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RESEARCH ARTICLE

Optimizing control of flea beetles through ecological engineering of vegetable agroecosystem in Kashmir

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Abstract

Ecological engineering is a concept of habitat manipulation to reduce dependence on insecticides. It is the intentional involvement of plant communities and insectary plants in managed landscapes influencing natural enemies survival. These natural enemies lead to reduction in pest population in environmentally acceptable production practices. Field experiments were conducted during 2019 and 2020 to evaluate impact of ecological engineering on the flea beetles, *Phyllotreta striolata* and *Altica himensis* and their natural enemies on brinjal crop. Three treatments with different plant species were worked out for pest management study. Results showed that Treatment I caused maximum increase in mean number of natural enemies (1.11/ 10 plants) which in turn brought maximum mean pest reduction. Treatment II caused second maximum increase in mean number of natural enemies (0.92/ 10 plants). Treatment III caused minimum increase in mean number of natural enemies (0.68/ 10 plants). The diversity of predators was documented in different treatments. Simpson's diversity index, Shannon-Weiner index and Evenness index were found higher in Treatment I followed by Treatment II and Treatment III. The maximum mean percent increase of natural enemies in main crop over control (250.52 %) with maximum mean % reduction of target pest (63.46 %) was observed in Treatment I. The mean percent increase of natural enemies in main crop over control (167.44 %) with mean % reduction of target pest (54.41 %) was observed in Treatment II. The mean percent increase of natural enemies in main crop over control (20.97%) with mean percent reduction of target pest (48.88%) was observed in Treatment III.

Keywords

Altica himensis, biological control, habitat manipulation, natural enemies, *Phyllotreta striolata*, treatments

Introduction

Monocropping of agroecosystem are often prone to outbreak of insect pests so production of the high-grade crop is not possible without chemical insecticides. Management by insecticides is now a norm for the whole world of agricultural practices and its use is growing day by day for pest management which has led to pest resistance (1), residue problem (2), harmful effects to non-target organisms (3), environmental pollution (4), deleterious impact on natural enemies and influence on human health (5, 6). The insecticides cause loss of habitat, environmental degradation (5-7) and loss of biological control (8). The pre-requisite for improved crop production, complications allied to monoculture, pest resistance (9) and invasive pest arrival (10-13) impede the implementation of viable and environmental eco-friendly management. On the other hand, there is a worldwide increase in demand for pesticide residue-free food (14, 15). Thus, the need is growing for switching from agrochemical to agroecological based pest management with the help of modern multi-dimensional ecological engineering (16). Ecological engineering promotes diversification of plants making conducive environment for natural enemies survival which in turn lead to pest management (17). Heterogeneity in structure of agricultural habitats for control of insect pests with a sustained population of natural enemies is need of the hour. Habitat modification is an alternative to chemical insecticides for pest control by supporting the population of natural enemies which in turn reduces pests through conservation biological control.

Brinjal is an economically important and highly traded vegetable cultivated in Kashmir on both small and large scale. A basis of income to all individuals who are involved in brinjal production from its farming till it gets to the ultimate consumer. Despite being a large producer, the yield of brinjal in country is low due to attacks by several insect pests. Flea beetles attack numerous plants and vegetables but they are attracted more to vegetable crops. The flea beetle is an economically important insect pest attacking vegetables specifically solanaceous crops (18). In huge numbers, they can cause irreversible plant damage in a short time (19). When in large group they collectively affect the yield of plants and in the initial stage of their development they can destroy plants (18-20).

