Universal Journal of Plant Science 4(4): 50-57, 2016
DOI: 10.13189/ujps.2016.040402 http://www.hrpub.org

Habitat Management: A Key Option to Enhance Natural Enemies of Crop Pest

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Abstract Enhancement of natural enemies through habitat management developed sustainable pest management systems. Landscape composition; especially complex and permanent habitat mainly woody vegetation increased the abundance of natural enemies of crop pest. Alternatively, temporary vegetation like horticultural systems decreased the abundance of natural enemies as for monocropping. The rate of parasitism is higher in diverse ecosystems than in non-diverse ecosystems due to the availability of food source, provision of nectar and sugar, as well as alternative hosts. The intensification of agricultural practices disturbed the diversity of ecosystem and ultimately reduced the abundance of natural enemies and consequently diminished the efficacy of biological control of pests in a particular ecosystem. Moreover, plant characteristics especially in long blooming period, larger floral area, maximum flower height, narrow and deepest corolla and higher number of open flower increase the accessibility of nectar or pollen for natural enemies. As a result, the fecundity and longevity of predator and parasitoid are increased. Manipulation of food sources for natural enemies especially honey dew and artificial food spray like sucrose with the supplement of protein helps to enhance the activities of natural enemies, predators and parasitoids. For example, the widely applicable shelter habitats such as beetle banks are suitable over wintering sites for predatory beetles especially for Carabidae, Staphylinidae and spiders. Increase of non-crop habitats for instance, field margins, fallow land, hedgerows etc. might improve the shelters for natural enemies. Apart from the plants in that habitat under attack from herbivore, they make responses towards natural enemies by producing Herbivore Induced Plant Volatiles (HIPVs) known as indirect plant defense. The habitat with abundant natural enemies makes such continuous support for plant by means of plant indirect defense. In a nutshell, habitat management not only conserves biological control but also provides other indirect services like increasing biodiversity, photosynthesis, the activity of soil biota, and reduced soil erosion. Besides, it can also ultimately maximize the yield and profitability of crops for the farmers and stabilize the sustainable pest management system.

Keywords Habitat Management, Ecosystem, Natural Enemies, Plant Characteristics, Herbivore Induced Plant Volatiles

1. Background

The conservation of biological control agents by means of habitat management is now smart way for sustainable pest management system. It is an ecologically based approach which aim is to provide favorable habitat for natural enemies to stabilize the biological control in an agro-ecosystem. It indicates providing favorable condition for natural enemies for their fecundity, longevity, and access to pollen, nectar or sugar [11,53,25]. If an agro-ecosystem is favorable for natural enemies, they increase their population which makes them more successful in pest control. Generally, plant resources are limited in most of the agro-ecosystems. Through habitat management like adding more flowering plants provision of pollen and nectar for the natural enemies is increased. Subsequently, large number of natural enemies is available in that agro-ecosystem.

We know natural enemies; predators, parasitoids, pathogens, and weed feeders etc. are the key element for biological control. In the present era, we are giving more attention to the biological control of pests. The service of biological control by natural enemy is about $ 4.5 billion/year in USA agriculture [31] and consequently the success of biological control ultimately reduced the application of chemical pesticide [36]. As we know, application of chemical pesticides causes huge environmental pollution due to drifting of chemicals into the environment, which later on causes huge pollution and also human health hazard. From the early history of crop protection, people completely depend on pesticides which

subsequently cause pest resurgence, pest resistance against pesticide and also secondary pest outbreak. In the long run, application of pesticides has diminished the abundance of natural enemies. As a result, most of the minor pests converted into major pests and cause huge losses of crop yield. Due to the bad impact of pesticides on the food sources, alternative hosts like field margin crop and other favorable conditions for natural enemies were affected tremendously. Most of agro-ecosystems are now unfavorable for the natural enemies due to the intensification of agricultural practices, high agricultural inputs (high yielding varieties, application of more fertilizer and chemical pesticides etc.) and disturbance by human management system [47,4].

