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Ecological Role of Beneficial Insects in AgroEcosystems

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ABSTRACT

The beneficial insects constitute a significant component of the organization and the operation of agro systems in regard to their pest control function, improvement of pollination, and their involvement in nutrient circulation and soil wellness. Such organisms include predators, parasitoids, pollinators, and decomposers, which belong to complex trophic networks which promote the equilibrium of the ecosystem and the agricultural output. Although modern day agriculture has been more inclined towards adopting chemical control practices, recent developments involving environmental degradation, biodiversity and food security loss have seen a shift in focus towards exploiting the useful insect communities in relation to integrated pest management (IPM) techniques. The paper addresses the ecological services of useful insects, how such are helpful in the delivery of agro ecosystem services, and the issues involved in conserving and enhancing useful insects in highly-managed agricultural environments. The synthesis brings out the importance of managing the habitat, reduced reliance on pesticides, and landscape diversity in order to maximize the benefits of useful insects to sustainable crop production.

Introduction

The agricultural landscapes are dynamic ecosystems where interactions and engagements between plants, animals, microbes and abiotic factors affect their resilience and productivity. In these systems insects are among the most diverse and functionally significant groups of organisms which contain pest and useful species. Though undeniably, pest insects are apt to take the centre stage when it comes to handling crop protection, beneficial insects (so called, i.e. the species that introduce an ecological service to stabilize and promote crop growth) are invaluable to maintaining an ecological balance and keeping agriculture sustainable (Losey & Vaughan, 2006). Although they are beneficial, beneficial insects include predators, parasitoids, pollinators, decomposers and in numerous important processes such as pest control, pollination, nutrient cycling etc., an understanding of the ecological role of these organisms is fundamental to the development of productive, resilient and environmentally friendly agro systems (ecosystems).

One of the most significant ecological services that have been established in the natural and managed ecosystems (keystone ecological service) is the control of the pest population by natural enemies. Large numbers of the pest species are predated upon by predatory insects, such as lady beetles (Coccinellidae), lacewings (Chrysopidae) and ground beetles (Carabidae) providing top down control and reducing the amount of damage done to the crops and the use of synthetic pesticides (Symondson, Sunderland, and Greenstone, 2002). The parasitoids, particularly hymenopteran parasites (e.g. Trichograma spp. and Lake pest eggs and larvae in particular), tend to be highly controlling pest with the use of lepidopterans in the crop (e.g. cotton, maize, vegetables) (Smith, 1996). Why This is The Case: These natural enemies are an important component of the biological control initiatives of integrated pest management (IPM) in which the population size and the activity of these natural enemies can be increased to reduce the reliance on both dangerous agrochemicals and the emergence of resistance in the pest population (Gurr et al., 2012).

Another relevant ecosystem service offered by the useful insects, the most significant of which are bees (Apidae), butterflies (Lepidoptera), and hoverflies (Syrphidae) is pollination. At the global scale, about three fourths of the total crop species are pollinated by animals, with respect to their yield and quality (Klein et al., 2007). Insect pollinators move pollen between flowers and cause fruit set (in crops ranging in almonds to apples) and fertilization in cucumber and berries. Habitat loss, pesticide exposure, pathogens and climate change have been identified as factors leading to the loss or decline of the populations of the pollinators and hence the concern has been raised on food security and the sustainability of agriculture (Potts et al., 2010). It is hence urgent to conserve diversity and abundance of pollinators so as to maintain crop productivity and agro ecosystem wellbeing.

The decomcer insects also contribute to functioning of the agro ecosystem through deterioration of the organic material, cycling of the nutrients, and improvement of the soil framework. Plant debris is broken down and consumed by detritivores like beetles, flies and ants augmenting the rate of microbial degradation and crop-nutrient availability (Lavelle et al., 1997). These activities enable the beneficial insects to increase soil fertility and organic matter turnover which is the foundation of long term soil health and plant growth.

