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Effective Augmentative Release of Natural Enemies and Agro- ecosystem Management in Integrated Pest Management

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ABSTRACT: For successful suppression of pest without judicious application of pesticides will obtain from use of different biological control entities like parasites, predators and microbials at specific time and place with as necessary application knowledge of it. The aim of biological control in Integrated Pest Management (IPM) system have application of different natural enemies for the pest control to manage them at below economic injury level (EIL). They are introduced from commercial source without hyperparasites and conserve them with use of different tools. In augmentation when we release the same with periodic interval at small numbers of population or once time in cropping period with more population according to the crop and necessities. The utmost result require the manipulation of agro ecosystem in such a way that they can easily live, reproduce and perpetuate on host. Farmer must aware about refuge -weed, rational use of pesticides, change in crop ecosystem with conventional tillage practices, mulches, alternate host plants, cover crop, shelter belt, banker and pollinators plants for survival and multiplication of natural enemies. So that the un necessary cost on application of insecticides, other input cost and soil hazards with environmental pollution may be decreased. By using IPM with biological entities the safe, hygienic and poison free food harvest will possible with conservation of biosphere.

Keywords: Habitat manipulation, parasites, natural enemies, IPM, Augmentation.

INTRODUCTION

Agroecosystem is complex one where human being act as the pivot role for its advantage with beneficial harvest of crop without much caring about the other creatures live in same ecological niche. In present era of crop industrialization for bumper and quantitate yield he use greater pesticide with other chemicals which are increasingly linked to elevated health risks for exposed populations of farmers, their consumers and other living organisms (Kim *et al*., 2017). Pesticides have adverse impacts on soil health, water quality, and wildlife habitat (Stehle and Schulz 2015). So the introduction of Biological control is adopted as a form of ecologically based pest management that uses one kind of organism i.e. the natural enemies to control another the pest (Hoddle and Van Driesche 2009). Natural enemies include parasitoids, predators, entomopathogenic nematodes, pathogens, competing microorganisms without hyperparasites of plant pathogens, herbivores feeding on weeds and weed seeds, competitors for resources and organisms producing toxins, termed antibiosis or allelopathy (Heimpel and Mills 2017) as they directly or indirectly acts as the pest control with its management. Biological control can be naturally occurring foreign agents classically introduced and established, released native or foreign agents augmenting populations or conserved or enhanced populations of native or foreign agents. Augmentative releases can be inoculative as building a population that is expected to act over generations or inundative where the organisms released are expected to generate immediate reductions. When we go for the use of natural enemies (parasites, predators and herbivores) for the sack of biological control of pest than for its survival, reproduction and perpetuation require congenial condition in field, may varies from crop to crop. Natural enemies and their habitat manipulate to enhance their population (Powell, 1986) by applying different cultural and management practices or by reducing the insecticides application. All are help to establishment and activity in nature by justifying its environment with definite need with reasonable assurance of success will possible.

Augmentation (propagation and release of mass produced entomophagous arthropods). Augmentation define with releases of natural enemies, which are non-native and can be purchased from vendors of beneficial organisms and released locally. The manipulation methods which includes all activities designed to increase numbers or effect supplemental or periodically release of existing natural enemies to boost their population with the supplemental availability of foods, shelters, pollens, protection to them so that they maintain the pest population at acceptable limits (Ridgway, 1977; King *et al*., 1981). The management objectives may be achieved by releasing additional numbers of natural enemies into a system or modifying the environment in such a way as to promote greater numbers or effectiveness. These releases differ from introduction in that these have to be repeated periodically. The augmentation include the activities as release of natural enemies, (inoculative, seasonal colonization for longer duration crops, supplemental release for re-introduction of natural enemies, strategic release-if supplemental because of suppression of them due to the abiotic and biotic environmental factors, programmed release/inundative, use of supplemental foods, and use of kairomones or other behavioral chemicals) so that their population enhanced at the given environmental conditions. Require insectary culture which provides adequate population to insure greatest latitudes in the timing and geographical coverage of release. Augmentation is most appropriate for situations where low levels of pests and damage can be tolerated. The periodic releases have following methods (Debachand and Hagen 1964).