Sustainable pest regulation system in an agro-ecosystem through habitat management produced more yield and profit to the farmers. Management of pest population below economic injury level (EIL) by the application of biological control as a part of habitat management is well known. In the IPM programme, biological control is an integral part. Biological control of pest through natural enemies gave better result in the earlier adoption of that strategy, but due to high intensification of agricultural system and high input of agrochemical the classical and inundation or inoculation approaches were not well established mostly in developing countries like Bangladesh [47,4].The non-crop habitat likes woody vegetation e.g. Forest and hedgerows and herbaceous vegetation like field margin, road side, and meadow provide shelter to the natural enemies. These habitats provide shelter to natural enemies, for example, carabid beetles, staphylinids spiders, coccinellids, syrphids, chrysalides, predatory parasitoids, and also predacious Heteroptera [42]. For instance, the Lepidopteran pest in corn, maize, soybean and wheat is successfully controlled by parasitoid, if 60% alternative host is available in the field margin of those agro-ecosystems [33]. For such an opportunity the main research question of this review paper focus on a) Does habitat management stabilize the ecological infrastructure where food sources, alternative prey, pollen, nectar, and shelter is available for natural enemy? b) Does the integration of those resources in an agro-ecosystem provide the best environment for natural enemies? c) Does habitat management enhances the biological control of pest and stabilizes the sustainable agricultural pest management system in a community?

2. Landscape Composition and Type of Habitat: Key Regulator of Natural Enemies Abundance

Landscape composition and habitat type regulate the population of natural enemies and subsequently stabilize sustainable pest management by natural enemies [24, 3, 43] of an agro-ecosystem. Generally, habitat types enhance natural enemy population by creating the provision of prey, availability of food and providing refuge and hibernation sites [32]. Woody habitat like forest vegetation increases the abundance of natural enemy's population and reduces pest pressure as. it is the permanent habitat and less disturbed by humans. Alternatively, temporary habitats like horticultural systems reduce the natural enemy abundance due to agricultural intensification, disturbance by human beings and huge application of pesticide. The main benefit of permanent habitat is that predator and parasitoid are possibly complete at least one life cycle which is not possible in temporary habitat [37]. Recent studied showed that application of biological control was more successful in diverse ecosystem than non-diverse ecosystem. For example, control of soybean aphid, *Aphis glycines*, was best in most diverse habitat than non-diverse habitat [18]. The most diverse ecosystem has more non crop host like alley crop, field margin crop, middle row of the main crop etc. which provide alternative food sources, more provision for nectar and pollen for natural enemies during unfavorable conditions. The increase in percentage of non-crop area in an ecosystem through habitat management positively correlated with the mortality of insects like the armyworm *Pseudaleta unipunctal* [38] and reduced the infestation by rape pollen beetles [50]

Figure 1. The schematic representation of landscape composition favorable for natural enemies population (Credit: Felix Bianchi, Assistant Professor, Farming System Ecology group, Wageningen University and Research Centre, The Netherlands).

In modern agricultural practices, the high value crop like Tea, Sugarcane, Coffee etc. and demand crop like Rice, Wheat etc. are cultivated in a large area. As a result, the surroundings of the main crops are always empty. Adding non crops like flowering or medicinal plant in the middle of main crops or around the alley of the land produced

additional services like increasing pollination of main crop, increasing the efficacy of bio-control and also providing medicinal services to the growers [33]. The non-crop habitat provides shelter, alternate food sources for the natural enemies and pollinators when they disturbed by agricultural practices in the main field. Subsequently, the rate of parasitism by natural enemies and pollination is higher in such farm management area. However, addition of non-crops has no negative impact on the main crops as they grow on unused area [5].

We already proved that landscape complexity and local management of habitat improved effectiveness of biological control of pest. For instance, soybean aphid is a serious pest of soybean. However, it has diverse hosts. The main bio-control agents of this pest are Coccinellid beetles. They are more successful in reducing the pressure of soybean aphid by adding cucurbitaceous crops or legume crops in the middle of the soybean crops. In field margin of soybean with grassy habitat is less attractive to Coccinellid beetle due to less attractive flower than with buckwheat stripes. Combination of the grassy habitat with buckwheat stripes increased the population of Coccinellid beetles and reduced the abundance of soybean aphid [24].This result indicated that addition of more crop rather than only soybean natural enemies Coccinellid beetles increased population than soybean aphid alone [54].