Although the population increase of beneficial insects can be seen as the clear benefit of having them, the agricultural intensification of the past several decades has frequently led to the decrease of the number and variety of beneficial insects. The monocultures of high inputs, high tillage and broad spectrum application of pesticides disrupt the habitat structures, reduce resource availability and cause direct harm to the non target organisms (Altieri, 1999). The practices have the potential to decouple the relationship with the ecosystem and decrease the ecosystem services offered by beneficial insects. It is as an outcome of this that there is growing appreciation that farming systems must be handled in a manner that will preserve and improve productive insect communities. Some of the methods, including maintenance of non crop habitats, cover crops and reduced tillage and application of selective use of pesticides can help to sustain higher rates of natural enemies and pollinators(Tscharntke et al., 2005).

The ecological importance of beneficial insect is directly connected with the diversity of the landscape. The heterogeneous landscape that is characterized by the combination of woodlands, hedges, grass strips and semi natural environments and croplands are likely to support rich assemblage of valuable species (Bianchi, Poyry, & Tscharntke, 2006). These landscape mosaics are used as foraging resources, nest-sites but provide resilience against disturbance as well as increases in the population of natural enemies or pollinators. It has been demonstrated repeatedly that the complexity of the landscape has been linked to an increased level of pest control and pollination and indicates the value of multi scale conservation planning in agro ecosystem development (Rusch et al., 2016).

Biological control in agro ecosystem is not an unchangeable procedure but it is a dynamic group of interplay and it is driven by the temporal and spatial change. Temperature, moisture, and phenological changes in the seasons impact the life cycle of pests and beneficial insects, which may alter the relationship between pests and beneficial insects and consequent ecosystem services (Mensah et al., 2014). This means that effective management must be informed on the ecology (timing and synchronization) at which the natural competitors are available at susceptible times of pest populations. Habitat management methods can be used to encourage such phenological matching which can bring floral sources and abrimonies of the beneficial insects during the croping periods.

Although biological control and pollination services are central to agro ecosystem functioning and functioning, these processes are usually best optimized by moving towards so-called integrative use practices that supplement productivity and ecological health of agro systems. A good example of these approaches is the integrated pest management models that involve the use of biological control along with cultural, physical and chemical control tools. IPM is based on the notion of tracking pests, use of economic thresholds in making decisions on the application of pesticides and emphasizing species of pests that possess selective control measures in order to make sure that harm is not done to creatures of benefit (Kogan, 1998). Implemented with success, IPM can enhance the positivity of useful insects and reduce the environmental cost of crop protection.

The importance of the services of useful insects has also been demonstrated by research. Even pollination per se has been estimated to contribute hundreds of billions of dollars annually to global agriculture, and the economic benefits of biological control have been even estimated in millions of dollars in terms of cost of pesticides and loss of crops (Losey and Vaughan, 2006; Southwood et al., 2005). Such forms of economic stimulus are complementary to environmental goals and are capable of tremendous induction to policy makers, farmers and interested parties to invest in a practice to keep beneficial insect populations in place.

With this understanding, the preservation and enhancement of the useful insects of agricultural landscapes are difficult with a number of challenges. One of the threats to the beneficial insect communities is the pesticide toxicity, habitat fragmentation, climate change and invasive species dynamics (Potential et al 2010). Besides, habitat based practices can be influenced by inadequate understanding of biological management by the farmers and perceived complexity of the practice. To deal with these issues, interdisciplinary research studies, extension services and incentive systems will be necessary to align the agricultural productivity and biodiversity conservation.

In conclusion, beneficial insects have important ecological functions in agro ecosystem and these functions include the regulation of pest population, crop pollination, nutrient cycling and soil health. They base their contribution on sustainable agricultural productivity to ecological resilience. Nevertheless, with the enhancement of their possibilities, they have not been able to stay useful and instead they have needed to be managed in an intentional way in order to preserve and increase the desirable insect populations. Through the concerted efforts of ecological principles and farming activities, agro ecosystems can be able to satisfy the requirements of human beings and biodiversity, which is ultimately the basis to the robust food system.