Predators for augmentation release

1. *Chrysoperla carnea.* The common green lacewing and an eastern lacewing species *Chrysoperla rufilabris* are available commercially. Larvae feed on cowpea, pea aphids, mites, insect eggs, thrips, scales, small caterpillars and whiteflies, Colorado potato beetle, grapes mealy bugs, red mites, tobacco bud worms often called aphid lions for their voracious appetites.

2. *Lady beetles.* Lady beetles from *Coccinellidae* family are one of the most commonly released natural enemies. They feed on aphids, mealy bugs, whiteflies and scales as well as insect eggs and small larvae. When released, lady beetles have a tendency to disperse so success is found with field-collected beetles that have been allowed to fly in captivity.

Parasitoids. Parasitoids are specialized natural enemies that develop on or inside a host insect they are either koinobioant or idiobiaont. Several tiny, non-stinging wasps are commonly used for augmentation biological control.

3. *Trichogramma*- The trichogramma wasp was was first rear commercially for biological control (Flanders, 1929). It is an almost microscopic *koinobiont endoparasite* wasp (eggs parasitoid) of many common moth pests. The larvae develop within the eggs, killing the embryo. Mature larvae pupate inside the host eggs and adult emerge from the eggs. It is used in row crop settings to manage caterpillar pests. *Trichogramma brassicae* parasitizes different *Helicoverpa* sp. of tomato, sugarcane and cabbage, cutworm, earworm in vegetable crops.

4. *Encarsia Formosa- Encarsia formosa* a species of chalcidoid wasp family *aphelinidae* is a great parasitoid of whiteflies and is used extensively in greenhouse flower and food production.

5. *Muscidifurax raptorellus* – It is the fly parasitoid most commonly produced for control of house flies. Female wasps lay more than one egg per host allowing parasitoid populations to increase quickly.

C. Pathogen

1. *Bacillus species of bacteria.* They are effective against different groups of insect pests having delta endotoxin production with the insecticidal crystal protein. Are stomach poison rapture in the gut cells alkaline pH of larvae and parasitized them with septicemia proceed to kill them. The *Bacillus thuringiensis* sub sp. *kurstaki* infects the larval, caterpillars of *lepidopterian* pests.

2. *Paenibacillus popilliae.* This bacterium produces "milky disease" in larvae of the Japanese beetle (*Popillia japonica*). The Japanese beetle was accidently introduced into the eastern U.S. in the early 1900s, and has steadily expanded its range westward. *Paenibacillus popilliae* was the first microbial control agent registered in the U.S.A.

3. ***Beauveria bassiana.*** It is a fungus that causes a disease called white muscadine disease in certain insects. This fungus infects hosts through the cuticle by adsorption germination and appressorium formation on host cuticle or body lining and does not need to be consumed to be effective. Killing the host by cyclic peptide toxin dextrin than fungus develops a downy white conidial covering the outside of the insect. Susceptible hosts include beetle larvae, *lepidopteran* larvae (caterpillars), aphids, fungus gnats, leafhoppers, mealybugs, whiteflies and other leaf-feeding insects.

4. ***Metarhizium brunneum.*** (previously known as *M. anisopliae*) is a soil-borne fungal mitosporic *deutromycotina* fungal pathogen commonly found in disturbed sites. It infects a variety of arthropods including ticks, whiteflies, thrips, mites, weevils, aphids and grubs. *Metarhizium brunneum* had been grouped with *M. anisopliae*, which is pathogenic of grasshoppers and locusts.

5. ***Isaria fumosorosea*.** It is naturally occurring fungus that attacks and kills several insect species including aphids, spider mites, thrips, weevils, leaf miners and whiteflies.

6. ***Nosema locustae*.** This biological control organism is a microsporidium, a type of protozoan. These single-celled life forms infect insect hosts grasshoppers causing slowly the reduced feeding, lower reproduction and moderate rates of mortality.