The main aim of study was to quantify the effect of integrating use of insectary plants, trap crops along with other non-host crops in an organic brinjal agroecosystem to reduce chemical dependence. Insectary plant and trap crop are suitable way of habitat management for insect pest suppression (21). Insectary plant is a flowering plant that upholds and intensifies the pollen and nectar source to natural enemies (22, 23), shelter to natural enemies (24), breeding sites for natural enemies (25). Non-host plants safeguard predators at the time of insecticidal spray and adverse weather conditions (10). Trap crop functioning could be enhanced by including multiple species within trap crop along with the main crop for improving pest control potential (26). The inclusion of companion plants which are non-host of key pest species increases plant diversity within crops that in turn have been shown to lead to a reduction in pest number (27, 28). Companion planting in mixture with trap crop reduces pest damage at small size. This demands additional study of trap crops and specially combined strategies that can be included with trap crop that can be of possible usage to growers demanding pest control at smaller scales using adaptable approaches. The present investigation was undertaken to study the efficacy of ecological engineering by integrating different non-host crops with main crop to provide excellent control of flea beetles as a substitute to chemical pest control.

Materials and Methods

Site of study

The effectiveness of ecological engineering against *P. striolata* (Fabricius) and *A. himensis* (Shukla) were evaluated during 2 years of field experiment on the brinjal crop at Mirgund, with a latitude of $34^0$13'79" N and longitude of $74^0$65'66" E on the border of Srinagar district connecting with Baramulla at an altitude of 1579 m asl. Fig. 7 reveals the weather data of the site selected.

Preparation of land

The 330 (30X11) Sq Mtr plot was selected for experiment from an open field of 3.75 acre of land. The area lies in temperate zone with alluvial soil rich in nitrogen and organic matter and is irrigated by stream water. The experimental plot was prepared in the second week of April 2019 and 2020 using a handheld tiller after which the experimental plot was harrowed and ploughed several times to obtain a good tilt. Weeds and stubbles were removed before transplantation. Weeding was done after every 3 weeks by hand hoeing. Beds were made as per the design and dimensions to start transplantation (Fig. 1).

Transplantation of seedling

Thirty days old brinjal (*Solanum melongena* L.; Variety: Shamli (seminis) from Directorate of Agricultural Sciences J&K) seedlings were transplanted on 17^{th} of April 2019 and 14^{th} of April 2020 respectively. Seeds were nursed in the polyhouse until transplantation. Non-host crops were transplanted on the same days as main crops except marigold which was transplanted 2 weeks after the main crop so that flowering coincides with pest and natural enemies incidence.

Study design

Three treatments were used with randomized block design, having 4 replicates per treatment with a plot size of (4X3 m) per replication excluding perimeter crop (Fig. 1). A buffer zone of 1.25 m was maintained within different treatments. In each plot crop spacing of (50X50 cm) was maintained. The field was maintained with different types of non-host and flowering plants throughout the year. Flowering plants rich in nectar were grown to attract beneficial insects and also provide shelter to natural enemies. A control plot was used having 4 replicates with a plot size of 4X3 mts per replication at a distance of 3 mts from the experimental plot. To evaluate the diversity of plant species used for habitat manipulation, literature that suggested establishment of different non-host and insectary plants to provide conducive habitat for insect pest control was reviewed. Three treatments of brinjal crop were used, with different combinations of non-host plants and a control plot for each treatment. The 3 treatments are depicted in (Table .1)

Collection of pests and natural enemies

Insect pests and natural enemies were collected using sweep net and hand picking from different treatments and control plots in the experimental field. Ten sweeps using sweep net were performed randomly at fortnightly intervals, from 20th-40th MSW (Meteorological Standard week) during 2019 and 2020. Insect pests were predominant flea beetles viz., *P. striolata* and *A. himensis*. The natural enemies were different species of spiders, ladybird beetles, bugs and lacewing. Assessment of population of pests and natural enemies was done by visual counting on 10 randomly selected plants in the middle row of each replicate at weekly intervals. Sampling was done early morning at 8-10 AM to avoid the escape of beetles as they are inactive in the morning. Extreme care was taken to prevent disturbance during the counting process. Pests and predators from different treatments were sorted out into different orders and families.