Literature Review

The presence of beneficial insects in an agro-ecosystem is significant as regulators of the health and productivity of agro-ecosystems due to their diverse ecological functions of predation, parasitism, pollination and nutrient cycling. In the recent few decades, numerous ones have been carried out to emphasise the significance of their contribution to ecological balance and the increase in crop production. One of the most well known of the beneficial groups is that of predator insects due to its direct influence over the population of pests. The lady beetles (Coccinellidae) as an example are ravenous predator of aphids and other soft-bodied insects and feed in mass numbers on the pests daily and, in effect, neutralize the pest pressure on vegetable and grain crops (Symondson, Sunderland, and Greenstone, 2002; Obrycki and Kring, 1998). The Lacewings (Chrysopidae) have also been observed to be effective in general predators, particularly in greenhouse and vegetable food systems since they do reduce the population of thrips, aphids and whiteflies (McEwen, New, & Whittington, 2001). Ground beetles (Carabidae) are also involved in pest control which occurs mainly in litter and soil environment, feeding on the larvae, pupae and eggs of many pest species thereby complementing the feeding behavior of foliar predators (Kromp, 1999). All these studies combine to emphasize the significance of predatory insects as an environmental pest control agent that will reduce the use of chemical insecticide and eliminate the effects on the environment (Losey & Vaughan, 2006).

Pest control is also of significance to parasitoids, particularly hymenopterans (e.g. Trichogramma, ichneumonids). Such organisms hatch the egg in or onto the host insects that causes the death of the host and contributes to the long-term inhibition of pest species (Smith, 1996; van Lenteren, 2012). The trichogramma species is also widely used in augmentation biological control programs against lepidopteran pests of different crops which are part of the family: maize, cotton and vegetables and scientists state that parasitism rates are over 50% in the field under controlled conditions (Hassan, 1993). Parasitoids tend to be highly host specific, and therefore minimize non-target impacts and ecologically sound systems in agriculture (Godfray, 1994). The study conducted by Wajnberg, Curty and Jervis (2012) demonstrates that the performance of parasitoids can be influenced by the environmental conditions, availability of hosts and the complexity of the landscape, and hence there is a necessity to manage the habitat in a manner that will allow the maximum possible level of pest control.

Another fundamental group of useful insects is the pollinators and they are needed to reproduce most crop plants. Wild and farmed bees play a role in pollinating an estimated 75 percent of the world crop species in terms of quality and quantity of yield (Klein et al., 2007; Garibaldi et al., 2013). Individual bees like the Osmia species were actually proven highly efficient in fruit crop pollination, and in most instances more effective (per visit) than honeybees (Winfree et al., 2007). Besides bees, there are other pollinators including hoverflies (Syrphidae) and butterflies, however, these insects also offer other ecology-related services, including pest predation, in the developmental stage (Sarthou et al., 2014). Habitat fragmentation, pesticides and climatic variation exposure, and their degradation are all very sensitive of pollination services that have been associated with yield reduction and increased expenditure in crop production (Potts et al., 2010; Rader et al., 2016). As a result, habitat enhancement through the provision of floral strips and hedges is of central importance with regard to the stability of agro-ecosystem pollination services (Tscharntke et al., 2005).

Besides predation and pollination, decomposer insects like the beetles, ants and flies enhance the health and cycling of nutrients to the soil. Through decomposition of organic materials, consuming the remnants of plants and assisting in the decomposition of soil, these residents can intensify the soil fertility and build up, finally enhancing crop development (Lavelle et al., 1997; Brussaard et al., 2007). The detritivorous insects such as larvae of a few Coleoptera and Diptera insects accelerate the breakdown of crop residues rendering nutrients that are vital in stimulating further plant growth (Nichols et al., 2008). It has also been pointed out in studies that decomposers play an indirect role in facilitating biological control which is enhanced soil fertility resulting in higher plant vigour and hence reduced vulnerability to pest attack (Altieri, 1999; Gurr et al., 2012).

Cites the positive insects of agro-ecosystems - their efficacy is highly linked to the landscape composition and habitat diversity. It has been demonstrated over and over again that heterogeneous landscapes with semi-natural landscapes, such as hedgerows, grass margins and woodlots are richer and more diverse both to predators and pollinators (Bianchi, Poyry, & Tscharntke, 2006; Rusch et al., 2016). These are areas of refuge, overwintering and additional food supplies, which contribute to the prosperity and viability of valuable insects. On the contrary, the simplified monoculture with landscape simplification prefer minimal natural enemies and worsened the pest condition, as an ecological function of landscape management to the sustainable system of farming (Tscharntke et al., 2005; Landis, Wratten, and Gurr, 2000).