Entomo pathogenic nematodes (EPN)

1. *Heterorhabditis indica*. It is more heat-tolerant than other *Heteorhabditis* species. Like *H. bacteriophora*, it is effective against lepidopteran and beetle larvae. In addition, it is used to manage fire ant, white grub in sugarcane, fungus gnats, flower thrips. Beekeepers utilize *H. indica* to manage the small hive beetle, *Aethina tumida.*

2. *Steinernema carpocapse*- Easily mass produced used against highly mobile pests inhabiting the soil surface and lepidopteran pests including codling moth, cutworm, armyworm.

3. *Steinernema feltiae*. This species is highly effective against fly pests. It is used to manage fungus gnats in greenhouses, interior scapes, and houseplants with armyworm, codling moth and corn earworm. It is also used to manage plant-parasitic nematodes including root nematodes.

Augmentation divided into two types as- I) Inoculative releases ii) Inundative releases

I) Inoculative releases. (Periodic colonization/ Build up initial parasitoid population so that immediate control followed by additional control wrought by progeny) (Liyang, 1984).

They have contain accretive release where small no. of natural enemies periodically released against low density of host population. These may be made as infrequently as once in a year to reestablish natural enemy. Here control is expected from the progeny and subsequent generations and not from the release itself. It is appropriate release for colonizing population to achieve the pest control. Interaction between the natural enemies and host persist more than one generation. Their control largely affected by progeny of beneficial forms released. Inoculation is the release of natural enemies where the goal is not an immediate suppression of the pest population but the introduction and gradual increase in populations over time. Inoculation aims to produce a more constant pressure of natural enemies on pests. It is not used for a rapid response to a pest outbreak. Inoculation like fixed release of 100 parasitoids of whiteflies monthly.

Example

1. *Fulgoraecia melanoleuca*. The koinobiont nymphal adult ectoparasites to control sugarcane pyrilla in south Gujarat.

2.*Pediobiusfoveolatus*. This bacterial parasitoid attacks larvae of the Mexican bean beetle, *Epilachna varivestis* on soybean and vegetable beans. Releases require proper timing to prevent population build-up of the target pest. They does not survive freezing temperatures and will not overwinter in the landscape, thus inoculative releases are required each and every season.

ii) Inundative releases (To flood or to overwhelm by great numbers)

It involves mass culture and release of natural enemies to suppress the pest population directly against the univoltine/ multivolitine eggs stages of host. They can not control the progeny of host so these are effective against pests having one or a few discrete generations every year. Where no prolonged interaction between the natural enemies and host persist. Here the control is from release itself.

Natural enemies exhibits an annual ovarian diapause and migrate any form its host at certain time of year (*Coccinallidae)* and its reproduction rate was low adverse to disperse require augmentation release because of its low densities. Inundation is the release of natural enemies with the goal of more rapid pest suppression. Because immediate effects are needed, inundation uses predatory insects or mites because they kill their prey immediately (David and Held 2020). Successful augmentation generally requires advanced planning, biological understanding, careful monitoring and optimal release timing. It is a control strategy that requires patience and realistic expectations.

Example

1. *Cryptolaemus montrouzieri*. (Mealybug destroyer) Adult and larval stages of the small beetle feed on mealybugs, aphids and immature scales. Mealybug destroyers do not reproduce well in the field and are most commonly used for inundative control in heavy mealybug infestations.

2. *Heterorhabditis bacteriophora*. These EPN nematodes naturally occur in the soil, but not at high enough levels to provide effective pest control. Require its inundative releases because its population can reduce by soil-dwelling insects. They control pests like Japanese beetle grubs, black vine and other weevils, Colorado potato beetle, cucumber beetle and corn root worm etc.