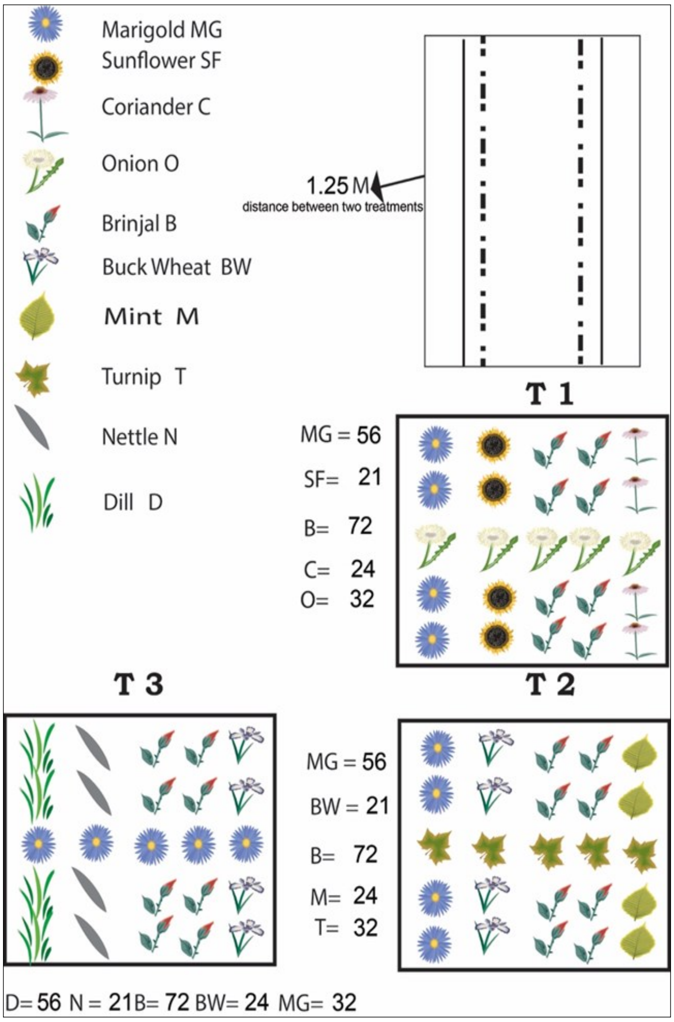

Fig. 1. Sketch of treatments.

Data analysis

Data on insect pest population and natural enemies obtained were subjected to analysis of variance (ANOVA) using the PAST software to check significance between different treatments. The interpretation of data was done using critical difference value. The biodiversity indices were also calculated using PAST and excel 2016 software. Simpson's diversity is a measure of the number of species as well as the abundance of each species. The Shannon-Wiener diversity index signifies both richness and evenness of a species in a community. Evenness index is a measure of the distribution of species in an ecosystem. Shannon-Weiner diversity index was calculated by (29) formula

$$H = -\sum_{i=1}^{S}(pi\ln pi) \qquad \text{Eqn. 1}$$

where pi is the number of individual species, ln is natural Log and S is the total no of species. Simpson diversity index was calculated by (30) formula

$$D = {n(n-1)}/{N(N-1)} \qquad \text{Eqn. 2}$$

where n is the number of individual species and N is the total number of all species. Evenness was calculated by (31) formula

$$e^{H/S} \qquad \text{Eqn. 3}$$

where H is Shannon-Weiner index and S is the total number of species.

Results

Ecological engineering is a component of agroecology as an outcome of some intervention where the concept is applied with some certainty in restoration of ecosystem, the concept is still in its infancy with regard to pest management particularly in brinjal. However, there are examples from other crop system where method has been successfully applied to pest management. For example, the planting of buckwheat, *Fagopyrum esculentum* as a cover crop in vineyard and Alyssum, *Lobularia maritima* (L.) between the rows of vegetables provides resources for predators and parasitoids resulting in reduced pest damage. The pest population starts to show up when temperature rises to around 15 ^{0}C Max. Temp, 4 ^{0}C Min. in March and