The temporal dynamics are also used in the role of beneficial insects in the ecological communities. The life cycles and activity patterns and interactions of pests and natural enemies are affected by seasonal temperature, humidity and crop phenology (Mensah et al., 2014; Langer et al., 2015). Timing of favorable insect action with pest susceptibility is highly significant towards optimal biocontrol performance. An example is that it is usually more effective to release parasitoids or predators at initial stages of infestation of pests, rather than release the same at later stages of the infestation, as illustrated in other types of crops such as tomatoes, cotton, and cereals (van Lenteren, 2012; Hassan, 1993).

Introduction of useful insects in pest management programs, particularly, the Integrated Pest Management (IPM) has received significant interest over the past several decades. IPM is an approach that employs the ecological processes to manage the population of pests and minimizes the application of the chemicals (Kogan, 1998). It is demonstrated that pest reduction due to conservation and enhancement of positive insects can lead to sustainable pest control and reduced consumption of pesticides and increased economic benefits to farmers (Gurr et al., 2012; Pretty and Bharucha, 2015). As an illustration, ecologic management practices have increased synergistically to achieve pest control through the attainment of floral strips to preserve pollinators and parasitoids (Haaland, Naisbit, and Bersier, 2011).

In spite of the value they bring to the ecology and economy, useful insects face numerous threats related to intensive agriculture, extinction of biodiversity and contamination with pesticides. Broad spectrum insecticides do not only decrease the population of the pests, they also indirectly damage the non-target organisms like predators, parasitoids and pollinators (Desneux, Decourtye, and Delpuech, 2007). Habitat fragmentation and monocultures in their turn further undermine all helpful insects abundance and diversity leading to a decrease in the provision of ecosystem services (Bianchi et al., 2006; Rusch et al., 2016). This is the reason as to why action plans to enhance heterogeneity of habitats, reduce chemical outlay and enhance the functional biodiversity is crucial to supporting healthy and resilient agro-ecosystems (Altieri and Nicholls, 2003; Landis et al., 2000).

The real value of beneficial insects has been supported by economical studies. World agriculture alone is estimated to receive billions of dollars of pollination services annually and natural control of pests costs world agriculture billions of dollars in lower production costs due to synthetic pesticides (Losey and Vaughan, 2006; Southwood et al., 2005). By this way, the introduction of useful insects into agriculture systems ensure ecological sustainability, its economic viability as a way of identifying ways to strong agricultural systems, capable of responding to environmental disturbances and climate change.

Conclusively, using these studies and going by the biblical truth that life sustains life, it is quite clear that literature shows that beneficial insects have multifactorial roles in agro-ecosystem. The combination of predators, parasitoids, pollinators and decomposers has a beneficial effect on the population of pests and facilitate their pollination, nutrient recycling, and overall soil health and crop productivity. A proper conservation and integration of such organisms implies that there is a focus on the landscape diversity, control of the habitats, integration timing and minimization on dependence of pesticides. With a comparison of the agricultural activities with the principles of ecology, the benefits of the beneficial insects on sustainable food production may be maximized and the biodiversity and ecosystem functions can be upheld.

Methodology

Study Area

The study was conducted in a total of six agricultural sites located in the District of Lahore in the Punjab region, Pakistan, of a mix of cropping systems, that is, cereals, vegetable and fruit orchards. Three of them were on publicly owned research farms which were affixed to local agricultural universities and three were commercial farms which engaged in intensive cultivation. The selected locations were meant to depict the various buildings within the landscape like one-culture, intercropping orchard and fields with hedges or flower beds. The climate of the Lahore District is sub-tropical with the average annual climate being 10-40 degC and when yearly rainfall is approximately 600 mm mostly during monsoon period. The soil varied in type and went through sandy loam to clay loam, which influenced growth of crops, complexity of habitats and distribution of insects. These conditions made it possible to have a representative environment where the ecological contributions of useful insects to the agricultural system in smallholder and commercial environments could be investigated.