3. How Plant Characteristics Influence the Natural Enemies Abundance?

Plant species in an agro-ecosystem influences the natural enemies' abundance. Efficient and sustainable habitat management depend on screening out of the plant species of a particular ecosystem most. The most important plant characteristics that greatly influences the abundance of natural enemies are the period of blooming, floral area, maximum flower height, [55] hue, chroma, corolla size [2] and number of open flowers [22]. Access to nectar and sugar largely depends on plant characteristics. The more access of nectar and sugar causes the higher percentage of fecundity and longevity of adult parasitoids [11, 53]. Predators mainly rely on prey resources for their growth and development but application of phloem fluid and pollen in their non-prey diet, it was increased their fecundity and longevity [14,21,44]. Not only the plant characteristics but also selections of plant species, like flowering plant, medicinal valued plant, or quick growing plant are also important factors. Selection of exotic plants with desirable characteristics, like longer bloom period, larger floral area increases the abundance of natural enemies than local species, as they are lack of such desirable characteristics. At the time of local species selection, emphasis should be given on above mentioned plant characteristics.

Plant species with long blooming period increases the overall abundance of natural enemies. The combination of early blooming and late blooming period plant species helps to tolerate the frost and cold during blooming. For instance, *Eupatorium perfoliatum* showed three times greater natural enemies' abundance than other plant species in Michigan local habitat in USA. The main reason for such responses by natural enemies is large number of nectar producing florets per floral area and shallow corolla depth. Both factors combinedly increase the accessibility of nectar or pollen and subsequently increase the abundance of natural enemies [16]. Most of the growers intend to target specific times of the crop growing season on increasing the effectiveness of biological control by natural enemies against the target pest in that season. If the pest attacks the crop in the early growing season, grower should select the best plant species for that cropping season. This could be termed as a seasonal factor. The floral area or diagram (means number of floral organs, their arrangement and fusion) of the selected species are also considered, because a maximum number of natural enemies attracted in a certain area of a specific season depend on such plant resources [22].Plants with narrow corollas increase the abundance of natural enemies [16]. But this finding is differs from some previous research explained that natural enemy access to nectar and pollen may be limited by floral morphology, especially narrow and deep corollas [56, 44, 26, 6]. Plant species under the family Asteraceae have late blooming characteristics, narrow disc flower which increase the nectar accessibility [16]. Therefore, the abundance of natural enemies is positively correlated with the selection of these plant species. The enhancement of natural enemies is also influenced by the flower's color and fragrance of selected species. It helps the natural enemies for recognition and detection of flower from a long distance [28]. The response of natural enemies is three or four times higher due to color saturation called chroma and hue [39, 2, 1]. So, research should be given more attention on different characteristics of plant for sustainable biological control in an agro-ecosystem through habitat management.

4. Why Manipulation of Plant Resources in Agro-ecosystem?

Natural enemies like predators and parasitoids do not depend on their prey for whole life cycle [7, 56]. They need non prey food sources at least one stages of their life time. The availability and manipulation of such food resources (natural and artificial) are the key factor for conservation biological control. Manipulation of natural food sources like increasing pollen and nectar producing plant and artificial application of honey dew, sucrose with protein supplement etc. help to enhance the activities of predator and parasitoid. Lacewing and lady bird beetle showed positive correlation with application of sucrose with protein supplement [15]. For this reason, application of artificial food sprays is also alternative non prey food for predator and parasitoid [57].The artificial food sources are now commercially

available and growers can easily apply these tools in the field for efficient biological control. Providing shelter for predators and parasitoids is also a key resource to improve efficacy of natural enemies. The agro-ecosystem is not always favorable for natural enemies and becomes unsuitable for them due to disturbance by human being and large application of pesticides. So providing alternative shelter helps them to over wintering in a particular ecosystem. The most popular shelter habitats are beetle banks. These beetle banks are suitable over wintering sites for predatory beetles in the families of Carabidae and Staphylinidae and also for spiders [51, 52].

5. Push-Pull Strategies: Innovative way of Habitat Management

Most of the plant emit volatile compound which attract both pest and natural enemies. Generally, the plant itself produces such volatiles to attract predator and parasitoid to kill their enemies. This could be termed as herbivore induced plant volatiles (HIPVs). Application of such approaches in habitat management schemes already proved [30] known as 'push-pull' strategies. Push- pull strategies means behavioral manipulation of pest and natural enemies through integration of stimuli that makes plant resources unattractive to the pests (push) and lure them to attractive source (pull) that ultimately reduced the pest. For instance, habitat manipulation through food and shelter control the stem borer incidence on sorghum and maize in east Africa [8]. Finally manipulation of plant resources reduced pest incidence, increased crop yield and profit for the growers [9,19].