Table 1. Cropping pattern in different treatments of the experiment

	Main crop	Trap Crop	Attractant	Repellent	Perimeter
Treatment 1	Brinjal (72) * *Solanum melongena* L.	Sunflower as border (21) *Helianthus annuus* L.	Coriander as intercrop (24) *Coriandrum sativum*	Onion as buffer (32) *Allium cepa*	Marigold (56) *Tagetes* sp.
Treatment 2	Brinjal (72) *Solanum melongena* L.	Turnip as buffer (32) *Brassica rapa*	Buckwheat as border (21) *Fagopyrum esculentum*	Mint as intercrop (24) *Mentha* sp.	Marigold (56) *Tagetes* sp.
Treatment 3	Brinjal (72) *Solanum melongena* L.	Marigold as buffer (32) *Tagetes* sp.	Buckwheat as intercrop (24) *Fagopyrum esculentum*	Nettle as border (21) *Urtica dioica*	Dill (56) *Anethum graveolens*

reaches peak around 31 ⁰ Max. Temp, 18 ⁰C Min in August and dip down to hibernation around 13 ⁰ Max. Temp, 2 ⁰C Min in November. The corresponding relative humidity and temperature are described in Fig. 7. The results showed the effect of different polyculture combinations against an increase in natural enemies and its subsequent impact on the reduction of pest number as is elucidated in (Supplementary Table 1). Two different predominant flea beetle species viz., *P. striolata* and *A. himensis* were recorded from engineered and control plots. The predators recorded during the study period included 4 families viz., Pentatomidae (*Zicrona caerulea)*, Coccinellidae (*Coccinella septempuntata*, *C. undecimpunctata*, *Oenopia conglobata*, *Hippodamia variegata, H. eucharis*, *Adalia tetraspolita*) Araenidae (*Linyphia triangularis*, *Steatoda triangulosa*, *Araneus diadematus*, *Enoplognatha* sp.) and Chrysopidae (*Chrysoperla carnea*). It is obvious from the data that the pest population was lower in the main crop with a greater number of natural enemies than in control. In the intercropped plots combinations of various non-host crops with host crop shielded the brinjal crop from pest infestation. Among 3 treatments, Treatment I caused the maximum reduction of pest on main crop compared to control. The mean population of 7.47 ±0.69 per 10 plants for *P. striolata* was observed on main crop compared to 19.89 ±0.64 per 10 plants on control. The mean population of 6.88 ±0.83 per 10 plants for *A. himensis* was observed on main crop compared to 19.39 ±1.12 per 10 plants on control. The maximum mean number of natural enemies was observed in Treatment I with population of 1.36 ± 0.05 per 10 plants on the main crop compared to 0.39 ± 0.14 per 10 plants on control. From (Fig. 6), it is clear that maximum mean percent reduction of *P. striolata* and *A. himensis* with 63.46 % was observed in the main crop over control plot. Similarly, the maximum percent increase of natural enemies with 250.52 % was recorded in main crop over the control plot.

Treatment II caused the second-best reduction of pests on main crop compared to control. The mean population of 9.14 ±0.18 per 10 plants for *P. striolata* was observed on main crop compared to 18.77 ±0.79 per 10 plants on control. The mean population of 7.35 ±0.95 per 10 plants for *A. himensis* was observed on main crop compared to 17.42 ±0.54 per 10 plants on control. The second maximum mean number of natural enemies was observed in treatment II with population of 1.39 ±3.86 per 10 plants on the main crop compared to 0.52 ±7.93 per 10 plants on control. From (Fig. 6), it is clear that the second maximum mean % reduction of *P. striolata* and *A. himensis* with 54.41 % was observed in the main crop over control plot. Similarly, the second maximum percent increase of natural enemies with 167.44 % was recorded in main crop over the control plot.