Successes story in Gujarat. The impressive success in the introduction and establishment of parasitoids *F. melanoleuca* ectoparasite koinobiont pupal adult parasitoids. (*Epiricania=Fulgoraecia*) *melanoleuca* (Fletcher) from laboratory mass reared culture at Biocontrol lab Navsari, Gujarat on sugarcane crop pest pyrilla *(P. perpusilla* Walker) (Sidhapara *et al.*, 2018). They found best attributes of natural enemies as is high fecundity, short life cycle as compared to its natural host. Its Neonate/first instar larvae possesses high searching capacity than its prey. Wider adaptability under adverse climatic condition. Excellent synchronization between *pyrilla* population and parasitoid appearance under field condition whenever the infestation of the *pyrilla* initiates with simultaneous the appearance of the parasitoid. Its larvae possesses the circular crochets thereby once encountered with its prey then easily and permanently attachment with its host body by without losing the established contact and thus leads to maximum parasitizing under field condition. Now-a-days the farmers of the south Gujarat are never applying any insecticide for the management of *pyrilla* as only due to self-perpetuation of *F. melanoleuca* under natural condition and its wider adaptability under south Gujarat climatic condition. Three seasons of sugarcane cropping was found the region so that in a year mono crop found to their perpetration and survival. Where cost on insecticide and its spraying wages are zero, millions of rupees have been saved indirectly by avoiding ground or aerial application of insecticides. Thus, the use of this potent parasitoid, *F. melanoleuca* for the management of *P. perpusilla* has been proved to be effective and notable success in cane growing areas of the Gujarat (Siddhapara *et al.,* 2018). The key note award by International Organization for Biological Control (IOBC), Trinidad (West Indies) for such remarkable and spectacular achievement in Gujarat.

Short difference between them

Sr. No.	Inoculative releases of augmentation	Inundative releases of augmentation
1.	periodic colonization/ Build up initial parasitoid population so that immediate control followed by additional control wrought by progeny	To flood or to overwhelm by great numbers on their host pest
2.	Reproduction rate is low to constant	Reproduction rate is very low
3.	Have prolonged interaction between the natural enemies and host persist. Here the control is from release periodically	Where no prolonged interaction between the natural enemies and host persist. Here the control is from release itself
4.	Initial population was low	Initial population is high
5.	No quick control achieved	Quick control achieved because their high initial application dose
6.	They may acclimatized with new environment on their host	They may not acclimatized with new environment on their host, because of their reproduction lower than normal due to biotic and abiotic factors

Management of agro ecosystem or ecological management for natural enemies. Conservation of natural enemies for biological control to enhancing the use of natural enemies (parasites, predators and herbivores) with increasing its population in given locality to adopt such management practices not only introducing them but given them a healthy and desirable environment so that they live, reproduce and show better performance by managing the pest at EIL level (Hajeck and Elienberg 2018). Anne for the sack of biological control of pest for healthy and poison free organic foods than for survival, reproduction and perpetuation of them require congenial condition in agro ecosystem. Natural enemies and their habitat manipulate to enhance their population by applying different cultural and management practices. All are help to establishment and activity in of nature by justifying its environment with definite need, reasonable assurance of success is possible.

1. Vegetational diversity–(Refugia maintenance and trap cropping). Shifting the cropping system to increase the effectiveness of a natural enemy is known as habitat manipulation**.** Refugia is a microhabitat that provides spatial or temporal shelter for pest natural enemies and supports biotic interaction components in ecosystems, such as pollinators or pollinating insects. Many adult parasitoids and predators like nectar sources, so refuges such as grasses, thin borders and cover crops provide refuge. Growing of susceptible plants near the major crop act as trap for main pest and they attract the natural enemies. Example- Cotton main crop-marigold trap crop in 10:2 rows in field.

Raise the flowering plant along the orchard border by arranging shorter plant toward main crop and taller toward the border to attract the natural enemies. Use of flowering plant at internal bunds of orchard.

The use of flowering refugia (yellow, violet, pink, red color) plant can maximize the role of insect as ecological services in agricultural ecosystem by providing natural enemies and pollinators with the sources of food and shelters to them (sunflower, king salad, zinnia, tridex) (Windriyanti *et al.*, 2023). Native Michigan perennial flowering plants can provide pollen and nectar to the natural enemies to survive over long term and to less need based pesticides spray and grater fruit set in mango with yields (MSU). They are *Larra bicolor,* parasitoid of mole crickets, commonly rest on nectar sources during the day and may remain overnight on their nectar source plants. Buckwheat (*Fagopyrum*), goldenrod (*Solidago*), shasta daisy (*Leucanthemum*), aster (*Aster*), and tickseed (*Coreopsis*) are floral resources commonly used maintain high numbers of parasitoids.