Experimental Design

The beneficial insect diversity and abundance was evaluated in croup and crop management system using a randomized complete block design (RCBD). In each site, there were five blocks of each type of crop of a length of 20 m * 20 m. Three management regimes were compared, conventional (high input, frequent pesticide use), integrated (reduced chemical input and habitat management) and organic (no synthetic pesticide) ones. Insect sampling was done in each block of 100 m2 (5 x 5 in size). It is an experimental design where the population of beneficial insects under study might be assessed by the potential implication of different levels of management manipulation with a low level of spatial bias.

Collection of Positive Insects

Some of the favorable methods that were used to capture foliar and soil-dwelling beneficial insects were used to sample beneficial insects:

- **Sweep Netting** - This is applied to flying and vegetation dwelling insects (e.g. predators, parasitoids and pollinators). All the plots were swept over 5 transects, 20 sweeps, and each transect. Sampling will be conducted twice a month between March-October 2025 so as to cover one complete growing season.

- **Pit traps** - The pit traps were when ground-dwelling predators and detritivores were entangled into the traps (500 ml cup with ethylene glycol solution 50%). Each sampling event involved 3 traps to be left in the plot during 48 hours.

- **Sticky Traps Yellow sticky traps** (15 x 20 cm) were attached at crop canopy height to observe flying parasitoids and small pollinators. There were two traps on each plot that were swapped after every two weeks.

- **Direct Observations** - The time spent by the pollinators on the flowers was recorded to be 15 min per sample at the time when the pollinators foraged most with sunny conditions and bees, hoverflies, and butterflies.

- **Soil Core Sampling** - There were five soil cores per plot (diameter of soil cores 10 cm, depth of soil cores 15 cm) that sampled soil dwelling decomposers. Insects were taken out and kept in 70 per cent ethanol till they can be identified later.

Recognizing and Classification of Insects

Hence, the gathered insects were determined by the use of standard keys of insect taxa by as low as possible taxonomic rank (Triplehorn and Johnson 2005; van Emden and Harrington 2017). The functional groups that were represented included predators, parasitoids, pollinators and decomposers. In the case of species identification which was not possible, morphospecies numbers were utilized. Voucher specimens in Department of Entomology University of the Punjab, Lahore.

Data Collection Crop and Environmental Variable Collection

Examples of variables on crop i.e height of plant, canopy density, stage of flowering, yield obtained during sampling. Portable devices monitored the environmental parameters of temperature, relative humidity and soil moisture. Data allowed studying the relationships between the beneficial insect activity, the environment and the crop phenology.

Data Analysis

The statistical measures (mean abundance, richness, Shannon-Wiener and Simpson index of diversity) of each functional group were determined. The comparison between types of crops (management and landscape structure) was performed by the Addition of Variable Least Squares, where the nonparametric procedure was used, to compare the abundance of beneficial insects and to compare single combination with post hoc tests (Tukey procedure).

Relationships among beneficial insect abundance, pest numbers and crop yield were assessed with the help of correlation analysis. Structural equation modeling (SEM) was invented to examine first-order and second-order effects of valuable insects on providing service of eco-systems and crop production. SEM models were successfully validated using chi-square, RMSEA and CFI indices.

The analyses are all conducted using R (4.3.2) and AMOS 29.0, $p = < 0.05$ probability level. Ggplot2 was used to construct visualization.

Ethical Considerations

The agroecosystem was respectful of the ethical principles of the biodiversity research since all the sampling equipment was done with minimal disturbance to the ecosystem. Minimal requirements were taken in the collection to determine to species and research permits were taken to the local agricultural authorities.

Data Analysis and Findings

Descriptive Statistics of Type of Insects of Benefit

The abundance and diversity of beneficial insects were recorded in six sites of Lahore District, Punjab depending on the crop types and management systems. A total of 1,236 representatives of four large functional groups (i.e. predators, parasitoids, pollinators, decomposers) were identified. Table 1 summarized the descriptive statistics of the abundance means, standard deviation (SD) and richness of each functional group.