6. Successful Habitat Management: A Maximization of Ecosystem Services

The shaping of recent agricultural landscapes through habitat management leads to increasing yield and profitability of a particular agro-ecosystem. It ensures and fulfills the social need by widening the range of ecosystem services [48, 49].The ecosystem services could be termed as processes which can meet and sustain the human demands [13]. The most key example of ecosystem services are fresh air and water, manipulation of climate, plant biodiversity, biological control of pests, diseases and weeds, and cultural or aesthetic values [10]. It might be maximized by successful habitat management tactics. In comparison to other types of pest management, habitat management strategies for pest control provide additional services, such as aesthetics, conservation of biodiversity, waste water treatment, and weed suppression during enhancing invertebrate biological control. Thus, habitat management strategy for pest control through natural enemies maximizes the ecosystem services. Addition of flowering plant adjacent to the main crop enhanced biological control of that particular area [4, 27]. The incorporation of such selected flowering plants around the particular ecosystem not only regulates the pest population but also increases the roadside vegetation, proper utilization of unused land, the rural beauty, and the local biodiversity [23, 35].

Besides, habitat management also indirectly improved the process of soil formation, photosynthesis, primary production, nutrient cycling, and water cycling that is only possible with proper habitat management tactics. Selected plant species not only provide resources for natural enemies, but also add food, fuel, or ornamental resources [17, 34, 20] for human beings. Through habitat management in an agricultural system the conservation of genetic diversity of selected plant and incorporation with local genotypes of non-crop plants is increased [40]. Continuous habitat management for the enhancement of natural enemies reduces erosion, improves activity of soil biota, regulates water runoff and leaching [41] and also creates provision for wildlife conservation and biodiversity [29] in a specific area. Conservation of wildlife and biodiversity is now a great concerned for researchers. The large part of the wildlife and biodiversity reserved in agro-ecosystem [46].Clearing the agricultural land and allowing growing only one or two species reduced the diversity of agro-ecosystem. Continuous destruction of the non-crop habitat, such as field margin, fallow land, hedgerows etc. reduced the shelter for natural enemies which indirectly enhanced the pest incidence. This is the result of the adoption of intensive agricultural practices. For example, due to modern agricultural practices, 38% of the endangered species are negatively affected in the USA [58]. In a nutshell, habitat management for enhancing natural enemies activity maximize the ecosystem services and stabilize a sustainable pest management system in a particular agro-ecosystem.

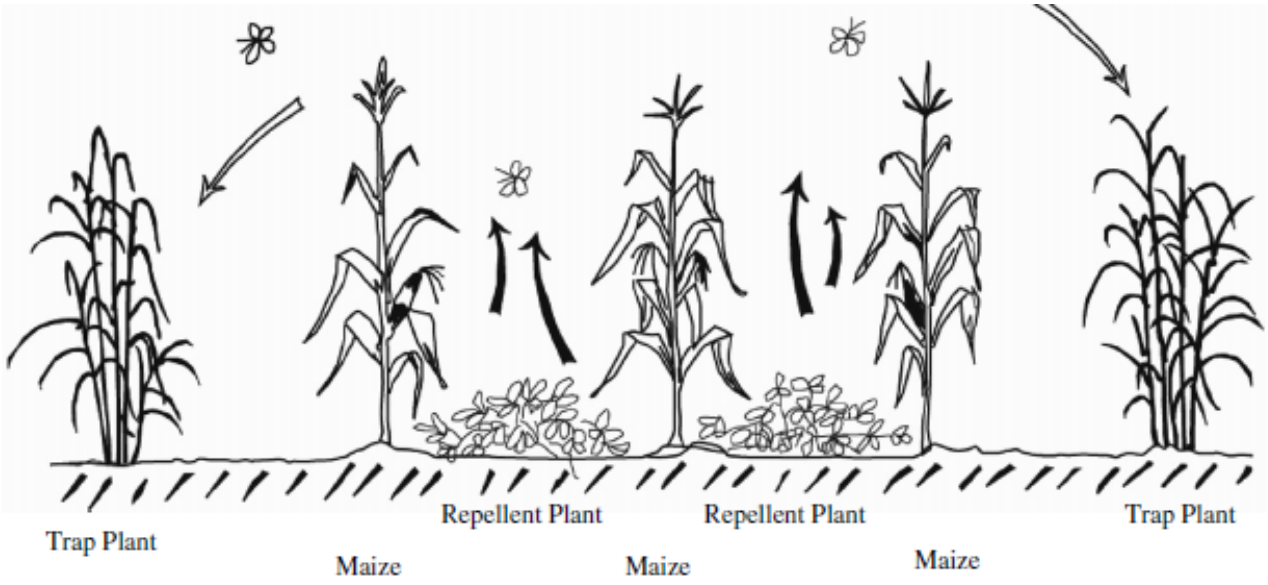

Figure 2. The diagrammatical representation of Push-Pull strategies and how it works to control cereal stem borers in Africa [30].