2. Alternate host and availability of different food sources (pollen, sap, nectar, honey dews). The common non plant supplements are food sprays such as synthetic honeydew or sugar water. These food supplements are applied to or adjacent to infested plants. Sugar sprays have been evaluated with parasitoids of white grubs and mole crickets act as the attractant and supplemental food source in unviability of main crop pest (David and Held 2020).

Compounds such as methyl salicylate, jasomnates and jasmonic acid are being experimentally evaluated as attractants for natural enemies in search of preyhosts. These compounds are host-induced plant volatiles or plant signaling chemicals which exploit the inherent attraction of natural enemies to plants infested with herbivores enhance the selective delivery of insecticides as the attract and kill with combination of trap crop (David and Held 2020).

3. Use of shelters. Different types of mulches, hedge row, bund with weed crop act as the shelters at non growing season of main crop. They promote moderate microclimate in season refuges and overwintering hibernating sites. Supply of artificial structure like rice husk, sugarcane trash in ratoon, different organic mulching act as the nesting sites provide the insect with suitable host range .Require eliminating predacious ants are effective.

4. Need based/Limited and recommended application of pesticides. The selectivity is a combination of insecticides toxicity and the probability of contact and can vary significantly between natural enemies and target pests (Brown, 1989). The selection of pesticides for their use having different selectivity criteria as physiological selectivity and ecological selectivity. In physiological selectivity the use of pesticides in such a way that they minimize direct toxic and sub lethal effect on beneficial insects as the ratio calculated LC_{50} between natural enemies and pest must favors on natural enemies. eq. use of acaricides as

Ovex, Dicofol, Tetradifon and Bt toxins for all *lepidopteran* larvae act as specific insecticides. Use of *Baculoviruse* -(NPV). Some Bacteria and entomopathogenic nematodes have the best records of development into products for use against turfgrass pests.

The bacterial insecticides like *Bacillus thuringiensis* are marketed as alternatives to conventional insecticides against caterpillars and white grubs called biological pesticides (David and Held 2020).

In ecological selectivity use of broad spectrum non selective insecticides can be made available and use them from irrigation water channel when the natural enemies activity was nil for effective and ecological sound pest control. As they are not fit for the soft, green, eco-friendly category of insecticides but they give low mortality of natural enemies with good suppression of target pest. But required careful application. Use of information regarding life table of pest are important at the time of application. When we know the exact stage of pest which are vulnerable to crop ETL then application of insecticides are resultful. Which enhance their application result with saving of labors and other input cost. There is another way other than above two selectivity to combine physiological and ecological selectivity for the protection gained by immature endo parasitoids within their host because of less exposure, less impact on them to the insecticides than their adult stages (Khan and Ruberson 2017).

Case study for ecological manipulation in paddy for brown plant hopper: The rice brown planthopper, (*Nilaparvata lugens* Stal.) in Philippines are studied for ecological manipulation with benefit of flowering plants as refuge to improve the role of egg parasitoids of brown planthopper as *Banyumas*: *Oligosita* and *Anagrus*. They sampled three rice fields: rice field adjacent to refuge, far from refuge, and rice field with no refuge using trapping procedure. Found that number of parasitoids emerged from the traps placed in the rice field with refuge having flowering plants (*Cosmos caudatus* and *Turnera subulata*) was higher than the other two rice fields. In addition, the number of unhatched parasitoids was lower in the rice with refuge compared to no refuge. These findings show that the refuge provides better environments for the parasitoid for their growth and perpetuation to manage *N. lugens* population (Sinalingga *et al*., 2019).

Case study 2.