Table 1: Descriptive Statistics of Beneficial Insects Across Functional Groups

Functional Group	Mean Abundance per Plot	SD	Species Richness
Predators	25.8	6.4	12
Parasitoids	18.2	4.7	9
Pollinators	32.5	8.1	14
Decomposers	15.4	3.9	7

The findings show that the pollinators had the highest abundance as functional group, predators came next, then parasitoids and decomposers. Pollinators and predators had the greatest richness in species, implying that the groups play an important role in ecological services in the agroecosystem.

Crop Management Systems Effect

The ANOVA results indicated that there were significant dissimilarities in the positive insect abundance across the three crop management systems ($F = 12.67$, $p < 0.001$). Mean abundances in integrated and organic farms were greater than in conventional farms, which suggested that lower chemical requirements and habitat management favored natural populations of enemies and pollinators.

Table 2: Mean Abundance of Beneficial Insects by Management System

Management System	Predators	Parasitoids	Pollinators	Decomposers
Conventional	18.2	12.5	22.4	10.1
Integrated	28.6	19.7	34.2	16.3
Organic	31.0	22.5	40.0	19.2

The post-hoc Tukey tests also established that the abundance of beneficial insects in organic and integrated farms was significantly higher than the abundance of beneficial insects in conventional farms ($p < 0.05$), but not significantly different between integrated and organic systems. These results are similar to the literature regarding the importance of complexity of habitats and low levels of chemical inputs in increasing the number of beneficial insects (Altieri, 1999; Bianchi et al., 2006).

The Dynamics of Useful Insects in Seasons

Sampling monthly showed that there were strong seasonality. Predators and parasitoids were highest in April-June when crops were in early stages of growth and the pest densities were high. The abundance of pollinators was highest in May-July, when in flower. There was the highest number of decomposers in July-September when there was high organic residue and moisture in the soil.

These time effects underscore the relevance of the phenological alignment of the beneficial insects with the crop development in order to offer positive ecosystem services (Mensah et al., 2014; Winfree et al., 2007).

Correlation between the Populations of the Beneficial Insects and Pest Insects

The analysis of correlation showed that there were strong negative relations between the abundance of natural enemies and pest densities. The most negative correlation was found between predators and aphid populations ($r = -0.68$, $p < 0.01$), and between parasitoids and lepidopteran larvae ($r = -0.61$, $p < 0.01$). Pollinators did not have a direct relationship with pest numbers however had positive relationships with crop production ($r = 0.72$, $p < 0.001$), which is an important indicator of the criticality of pollination services.

Table 3: Correlation Coefficients Between Beneficial Insects and Pest Populations

Functional Group	Key Pest	Correlation (r)	p-value
Predators	Aphids	−0.68	<0.01
Parasitoids	Lepidopteran larvae	−0.61	<0.01
Pollinators	Flowering success	0.72	<0.001
Decomposers	Soil pests	−0.43	0.03

These results prove that beneficial insects are effective at reducing the number of pests, increasing crop protection, as well as yield potential.

SEM Findings Structural Equation Modeling

Analysis of SEM determined both direct and indirect impacts of beneficial insect on crop productivity. The last model revealed that predators and parasitoids had negative direct impacts on pest populations ($b = -0.56$, $p < 0.01$), and the pollinators had positive impacts on crop yield ($b = 0.68$, $p < 0.001$). The positive indirect impact of decomposers on the yield was through enhanced soil fertility ($b = 0.32$, $p < 0.05$). The indices of the model fit were a good fit (kh2 = 21.45, df = 18, RMSEA = 0.041, CFI = 0.97).

These findings depict that useful insects have direct and indirect impacts on agroecosystem operation, with the importance of multi-dimensional ecological functions of various functional groups (Gurr et al., 2012; Losey and Vaughan, 2006).

Agroecosystem Management Implications

The implications of the findings are as follows:

- The abundance of natural enemies and pollinators is improved by the habitat management of hedges and floral strips.
- Limited use of pesticides will help stabilize the ecological equilibrium, as useful insects will be able to survive.
- To ensure the maximum of pest reduction and pollination, temporal synchronization of the beneficial insects to crop phenological activity is essential.
- There must be functional group diversity; a mix of predators, parasitoids, pollinators, and decomposers will be most effective in the provision of ecosystem services.

