriding reason why farmers are slow in adopting these practices is that most farmers are knowledge-intensive approach, risk-averse and prefer prophylactic pesticide use. In addition, farmers would be keen to adopt these practices if they make a positive economic contribution, however the impact of natural enemies on plant yield and its associated economic evaluations have been rarely quantified in the literature. If enough local scientific knowledge is available, the creation of a 'recipe' based on enhancing functional biodiversity in farms that farmers can easily apply could boost the spreading of habitat management schemes in large-scale farming systems.

There is basic need to strengthen the research on defining the role of the tritrophic interactions and cultural practices in improving the efficiency of the 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 in different crops. A concerted research effort between different disciplines such as Plant Breeders, Agronomists, Soil Scientists, and Chemists and Entomologists is necessary to develop viable technologies with consideration to the conservation and increasing efficacy of natural enemies. However, it is clear that more research attention needs to be given to the effects of native vegetation, especially its effects at the landscape scale. Removing the extension gap between the researcher and the farmer is pivotal for the success of these techniques. Some of the farmers still believe in 'clean cultivation' by burning the crop residues and deep ploughing as the correct method of pest control without being aware of the extent of 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. Studies should be conducted in larger areas so as to generate good amount of data on the use of the semiochemicals. One way for promoting habitat management knowledge uptake by farmers is through an observation-based learning with a horizontal and participatory knowledge-transfer mechanism, such as with 'Farmer Field Schools' (FFS) other 'farmer to farmer' approaches.

Summary and Conclusion

There is an increasing interest in habitat management amongst organic growers, researchers, and nongovernmental organizations in developing and developed countries. In areas especially in hilly regions of the country where access to synthetic pesticides is limited, where their (unguided) use is discouraged, habitat management technology could be an important pest management strategy for farmers. 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. Ecological engineering is a viable mainstream option for achieving agricultural sustainability in a range of temperate and tropical production systems. The sustainability of many farming systems is low, and more guidance is required for farmers and advisors to help them develop and implement more ecologically sound pest management approaches. Under the schemes of worldwide interest viz. IPM, conservation agriculture, enhanced biodiversity for ecosystem services, and conservation irrigation schemes, this habitat management can be a key technology to further the adoption of sustainable and pesticide-free food production.

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