7. Habitat Management: Future Research Direction

Habitat management for enhancing natural enemies to regulate pest population below economic injury level (EIL) and it's sustainability of control pest undoubtedly a creative approaches in the crop protection system. The components which are responsible for effective habitat management like landscape composition and habitat type, selected plant species and their characteristics, manipulation of plant resources like honey dew and artificial food spray e.g. Sucrose with protein supplement already discussed in previous section from different point of view. More investigation on landscape complexity and habitat type should be required and a model how to design a landscape and habitat to maximize ecosystem services of a particular area in relation with natural enemies is also needed to be developed. Application of artificial food sources may indirectly increase the abundance of pest population. Previous research showed that application of artificial food sources gave positive correlation with the abundance of natural enemies [49]. There is no concrete information in the literature about the indirect effect, such as the increase of pest abundance due to the application of artificial food sources. Besides, the effect of artificial sources between the interaction of natural enemies diversity and biological control still need to investigate further [19,51].So, further research investigation should focus on how to explore the effect of application of artificial food source on natural enemies for managing crop pests. The shelter of natural enemy through the placement of alternative host, beetle banks and push-pull techniques was described in different literatures [30]. Both beetle banks and push-pull tactics may be used successfully in habitat management program. But how long those two strategies will sustained in managing ecosystem needs further investigation. Beetle banks increased the activity and density of ground beetles in field but this did not increase the fly egg predation in that area [45]. So, future research should focus on the sustainability of two approaches for controlling crop pest.

Application of pesticide is the last resort for IPM strategy. Growers have to apply pesticide when there is no alternative way to manage the pest. Timing of pesticide application should be appropriate so that natural enemies can escape from adverse effects of pesticides. For this reason, growers should develop a calendar approach when and how to apply minimum pesticide for the management of pest in a particular ecosystem. Screening out of plant species for habitat management helps to identify best plant of agro-ecosystem. The selection of plant species on the basis of external characters like colour and hue is not always wise. Because, plants have some indirect effect like invasive nature to main crop and also some chemical effect like allelopathy to other crops. So, more laboratory experiment will be needed for the best selection of plant species. Plant characters like narrow corolla increase the abundance of natural enemies [16], but this finding is controversial from previous research they proved that natural enemy access to nectar and pollen could be limited by narrow corolla [56,44,26,6]. So, further investigation will be needed for more concrete findings. Stabilization of non-crop habitat indirectly maximizes the ecosystem services including conservation of biological control [9]. But the explorations of which conservation biological approach gives maximum ecosystem services need further research. The abundance of natural enemies' population did not always provide effective pest management system. The food habit of most predator and parasitoid is variable. It may be generalist (feeding on more than one species) or specialist (feeding on single species). Further research about the food habit and how these

food habits could be used for efficient habitat management will be needed. If we add flowering plants in the field margin increase the access of pollen, nectar and sugar of natural enemies and subsequently enhance natural population. But it could also affect the pests which are antagonists to biological control agents [1] and leads to negative feedback for crop. HIPVs attract the natural enemies to kill the pest but it could also attract pest which create negative consequence for crop protection. So during plant selection researchers should give more priority that the plant volatile attract pest or not. Exploration of behavioral mechanism of predator and parasitoid enhance the successful habitat management strategy. The parasitoids are able to extensive use of semi-chemicals for host selection [12]. The manipulation of behavioral mechanism of natural enemies, and pests described in the Khan push-pull strategy well enough [30].

8. Concluding Remarks

The successful habitat management reduced the pest population below economic injury level by enhancing the activity of natural enemies. The integration of different key components in that concept and solving the limitation through further research established favorable agro-ecosystem for natural enemies. In that way we can maximize the ecosystem services of managed ecosystem for farmers.

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