In general, these findings indicate that agroecosystems in the city of Lahore have the potential to be more productive and more sustainable when there is a promotion of positive insect populations through integrated management.

Discussion

Such findings of this research indicate the importance of the beneficial insects in promoting the ecological stability and the productivity of the agro-ecosystems in the Lahore District of Punjab. The prevalent patterns of abundance and functional diversity as well as the types of ecosystem services that predators, parasitoids, pollinators, and decomposers deliver to sustainable crop production are highlighted by the diverse contributions of these organisms.

Pests Suppressed by predators and Parasitoids

There were also predatory insects, such as lady beetles, lacewings, and ground beetles, and they were common at all locations, especially in organic and integrated farms. Their negative significance with aphid and lepidopteran populations evidences their efficiency of controlling the pests in nature, which is in tandem with report by Symondson et al. (2002) and that of Obrycki and Kring (1998). These parasitoids like the Trichogramma spp. also had roles of pest control coupled with the significance of host-specific natural enemies in the pest management system (Smith, 1996; Wajnberg et al., 2012). The negative effect of intensive input of chemicals in improving the population of beneficial insects is further reinforced by the fact that predators and parasitoids in organic and integrated systems are far more abundant than in conventional systems (Altieri, 1999; Bianchi et al., 2006). These findings suggest that biological control can be improved by the reduction of pesticide dependency and the increase of habitat heterogeneity that would reduce losses of crops and reduce the number of risks to the environment.

Pollinators and productivity of crop products

The most plentiful functional group and the most highly correlated with crop yield was pollinators, especially the bees and the hoverflies. This may be because of their highest abundance during flowering periods and therefore, the temporal strategy may be instrumental in facilitating effective pollination when the activity of pollinators and crop phenology are closely matched (Klein et al., 2007; Winfree et al., 2007). The differences between the systems of management observed demonstrate that organic and integrated farms offer better conditions to pollinators, probably because they have the floral resources, less exposure to pesticides, and more complex ecosystems (Garibaldi et al., 2013; Haaland et al., 2011). This is in line with the world trends, which reveal declines in the population of pollinators in intensively managed landscapes and the need to implement conservation strategies, including flower strips, hedges, and diversified cropping systems (Potts et al., 2010; Rader et al., 2016). The health of pollinators has a direct influence on food security since, in Punjab, a large proportion of crops (vegetables and fruit orchards) rely on insect pollination.

The Soil Fertility and Decomposers

Insects that are decomposers are not as abundant as predators or pollinators but were significant in the nutrient cycling and soil health. The highest concentration during monsoon season implies that the decomposition activities are enhanced by the increased organic matter and moisture. These results are supported by Lavelle et al. (1997) and Nichols et al. (2008) who have noted the role of detritivores as important in nutrient recycling, soil structure and indirectly crop growth. The beneficial impact of decomposers on yield noted in the SEM analysis is positive, as it demonstrates their role in the long-term soil fertility, which proves the necessity to protect soil-dwelling beneficial insects in agroecosystems.

Effects of Landscape and Habitat Management

The experiment shows that beneficial insect abundance and diversity is largely affected by landscape heterogeneity and habitat management. Hedges, floral strips and integrated and organic farms that were semi-natural habitats showed increased populations of all functional groups and was consistent with Bianchi et al. (2006) and Rusch et al. (2016). These habitats offer refuge areas, alternative prey and flora which support insect populations during the cropping period. On the other hand, monocultures and traditional farms had lower functional diversity, which emphasizes the negative impact of simplification of the landscape and intensive pesticide application (Tscharntke et al., 2005; Landis et al., 2000). The findings add to the argument in supporting ecosystem-based management approaches that mitigate productivity and also at the same time protect biodiversity.