However, Treatment III caused the minimum reduction of insect pests. The mean population of 9.08 ±0.18 per 10 plants for *P. striolata* was observed on main crop compared to 18.46 ±0.37 per 10 plants on control. The mean population of 9.63 ±0.19 per 10 plants for *A. himensis* was observed on main crop compared to 18.16 ±0.37 per 10 plants on control. The lowest mean number of natural enemies was observed in treatment III with population of 0.60 ±0.32 per 10 plants on the main crop compared to 0.50 ±0.25 per 10 plants on control. From (Fig. 6), it is clear that the lowest mean percent reduction of *P. striolata* and *A. himensis* with 48.88 % was observed in the main crop over control plot. Similarly, the percent increase of natural enemies with 20.97 % was recorded in main crop over the control plot.

It is evident from data (Supplementary Table 1) that the maximum mean number of natural enemies on four non-host plants was found in Treatment I (1.11/ 10 plants) > Treatment II (0.92/ 10 plants) > Treatment III (0.68/ 10 plants). It is also obvious from data that the maximum mean number of pests viz., *P. striolata* and *A. himensis* on four different non-host plants was recorded from Treatment I (11.73/ 10 plants) > Treatment II (9.82/ 10 plants) > Treatment III (7.92/ 10 plants). The diversity indices of predators in control and intercrop systems of different treatment s were presented in Table 2. The data showed that the diversity of natural enemies was relatively higher in Treatment I> Treatment II> Treatment III. In the present study, Simpson, Shannon-Weiner and Evenness index of natural enemies was found to be 0.73, 1.63 and 0.93 in the intercropped systems compared to control of 0.55, 0.93 and 0.36 in Treatment I. In Treatment II, Simpson, Shannon-Weiner and Evenness index of natural enemies was found to be 0.68, 1.39 and 0.57 in the intercropped system compared to the control of 0.56, 0.98 and 0.38. In Treatment III, Simpson, Shannon-Weiner and evenness index of natural enemies was found to be 0.65, 1.28 and 0.51 in the intercropped system compared to the control of 0.56, 0.98 and 0.38.

Discussion

Although ecological engineering has been used elsewhere for the control of pest in different crops, nevertheless no work has been done for evaluation of this method against *P. striolata* and *A. himensis* on brinjal crop in Kashmir. It was found that heterogeneity in plant culture influenced the number of natural enemies which in turn reduced the insect pest incidence in the main crop over control plots. This was in agreement with earlier findings that polyculture was having the lowest pest population than control with an increased number of natural enemies in polyculture compared to control (32). The non-host plants when raised with host plants was found to reduce pests and promote natural enemies. Border crop and intercrop along with main crop hinders insect pest development and favours natural enemies by providing supplementary food and refugee (7). Insect pest outbreak is scarce in polyculture due to potential of the multiple plant culture to be self -reliant through natural pest control by building up the number of natural enemies (33, 34). Among three treatments, Treatment I with (main crop brinjal and border crop of sunflower as a trap, intercrop of coriander as an attractant, buffer crop of onion as repellent and marigold as perimeter crop) was found to be best for pest control in

Fig. 2. Treatment I.

Fig. 3. Treatment 2.

Fig. 4. Treatment 3.

comparison to other two treatments during both years of study. The presence of suitable combination of non-host

Fig. 5. Control plot of sole crop of brinjal.

and flowering plants played role in having the maximum mean number of natural enemies and maximum pest reduction in Treatment I. This was in line with earlier report where it was found that colonization of insect pests on host plants was impacted by the existence of non-host plants (35). Treatment I was having maximum mean percent reduction of pests viz., *P. striolata* and *A. himensis* in main crop over control plot. Similarly, the maximum percent increase of natural enemies in the main crop over the control plot was recorded in the same treatment. It was observed that change in cropping pattern could change insect pest number and suppress insect pests of brinjal crop in an eco-friendly manner. Results corroborated with findings detecting potential of sunflower as an excellent crop to attract abundant natural enemies. Insect pests were minimum in treatment with a combination of marigold and coriander. This could be due to the inability of insect pests to locate the host plant due to volatiles that has either repellent or deterrent effect (37). Marigold increases longevity and fecundity of natural enemies by providing nectar and pollen (38). Results also agree with finding that insect pest number was reduced in brinjal crop when brinjal was intercropped with coriander (39). The use of onion as a buffer crop in Treatment I may also contribute to pest reduction. This may be explained by