In Maize (*Zea mays* L.) the major pest is fall army worms *Spodoptera frugiperda* (J. E. Smith). Some parasitoids have been recorded attacking *S. frugiperda* in South America, such as *Campoletisgrioti* (Blanchard), *Cotesia margiventris* (Cresson), *Chelo nusinsularis* (Cresson), *Apanteles* spp. For study they grouped the refugia A, B and C to see their result and impact on maize pest. Having refugia A with plant like *Gossypium barbadense, Aster* sp., *Foeniculum vulgare, Coriandrum sativum,* and *Lavandula officinalis.* Refugia B having *Helianthus annus* (Cultivated Herb), *Nicandra physaloides* (Weed), *Salvia officinalis* (Aromatic Woody plant), *Bidens pilosa* (Weed) and *Artemisia absinthium* (Weed). Refugia C having *Malva parviflora* (Weed Herb), *Rosmarinus officinalis* (Aromatic Shrub), *Phaseolus vulgaris* (Cultivated Herb), *Galinsoga parviflora* (Weed Herb), *Sorghum halepense* (Cultivated Herb). They use Approximately 30 seeds of every species were sown in the plant nursery. One week before the maize sowing they were transplanted in the field, when seedlings had seed leaves, in such a way as to create five 7.5 m^2 plots or "refuge patches", made up of 10–12 seedlings of one species each. The three refuge patches were replicated once, and all of them were established in close proximity to the maize plot, as shown in Fig. 1.

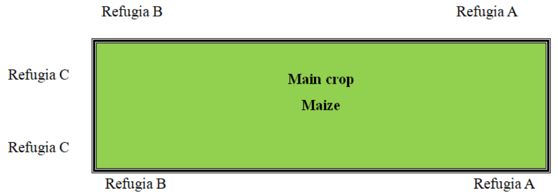

Fig. 1.

They concluded that after observation and sampling, Refuge A where the highest abundance and species richness were found. The plant species *Foeniculum vulgare* and *Gossypium barbadense* in Refuge A, *Bidens pilosa* in Refuge B, and *Malva parviflora* and *Galinsoga parviflora* in Refuge C, retained the highest number of both parasitoid and predator species. For parasitoids collected in the refuges, there are three species that have been reported as parasitoids of *Spodoptera frugiperda, Eucelatoria* sp, *Chelonus insularis*, and *Apanteles* sp., which were more abundant in Refuge B, especially in *N. physaloides* and *B. pilosa*, although in *P. vulgare* (refuge A) there was a high abundance of *Apanteles* sp. and *C. insularis*. For predators species found in maize crops were also collected as *Allograpta exotica, Orius insidiosus, Chrysoperla externa,* and *Condylostylus similis*. The *A. exotica* was mainly found in Refuges A and C. Although its highest abundance was recorded in *G. barbadense* (refuge A); *C. externa and C. similis* were abundant in the three refuges. *Chrysoperla* and *Consdylostylus* are more generalist, whilst *Orius* and *Allograpta* feed mostly on aphids (Quispe *et al*., 2017).

CONCLUSIONS

All above natural enemies and respective example of their ecological management give in depth idea about how to manage their habitat for their host specificity, synchrony with the host pest, high fecundity, low mortality and ability to survive with crop management. It is prime important to take care of natural enemies after their release in new locality using different ecological methods so that they easily adopt the new environment and showing result of biological control of pest. Rationalized use of pesticides with information about their physiological or ecological selectivity enhances their application result with harboring and maintaining the population of natural enemies in vicinity of crop. They also reduce cost of different inputs, its application wages and detrimental effect on the environments. Huaman being as central role in industrial agro ecosystem management as *VASUDEV KUTUMBKAM* will be important for sustainable and incredible life on earth (All live symbiotically and trust ship on biosphere of earth).

FUTURE SCOPE

In today's climate changing scenario new hybrids varieties are developed only for quantitative higher yield without much bother about the devastating emergence of new strains of pest. We can't solely depends on the application of new novel pesticides for suppressing them. But required in detail study of selectivity of the commercial available insecticides while applying them in the field with their impact analyses on the natural enemies. There will be lots of scope to identify many class of invertebrate and herbivores till we are not knowing their role in eco-friendly pest management. Scope for collecting much information about crop, pest and their natural enemies with their complex interactions in respective ecological and climatic region. They are helpful to farmer to reduce the indiscriminate application of insecticides with enhance the bio safety approach required for environment. The IPM with biological control having lower chance to pest to develop genetic resistance against the present insecticides. Lots of awareness programs and extension activity will required at farm level for observation, analyses and decision making for raising the refugia-banker plant-cover -rely crop system, conservation of organic mulches, green manuring along the main crop. Which facilitated the healthy environment for the growing natural enemies for their direct and in direct benefit in reducing the negative impact of pest population.

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Conflicts of Interest. None.

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