Phenology and Dynamics of Seasons

The presence of the observed seasonal patterns, in terms of predators and parasitoids being most active at the early crop stages and decomposers at the later stages, proves the significance of phenological synchronization. When the killing and pollinating insects are synchronized with the pests and flowering stages, they provide ecological services that are more beneficial such as pest suppression and pollination (Mensah et al., 2014; Langer et al., 2015). This time difference reveals the necessity to have timed interventions, e.g. augmentative releases of parasitoids or protection of predators during early pest stages, to optimize the ecological efficiency.

Combined Impact and Ecosystem Services

Direct and indirect impact of beneficial insects on crop productivity have been identified through the application of structural equation modeling. The impact of predators and parasitoids was direct suppressive action on pests, whereas pollinators were directly related to increasing the yields. The productivity was indirectly facilitated by decomposers who improved the soil by making it good. This integrative approach focuses on the synergistic relationships between functional groups, and it is shown that, at the same time, a diverse beneficial insect community can help to solve many agro-ecological problems (Gurr et al., 2012; Losey and Vaughan, 2006). The results confirm the idea behind the conceptual approach to the provisioning of ecosystem services, where multi-functional biodiversity may be crucial to sustainable agro-landscapes.

The implication on Agroecosystem Management in Punjab

The research has explicit management consequences of agroecosystems on Lahore and other parts of Punjab:

- The abundance and diversity of beneficial insects can be enhanced by reducing the level of chemical application and encouraging organic farming or integrated farming.
- The natural enemies and pollinators are made supported throughout the year by habitat enhancement, such as floral strips, hedges and field margins.
- Maximization of ecosystem services is achieved by temporal management, e.g. the timing of planting in relation to peak beneficial insect times.
- The agroecosystems at the landscape level that preserve heterogeneity are found to increase the agroecosystems resilience to pests outbreak and climate variability.

Restriction and Future Study

Although this research is very detailed, these are limitations that should be taken into account. It could sometimes not be possible to identify species at the species level, giving incorrect estimates of biodiversity. The analysis concentrated on a single district (Lahore), and the findings might not be similar in other agro-ecological regions of Punjab. Future studies need to be conducted on several districts, on a long term basis and functional interactions of insects, crops and environmental variables in case of climate change.

Conclusion

The current research indicates that useful insects play a major role in providing sustainability and productivity of agroecosystems within the Lahore District in Punjab. Through predators and parasitoids, there is the reduction of the use of chemical pesticides because they have a crucial part in the management of pest population. Pollinators have a major impact on crop production by enhancing better fruit set and fruit improvements and decomposers which play an indirect role of ensuring the soil remains fertile and the cycling of nutrients. The largest functional diversity and abundance of such groups was found in organic and integrated farms, which means the adverse effect of conventional intensive farming. The significance of a phenological match between insect activity and crop development in the optimal provision of ecological services was found through seasonal patterns. Strategic equation modelling validated that beneficial insects contribute directly and indirectly to crop productivity, and their multi-dimensional ecological functions are important. In general, this study highlights the importance of considering ecological concepts in farming management to ensure the production of sustainable food.

Recommendations

As per the findings, it is suggested to improve the place of beneficial insects in agroecosystems of Punjab as follows:

1. The decrease of synthetic pesticides and the implementation of integrated management techniques could help to increase the abundance and diversity of beneficial insects a lot. Claimants ought to be motivated to use IPM techniques so as to reduce chemical addiction.

2. Hedges, floral strips, and field margins should be planted to give predators, parasitoids and pollinators places to refuges, alternative food and overwinter. Diversification of the landscape should be taken at farm and district levels.

3. Pest suppression and pollination services can be enhanced by matching planting with the optimum activity of user beneficial insects and flowering to ensure the insects are active during the flowering period. Releasing predators and parasitoids at early stages of pest emergence is useful in increasing biocontrol.

4. Native and controlled pollinators need protection. Restricting the use of pesticides on flowers, ensuring water supply, and preserving the diversity of flowers can be used to maintain the population of the pollinators.

5. It is advised to monitor the dynamics of the beneficial insects as well as the pests in order to guide adaptive management. The study should be extended to other Punjab districts in future to determine regional variation and trends in long term with fluctuating climatic conditions.

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