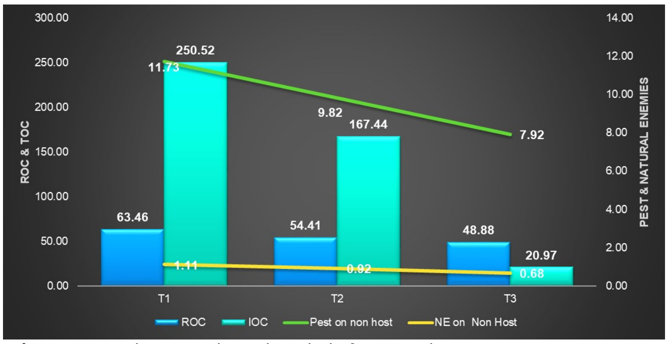

Fig. 6. Pest reduction in brinjal pooled of 2019 and 2020.

presence of volatile oils in aromatic plants which impede with feeding, host plant location, distribution ultimately resulting in decreased pest incidence (40). Results are also in line with finding, that intercropping of brinjal with cluster bean and onion reduced insect pest incidence (41). The diversity of natural enemies was high in intercropping plots compared to control. Results obtained are supported by earlier findings that intercropping increased natural enemy diversity (42). Among three treatments, Treatment I

Table 2. Diversity indices of predators in different treatments

	Cropping Pattern	Simpson diversity index	Shannon-Weiner diversity index	Evenness index
Treatment I	Control (sole crop of Brinjal)	0.55	0.93	0.36
	Brinjal+Sunflower+Coriander+Onion+Marigold	0.73	1.63	0.93
Treatment II	Control (sole crop of Brinjal)	0.56	0.98	0.38
	Brinjal+Buckwheat+Turnip+Mint+ Marigold	0.68	1.39	0.57
Treatment III	Control (sole crop of Brinjal)	0.56	0.98	0.38
	Brinjal+Nettle+Buckwheat+Marigold+Dill	0.65	1.28	0.51

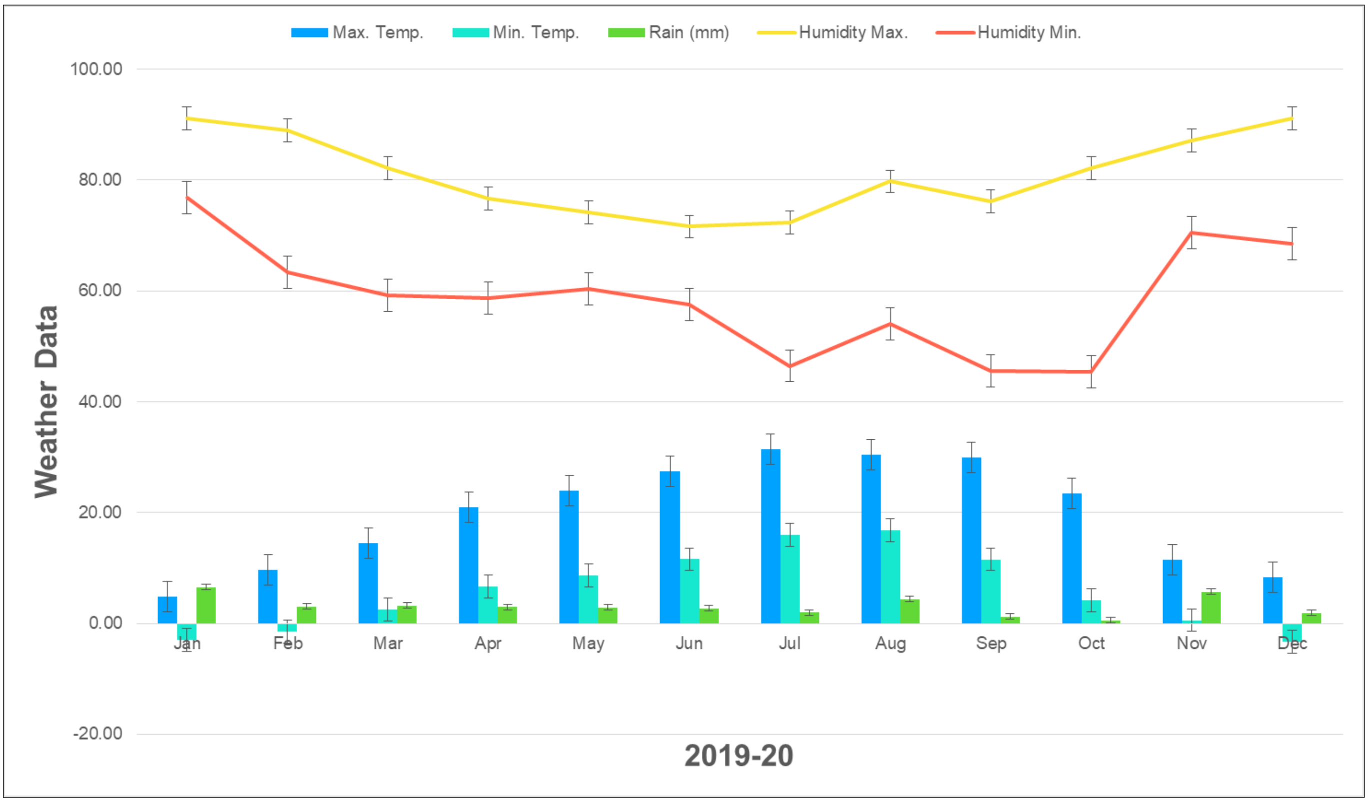

Fig. 7. Weather data pooled of 2019 and 2020.

was found to have highest diversity indices than other treatments. Intercropping vegetables with castor, cowpea, agathi and rosell was found to have increased diversity, richness and evenness of predators compared to sole crop (43). Attributes which make biological control agents eminent for ecological pest management are its environmental safety, cost effective, non-hazardous to human health whereas chemical insecticides cause environmental pollution, resistance in target pest and are hazardous to human health.

Conclusion

Rising concern about adverse effect of chemical insecticides on non-target organism have necessitated shift from chemical to ecological management of pests. Worldwide agro-economic research is devising new ways of implementing conventional approach of pest management practices with a scientific angle and mass economic approach to reduce chemical insecticide reliance. One of such method is ecological engineering. Ecological engineering approaches viz., attractant, trap, repellent and perimeter cropping has been explored to make main crop unacceptable to pest and enhance natural enemies. From the experimental findings, it may be concluded that the combination of (main crop brinjal and border crop of sunflower as trap, intercrop of coriander as attractant, buffer crop of onion as repellent and marigold as perimeter crop) was found to be the best option for maximum insect pest reduction. It depicted best potential for reducing number of insect pests by sustaining maximum number of natural enemies. The suitable crop modification in brinjal will help in decreasing insecticidal application thus ameliorating environmental pollution and also providing an ecological way out for managing insect herbivores of brinjal in an eco-friendly manner.

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Authors contributions

SM conducted experiments, carried field visits, collection of predators and wrote the manuscript. AAB helped in layout design of the experiment and edited the manuscript. AS performed statistical analysis of data. MM prepared the concept and design of the experimental field. We confirm that the order of authors listed in the manuscript has been approved by all of us. Corresponding author is responsible for communicating with the other authors about progress, submissions of revision and final approval of proofs. The authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no competing interests. This is authors own original work which has not been published elsewhere.

Ethical issues: None

Supplementary data

Supplementary Table 1. Effect of different cropping treatments on the mean abundance of flea beetle adults and natural enemies per 10 plants on brinjal during 20th–40th Meteorological standard week MSW (Pooled of 2019 and 2020).

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